# "Descemet Membrane Detachment": A Novel Concept in Diagnosis and Classification

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• PURPOSE: To examine the optical coherence tomography (OCT) and histologic features of Descemet membrane detachment (DMD) to ascertain the involvement of the pre-Descemet layer (PDL).

• DESIGN: Retrospective, observational case series.

• METHODS: Clinical, histopathologic, and OCT features of a cohort of 41 cases with diagnosis of DMD from 4 centers were studied. OCT images were evaluated independently by 3 observers for number of detached layers (1 or 2), reflectivity, configuration (straight line or wavy), distance from posterior stroma, and presence or absence of a tear with any scrolling of the torn edges. Five had a histology specimen. The main outcome measure was the involvement of the PDL in DMD and its confirmation by histology.

• RESULTS: Three types of DMD were identified: type 1, where the PDL and DM were detached together; type 2, where only the DM was detached; and mixed, where the PDL and DM were detached but also separated from each other. These were further found to be rhegmatogenous or nonrhegmatogenous depending on the presence of absence of a tear in DM or both layers. Histology confirmed involvement of PDL in all 5 cases and showed it to be infiltrated by cells in 3 of 5 cases.

• CONCLUSIONS: The PDL is involved in DMD. This fact significantly changes our understanding of DMD and could have implications for management. The detached PDL can be infiltrated with cells. A prospective study in relation to etiology and types of DMD is needed. (Am J Ophthalmol 2020;218:84–98. © 2020 Elsevier Inc. All rights reserved.)

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DESCEMET MEMBRANE DETACHMENT (DMD) HAS been recognized as a pathology of the posterior cornea, occurring especially after complicated or multiple intraocular surgery, for close to a hundred years.[1] The first cases with this condition were described by Fuchs as recorded by Samuels in his thesis.[1] Persistent edema of the overlying corneal stroma and epithelium is the hallmark clinical feature. Vision is affected when edema involves the pupillary area. There have been several attempts at classifying DMD based on pathology, clinical features, and imaging techniques.[1,2] The first reported classification was based on pathology and described 3 types of DMD: active (pushed back), passive (pulled back and torn away), and a third type due to difference in elasticity of DM and the anterior parenchyma.[1] Mackool and Holtz[3] described DMD as planar where the distance of the DMD from the posterior stroma was 1 mm or less and nonplanar where the separation was greater than 1 mm. These were further subdivided into peripheral (peripheral 3 mm of the cornea) and/or central. A contemporary classification based on anterior segment (AS) optical coherence tomography (OCT) has been proposed by Jacob and associates,[4] who divided DM detachment into rhegmatogenous, tractional, bullous, and complex and suggested treatment protocols based on the classification proposed.

DMD is reported to be most common following cataract and other intraocular surgery, especially when associated with intraoperative complications or multiple surgeries.[1,5] Besides an iatrogenic etiology, DMD can be secondary to trauma or occur spontaneously. Both iatrogenic and traumatic DMD can occur early or late after the event.[1,3,5,6] Spontaneously occurring DMD is seen in acute hydrops associated with ectatic corneal disorders, especially keratoconus.[7]

The demonstration of the pre-Descemet layer (Dua's layer, PDL),[8] recently also termed the Dua-Fine layer by the American Association of Ocular Oncologists and Pathologists,[9] has added another dimension to DMD. None of the descriptions and classifications of DMD take into consideration the PDL. Dua and Said reported a case where the PDL and the DM detached independent of each other, with the latter showing a tear and scrolled edge.[10] We undertook a retrospective analysis of anterior segment OCT images, clinical history, and histology of DMD to ascertain the association of PDL detachment in DMD and report novel findings that



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**TABLE.** Demographics and Types of Descemet Membrane Detachment in the Groups of Patients Studied

| Diagnosis | Number of Cases | Age Range/Median | Sex, F/M | DMD | | | Duration to Diagnosis | Comments |
|---|---|---|---|---|---|---|---|---|
| | | | | Type 1 | Type 2 | Mixed | | |
| Cataract | | 45-83/62 | | 10 | 13 | 6 | Day 1 to | Treated with intracameral |
| Phacoemulsification | 26 | | 12/14 | | | | 12 weeks | injection of air or C3F8, or |
| SICS | 3 | | 1/2 | | | | | conservatively. DSEK in 2 cases |
| | | | | | | | | and DMEK in 1 case. |
| Acute hydrops | | | | | | | Within | Treated conservatively with |
| Keratoconus | 3 | 24-30/24 | 1/2 | | | 3 | 1 week | hypertonic saline and carmellose |
| PMD | 1 | 62 | 1/0 | | | 1 | | drops. One patient subsequently |
| | | | | | | | | had PK. |
| Descemetocele | 3 | 71-83/80 | 2/1 | | 2 | 1 | 1 week to | Treated with cyanoacrylate glue |
| | | | | | | | 3 weeks | and PK in 1 case |
| Failed corneal graft | | | | | | | | |
| PK for keratoconus | 2 | 24, 52 | 0/2 | 2 | | | >1 month | Treated with repeat PK |
| PK for corneal scar | 2 | 71, 76 | 0/2 | 2 | | | >2 months | Treated with repeat PK |
| DSEK | 1 | 82 | 1/0 | 1 | | | 1 week | Treated with PK |

C3F8 = perfluoropropane gas; DMD = Descemet membrane detachment; DMEK = Descemet membrane endothelial keratoplasty; DSEK = Descemet stripping endothelial keratoplasty; PK = penetrating keratoplasty; PMD = pellucid marginal degeneration; SICS = small-incision cataract surgery.

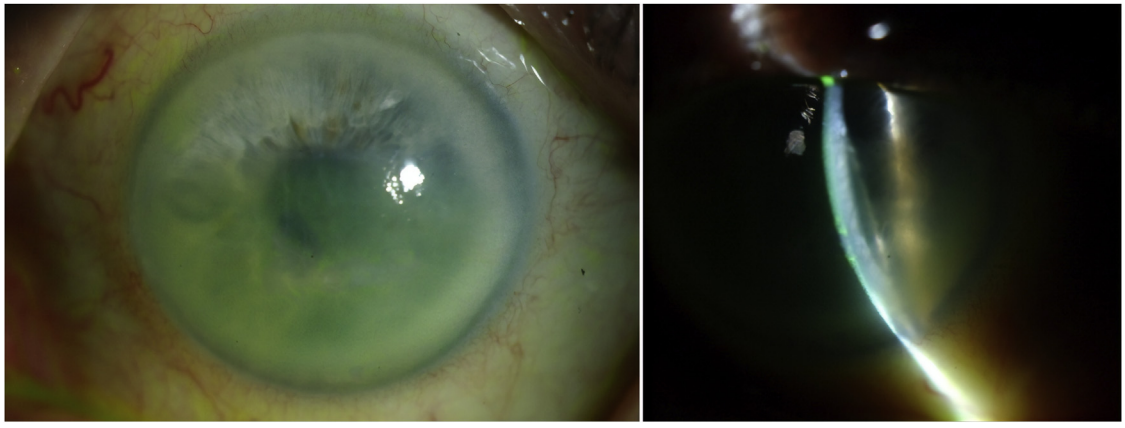

**FIGURE 1. Persistent corneal edema post cataract surgery. Left. On diffuse illumination, the lower two-thirds of the cornea is edematous. Right. The slit beam shows a "taut" straight Descemet membrane detachment.**

enhance our understanding of DMD, with diagnostic and potential therapeutic implications.

