The application of infrared imaging and optical coherence tomography of the lacrimal punctum in patients undergoing punctoplasty for epiphora

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Abbreviations:

OCT – optical coherence tomography

EDI – enhanced depth imaging

ASM – anterior segment module

IR – infrared

HEYEX – Heidelberg Eye Explorer

NLDO – nasolacrimal duct obstruction

ABSTRACT

Purpose: To determine the application of imaging the stenotic lacrimal punctum with infrared photographs and optical coherence tomography (OCT), and to identify characteristics of the lacrimal punctum in patients who benefit from punctoplasty.

Design: Case-Control Study

Subjects: 20 patients with epiphora who were listed for punctoplasty, and 20 healthy controls.

Methods: Prospectively, 20 patients listed for punctoplasty were asked to rate their epiphora, using the Munk score, before and after punctoplasty. They also underwent pre-operative OCT and infrared imaging of the affected punctum. They were divided into two groups, depending upon whether their epiphora improved or not, and were compared to 20 healthy controls.

Main Outcome Measures: Measurements of puncta from infrared and OCT images were taken along with Munk scores of patients' epiphora.

Results: The infrared image measurements were significantly smaller in those patients whose epiphora improved compared to those that did not, in both the area of the punctal aperture and in the maximum punctal diameter. Additionally those patients with improvement in epiphora had a significantly smaller preoperative punctal diameter at 100μm depth on OCT, as compared to healthy controls; this was not observed in patients whose epiphora failed to improve. There was no significant difference in the punctum diameter between the three groups at the punctum surface entrance or at 500μm depth.

Patients with epiphora had a higher tear meniscus within the punctum compared to healthy controls.

Conclusions: Lacrimal punctum infrared and OCT imaging may be helpful in predicting patients more likely to benefit symptomatically from punctoplasty, with patients with smaller puncta have greater symptomatic improvement. However, it also suggests that inner punctum diameter (not readily measurable by slit-lamp examination), rather than the surface diameter, is correlated with outcome. Additionally, OCT measurements of the tear meniscus height within the punctum may be related to the degree of epiphora.

Keywords: Lacrimal punctum, stenosis, epiphora, optical coherence tomography, non-invasive, infrared, ampulla, punctoplasty.

INTRODUCTION

The treatment of epiphora can be challenging for the clinician, especially when nasolacrimal duct obstruction (NLDO) is excluded. If the lacrimal puncta are thought to be site of critical flow resistance, punctoplasty is often undertaken to enlarge the entrances to the drainage system. Punctoplasty can, however, be ineffective and may rarely worsen epiphora due to impairment of the lacrimal pump [1], or by scarring and contracture of the surgical opening. The uncertainty over outcome after punctoplasty indicates a poor understanding of punctal dynamics, and in identifying the clinical characteristics that may predict a beneficial outcome for the procedure.

A large range of physiological punctal size and morphology allows adequate physiological tear drainage [2],making it difficult to define whether a punctum is "normal" or whether it represents an acquired stenosis that is amenable to punctoplasty. An improvement in identifying those patients who are most likely to benefit from punctoplasty is, therefore, beneficial.

Optical coherence tomography (OCT) is commonly used for examining the retina and cornea. Only recently has it been used to image the lacrimal punctum and to determine normal OCT characteristics in healthy individuals without epiphora [2-5]. OCT imaging is readily available in the ophthalmic clinic as a painless, non-invasive and convenient imaging tool, and has been described as "*in vivo* clinical biopsy"[6]. OCT can image up to 1.6mm depth [7] in skin, usefully imaging superficial tissue layers. However, the semitransparent nature of the conjunctiva may allow deeper penetration or greater detail in the peripunctal area.

OCT devices have rapidly evolved to deliver detailed tissue images. The initial "time domain" OCTs developed into up to 100 times faster "spectral domain" OCTs [6].

