ORIGINAL ARTICLE

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Anterior Segment OCT: A Comparison of Time Domain and Spectral Domain Technologies

Abstract

Purpose: *To demonstrate the usefulness of anterior segment optical coherence tomography (OCT) for the evaluation of eyes after Descemet's membrane stripping endothelial keratoplasty (DSEK) surgery. A comparison of anterior segment time domain OCT (TD-OCT) and anterior segment spectral domain OCT (SD-OCT) specifications. To demonstrate and explain image artifacts common in OCT imaging.*

Methods: *Review images from successful and unsuccessful DSEK patients. Review images captured by the TD-OCT Visante® (Carl Zeiss Meditec, Inc, Dublin, CA), and the SD-OCT RT-Vue® (Optovue, Inc, Fremont, CA). Compare modality specifications and discuss common image artifacts.*

Conclusions: *Both TD-OCT and SD-OCTs are useful for following patients after DSEK surgery. The faster scan speed and higher resolution from SD-OCT technology provide images with more detailed information about the layers of the cornea, while the longer wavelength and the stronger optical power of TD-OCT technology provide a longer scan length that gives a more complete image of the anterior segment. Artifacts from OCT imaging are discussed and identified.*

Key Words

anterior segment OCT, time domain OCT, spectral domain OCT, Fuch's Dystrophy, Descemet's Stripping Endothelial Keratoplasty (DSEK), imaging artifacts

Introduction

OCT is a well known and frequently used technology to image the posterior segment. In most practices OCT has become a more frequent procedure than FFA.[1] In May 2005 Carl Zeiss Meditec, Inc. (*Dublin, CA*) released the Visante®, an anterior segment OCT. Using TD-OCT technology, the Visante creates cross-sectional images of the anterior segment structures. It also provides measurement tools to document and follow changes in the cornea, angle, and anterior chamber.

In the fall of 2007, several manufactures released the SD-OCT technology for posterior segment OCTs. In 2007, instead of developing a stand alone anterior segment OCT, Optovue, Inc. (*Fremont, CA*) released the Cornea-Anterior Module (CAM) that could be mounted on their SD-OCT, RT-Vue® to create cross-sectional images of the anterior segment. Like the Visante, the RT-Vue also provides measurement tools to document and follow

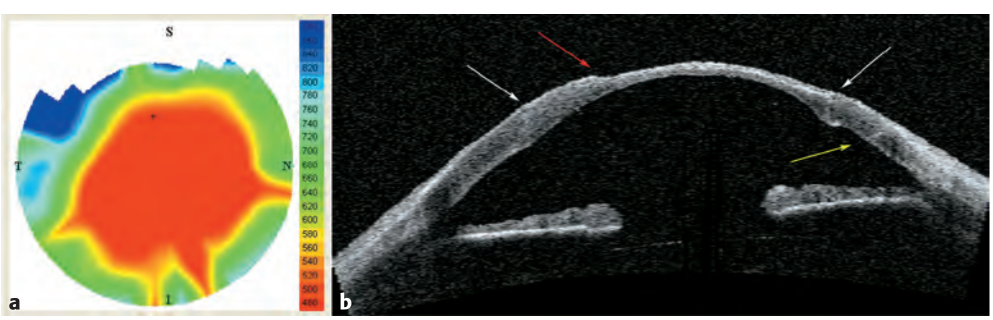

Figure 1: Failed PK imaged on Visante®. (a) Pachymetry map. (b) Horizontal cross section. White arrows: Scars at donor-host interface. Below white arrows: Slight endothelial misalignment is helpful in identifying the location of the corneal graft. Red arrow: Demarcation from the normal to the thin section of cornea. Yellow arrow: Scar. Likely a result of cataract surgery performed 16 years ago. (*Photos: Rona Lyn Esquejo-Leon, CRA*)

changes in the cornea, angle, and anterior chamber.

Both technologies help cornea and glaucoma specialists follow, diagnose, and treat their patients. Images from both TD-OCT and SD-OCT technologies of post-operative DSEK patients are discussed to illustrate the similarities and differences between the technologies, and common artifacts in anterior segment OCT images are discussed.

Fuchs' Dystrophy

Fuchs' Dystrophy is a genetic disorder that causes dysfunction of the corneal endothelium, ultimately resulting in corneal edema. Clinically, guttatae (small deposits in the endothelial layer) are present. When corneal edema is severe enough to decrease vision, a penetrating keratoplasty (PK) has been the standard operation performed. A PK requires a 360 degree, full thickness incision in the cornea. The entire thickness of the recipient's edematous cornea is replaced with a full thickness donor cornea. OCT can document the graft healing and also measure graft thickness. Figure 1 shows Visante images of a patient with a failed PK due to chronic epithelial defect and dry eyes. The pachymetry map (Figure 1a) is created from thickness measurements from 16 cross-sections. In this patient, the central corneal thickness is 240 microns. Normal thickness is 540-560 microns.

Over the last several years, a new operation has been developed for patients with Fuchs' dystrophy, Descemet's membrane stripping endothelial keratoplasty (DSEK). DSEK replaces the abnormal, recipient Descemet's membrane and corneal endothelium, about 50 microns thick, with donor endothelium and corneal stroma, about 120 microns thick. OCT documents adherence of the donor cornea to the recipient cornea. Figure 2 shows a series of post-operative images of a successful DSEK. Documentation of the adherence of donor cornea to recipient cornea is especially helpful during the rare occasion that the donor cornea does not adhere properly (Figures 3,4).