## METHODS

• **SAMPLE COLLECTION:** Forty-one cases with a diagnosis of DMD, from the OCT database over a period of 5 years, were retrospectively studied. Twenty-three cases were from the All India Institute of Medical Sciences, New Delhi, India; 14 from the Queens Medical Centre, Nottingham, UK; 3 from Narayana Nethralaya, Bangalore, India; and 1 from the Optimed Eye and Laser Clinic, Queenswood, South Africa. Twenty-nine patients had DMD following cataract surgery (phacoemulsification [26] and small-incision cataract surgery [3]); 5 had corneal transplants (4 failed penetrating keratoplasty [PK] and 1 failed Descemet stripping endothelial keratoplasty (DSEK); 4 had corneal ectasia with

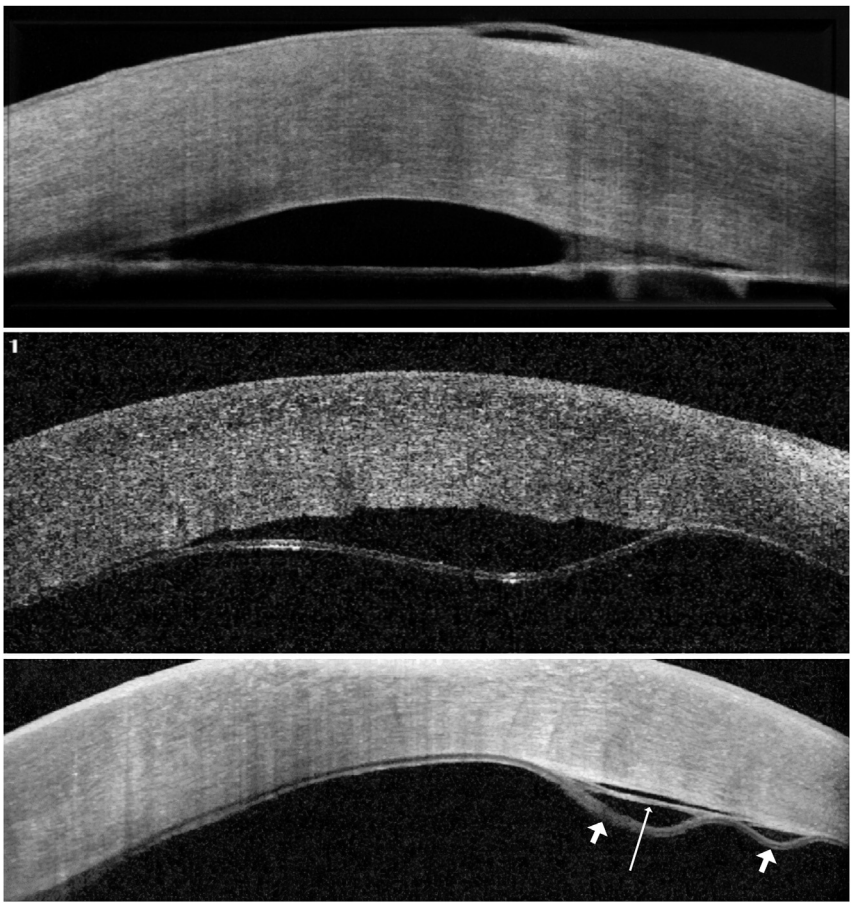


**FIGURE 2. Anterior segment optical coherence tomography (ASOCT) images of the 3 types of Descemet membrane detachment (DMD) for comparison. Top. Type 1; the DMD is a straight line and "taut," like the chord of a circle. This is the separation of the pre-Descemet layer (Dua's layer, PDL) together with the Descemet membrane (DM), which remain attached to each other (Heidelberg Spectralis OCT). Middle. Type 2; the DMD is undulating and is made of 2 parallel hyperreflective lines separated by a narrow dark space. This is the characteristic OCT appearance of the DM (RTVue, Optovue OCT). Bottom. Mixed; the DMD has 2 components, an anterior hyperreflective band representing the PDL (long thin arrow) and a posterior undulating band made of 2 fine hyperreflective lines separated by narrow dark space representing the DM (short thick arrows), as in the top image (Heidelberg Spectralis OCT).**

acute hydrops (3 keratoconus and 1 pellucid marginal degeneration), and 3 had history of descemetocele following corneal infections. Patient details are given in the Table. All cases had OCT performed at presentation. Those from Nottingham and the case from Queenswood had OCT with the anterior segment attachment to the Heidelberg Spectralis OCT, wavelength 870 nm (Heidelberg Engineering GmbH, Heidelberg, Germany) and the rest had it with the RTVue, wavelength 840 ± 10 nm (Optovue, Inc, Fremont, California, USA). High-resolution vertical and horizontal OCT sections were obtained. Scans were performed to cover the area of detachment. Each of the 41 patients had between 20 and 45 high-resolution scans in both the vertical and horizontal orientations. As the study was retrospective in nature, it was categorized as an audit of patient notes with no direct involvement of patients.

• **CLINICAL EVALUATION AND OCT ANALYSIS:** The clinical history, treatment offered, and clinical notes including slit-lamp and OCT images were reviewed in the context of the knowledge of the posterior corneal anatomy with regard to the Descemet membrane (DM) and PDL. All scans were independently reviewed by 3 of the authors (H.D., D.S., and A.R.) and types of DMD recorded. The distance between the detached layer(s) and the posterior surface of the cornea was

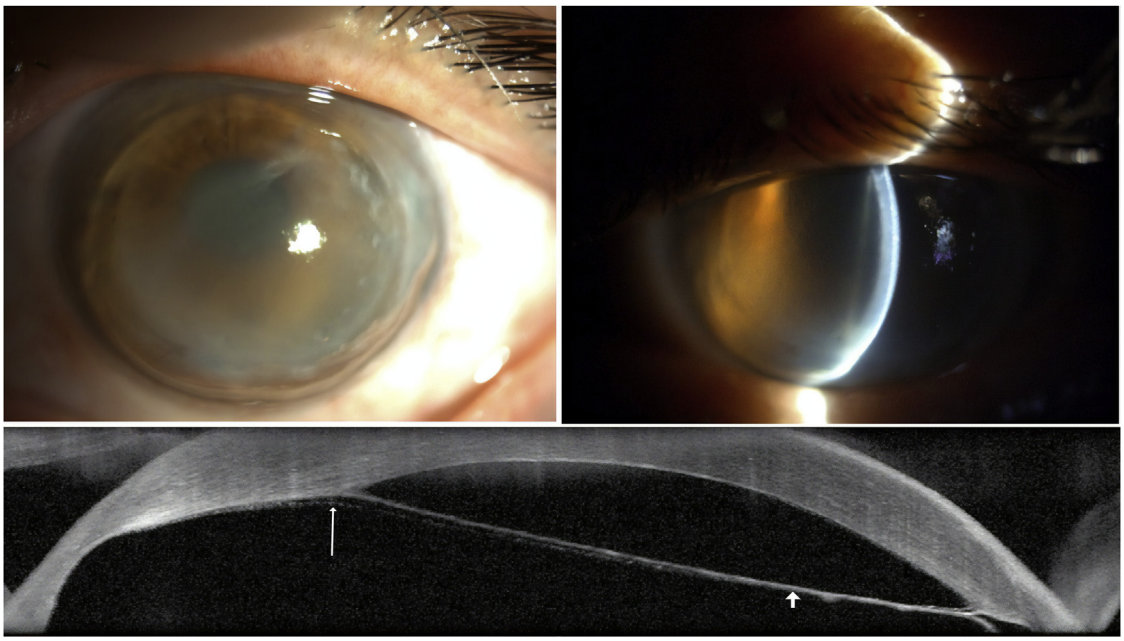

**FIGURE 3. Top left. The lower two-thirds of the full-thickness corneal graft is edematous (diffuse slit-lamp image). Top right. The slit view shows a taut, straight Descemet membrane detachment (DMD). Bottom. Anterior segment optical coherence tomogram (Heidelberg Spectralis OCT) showing the hyperreflective band, like the chord of a circle, representing the detached pre-Descemet layer (Dua's layer, PDL) and Descemet membrane in a type 1 DMD. At 1 end the endothelial cell surface is visible (long thin arrow) and for the most part the PDL and DM cannot be differentiated from each other (short thick arrow)**

measured at the point of greatest separation. Statistical analysis was performed using the Statistical Package for Social Sciences for Windows, version 19 (SPSS Inc, Chicago, Illinois, USA). Differences between observers were analyzed using 1-way analysis of variance.