Aggregation of multiple spectral domain OCT scans then provided “enhanced depth imaging” (EDI) OCT[8]. Furthermore, customized anterior segment lenses, have led to “swept source” OCT, enabling greater tissue penetration with the use of a longer wavelength of light[6]. All of these advances in OCT mean that images of higher resolution can be acquired in the lacrimal punctal area [2].

We report the application of spectral domain OCT with an anterior segment module, and EDI scanning protocols, for *in vivo* assessment of the lacrimal puncta of patients with punctal stenosis and listed for punctoplasty. The application of this technique, and quantitative measurements of punctal size is provided for a cohort of patients undergoing punctoplasty for epiphora. We compare the data from patients whose symptoms improved after punctoplasty, and those whose symptoms did not, with asymptomatic healthy volunteers [2]. Recommendations will be made for punctal OCT measurements in future research.

MATERIALS AND METHODS

Ethics

Regional Ethics Committee approval was obtained (LREC ref: 14/LO/1450; 153332 Westminster NRES Committee). The research adhered to the tenets of the Declaration of Helsinki.

Subjects

Twenty patients listed for punctoplasty for treatment of epiphora were recruited prospectively and written informed consent was obtained for the study. Information regarding age, gender, and ethnicity, was obtained from all participants.

Patients were excluded if they did not have a lacrimal drainage system fully patent to irrigation, or if they had undergone previous surgery to the eyelids or lacrimal drainage system.

Pre-operative assessment of epiphora

Prior to undergoing punctoplasty, patients were asked to grade the degree of epiphora on a typical day in each eye, using the Munk scoring system -- with a Munk score of “0” for no epiphora, “1” for epiphora requiring dabbing with a tissue less than twice a day, “2” for dabbing 2-4 times daily, “3” for dabbing 5-10 times daily, and “4” for epiphora requiring dabbing more than ten times a day [9].

Image acquisition protocol.

OCT image-sets of both lower lacrimal puncta were obtained by a single operator (H.T.) prior to punctoplasty, using a previously-described method [2]. Briefly, a single Spectralis OCT device with “Anterior Segment Module” (ASM) (Heidelberg Engineering, Germany), which consists of an add-on lens and dedicated software, was used. This system acquires 40,000 A-scans per second with a 7μm axial resolution in tissue, and a transverse resolution of 14μm. All images for this study were acquired using the scleral setting, a mode in which EDI-OCT can be performed. Each cross-sectional image subtended an angle of 15º, covering an eyelid length of approximately 8mm, and single scans were acquired with the automated real time (ART). In order to align the punctum opening with the scan, the nasal lower eyelid was gently rolled to evert the punctum (Figure1A). Simultaneous IR images were taken by the Spectralis system and displayed alongside the OCT images (Figures 1A and B). As the punctum was usually oval, the axis of the scan was rotated to align with the largest diameter of the punctum aperture, usually parallel to the mucocutaneous junction.

Image analysis

Images were analyzed using Heidelberg Eye Explorer (HEYEX) software (version 1.6.8). All measurements were taken twice, by the same individual, with the second performed without being able to see the location or size of the first measurement, and then an average taken. All lines were drawn manually.

The infrared images provide 2 measurements: the area of the punctal aperture (Figure 2A) and the maximum diameter of the opening (Figure 2B). A change in greyscale was used to determine the darker punctum from the lighter lid margin and a line was drawn at this change and the software generated the area within this shape drawn. Following this, the maximum diameter of this shape was hand generated and measured.

The OCT image aligned with the maximum punctal diameter on IR imaging was used to derive 5 characteristics. The punctal diameter was measured at three depths: at the external surface (Figure 3A), taken at the punctal opening by forming a tangent connecting the highest points on the nasal and temporal punctal walls; the second diameter was at 100µm below this surface measurement (Figure 3B); and the third was at 500µm below the surface (Figure 3C and 3D). The other two OCT characteristics were punctal depth (Figure 3E) and the depth of the intrapunctal tear meniscus (Figure 3F), both measured from surface tangent. Four of the parameters were taken as previously described [2]; However, the punctal aperture at 100µm depth was added because other papers have assessed punctal size from within the opening, rather than at the surface [3-5]; a depth of 100µm was chosen to reflect a comparable intrapunctal measurement.

