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Article

Morselized Amniotic Membrane Tissue for Refractory Corneal Epithelial Defects in Cicatricial Ocular Surface Diseases

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Purpose: To evaluate the clinical efficacy of morselized amniotic membrane and umbilical cord tissue (MAU) in treating refractory corneal epithelial defect in ocular cicatricial diseases.

Methods: Retrospective review of four patients with ocular cicatricial diseases treated with topical MAU for corneal epithelial defects refractory to conventional treatments including topical lubricants, autologous serum, bandage contact lens, and tarsorraphy. Their symptoms, corneal staining, conjunctival inflammation, and visual acuity were compared before and after treatment.

Results: After topical application of MAU twice daily, two patients demonstrated rapid corneal epithelialization with prompt visual acuity improvement at the first day. All patients showed corneal epithelialization in 7.3 $\pm$ 2.6 days accompanied by a significant relief of symptoms, reduction of ocular surface inflammation, and improvement of visual acuity.

Conclusion: This pilot study suggests topical MAU can be developed into a novel treatment for treating refractory corneal epithelial defects.

Translational Relevance: Topical MAU can be an effective novel treatment for refractory corneal epithelial defects.

Introduction

Cicatricial ocular surface diseases caused by diverse etiologies such as ocular cicatricial pemphigoid, Stevens-Johnson syndrome, toxic epidermal necrolysis, and chemical burns are frequently associated with a myriad of ocular complications leading to significant visual morbidity. Ocular surface involvement is characterized by conjunctival scarring that progresses to lid margin scarring, development of symblepharon, and foreshortening of the fornix.[1,2] Depending on the location, symblepharon might obliterate the tear reservoir and interfere with effective replenishment of tears in the meniscus and ocular surface leading to dry eye. In addition, these cicatricial complications if associated with lid margin keratinization, scarring, and mal-aligned lashes invariably cause blink-related trauma to the ocular surface and correlate significantly with persistent ocular surface inflammation leading to corneal epithelial breakdown.[1,3,4] Consequently, corneal blindness frequently ensues in an advanced stage of cicatricial ocular surface diseases.[5–8]

Inflammation and fibrosis are the two main pathologic processes of the aforementioned cicatricial ocular surface diseases.[6] Conceivably, measures directed to suppress this inflammatory/scarring cascade should be valuable. Conventional measures include systemic immunomodulators as well as topical tear lubricants, steroids, autologous serum, bandage contacts lens (BCL), and scleral lens.[6,8–10] Another therapeutic modality is transplantation of cryopreserved amniotic membrane (AM), which has been shown to suppress inflammation, angiogenesis, and scarring so as to promote epithelial wound healing.[11] For example, persistent or refractory corneal epithelial defect has been successfully managed by securing single[12,13] or multiple[12–18] layers of AM by sutures or fibrin glue.[19–22] To facilitate the ease and ready use in

Table. Summary of Relevant Clinical Data

Subject Number	Age, y	Gender	Eye	Concomitant Disease	Prior Treatment	Symptoms	
						Pre	Post
1	92	Female	R	Exposure keratopathy	Cyc, Tar, AT, AS, PO	pa, pho, i, BV, bur, mu	-
2	85	Female	R	DED, EBMD	Cyc, PK, AT, BCL, PO	pa, dry, i, BV, mu	mu
3	68	Female	L	HSV	Cyc, OMG, PK, AT, BCL, PO	dry ,i, red, BV	-
4	69	Female	R	DED, RA	Cyc, PK, AT, BCL, PO	pa ,dry, pho, i, BV, bur, mu	i, mu

AT, artificial tears; AS, autologous serum; BCL, bandage contact lens; bur, burning; BV, blurred vision; Cyc, cyclophosphamide; dry, dryness; i, irritation; L, left; mu, mucous; OMG, oral mucosal graft for lid reconstruction; pa, pain; pho, photophobia; PK, PROKERA placement; PO, punctal occlusion; Post, postoperative finding; Pre, preoperative finding; R, right; RA, rheumatoid arthritis; red, redness; Tar, tarsorraphy.