• **HISTOLOGIC EXAMINATION:** Tissue was available for histologic examination from 5 cases: 2 subjects had DMD post phacoemulsification (1 was treated with Descemet membrane endothelial keratoplasty [DMEK] and 1 with DSEK); 2 had PK for failed previous full-thickness grafts with DMD; and 1 had PK post resolution of acute hydrops. Full-thickness corneal tissue samples (3 specimens) were cut in 2 halves; and tissue removed by stripping during endothelial keratoplasty (2 specimens) was flattened on paper. All samples were fixed in formalin and paraffin embedded (1 was resin embedded), and sections of 7-10 μm were mounted on glass slides and stained with hematoxylin-eosin (resin sample was stained with toluidine blue) for light microscopy. Sections were scanned with the Nanozoomer Digital Pathology Microscopy System (Hamamatsu, Hamamatsu City, Japan) at 40× magnification and examined for number of detached layers and cellular infiltration (4 samples) and by light microscopy at 40× (1 sample).

## RESULTS

• **CLINICAL HISTORY AND MANAGEMENT:** All cases with DMD following cataract surgery were diagnosed within 4 weeks of surgery, except for 2 that presented after 2 and 3 months, respectively. All cases were treated with intracameral injection of air or perfluoropropane. Three required endothelial keratoplasty (2 DSEK and 1 DMEK). All 4 cases with acute hydrops were managed conservatively with 5% sodium chloride drops and topical lubricants (carmellose 0.5% 4-6 times a day) until the hydrops resolved in 4-6 months. One of these required PK subsequently. All 4 cases with DMD associated with failed PK were treated with repeat PK and the 1 case with failed DSEK had rebubbling and subsequently a PK. The 3 cases with descemetocele were following bacterial keratitis and nonhealing epithelial defects. These were glued with cyanoacrylate glue and 1 was followed by PK. Clinically all patients had corneal edema. DMD was seen on slit-lamp

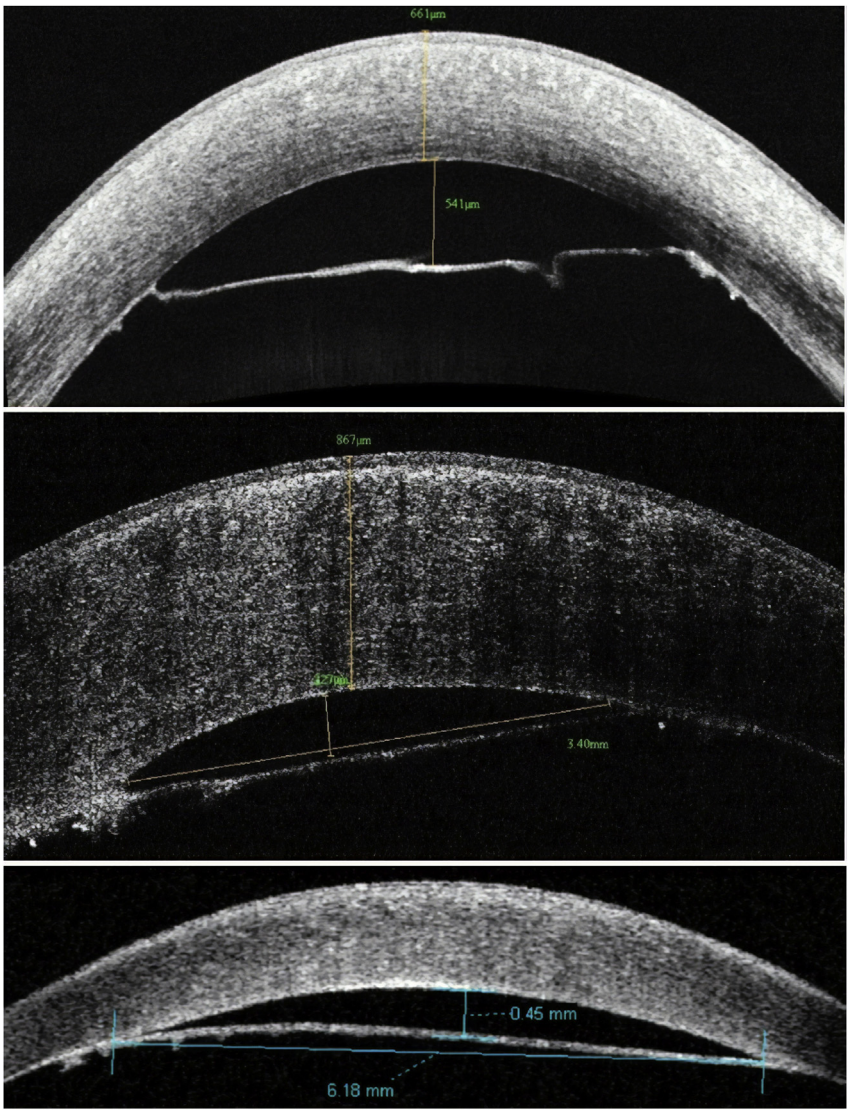


**FIGURE 4. Anterior segment optical coherence tomograms (RTVue, Optovue) of 3 different patients (Top, Middle, and Bottom), showing type 1 Descemet membrane detachments (DMD). The distance of the detached pre-Descemet layer (Dua's layer, PDL) was less than 1 mm in all these cases, indicating planar DMD. The detached PDL with the DM appears as a straight hyperreflective line, like the chord of a circle, in all 3 cases. The top image shows a "fold," indicating some scarring in the PDL.**

examination but visibility depended on the extent of overlying corneal edema (Figure 1).

• **ANTERIOR SEGMENT OCT FINDINGS:** ASOCT of DMD showed 3 patterns:

(1) A straight taut DMD, like the chord of a circle, made of a thick hyperreflective strand, which at places showed a double contour. This was termed type 1 DMD (Figures 2-5). The straight taut hyperreflective strand represented the detachment of the PDL and DM from the posterior stroma but with each remaining attached to the other. At times the DM presented as a double contour line on the posterior aspect of the PDL. Type 1 DMD was seen in a total of 15 cases, including 10 with post–cataract surgery DMD, all 4 cases of DMD associated with failed previous PK, and 1 with failed DSEK.

(2) An undulating DMD, which on OCT was made of a single layer of sharply delineated hyperreflective parallel lines separated by a nonreflective narrow