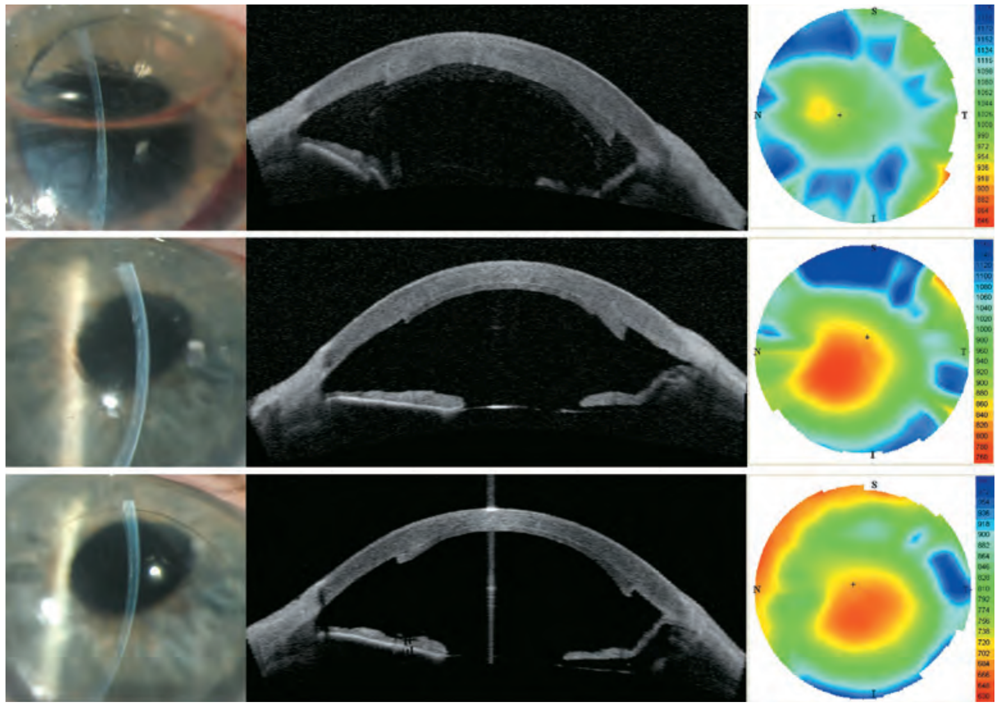

Figure 2: Successful DSEK imaged on Visante. (Top) 1 day post op. Thickened cornea with adhesion of the entire graft. (Center) 2.5 weeks post op. Reduced thickening, graft still in place. (Bottom) 7 weeks post op. Reduced thickening, graft still in place. (*Photos: Debra Cantrell, COA*)

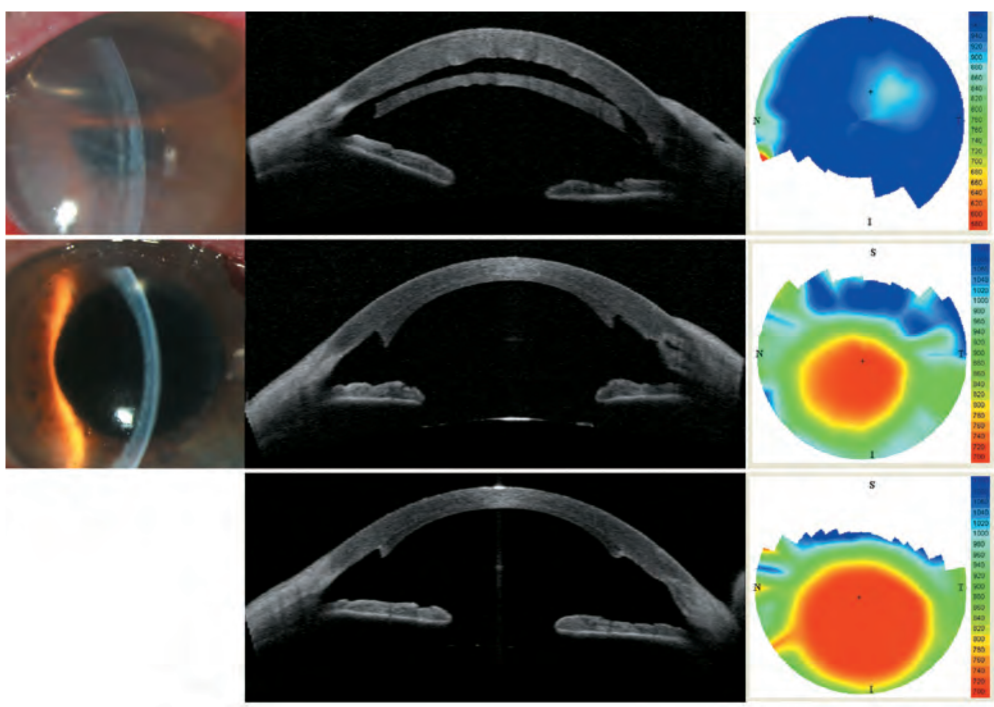

Figure 3: Unsuccessful DSEK imaged on Visante. (Top) 1 day post op. Slipped endothelial graft. (Center) 1 week post op. Graft in place after second surgery. (Bottom) 7 weeks post op. Reduced thickening, graft still in place. (*Photos 3d,e,f,g,h,i: Debra Cantrell, COA*)

In Figure 3, it is important to notice the complete detachment of the endothelial graft requiring another operation to reposition the graft. If the graft were partially attached, an air bubble would have been injected into the anterior chamber to push the graft into place. Anterior segment OCT imaging can be helpful in deciding the treatment for patients with unsuccessful adhesion of their DSEK graft.