The definition of grading or severity is detailed in the text.

the office, sutureless self-retaining cryopreserved AM via PROKERA (Bio-Tissue, Inc., Miami, FL) has been developed to treat persistent and refractory corneal epithelial defects.[23–27] Nonetheless, the aforementioned methods of applying cryopreserved AM may not be amenable in eyes with cicatricial processes. For example, symblepharon and fornix shortening may preclude the use of PROKERA. That was why we have developed a morselized form of cryopreserved AM and umbilical cord tissue (MAU) and presented our preliminary success of using topical application of MAU in treating refractory corneal epithelial defects in four consecutive cases of cicatricial ocular surface diseases.

Methods

This study was approved by the ethics committee of the Ocular Surface Research and Education Foundation (Miami, FL) according to the Tenets of the Declaration of Helsinki to retrospectively review four patients with cicatricial ocular surface diseases that were consecutively seen at Ocular Surface Center (Miami, FL) between June 2015 and August 2015.

Preparation of MAU

AM and umbilical cord (UC) tissues are procured in compliance with American Association of Tissue Banks Standards from eligible pregnant women following elective cesarean section delivery under full informed consent. The AM and UC tissues are aseptically processed in accordance with current Good Manufacturing Practices and current Good Tissue Practices regulations into a morselized form by the proprietary CRYOTEK method (TissueTech, Inc., Miami, FL). MAU consists of 25% to 33% wt/vol AM and UC tissues in 0.9% wt/vol sodium chloride added with 250 μg/mL Amphotericin B (Mediatech, Inc., Manassas, VA), an antifungal agent. MAU is packaged into ophthalmic tubes which delivers 20 to 50 μL of MAU per drop.

Patients

All four patients presented with ocular cicatricial diseases manifesting medial canthal scarring, fornicial shortening, symblepharon, occluded puncta, and distichiasis. Their inflammatory activity of the cicatricial disease had been treated with oral cyclophosphamide at the dosage of 1 to 2 mg/kg for a mean of 12.1 ± 10.4 months with titration according to monthly complete blood count and urine analysis to maintain the peripheral white cell count of at least 3000 cells/mm^3.[2]

The Table summarizes the patients' demographics, ocular comorbidity, concomitant treatment, and clinical manifestations including symptoms and signs at the presentation. Conjunctival inflammation was graded according to the conjunctival injection as none (0), mild (1), moderate (2), and severe (3). The corneal surface integrity was scored as clear (0), scattered superficial punctuate keratitis (SPK; 1+), moderate SPK (2+), and diffuse SPK with or without corneal epithelial defects (3+). The tear function was assessed by the fluorescein clearance test as reported[28] using the Schirmer paper strip following topical application of 5 μL of Fluroress (Akorn Inc., Abita Springs, LA). The diagnosis of dry eye disease (DED) was based on the wetting length of less than 3 mm at the 10th and 20th minute. For Case #2 who presented with epithelial basement membrane dystrophy (EBMD),

Table. Extended

Subject Number	Conjunctival Grading		Corneal Grading		Visual Acuity	
	Pre	Post	Pre	Post	Pre	Post
1	1	1	3	1	20/400	20/50
2	2	1	3	1	20/400	20/100
3	2	1	3	0	20/60	20/40
4	2	1	3	1	20/80	20/50

the diagnosis was confirmed by observing corneal epithelial wrinkles or breaks by the "screwdriver test," which applies a dry Weck-Cel sponge (Beaver-Visitec International, Inc., Waltham, MA) directly to the corneal surface and makes a 90° twist upon contact.[23] Consequently, epithelial debridement was performed to remove the entire loose epithelium. Because their persistent corneal epithelial defects were refractory to a number of conventional treatments (summarized in the Table), MAU tissue was applied twice daily in all four patients. Their clinical responses during the follow-up visits were documented in the same manner afterward. Descriptive statistics for continuous variables are reported as the mean ± SD and analyzed using SPSS software, version 19.0 (SPSS Inc., Chicago, IL). A P value less than 0.05 was considered statistically significant.