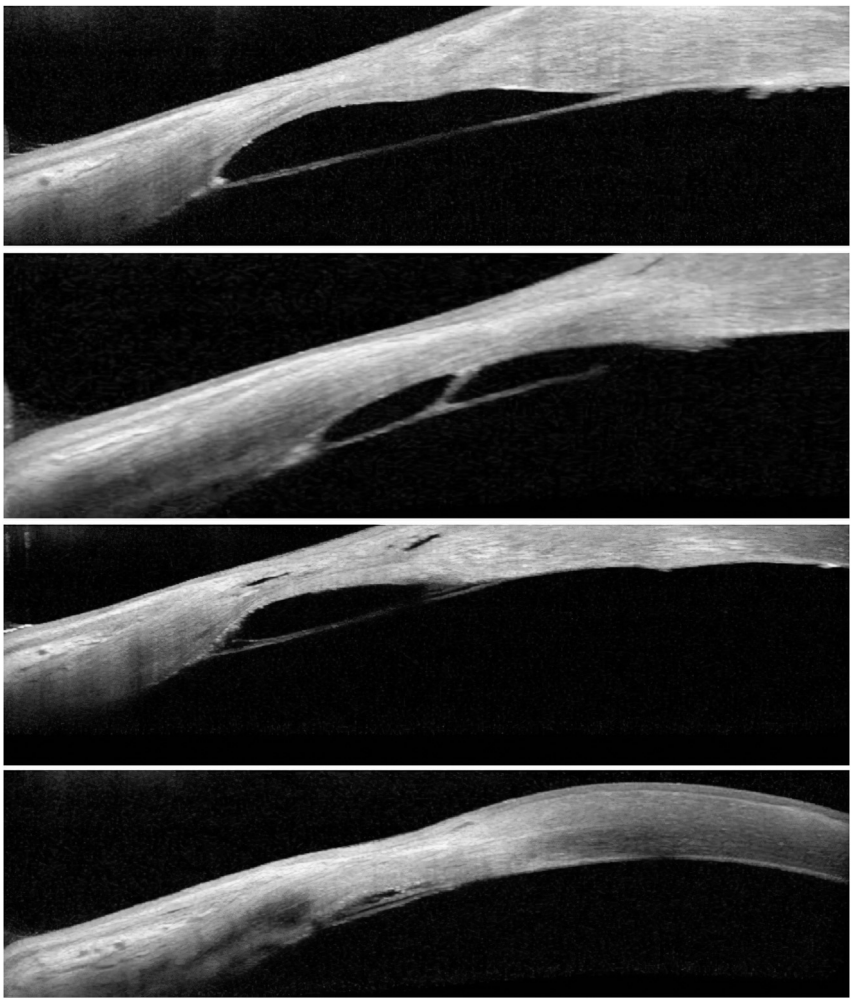

**FIGURE 5. Anterior segment optical coherence tomograms (Heidelberg Spectralis OCT) of a patient with pellucid marginal degeneration of the cornea and acute hydrops. Top row. A type 1 Descemet membrane detachment (DMD) is seen as a characteristic straight line, like the chord of a circle, representing the pre-Descemet layer (Dua's layer, PDL) and the Descemet membrane (DM). Second row. A strand of tissue is seen extending from the posterior corneal surface to the anterior surface of the PDL. This is a strong indication that the detached tissue is the PDL. Third row. A separation of the PDL and DM is seen at either end where the DMD is attached to the posterior stroma. Bottom row. The separation between PDL and DM is clearly visible, suggesting the presence of a mixed DMD, which represents the detachment of the PDL and DM and their separation from each other. Dark spaces seen in the corneal stroma in the third-row and bottom-row images represent fluid pockets of acute hydrops.**

hyporeflective (dark) space (Figures 2 and 6). This represented the detachment of the DM from the PDL with the latter remaining attached to the posterior stroma and was termed type 2 DMD. This was seen in a total of 15 cases, including 13 with post–cataract surgery DMD and 2 cases with descemetocele. The double-contour parallel thin line appearance of the DM was better visualized with the Heidelberg OCT than with the RTVue OCT.

(3) A combination of the above 2 features with 2 distinct lines of "DMD": the anterior taut hyperreflective line like a chord of a circle representing the PDL separated from the posterior stroma, and another posterior straight or undulating double contour line (like in type 2 described above) representing the DM, with the latter also separated from the former (Figures 2 and 7). This was termed "mixed DMD." In other words, the mixed DMD represented the detachment of the PDL and DM

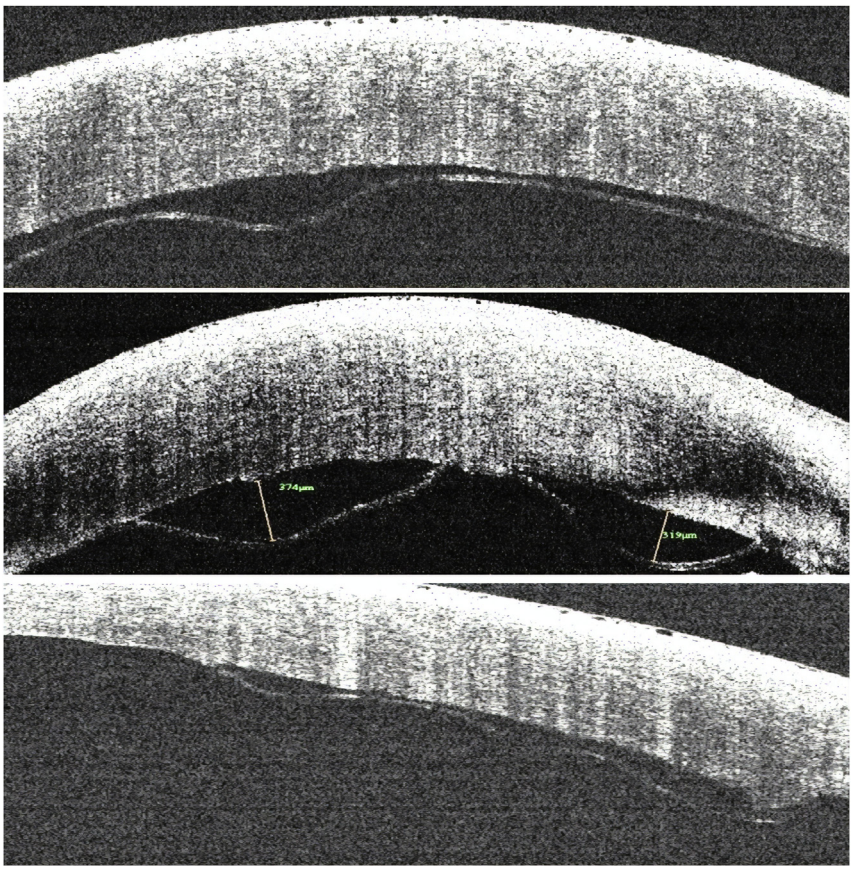


**FIGURE 6. Anterior segment optical coherence tomograms (RTVue, Optovue) of 3 different patients (Top, Middle, and Bottom) with type 2 Descemet membrane detachments (DMD) representing the separation of the Descemet membrane (DM) only. The DM is undulating and in the middle image can be seen to be attached to the posterior surface of the cornea, suggesting 2 separate areas of DMD. In all 3 cases the DMD was planar (ie, the separation was less than 1 mm).**

and of the latter from the former. A mixed DMD was seen in a total of 11 cases, including 6 with post–cataract surgery DMD, all 4 cases of acute hydrops, and 1 case with a descemetocele.

The detached layer usually presented as 1 continuous sheet but in 3 cases there were more than 1 area of detachment with the DM/PDL remaining attached in between (Figure 6). In 2 cases of mixed DMD, a strand of hyperreflective tissue could be seen extending from the posterior stroma to the detached PDL (Figure 5). This was not seen in any case of type 2 DMD. There was 100% concordance among the 3 observers in distinguishing the 3 types of DMD ($F = 0.000$, $P = 1.0$).

In all types of DMD, the detached layer(s) either were intact (nonrhegmatogenous) or showed a tear (rhegmatogenous) in the detached DM (5 cases) or in both DM and PDL (4 cases) (Figure 8). The torn edge of the DM in type 2 or mixed DMD showed a prominent scroll while the torn edge of the DM + PDL attached to each other showed a "rounding off" or a less prominent scroll (Figures 8 and 9). In both instances, the posterior (endothelial) surface of the scroll was on the outside. In cases of acute hydrops with mixed DMD the OCT features over some parts of the total area of the DMD were that of a type 1 DMD and in other parts demonstrated the features of a mixed DMD, with separation of the detached PDL and DM from each other, especially in the vicinity of a tear. This was seen in all cases of acute hydrops, where both the DM and PDL were torn (Figure 9). In no case of mixed DMD was the PDL torn with an associated intact DM. In the case where a type 1 DMD was noticed post-DSEK, the entire host DM over a diameter of 9 mm had been removed at the time of surgery. Postoperatively, the DMD was seen as a hyperreflective line apposed to the DSEK graft, which was thicker in the area corresponding to the DMD compared to the rest