Automatic pachymetry (corneal thickness) performed by the Visante can be more reliable than pachymetry measured by ultrasound, the gold standard. Measuring corneal thickness after a DSEK with ultrasound can provide a falsely low measurement

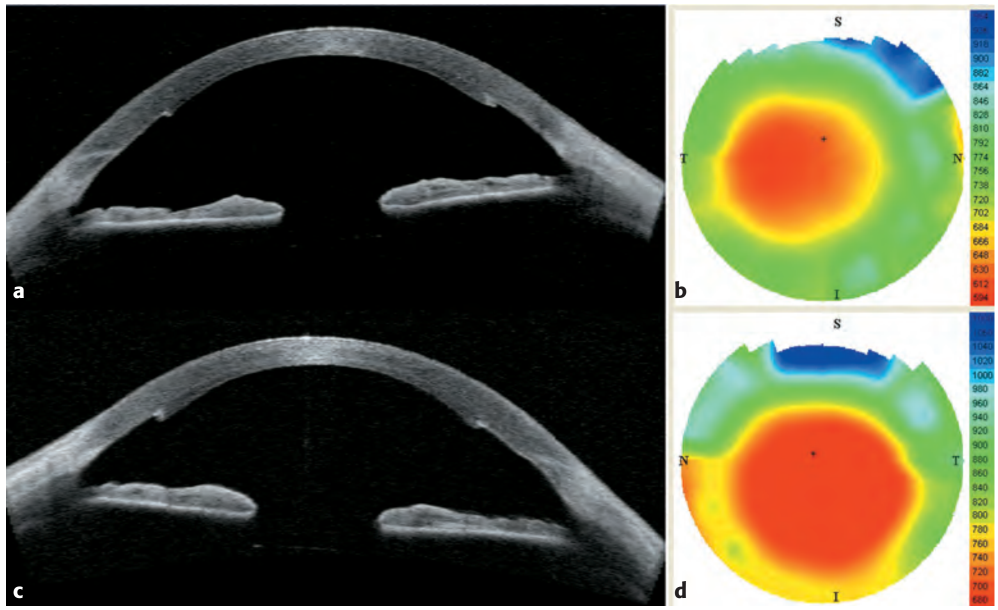

Figure 4: Successful/repositioned DSEK in same patient as figure 3 imaged on Visante. A comparison of OD and OS. (a,b) OD 7 months post-op. Successful adhesion of endothelial graft. (c,d) OS 4 months post-op after repositioning corneal graft. Note that the cross section and the topography are nearly identical in both eyes. (*Photos: Debra Cantrell, COA*)

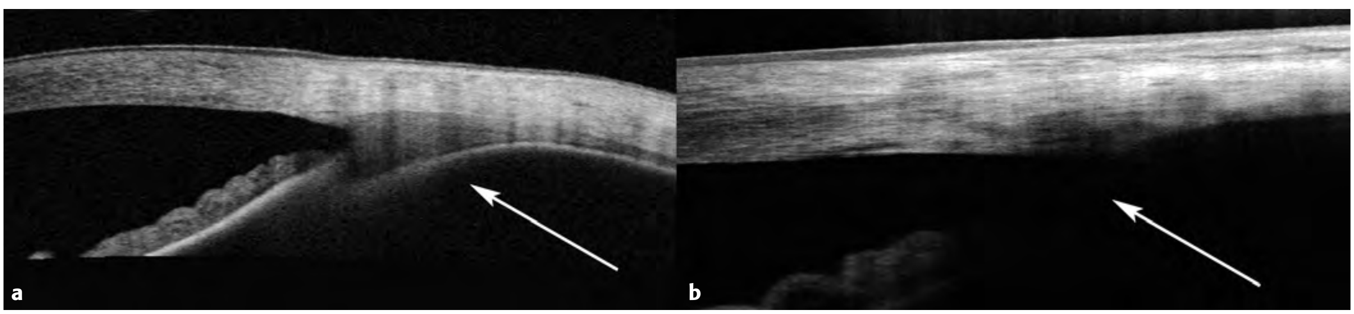

Figure 5: Specification comparison: The longer wavelength of light and stronger optical power allow the TD technology to penetrate deeper into the angle. Normal eye of same patient. (a) Imaged on Visante. *(Photo: Rona Lyn Esquejo-Leon, CRA)* (b) RT-Vue *(Photo: Carl Denis, CRA)*. White Arrows: Scleral spur and trabecular meshwork.