Patients were contacted by telephone 4-6 months following punctoplasty and asked to rate their epiphora for each eye using the Munk score. Statistical analysis with Student's t-testing was performed using commercially available software (Intercooled Stata for Windows, Version 9, Statacorp LP, USA).

RESULTS

Patients underwent punctoplasty at a median age of 54 years (range 29-82), and the median age of healthy volunteers was 37 years (range 27-64). Twelve (60%) of the patients and 9 (45%) of the healthy controls were female. Eight (40%) patients and 10 (50%) controls were Caucasian, 8 (40%) patients and 9 (45%) controls were Asian, and 4 (20%) patients and 1 (5%) controls were Afro-Caribbean.

Half of the patients had a unilateral punctoplasty, and the other half had bilateral disease.

Munk scores

Munk scores improved by a mean of 1.7 (range -1 to 4) after punctoplasty and 57% of treated puncta (17 puncta in 12 patients) had reduced epiphora, 37% (11 puncta of 7 patients) had no change in their epiphora, and 6.7% (2 puncta of 1 patient) had worse epiphora after surgery.

Infrared images

The two measurements from IR images were significantly smaller for patients in whom epiphora improved, as compared to those who did not improve -- in both the area of the punctal aperture (0.091mm^2 (sd 0.064) ***vs*** 0.149 mm^2 (sd 0.083); p=0.04), and in maximum punctal diameter (367μm (sd 138) ***vs*** 547μm (sd 204); p=0.02). These two IR measurements were also significantly smaller than controls for patients in whom epiphora improved, with a punctal area of 0.091mm^2 ***vs*** 0.137mm^2 (sd 0.068) (p=0.02) and maximum punctal diameter of 367μm (sd 138) ***vs***

500μm (sd 130) (p=0.006). There was no significant difference between patients in whom epiphora did not improve, as compared with control subjects.

OCT Images: Measurement of punctal width.

The patients with stenotic puncta showed the same three distinct tissue layers on OCT as reported for normal subjects.[2]

Patients in whom epiphora improved had a significantly smaller OCT punctal width at 100μm depth as compared to control subjects (175μm (sd 124) ***vs*** 257μm (sd 123); p=0.02) in contrast, the width at this depth was similar in patients without improvement in epiphora (224μm (sd 157)) and control subjects.

Notably, there was no significant difference in punctal widths in the 3 groups at the punctal surface (645μm (sd 150) for controls, 583μm (sd 169) for improvers and 653μm (sd 164) for non improvers) or at the 500μm depth (50μm (sd 104) for controls, 43μm (sd 55) for improvers and 35μm (sd 61) for non improvers).

OCT images: Punctal depth

There was no significant difference in the depth of punctum visible on OCT between control subjects, patients in whom epiphora improved and those in whom epiphora did not improve (543μm (sd 327), 557μm (sd 370), and 551μm (sd 344), respectively).

In these near physiological conditions, the puncta appeared closed at a depth of 500μm in 38% (15/40) control puncta, 47% (8/17) puncta where epiphora improved, and 54% (7/13) puncta where epiphora failed to improve.

OCT images: Fluid level

A fluid level was seen on OCT within the punctum of 70% (28/40) healthy puncta, 88% of (15/17) puncta where epiphora improved and 85% (11/13) puncta where epiphora did not improve. The average depth of the fluid level was 192μm (sd

207) in controls, 78.6μm (sd 41.6) in puncta where epiphora improved and 73.9μm (sd 44.6) in puncta where epiphora did not improve. The depth within the puncta whose epiphora improved was significantly smaller than control subjects (p=0.04). Although the puncta whose epiphora did not improve had a similar and slightly smaller depth than improvers, they did not show statistical significance.