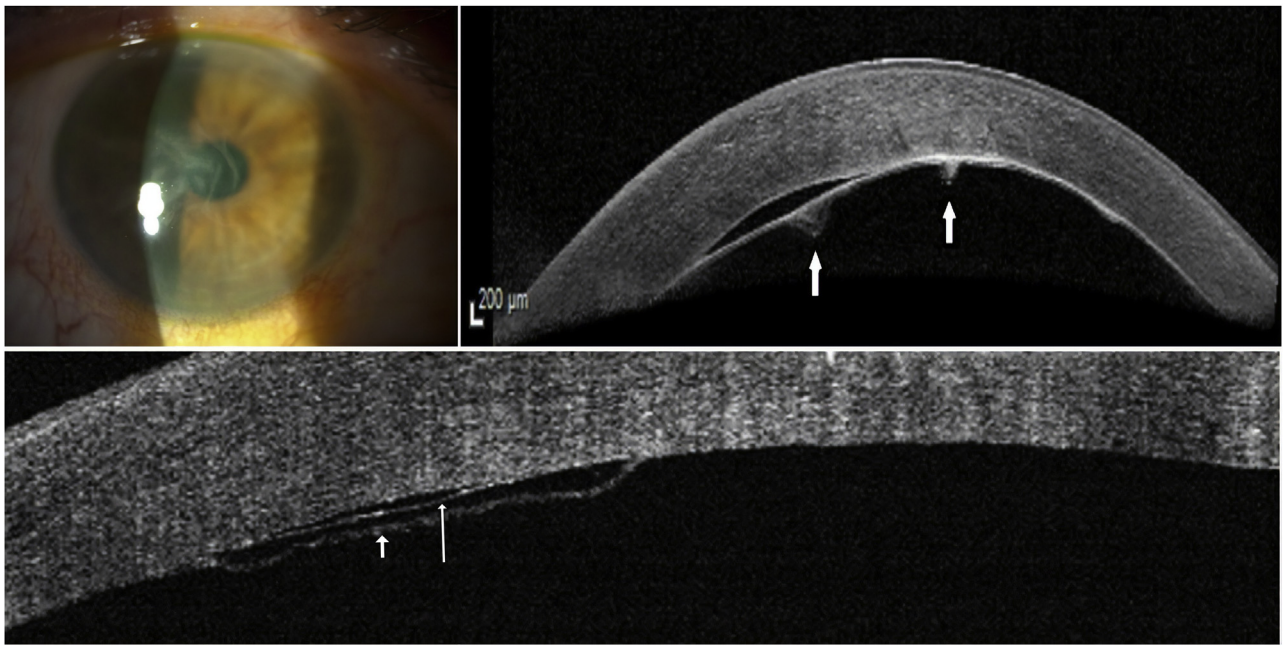


**FIGURE 7. Top left. Postoperative persistent corneal edema following cataract surgery. Top right. An anterior segment optical coherence tomogram (Heidelberg Spectralis OCT) (ASOCT) of the cornea shows a mixed Descemet membrane detachment (DMD). The component representing the pre-Descemet layer (Dua's layer, PDL) is seen as a straight taut line, like the chord of a circle. Posterior to it, 2 undulating areas (arrows) are seen, representing the separation of the Descemet membrane from the PDL. Bottom. ASOCT (RTVue, Optovue) of another patient illustrating a mixed DMD. The DMD is made of 2 lines, 1 anterior hyperreflective line representing the detached PDL (long thin arrow) and a posterior undulating hyperreflective line representing the detached Descemet membrane (short thick arrow).**

that was attached (Figure 9). Only 2 type 2 DMD were nonplanar (measuring 1124 and 1082 µm, respectively). The rest were planar, with the detachment distance ranging from 170 µm to 714 µm (mean 320.22 ± 180.92 µm). All type 1 and mixed DMD were planar (Figure 4).

• **HISTOPATHOLOGY AND CORRELATION WITH ANTERIOR SEGMENT OCT:** All tissues available for histologic examination were from either type 1 or mixed DMD cases. The PDL was clearly visible as a collagenous layer (Figures 10-12). The substance of the PDL did not show any cells in 2 cases (Figures 10 and 11), but infiltration with cells was seen in 3 cases (Figures 12 and 13). There were no mononuclear cells seen infiltrating the posterior stroma. Morphologically the cells infiltrating the PDL too were not mononuclear cells. In the 5 cases where histopathology was available, it correlated with the ASOCT findings. All 3 cases diagnosed as type 1 DMD on ASOCT showed the PDL and DM together on the histology sections. Both cases that were diagnosed as mixed DMD on ASOCT showed the PDL and DM on histology, which were detached from the posterior stroma and also separated from each other.

## DISCUSSION

THE CLEAVAGE PLANES BETWEEN THE PDL AND DEEP corneal stroma and between the PDL and DM have been clearly demonstrated during deep anterior lamellar keratoplasty performed by Anwar's Big Bubble (BB) technique in vivo[11,12] and in simulated deep anterior lamellar keratoplasty ex vivo in eye bank eyes.[8] Air can cleave the PDL and DM together in what is termed the type 1 BB, the DM from the PDL in the type 2 BB, and a combination of type 1 BB and type 2 BB, with the latter being partial or complete, termed mixed BB.[8,13,14] From the cases presented in this study it is evident that clinically, DMD too follows the same pattern. When DMD involves the separation of the PDL from deep stroma with the DM attached to its posterior surface, as in a type 1 BB, the ASOCT image shows this as a

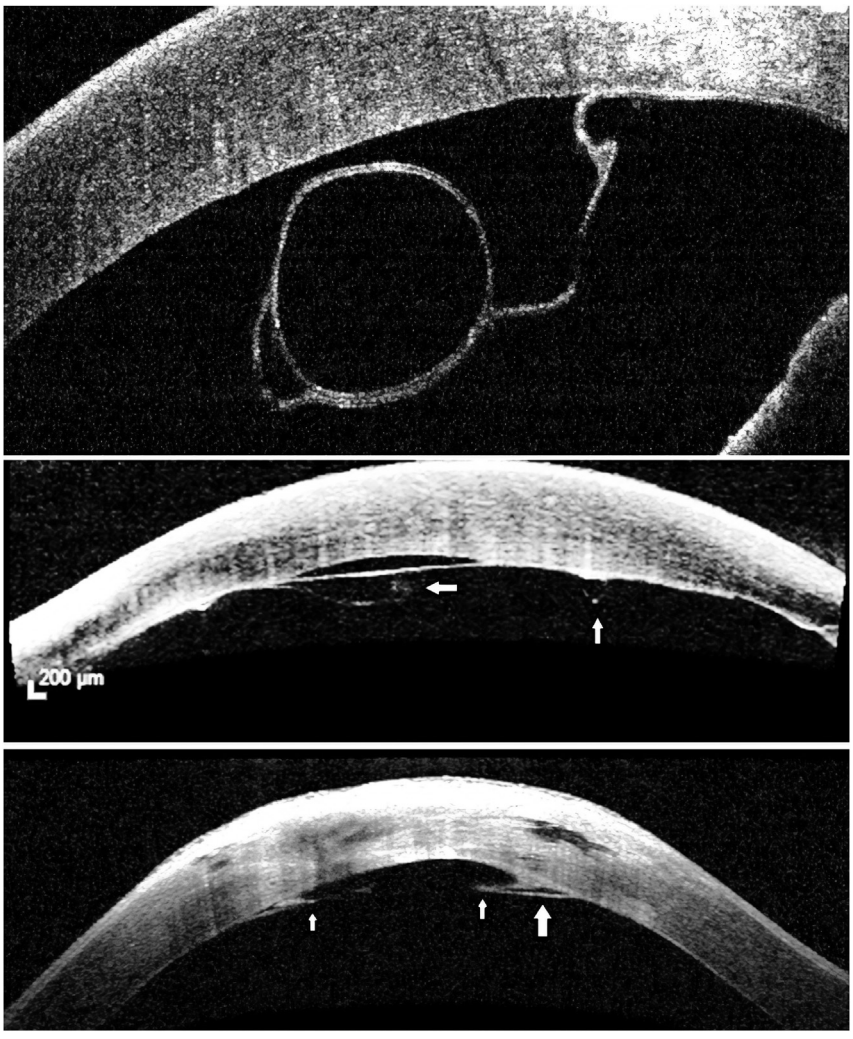


**FIGURE 8. Anterior segment optical coherence tomograms (ASOCT) of 3 different patients (Top, Middle, and Bottom) showing rhegmatogenous Descemet membrane detachment (DMD). Top. OCT (RTVue) showing a nonplanar type 2 DMD post-phacoemulsification, with the Descemet membrane (DM) forming a scroll with the posterior surface outside, as is typical of the DM. Middle. OCT (Heidelberg Spectralis) showing a mixed DMD. The anterior hyperreflective straight and taut line, like the chord of a circle, is the detached pre-Descemet layer (Dua's layer, PDL). Posterior to it is the slightly sinuous thinner hyperreflective line with a scroll at the torn end (horizontal arrow) representing the detached and torn DM. The other end of the DM is visible as a fold (vertical arrow). In this rhegmatogenous DMD the DM was torn but the PDL was intact. Bottom. OCT (Heidelberg Spectralis) of acute hydrops in keratoconus, showing a mixed rhegmatogenous DMD where both the PDL and DM are torn. The torn ends of PDL and DM (small arrows) are "rounded off" and attached to each other. The gap between the torn ends corresponds to an area of "excavation" in the posterior cornea. The separation of DM from PDL (mixed DMD component) is visible at 1 end (large arrow) of the DMD. Dark spaces in the stroma represent fluid pockets seen in acute hydrops.**

relatively thicker, taut, hyperreflective, straight line like the "chord of a circle." When only the DM is separated, as in a type 2 BB, the ASOCT image shows a relatively thin, undulating hyperreflective line. When DMD includes the separation of the PDL and DM individually, from the deep stroma and from each other respectively, it would mimic the cleavage of a "mixed BB," showing 2 hyperreflective lines, but retaining their "chord of a circle" and "undulating" characteristic, respectively.