Results

As summarized in the Table, all four patients were female with the average age of 78.5 ± 11.9 years. Associated comorbidity included exposure keratopathy (Case #1), EBMD (Case #2), DED (Case #2 and #4), Herpes Simplex Keratitis (HSV; Case #3), and rheumatoid arthritis (Case #4). At presentation, the inflammatory activity of two patients (Case #1 and #2) had been controlled by oral cyclophosphamide while that of the other two (Case #3 and #4) remained active. Besides systemic cyclophosphamide, they had been treated with the conventional medical treatments including lubricating drops or ointments ($n = 4$), autologous serum ($n = 1$), and BCL ($n = 3$). All eyes had punctal occlusion caused by the disease process. Three eyes (Case #2, #3, and #4) had received placement of self-retained cryopreserved AM (PROKERA) 18, 44, and 1.5 months ago, respectively, without success due to the presence of symblepharon. Case #1 underwent nasal and temporal tarsorraphy. Case #3 received oral mucosa graft for eyelid reconstruction.

Despite the aforementioned treatment, these patients complained of ocular irritation and blurred vision and ocular pain ($n = 3$), dryness ($n = 3$), mucous discharge ($n = 3$), photophobia ($n = 2$), burning ($n = 2$), and redness ($n = 1$). Examination confirmed the presence of symblepharon with fornicial shortening, occluded puncta, and distichiasis. Case #1 presented with an infrequent and incomplete blinking. The conjunctiva inflammation was graded as 1 (Case #1) and 2 in the other three eyes. All eyes had corneal epithelial defects and 3+ SPK. The visual acuity was 0.5 (Case #3), 0.6 (Case #4), and 1.3 logMAR (Case #1 and #2).

All four patients used MAU tissue twice daily without other treatments for 7.3 ± 2.6 days without any difficulty or adverse effect. Within a few days after application, all patients reported a significant relief of symptoms as evidenced by consistent reduction of ocular surface inflammation and rapid corneal epithelialization at Day 1 for Case #1 (Fig. 1) and Case #2 (Fig. 2), Day 2 for Case #3 (Fig. 3) and Day 4 for Case #4 (Fig. 4). Intriguingly, regardless of incomplete epithelialization, two eyes (Case #1 and #2) at Day 1 exhibited improvement of the visual acuity from 1.3 to 0.6 logMAR and from 1.3 to 1 logMAR, respectively. Complete epithelialization was noted in 5 days (Case #1), 6 days (Case #3), 7 days (Case #2), and 11 days (Case #4), respectively. Conjunctival inflammation was reduced from grade 2 to 1 in three eyes (Cases #2, #3, and #4) and remained unchanged as grade 1 in one eye (Case #1). Ocular pain was resolved in all three eyes (Case #1, #2, and #4) and two eyes (Case #1 and #3) reported complete symptomatic resolution of irritation ($n = 2$), blurred vision ($n = 2$), pain ($n = 1$), dryness ($n = 1$), photophobia ($n = 1$), redness ($n = 1$), burning ($n = 1$), and mucus formation ($n = 1$). The other two eyes had most symptoms resolved but there remained mild irritation (Case #4) as well as mucus formation (Case #2 and #4). There was also an improved visual acuity in all eyes from 0.9 ± 0.4 to 0.45 ± 0.1 logMAR ($P = 0.7$) when corneal epithelialization was completed.