OCT images: Lacrimal ampullae

Although three control puncta showed ampullae on OCT (Figure 4), none of the patients with epiphora showed an ampulla on OCT.

DISCUSSION

New findings.

This pilot study shows that the quick, non-invasive investigations of OCT and IR imaging can be performed with punctum stenosis, and that patients with smaller punctal area and maximum diameter on IR imaging are more likely to benefit from punctoplasty. The results of the OCT measurements suggest, however, that the important measure of punctal function is their reduced diameter just within the punctum, rather than at its entrance -- with a significant difference (between the punctoplasty success and control groups) in the punctal width at 100μm depth, but not so at the punctal entrance or at 500μm depth. We propose that future OCT studies should use measurements of punctal size at 100μm depth.

The intrapunctal meniscus occurred at a significantly greater depth in control subjects as compared to patients whose epiphora improved, this possibly suggesting a minor degree of distal resistance to flow in patients with epiphora – for example, reduced canalicular pump function or nasolacrimal duct flow resistance, unable to be detected with syringing. Interestingly, using OCT, measurements of the height of the lower lid tear meniscus have shown significant reduction when patients become epiphora-free after punctoplasty[10]. These OCT characteristics of the tear meniscus on the lid margin and in the punctum could be further investigated for correlation with the degree of epiphora or its aetiology; this, in turn, may help to more accurately select patients for punctoplasty.

The average punctal width found at 100μm depth was 257μm in our healthy controls, this being in accord with other reports of 215μm [4] and 247μm [3], and we would suggest using this depth as a standardized location for measuring punctal width – to thereby facilitate future comparative studies.

The IR maximal punctal diameter was smaller than the OCT punctum external surface diameter. This is because the IR measurement was taken where a degree of shade occurred, which is within the punctum and not at the very surface. The measurements suggest that the IR maximal punctal diameter corresponded to a depth within the punctum of between 0 and 100μm.

The horizontal canaliculus has not been visualized in any puncta with the current OCT technology, suggesting that the full length of the vertical canaliculus has not been imaged in a single scan. The largest depth seen was 1308μm in a control patient where the punctum lumen was still open at this depth. It is challenging to image the whole punctum depth, as this requires alignment of the OCT angle within the vertical lumen throughout its length, along with stable lid eversion.

Epiphora score

The Munk score was used because it asks, with one simple question, the patient to capture their epiphora on a typical day for them. There are other more complex epiphora scoring systems available for example the ‘Lac-Q’ questionnaire

[11], which asks 9 questions, some of which are not relevant to punctal stenosis such as stickiness, and the 'Impact of epiphora on vision-related quality of life' questionnaire [12] with 10 questions. However, it is not necessarily useful to ask multiple questions when one will capture the severity, especially if multiple questions ask about activities that the patient may only rarely undertake such as nighttime driving.

Limitations and possible future applications for punctal imaging

This study is limited in the number of subjects examined, and by the large range of punctal diameters in healthy subjects [2]. The median age difference, 54 vs. 37 years, between the epiphora group and healthy control is also limitation of this study. This was due to the collection of controls being done before collecting patients with epiphora, in order to test whether OCT punctum imaging was feasible. Future studies could try to age match controls in order to reduce the chance of any difference being due to aging changes of the punctum.

The decision to undertake punctoplasty was also made by several physicians, with no strict definition for "punctal stenosis" [13]. The variation in punctal sizes in the patients listed for punctoplasty merely underlines the need for a more objective method of assessing which patients might benefit from surgery.

All measurement lines were hand drawn as currently there is no software generated specifically for the punctum. However, this would be beneficial for reducing human error and improving repeatability and comparison from patient to patient or the same patient at different time points.

Due to the knowledge that tears flow through the upper punctum as well as the lower [14, 15], imaging the upper punctum was attempted initially in control subjects.