Such separation along the cleavage planes offered has also been shown to occur in deep fungal infections[15]

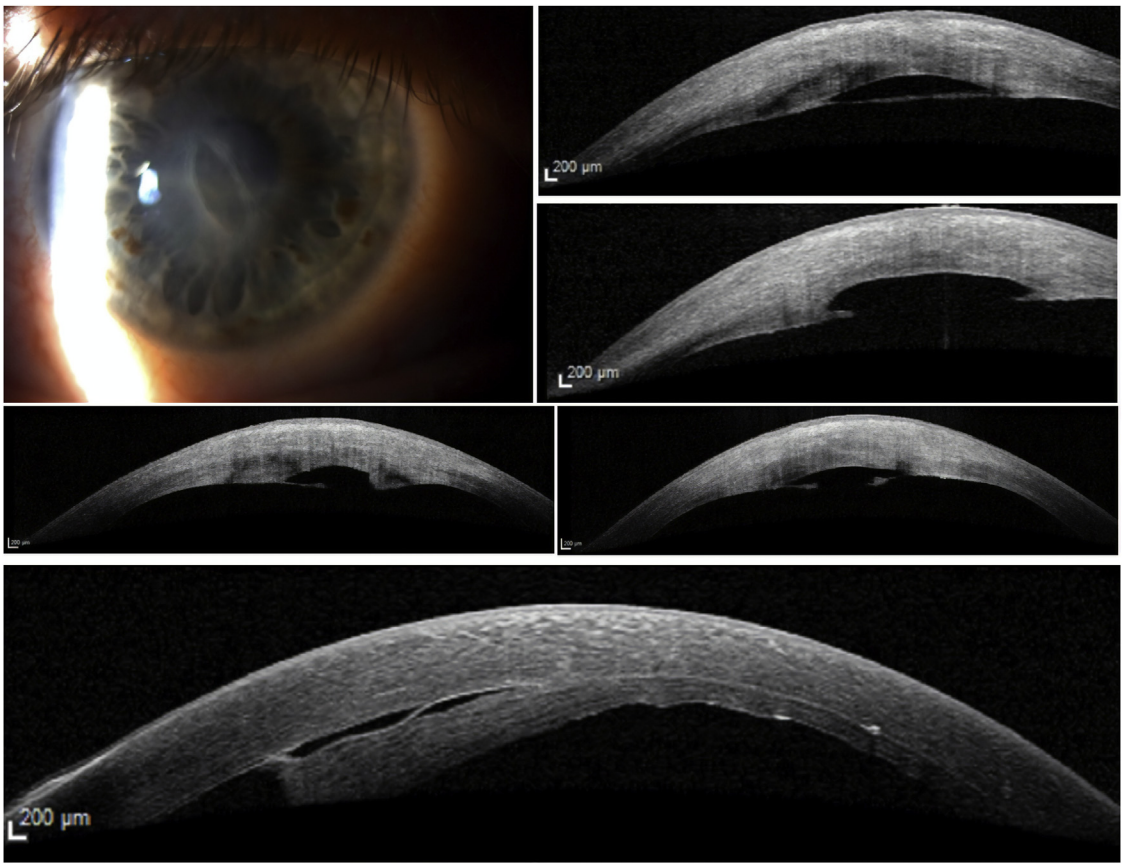


**FIGURE 9. Top left. Slit-lamp diffuse illumination image of a cornea with resolving acute hydrops. The outline of the tear in the posterior layers is clearly visible as a while oval. Top right. Anterior segment optical coherence tomogram (ASOCT) through the cornea superior to the upper end of the tear. A type 1 Descemet membrane detachment (DMD) is seen as a hyperreflective, straight, taut line. Second from top right. ASOCT through the cornea through the center of the tear showing segments of the detached pre-Descemet layer (Dua's layer, PDL) and Descemet membrane (DM), which are attached to each other. The torn ends are "rounded off." The gap between the torn ends corresponds to an excavation in the posterior stroma. Middle left. ASOCT through the cornea between the center and lower end of tear. The torn end of the type 1 DMD shows a prominent scroll on the right-hand side. Middle right. ASOCT through the cornea close to the lower end of the tear. Some scrolling/"rounding off" of the torn ends of the PDL and DM is seen. Bottom. ASOCT showing a type 1 DMD after Descemet stripping endothelial keratoplasty (DSEK). The detached PDL is seen as a hyperreflective white line, which is partly apposed to the underlying DSEK graft, which in turn is thicker in the area corresponding to the DMD compared to the area where it is well attached. The type 1 DMD is different here in that there was no DM, which was stripped off during the DSEK procedure. All ASOCT images were with the Heidelberg Spectralis OCT.**

and in 1 case following cataract surgery where we reported what we now term the mixed DMD.[10] In this series of cases, besides cataract surgery, DMD was associated with (failed) PK and chronic edema and with acute hydrops in keratoconus and pellucid marginal degeneration and in association with descemetoceles. Corneal edema is known to be an effect of DMD but conversely it can be the cause of DMD, in particular type 1 DMD, as seen in failed corneal grafts where chronic corneal edema secondary to endothelial failure precedes the occurrence of DMD.

Based on the presence or absence of a tear, 2 further variations can occur in the different types of DMD. The DM can be intact (nonrhegmatogenous) or torn (rhegmatogenous DMD) in any of the types of DMD; and the PDL too can be torn, together with the DM, in Type 1 and Mixed DMD.[10] A tear in the PDL alone, without a tear in DM, in type 1 or mixed DMD was not seen and