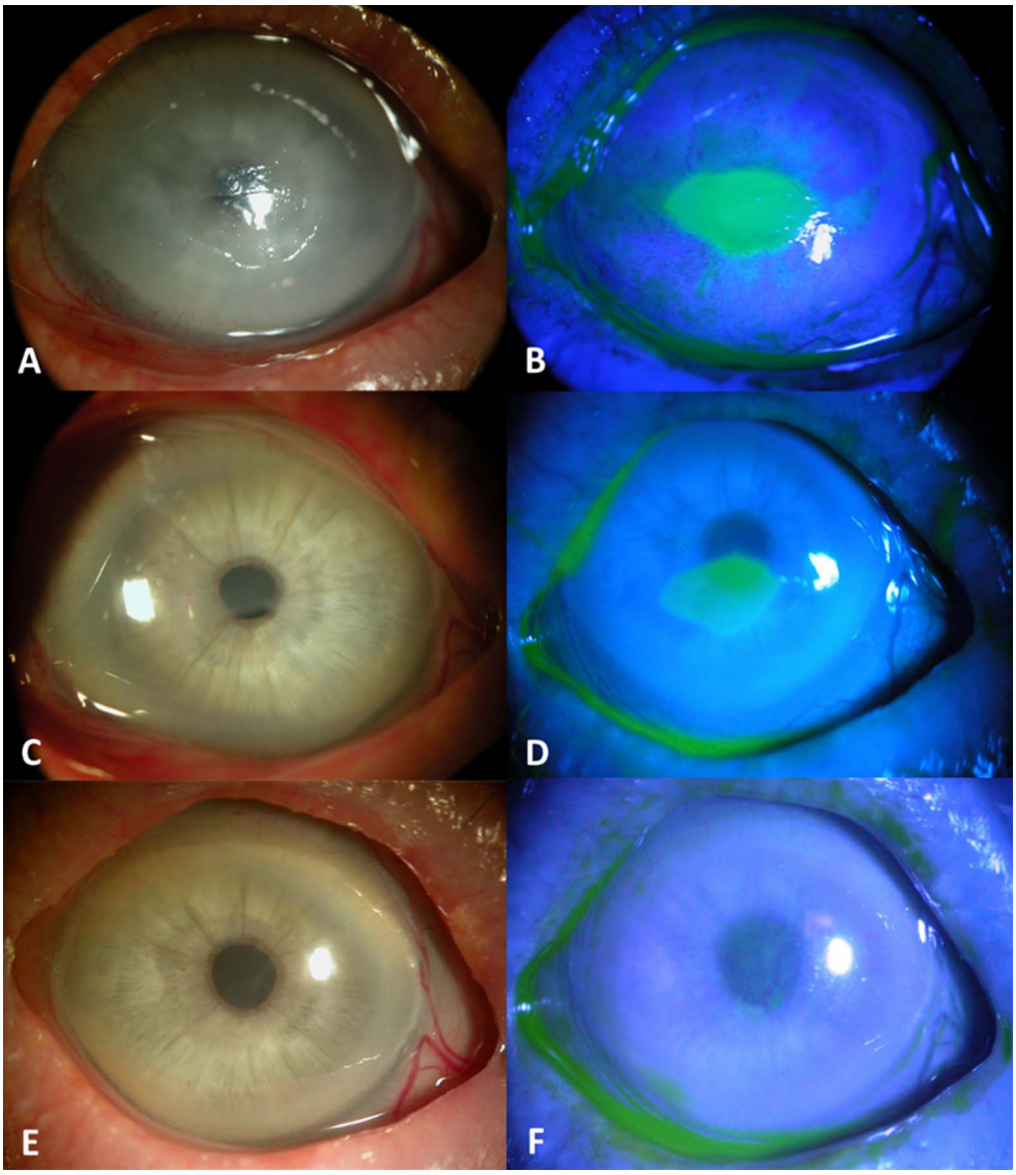

Figure 1. Clinical Course of Case #1. The refractory central corneal epithelial defect with sharp, distinct, irregular border in OD (right eye) (A, B) showed progressive improvement at Day 1 (C, D), and Day 5 (E, F) after topical application of MAU with the visual acuity improved rapidly from 20/400 to 20/80 at the first day. The defect size greatly reduced with progressive epithelialization as suggested by a smoothened edge in 1 day (C, D). All symptoms resolved and visual acuity regained to 20/50 at Day 5.