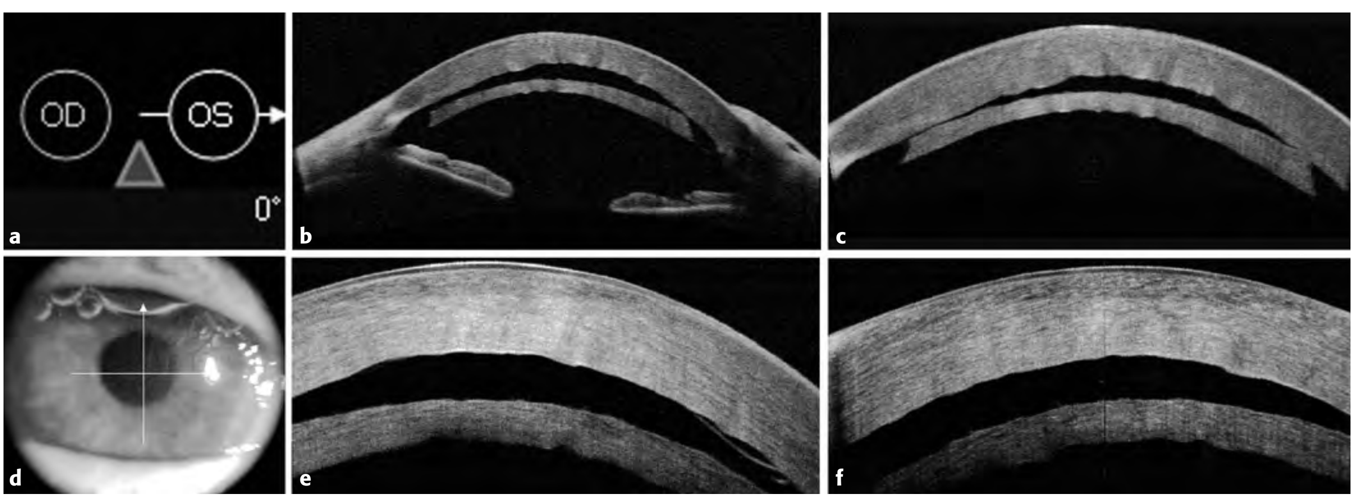

Figure 6: Specification comparison: Scan length and depth. TD technology's longer and deeper scan length provide a more complete image while SD technology's shorter wavelength provides greater resolution. Unsuccessful post-op. (a) Visante scan guide. (b) Visante scan 16 x 6mm. 16mm scan length shows limbus to limbus view including an overall view of the unattached endothelial graft. (c) Visante scan 10 x 3mm. 10mm scan length shows entire cornea including an overall view of the unattached endothelial graft. (d) RT-Vue external image with scan guide. (e) RT-Vue horizontal scan 6 x 2mm. (f) RT-Vue vertical scan 6 x 2mm. 6mm scan length shows the center of the unattached endothelial graft. Scan does not show the edges of the endothelial graft. *(Photos d,e,f: Bruno Bertoni, CRA, OCT-C; Tamera Davis, CRA)*

as ultrasound measurement depends on detecting acoustic interfaces. If ultrasound detects the donor–recipient interface as the posterior surface and not the donor endothelium, a falsely low corneal thickness will be measured from the surface to the donor-recipient interface. Figures 2 and 3 show how corneal thickness typically changes post operatively for successful and unsuccessful DSEK patients.

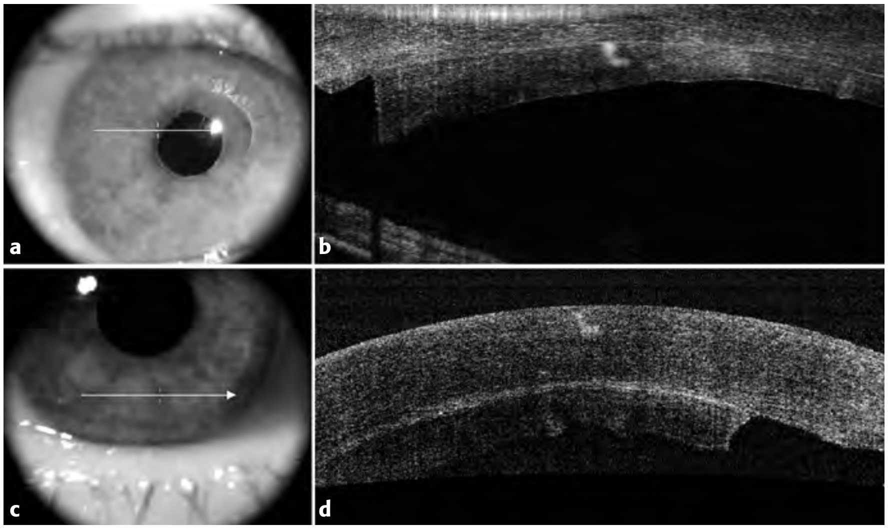

Figure 7: Specification comparison: Scan length and depth. To see the edges of the DSEK graft with SD technology, it is necessary to capture multiple images. Imaged on RT-Vue. (a,b) Scan moved up and to the left. (c,d) Scan moved down and to the right. The scan line on top of an external image of the cornea gives location on the cornea of the scan. *(Photos: Bruno Bertoni, CRA, OCT-C; Tamera Davis, CRA)*

Specification Comparison

The importance of anterior segment imaging for DSEK patients is shown above. The images used to demonstrate this were obtained using the Visante in the Kittner Eye Center at the University of North Carolina at Chapel Hill. To compare TD-OCT to SD-OCT technology, images taken by the Visante at University of North Carolina are compared to images taken with the RT-Vue from Doheny Eye Institute, Los Angeles, California. Also, the specifications provided by each vendor are compared and explained.