However this was technically challenging due to difficulty in rotating the punctum opening to face the OCT machine, in a direction half way between complete upper lid eversion and the normal slightly posteriorly angled position of the upper lid punctum. This is presumed to be due to the larger height of the upper lid tarsus. Future development of OCT machines may perhaps enable greater angulation of the scanning beam to include examination of the superior punctum.

By measuring aspects of punctal morphology which are not visible with slit lamp biomicroscopy, IR and OCT imaging of the lacrimal puncta may help determine which patients would benefit from punctoplasty; it might also help predict patients with lacrimal pump failure or functional NLDO, in whom punctoplasty might be ineffective. This latter group of patients may be identifiable from OCT parameters such as punctal aperture, presence of an ampulla, or depth of the intrapunctal fluid meniscus.

A future study might select patients with unilateral epiphora, to allow an intra-subject comparison of two systems and repeat the IR and OCT examinations post operatively such as at 6 months.

LEGENDS

Figure 1. Images of each punctum were taken and displayed simultaneously using Infrared (left panels) and Optical Coherence Tomography (OCT) (right panels). These are the lower puncta of right eyes being everted by a cotton bud. The line indicates the axis of the scan, which was rotated to align with the largest diameter of the punctum aperture, usually parallel to the mucocutaneous junction. **[A]** shows a narrow punctal entrance which is open to a deep depth, whereas **[B]** shows a wide punctum which rapidly tapers into a narrow lumen.