Discussion

Persistent or recurrent corneal epithelial defect is a frequent corneal complication in cicatricial ocular surface diseases and the prime reason leading to corneal blindness.[6] Indeed, cicatrization-induced severe dry eye and lid margin/tarsal related microtrauma are significantly correlated with corneal pathologies.[1] As shown herein, conservative treatments such as topical lubricants, autologous serum, bandage contact lens, and tarsorraphy failed to treat these corneal epithelial defects. Although refractory cases can be benefited by scleral contact lens,[29] its use was limited in patients as illustrated in this study due to the presence of significant symblepharon. Similarly, placement of PROKERA could not be instituted due to symblepharon in three of four patients. To circumvent these limitations, we have developed MAU and shown its encouraging efficacy in promoting epithelialization, reducing corneal

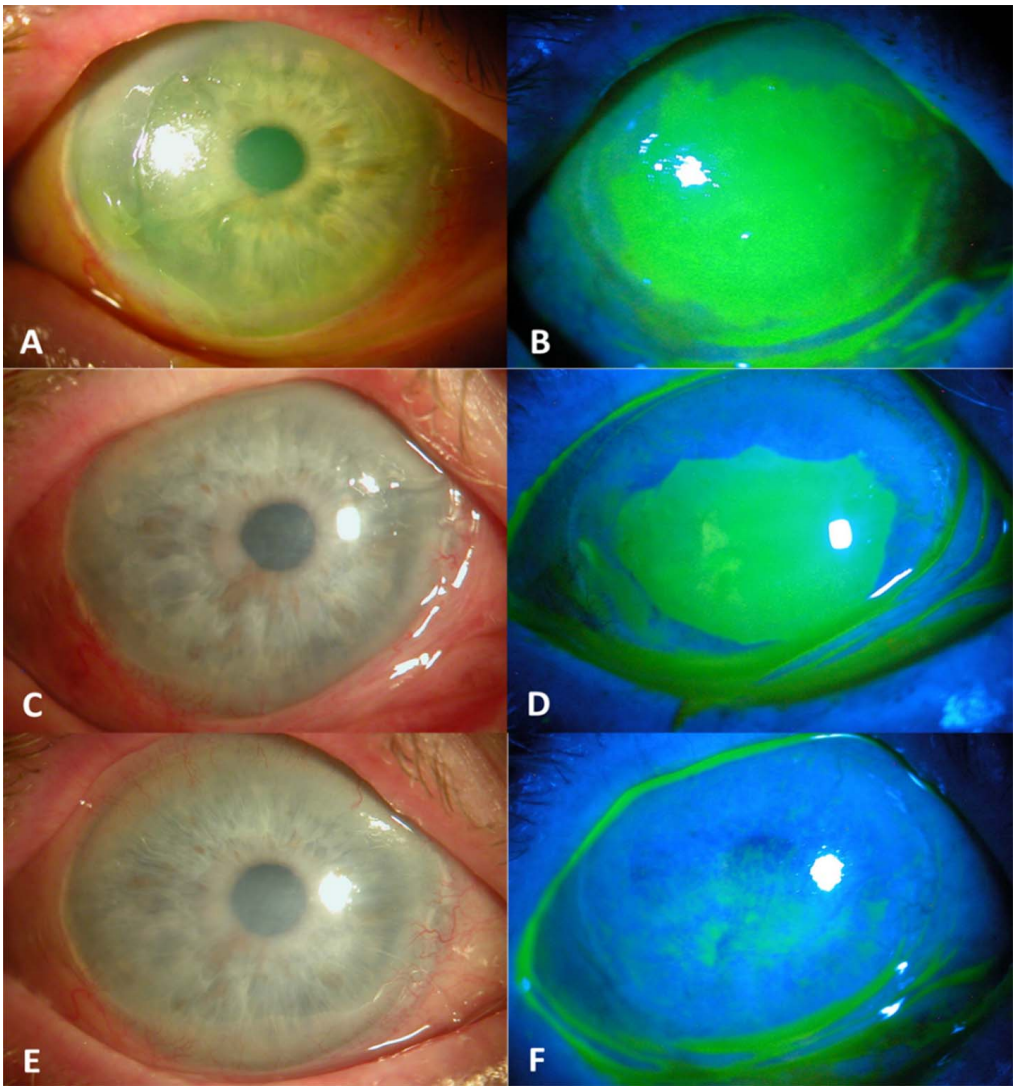

Figure 2. Clinical Course of Case #2. The OD (right eye) received corneal epithelial debridement to remove the entire loose epithelium due to EBMD (A, B). This large corneal epithelial defect showed rapid epithelialization at Day 1 (C, D) and completely healed at Day 7 (E, F) after topical application of MAU. Ocular surface inflammation was reduced and the visual acuity improved rapidly from 20/400 to 20/200 at the first day. Most symptoms resolved and visual acuity eventually regained to 20/100 at Day 7.

staining and conjunctival inflammation, and improving the visual acuity.