Super Luminescent Diode (SLD) Wavelength, Optical Power, Scan Depth and Length

The Visante has a longer wavelength of light and stronger optical power (Table 1) than the RT-Vue OCT. Together, these two specifications allow the Visante to penetrate deeper into the angle making details like the scleral spur and trabecular meshwork more visible (Figure 5). It allows for the scan length to be longer and deeper as shown in the 16 x 6mm Visante images. In Figure 6, the benefit of a longer scan length is noticeable when trying to determine if a slipped DSEK is adhering to the cornea at any location. With a 6mm scan length centered on the cornea, the edges of the graft cannot be seen. It is necessary to capture 2 - 3 images to get the same overall image captured with a 16mm scan length image (Figure 7). In Figures 6d

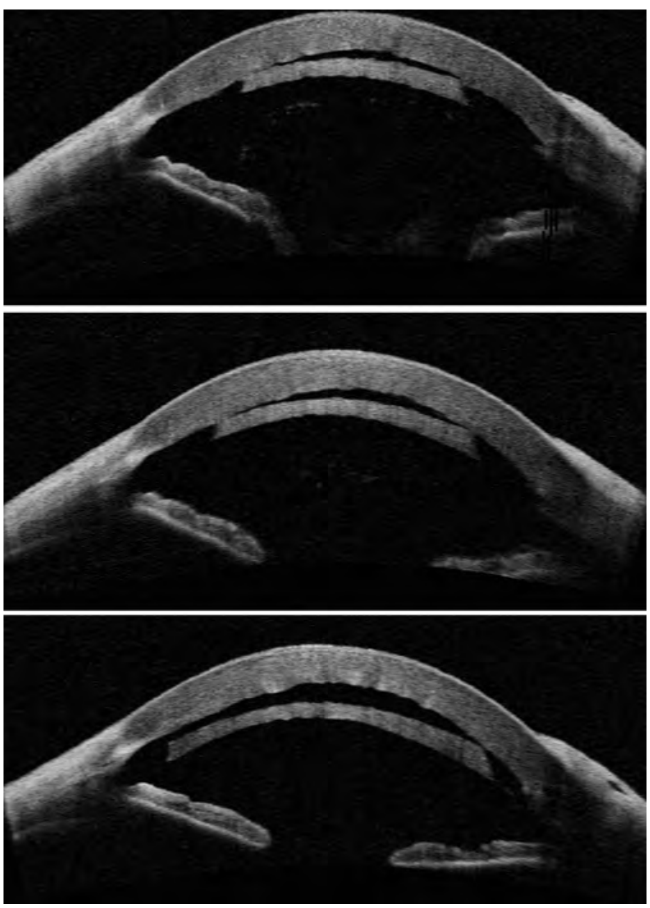

Figure 8: Specification comparison: Scan guide. Prescribed Visante image sequence for unsuccessful DSEK. Each image was taken about 1-2mm apart starting superiorly and gradually moving inferiorly. The scan guide for all of these images looks as it does in Figure 6a with OS highlighted and an arrow indicating the direction of the scan. There is no indication of where on the cornea the scan was taken.

Table 1: TD and SD-OCT specification comparison figures as provided by the manufacturers.

Specifications	Visante® Time Domain	RT-Vue® Spectral Domain
SLD Wavelength	1310nm	840nm
Scan Speed A-Scans/sec	2000	26000
Axial Resolution	18µm	5.0µm
Transverse Resolution	60µm	15µm
Scan Depth	3mm, 6mm	2-2.3mm
Scan Length	10mm, 16mm	1-3mm, 2-8mm
Optical Power	< 6500µW	750µ
Image Averaging	0 or 4	0-16

and 7a,c the location of the OCT scan is represented by the scan line on top of the external image on the RT-Vue.

In Figure 6a, using the Visante, there is only a graphic showing which eye was imaged and the direction of the scan, but no indication of where on the cornea the scan was taken. Knowing exactly where the scan was acquired from on the cornea is clinically helpful. The images in Figure 8 were taken in a prescribed sequence so that the ophthalmologist would know that they were taken approximately 1-2 mm apart, starting superiorly and gradually moving inferiorly. However, there is no indication of this on the report. The scan guide for all of these images looks as it does in Figure 6a.