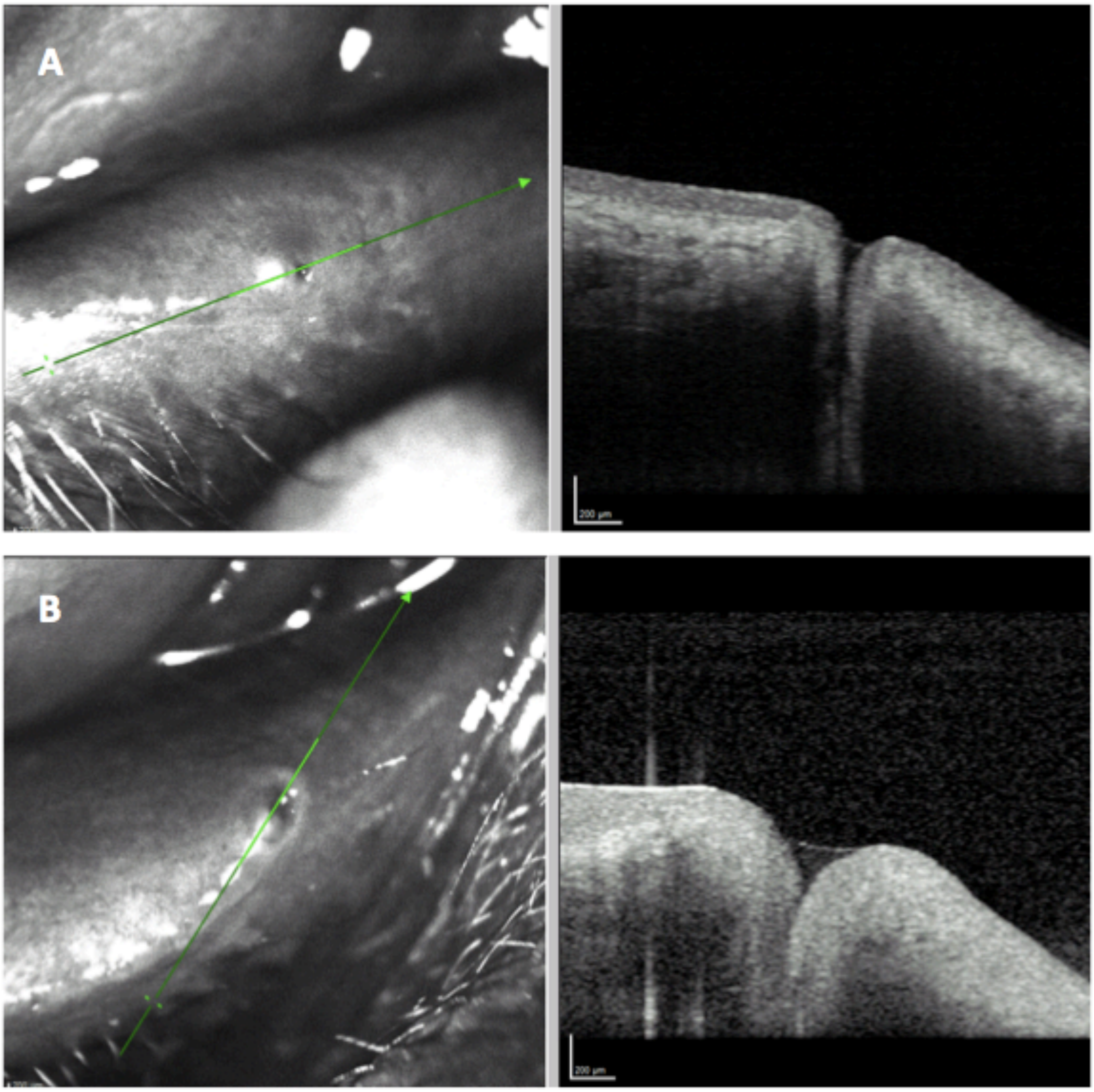

Figure 2. The punctal dimensions derived from infrared images were (A) the area of punctal aperture (within white circle) and (B) the maximum diameter of punctum opening (white line).

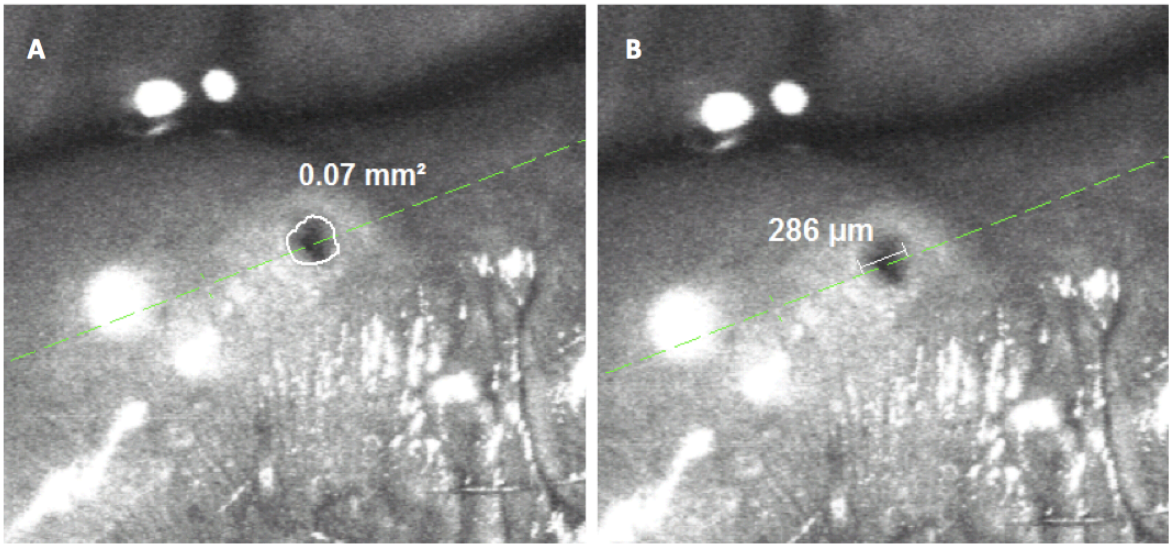

Figure 3. The punctal dimensions derived from OCT images were; **[A]** the external surface punctal aperture, taken at the opening of the punctum by forming a tangent connecting the highest points on the nasal and temporal punctal walls.