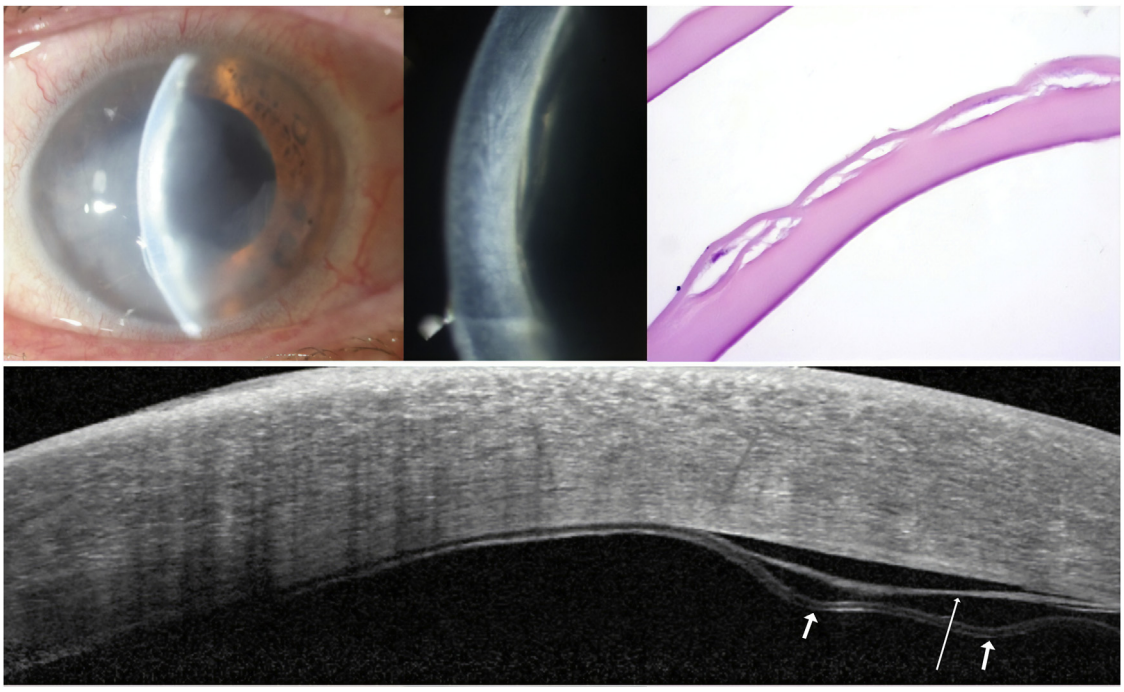

**FIGURE 10. Top left. Diffuse-illumination slit-lamp image of a cornea after cataract surgery showing persistent corneal edema. Top middle. Slit view of the cornea shows detached layers of Descemet membrane detachment (DMD) (mixed DMD). Top right. Histology (hematoxylin-eosin stain, original magnification ×400) of the tissue removed during Descemet membrane endothelial keratoplasty (DMEK) shows a segment where the pre-Descemet layer (Dua's layer, PDL) is separated from the underlying Descemet membrane, confirming the mixed DMD. No cells are visible in the PDL stroma. Bottom. The DMD is illustrated in the preoperative optical coherence tomogram (OCT; Heidelberg Spectralis); where detached PDL (long thin arrow) and DM (short thick arrows) are clearly visible, the latter as a double-contour image of 2 parallel thin hyperreflective lines separated by a narrow dark space.**

is unlikely to occur. It is very likely that when both DM and PDL tear, as seen with acute hydrops, the ASOCT appearance is that of a mixed DMD. That acute hydrops results from a tear in both DM and PDL was first proposed by Dua and associates.[8,16] Yahia Chérif and associates[17] have shown that rapid resolution of acute hydrops can be induced by approximating the torn edges of the PDL with deep mattress sutures, leaving the curled edges of the torn DM separated. Recently Parker and associates[18] while performing Bowman membrane transplant in keratoconus eyes, provided evidence to confirm that a tear in PDL is needed for acute hydrops to occur and that a tear in DM by itself is not sufficient. The altered collagen and ground substance in keratoconus is also a contributory factor.[19]

The Descemet membrane by itself is detached only in a type 2 DMD, but technically it is detached in all 3 types, though attached to the detached PDL in type 1 and detached from the detached PDL in mixed DMD. Hence the term DMD can be retained to describe the overall condition, with the exact nature being qualified by the different types and whether a tear is present or not. Though OCT images often correlate with histology, the reflectivity is not determined by the histology of the tissue examined but by differences in refractive indices between tissues. The DM, especially with high-resolution OCT, often but not always appears as 2 closely approximated thin lines running parallel to each other (double contour line). This appearance is seen in the normal cornea[20,21] and ex vivo with DM/endothelium separated as a type 2 BB.[22] Using ultra-high-resolution OCT, Bizheva and associates[23] have demonstrated the PDL and DM/endothelium in the living human eye.

Histologic evidence of the involvement of PDL and DM in this series was limited to 5 cases but these, together with the ASOCT findings, provide compelling evidence of the involvement of PDL in DMD and support the proposed classification. All 3 cases where keratoplasty was performed (3 penetrating keratoplasty and 2

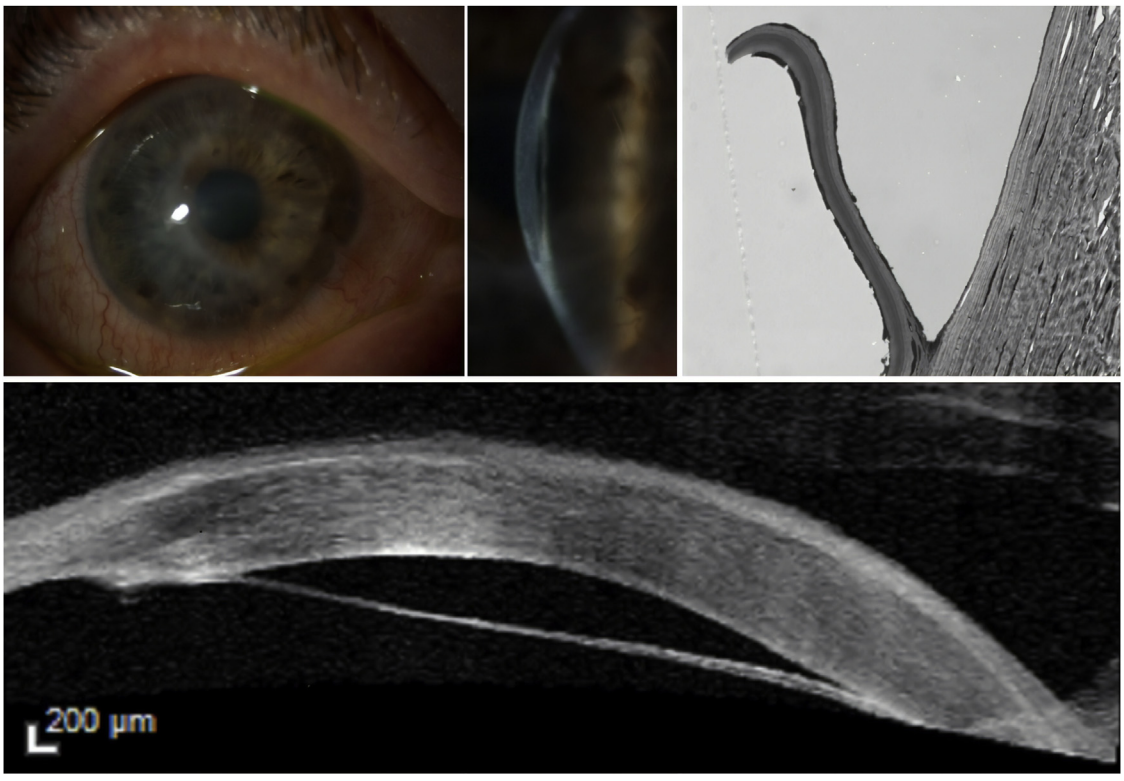


**FIGURE 11. Top left. Slit-lamp diffuse-illumination image of a cornea that had a small eccentric full-thickness graft for keratoconus. There was persistent edema in the host bed that eventually resolved, following which a Descemet membrane detachment (DMD) was noted. Top middle. Slit view showing the DMD as a taut, straight line like the chord of a circle. Top right. Histology (hematoxylin-eosin stain, original magnification ×400) of the tissue removed during a repeat penetrating keratoplasty (PK) shows a segment of the type 1 DMD where the banded and nonbanded layers of the Descemet membrane (DM) and pre-Descemet layer (Dua's layer, PDL) are clearly visible. The PDL has a single layer of cells lining its anterior surface but no cells are visible in the stroma of the PDL. No inflammatory cell infiltration is seen in the PDL or posterior corneal stroma. The PDL was artefactually transected during sectioning for histology. Bottom. The type 1 DMD is illustrated in the preoperative optical coherence tomogram (OCT, Heidelberg Spectralis) as a straight, taut, hyperreflective line like the chord of a circle.**

endothelial keratoplasty) had long-standing corneal edema. On histology the detached PDL demonstrated no cells in 2 cases and sparse cells were seen in the other 3 cases. Though no specific staining for the nature of the cells was done, morphologically they did not appear to be mononuclear inflammatory cells and the adjacent corneal stroma too did not show any inflammatory cell infiltration. It is quite likely that these were keratocyte-derived cells, myofibroblasts/fibroblasts invading from the adjacent stroma. Cicatrization within the PDL may induce contracture and rigidity, making it more difficult to reattach by rebubbling. In type 1 DMD the chord length of the DMD appears to be shorter than the overlying stroma from which it has detached. This could be owing to scarring and contracture in long-standing cases but can be due to the elastic recoil of the PDL, which is known to have a high content of elastin that is uniformly distributed along its entire thickness and length (except the extreme periphery).[24] In contrast, the elastin content is concentrated as a dense band on the anterior 10%-20% of the DM, which explains the scrolling characteristic, always with the endothelium outside.[25] The scrolling of the type 1 DMD tissue in rhegmatogenous cases is by virtue of the DM attached to the PDL.[25] Thus for type 1 it would be logical to treat earlier while its elasticity is maintained and before contracture has set in. In the latter situation, a relaxing incision in the DMD may be needed.[2] Several approaches with reasonable success in