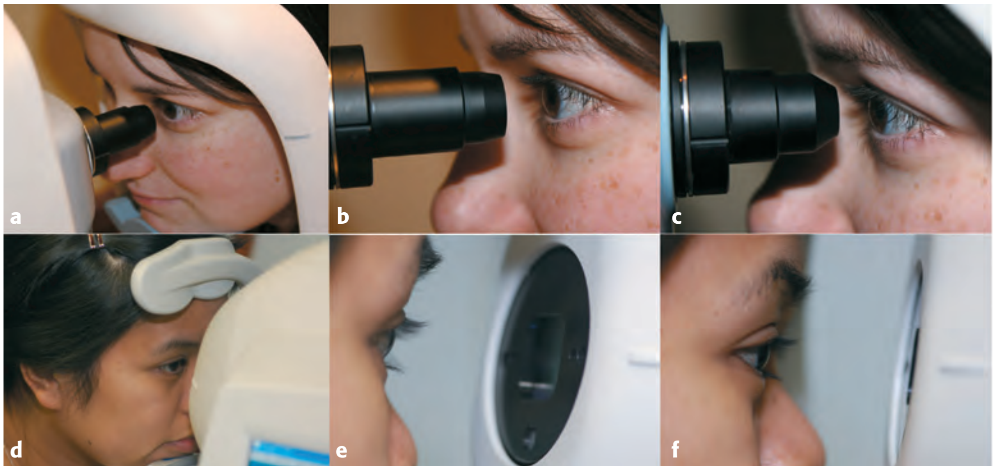

Figure 9: Specification comparison: Lenses. (a,b) Patient at RT-Vue with CAM-L (c) Patient at RT-Vue with CAM-S. (d,e,f) Patient at Visante. *(Photos 9a,b,c: Bruno Bertoni, CRA, OCT-C; Tamera Davis, CRA)*

Resolution, Scan Speed, and Image Averaging

The RT-Vue's shorter wavelength of light and lower optical power make it safe to use for imaging the retina, but requires external lenses to image the anterior segment. (Figure 9 a,b,c). Because the Visante is TD-OCT technology, the moving mirror inside the spectrometer limits its scan speed and ultimately its resolution (Table 1). The advanced technology in the SD-OCT is capable of capturing OCT images without a moving mirror. This creates a faster scan speed and creates images with higher resolution (Table 1).[2] The higher resolution of the RT-Vue is noticeable in the increased detail in the images in Figure 6e,f. The variable scan length and lens options of the RT-Vue allow for more control over resolution (Figure 10). Resolution can appear to be increased with image averaging. Figure 11 shows the difference between images that have not been averaged on both the Visante and the RT-Vue and images that have been averaged.

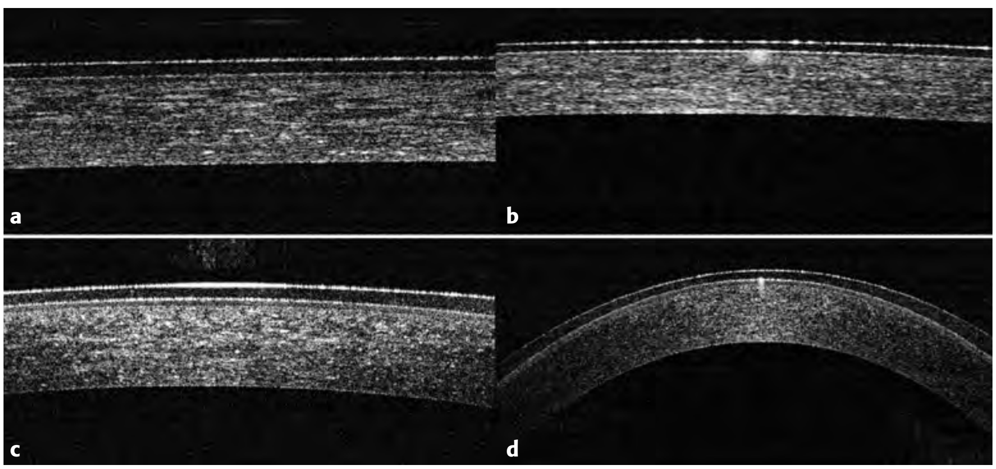

Figure 10: Specification comparison: SD resolution. The variable scan length and lens options of the RT-Vue allow for more control over resolution. (a) CAM-S, 1.00mm Scan Length (b) CAM-L, 2.00mm Scan Length (c) CAM-S, 3.00mm Scan Length (d) CAM-L, 8.00mm Scan Length. *(Photos: Bruno Bertoni, CRA, OCT-C; Tamera Davis, CRA)*

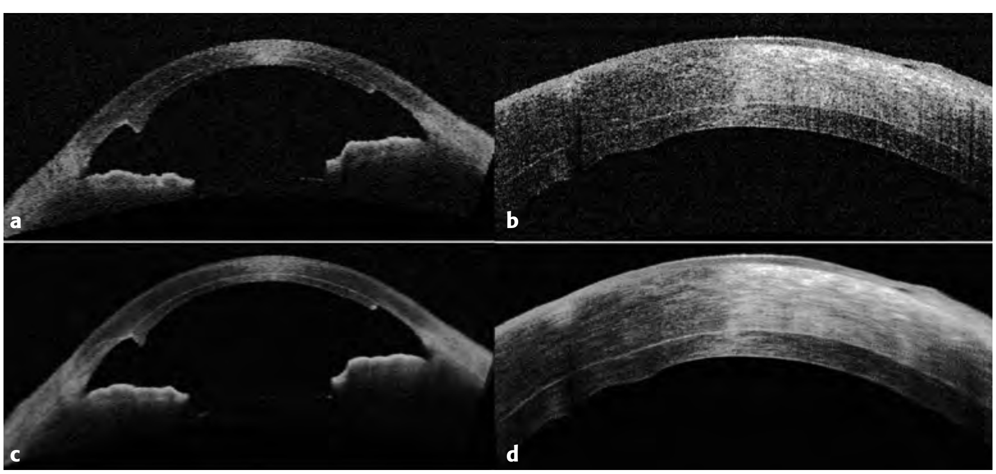

Figure 11: Specification Comparison: TD and SD image averaging comparison. Successful post-op DSEK images from different patients. (a) 16 x 6mm Visante image. No averaging. (b) 6 x 2mm RT-Vue image. No averaging. (c) 16 x 6mm Visante image. 4 images averaged together. (d) 6 x 2mm RT-Vue image. 8 images averaged together. *(Photos 11b,d: Bruno Bertoni, CRA, OCT-C; Tamera Davis, CRA)*