[B] the punctal width at 100µm below the surface (white line), measured vertically from the tangent at the lateral punctum wall and in parallel to the tangent (in grey).

[C] the punctal width at 500µm below the surface (white line), measured vertically from the tangent (in grey) at the lateral punctal wall. In this patient's right eye the punctum appears "closed" at 500µm depth.

[D] the punctal width at 500µm below the surface (white line) in the left eye of a different patient, measured vertically from the tangent (grey line) at the lateral punctal wall, showing an open punctum that is able to be measured.

[E] the punctal depth (white line), measured from the deepest part of the punctum to the tangent, along a vertical line, parallel to the lumen (grey line).

[F] the depth of the intrapunctal tear meniscus (white line), measured from the deepest part of the fluid level to the tangent (grey line).

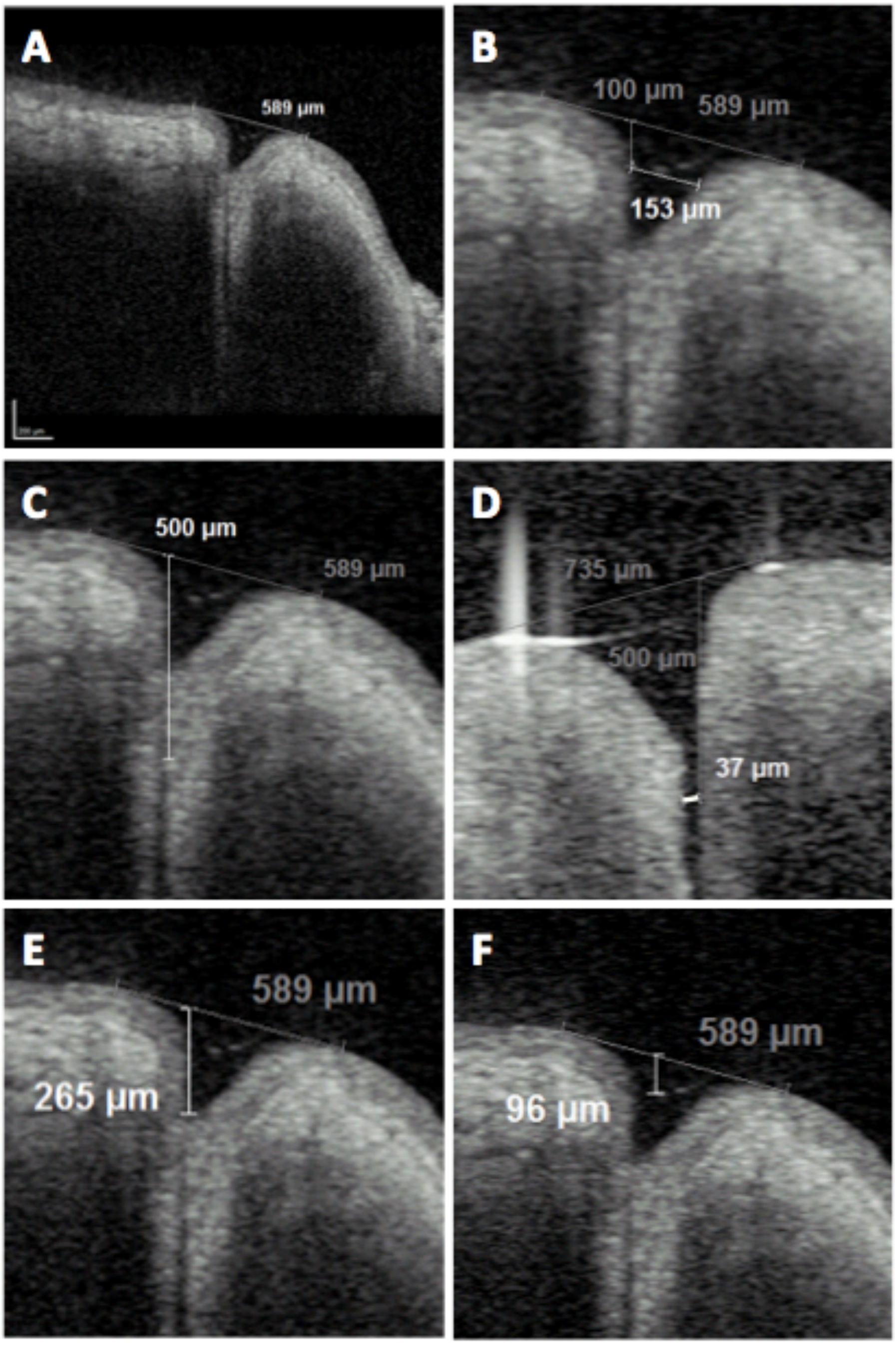

Figure 4. OCT images show **[A]** punctum where no ampulla is visible, **[B]** and **[C]** where ampullae were visible and **[D]** where an ampulla was visible with a misaligned scan through the conjunctiva.

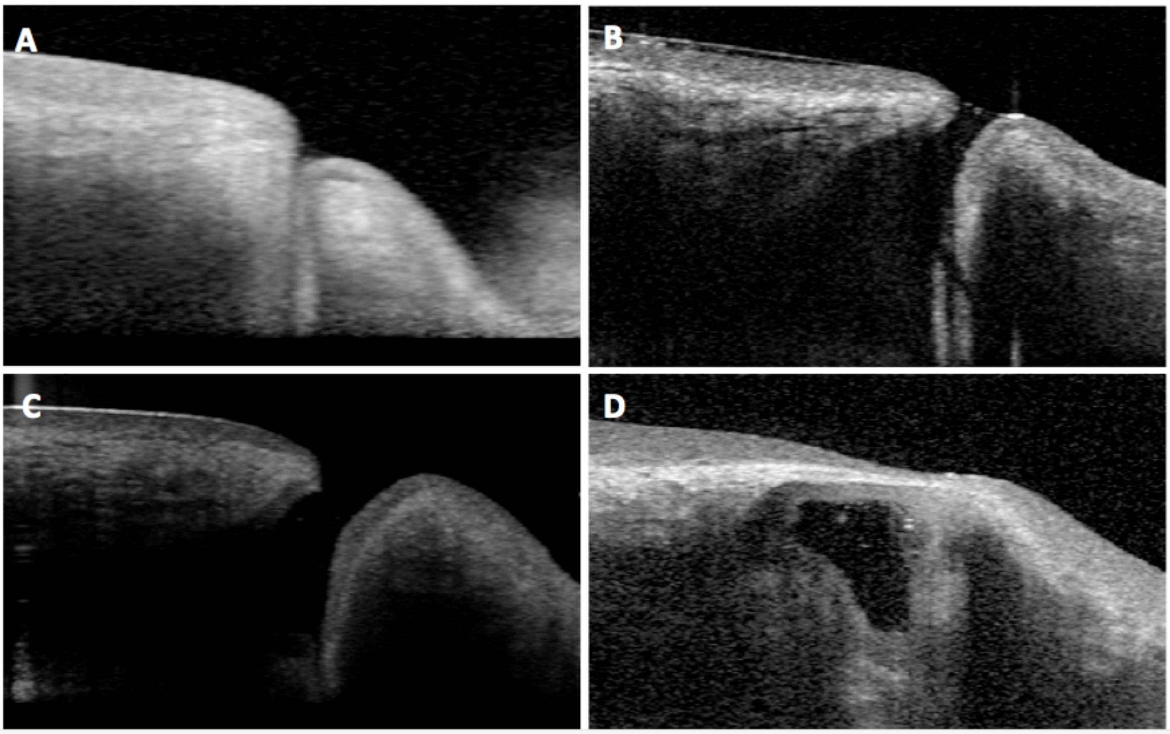

Table 1. Demographics and punctal characteristics

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