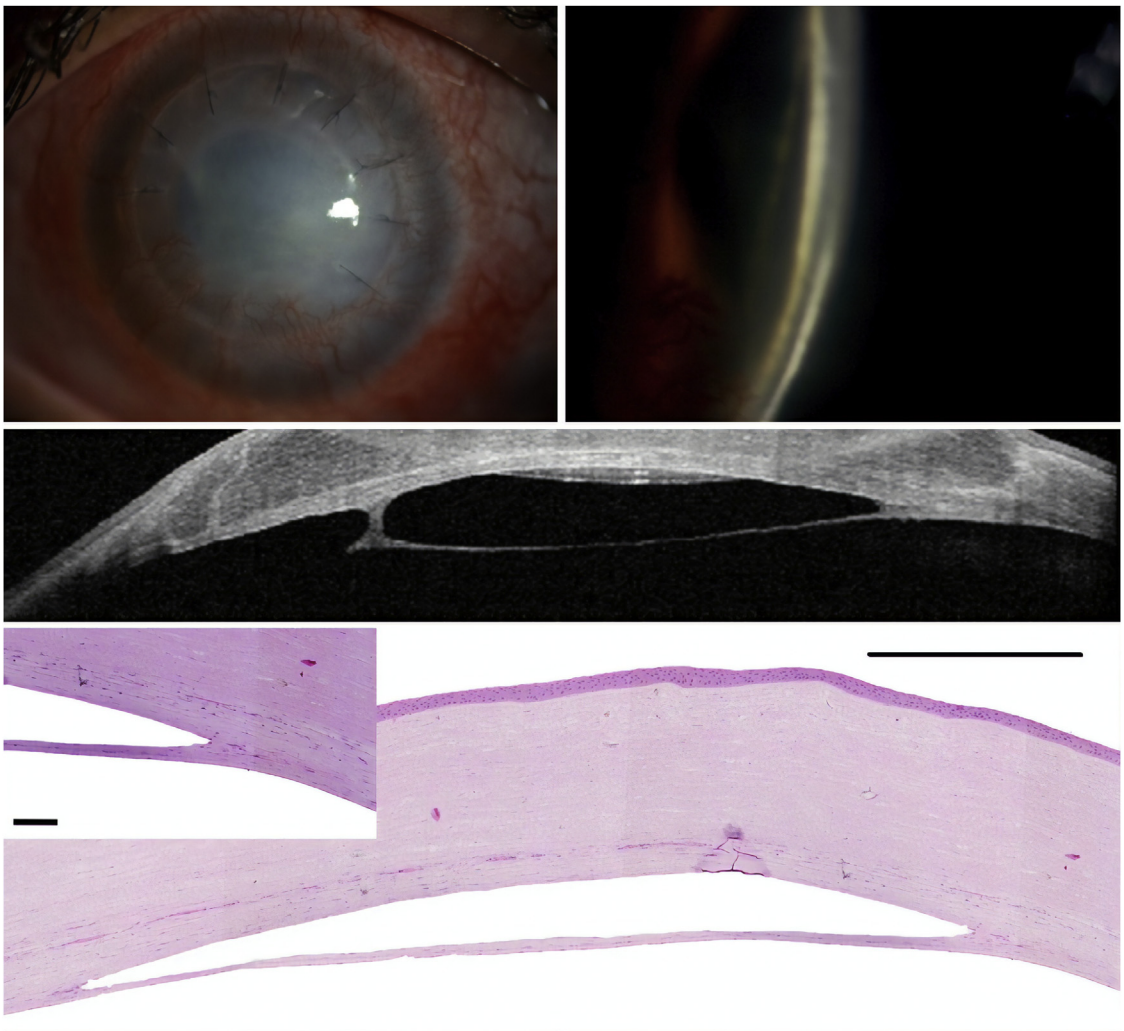

**FIGURE 12. Top Left. Slit-lamp diffuse-illumination image of a cornea with a failed full-thickness corneal graft with scarring and vascularization. Top right. Slit view shows Descemet membrane detachment (DMD) as a straight, taut line. Middle. Anterior segment optical coherence tomogram (ASOCT, Heidelberg Spectralis) image showing the type 1 DMD as a hyperreflective, taut, straight line, like a chord of a circle. There is a broad, hyperreflective strand extending from the posterior stroma to the pre-Descemet layer (Dua's layer, PDL). Bottom. Histology (hematoxylin-eosin, bar = 500 μm) showing that the DMD is made of the collagenous PDL. The Descemet membrane was artefactually lost during processing but was reported as having no endothelial cells. There was increased cellularity of the PDL in both the detached and the attached parts (inset, bar = 100 μm).**

the management of DMD have been described in the literature, but none of them have considered the involvement of the PDL in the DMD and the differences between the different types of DMD.[2–6,26,27] Hence it is difficult to make a judgment on which would be the best approach for each type and the effect of early or late intervention. A prospective approach, in the light of the knowledge presented in this paper, combined with etiology (idiopathic, spontaneous, trauma including surgery, tumor, traction, inflammation) would provide valuable answers.

The limitations of this study relate to its retrospective nature, etiologic heterogeneity, and use of 2 different OCT machines. However, no significant clinical differences have been reported when different spectral-domain OCT machines were compared.[28,29] The OCT findings were consistent across these variables, indicating that the pathologic anatomy of DMD, types 1 and 2 and mixed, remains the same across the etiologies studied. The OCT scan should cover the entire extent of the DMD to reveal the true nature of the type of DMD.

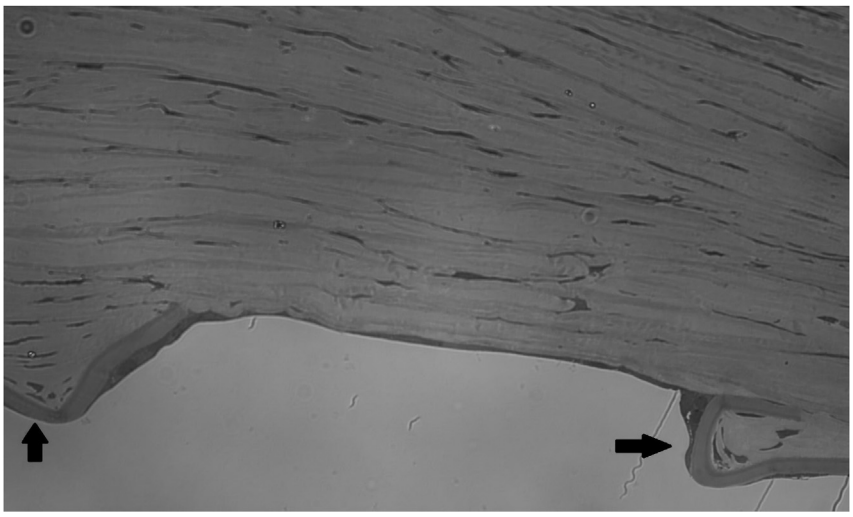

**FIGURE 13. Histology (resin-embedded ultrathin section, toluidine blue stain, original magnification ×1000) of cornea removed at penetrating keratoplasty after resolution of acute hydrops. The torn ends of the Descemet membrane (DM) and pre-Descemet layer (Dua's layer, PDL) are visible with prominent endothelial cells on the posterior surface and extending across the stroma between the ends of the break. There is an excavation of the stroma in the area corresponding to the break. A prominent scroll of 1 torn end of DM and PDL with the endothelial surface outside is seen (horizontal arrow). There is increased cellularity of the PDL stroma at both ends (arrows), but no mononuclear cell infiltration is seen in the PDL or posterior corneal stroma.**

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