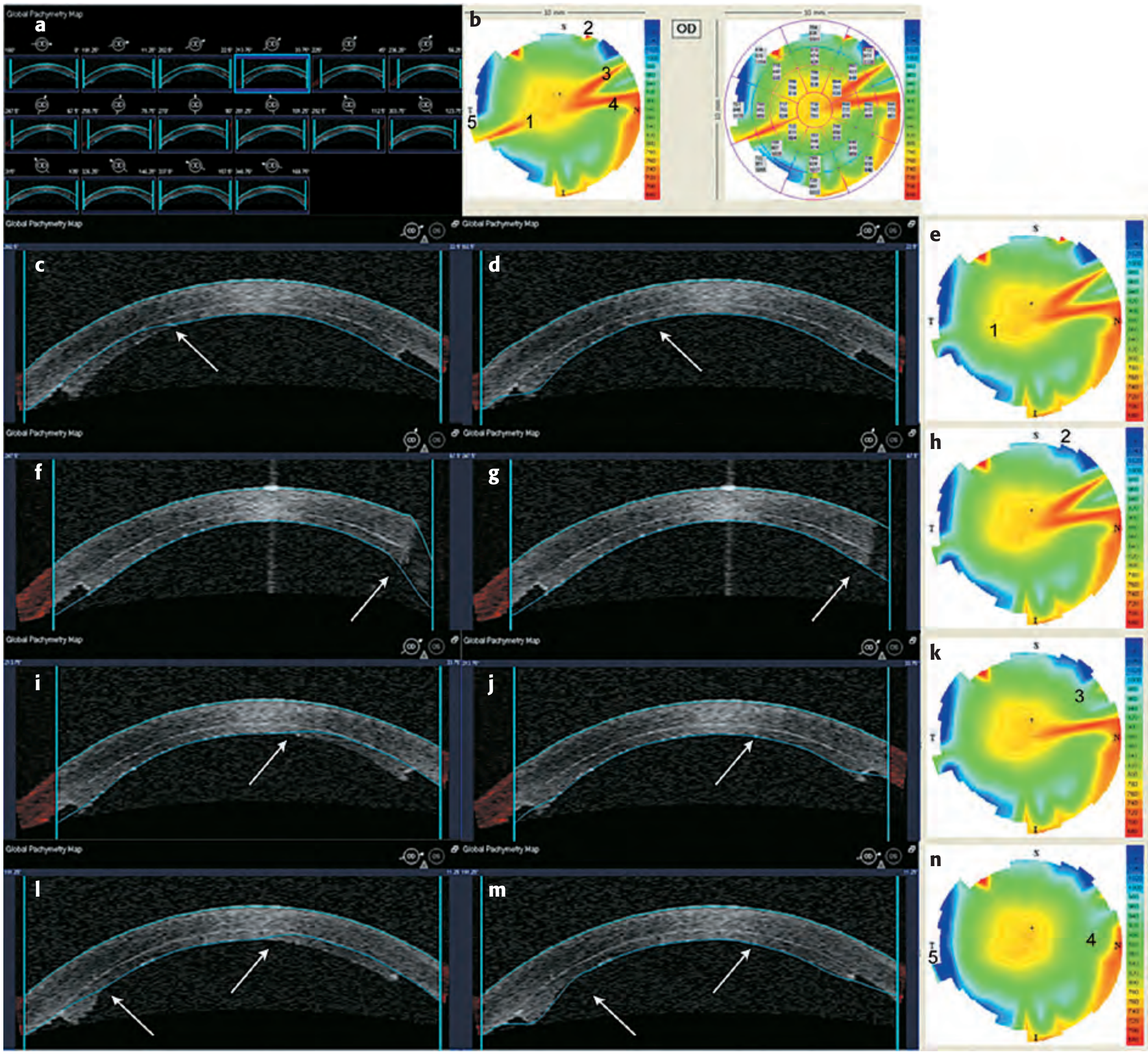

Figure 12: Artifact: Algorithm failure in corneal pachymetry on Visante due to improper placement of corneal surface lines.. (a) View of all 16 OCT images used to calculate corneal thickness. (b) Pachymetry map with algorithm failures labeled 1-5. (c, i, l) Posterior corneal surface line does not follow the endothelial graft. White arrow: Point where corneal surface line stops following the posterior surface of the graft and begins to follow the donor-recipient interface. (d,j,m) Posterior corneal surface line moved to proper location. White arrow: Point where corneal surface line was corrected to follow the posterior surface of the cornea instead the donor-recipient interface. (e) Pachymetry map after algorithm has recalculated. 1:The inferotemporal thinning artifact is no longer present. Compare to 1 in 12b where thinning artifact is present. (f) OCT image not complete. Anterior and posterior corneal surface lines create false thinning measurement. (g) Anterior and posterior corneal surface lines repositioned. (h) Pachymetry map after algorithm has recalculated. The small superonasal thinning artifact at the edge of the map is no longer present. Compare to 2 in 12b where thinning artifact is present. (k) Pachymetry map after algorithm has recalculated. The superonasal thinning artifact is no longer present. Compare to 3 in 12b where superonasal thinning artifact is present (n) Pachymetry map after algorithm has recalculated. The superonasal thinning artifact is no longer present and the small inferotemporal thinning artifact is no longer present. Compare to 4 and 5 in 12b where thinning artifacts are present.

Artifacts