Although pathogenic elements of these cicatricial diseases can be multiple, the common denominators are chronic inflammation and fibrosis, which are also interrelated. The clinical efficacy of MAU might be attributed to AM's anti-inflammatory, antiscarring, and antiangiogenic actions. To pursue the active relevant tissue characteristics in AM, we have biochemically purified and characterized a unique matrix termed HC-HA/PTX3 from AM responsible for AM's anti-inflammatory, antiscarring, and antiangiogenic actions[30–36] (also reviewed in refs. 37, 38). HC-HA/PTX3 is formed by a tight association between pentraxin 3 (PTX3) and HC-HA complex, which consists of high molecular weight hyaluronic acid (HA) covalently linked to heavy chain 1 (HC1) of inter-α-trypsin inhibitor (IαI) through the catalytic action of tumor necrosis factor–stimulated gene-6. We have recently reported that HC-HA/PTX3 is also present in the UC.[39,40] HC-HA/PTX3's anti-inflammatory action applies to activated but not resting neutrophils,[30,35] macrophages,[35] and lymphocytes[30] (i.e., extending from innate to adaptive immune responses). In addition, HC-HA/PTX3's antiscarring action applies to human corneal fibroblasts to downregulate the transforming growth factor–β1 promoter activity[36] and its antiangiogenic

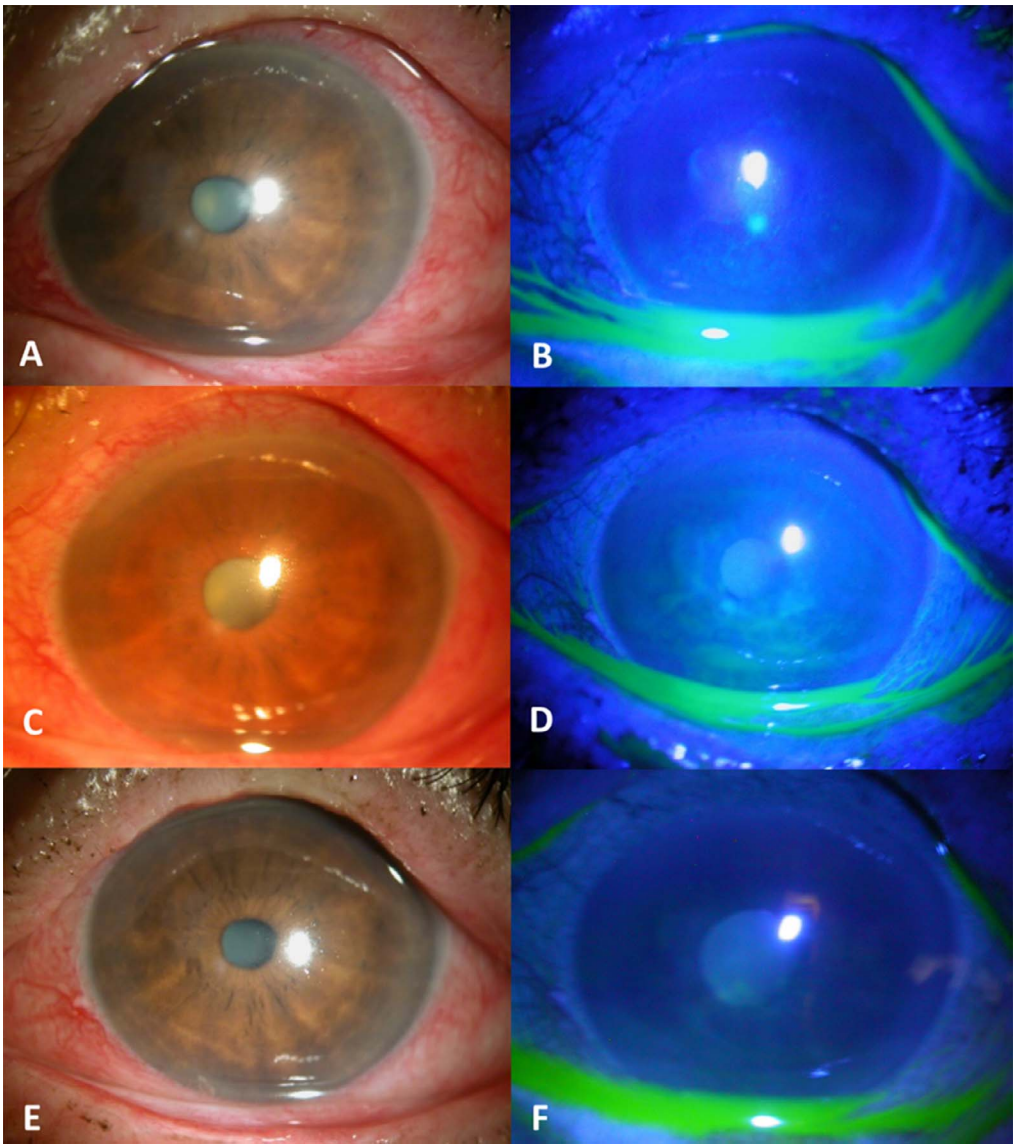

Figure 3. Clinical Course of Case #3. The refractory corneal epithelial defect in OS (left eye) (A, B) showed epithelialization at Day 2 (C, D) and continuous improvement with reduced SPK and inflammation at Day 6 (E, F) after topical application of MAU. Her visual acuity improved from 20/60 to 20/40. The cicatricial disease remained active despite oral cyclophosphamide treatment.

action applies to human umbilical vascular endothelial cells to inhibit cell viability, proliferation, migration, and tube formation.[41] Besides exerting anti-inflammatory, antiscarring, and antiangiogenic effects, HC-HA/PTX3 also distinctively maintains limbal niche cells to support the quiescence of limbal epithelial stem cells toward regeneration.[42] Collectively, these data explain how MAU can be an effective alternative to treat refractory corneal epithelial defects in cicatricial ocular surface diseases.

We formulated MAU by combining AM with UC from the same donor taking advantage of the high content of high molecular HA in UC.[39,40,42] The high HA content might help lubricate the ocular surface to stabilize the tear film[43] and might explain why Case #1 and #2 experienced instant symptomatic relief and rapid improvement of vision one day after topical administration even before complete epithelialization (Figs. 1 and 2). Importantly, the epithelialization rate of Case #1 and #2 was faster than that of Case #3 and #4, suggesting that epithelialization might be influenced by the underlying inflammatory activity, which was controlled in the former two cases, but not the latter two cases, by oral cyclophosphamide. In this study, topical application of MAU twice a day

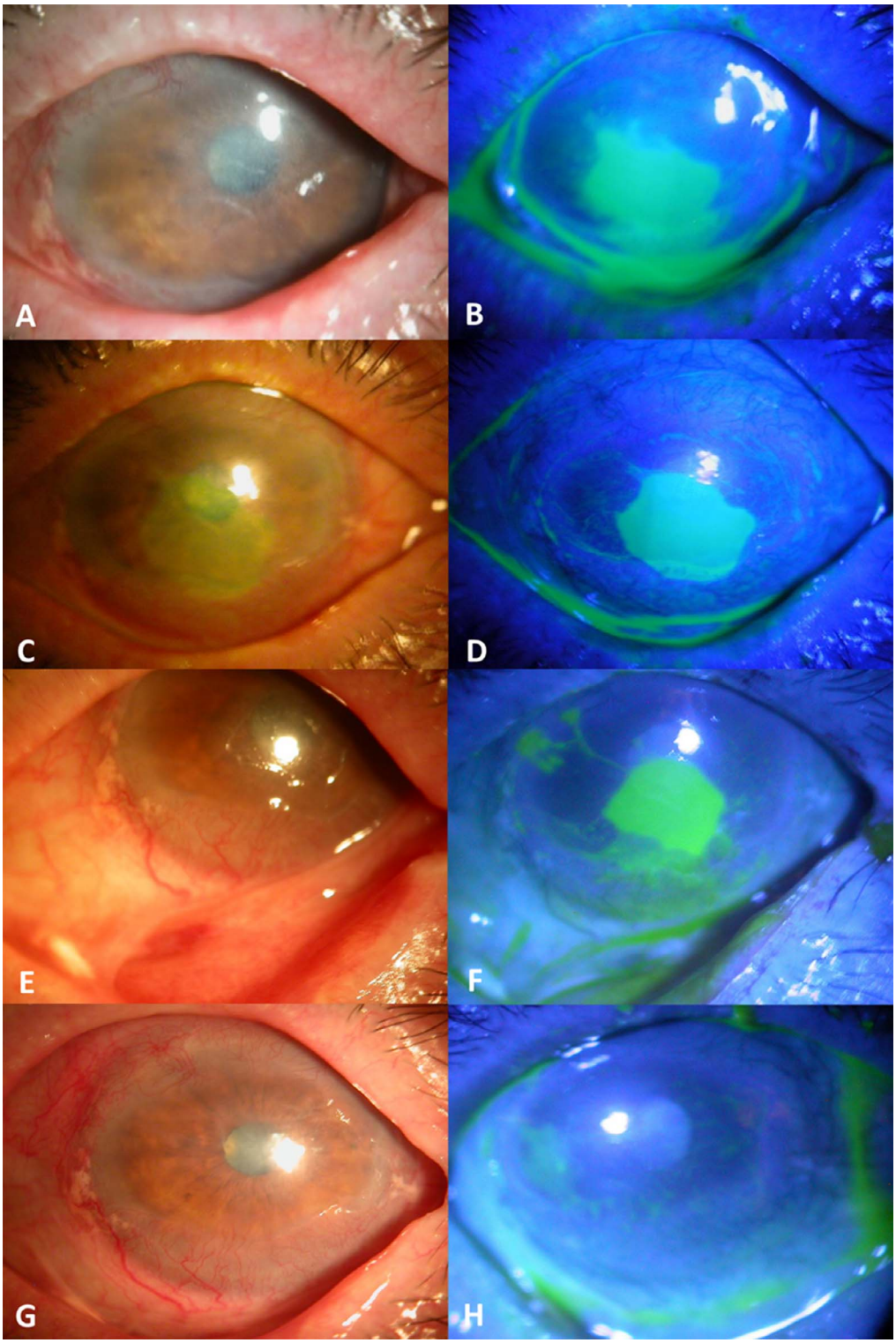

Figure 4. Clinical Course of Case #4. The refractory corneal epithelial defect in OD (right eye) (A, B) showed progressive improvement at Day 4 (C, D), Day 7 (E, F), and Day 11 (G, H) after topical application of MAU. Her visual acuity improved from 20/80 to 20/50. The cicatricial disease remained active despite oral cyclophosphamide treatment. Pressure patching for 2 days was performed because of the sunken globe to avoid nocturnal exposure.[44] At Day 4 post application, 0.05 mL inferior subconjunctival kenalog was injected to control conjunctival inflammation.

appeared to be sufficient in all four patients presumably because of punctal occlusion that delays tear drainage. In line with this thinking, topical MAU might also be applied in eyes with bandage contact lens or scleral lens. Future studies are needed to determine the optimal application regimen in eyes without punctal occlusion. Our preliminary success reported herein warrants additional prospective controlled studies.

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Disclosure: Dr. Tseng has obtained a patent (US 14/729,489 and PCT/US2015/033955) for the method of preparation and clinical uses of amniotic membrane and morselized form of cryopreserved AM and umbilical cord tissue. **A.M. Cheng,** Ocular Surface Center (E); **L. Chua,** TissueTech, Inc. (E); **S.C. Tseng,** TissueTech, Inc. (E, F) (P)

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