With all imaging modalities, it is important to understand the artifacts that can be produced. Some of these artifacts will seem familiar from posterior segment TD-OCT, posterior segment SD-OCT, and corneal topography. It is important to recognize artifacts and understand how they were created so that the artifacts are not confused with pathology.

Algorithm Failure in Corneal Pachymetry

The pachymetry algorithm failure happens when the corneal surface lines fail to follow the anterior and posterior surfaces of the cornea accurately. This could happen from poor scan quality, obstruction by the eyelids, or confusing pathology. Since there are 16 cross-sections that compose one pachymetry map on the Visante, these algorithm failures tend to follow one of those cross-sections. It is possible in the Visante to redraw the corneal surface lines to put them in the proper location (Figure 12).[3] Eyelid artifacts are the most common reason for algorithm failure. In Figure 13, the superior portion of the pachymetry map is missing due to eyelid blocking during image acquisition. To prevent eyelid blocking, hold lids during image acquisition.

Shadowing

Figure 14 demonstrates an artifact common to posterior segment OCT called "shadowing". The air bubble in the anterior chamber creates a shadowing artifact that makes the iris appear to dramatically dip into the posterior segment of the eye (14a, white arrow). The lines that follow the edge of the Intacs (*Addition Technology, Inc., Des Plaines, IL*) implant are causing shadowing in the iris (14b, white arrows).

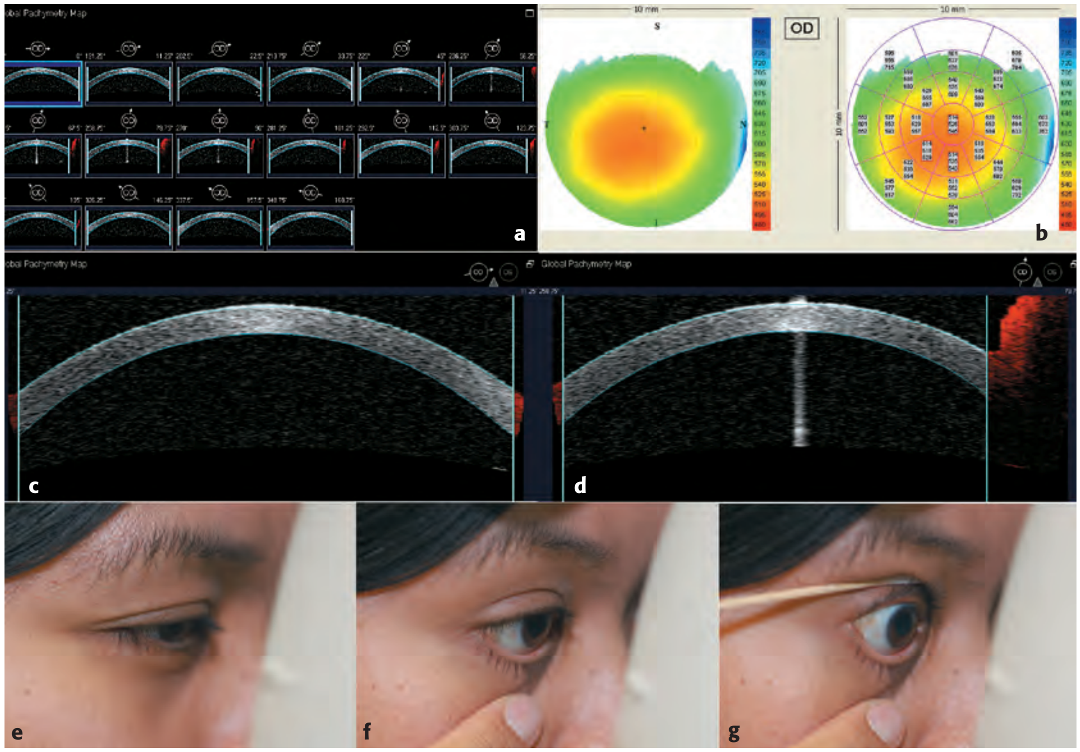

Figure 13: Artifact: Algorithm failure in corneal pachymetry on Visante due to eyelid artifact.. (a) View of all 16 OCT images used to create the pachymetry. (b) Pachymetry map. (c) Horizontal image. Corneal surface lines and vertical analysis limit in proper location. (d) Vertical image. Corneal surface lines in proper location. Vertical analysis limit cropped off lid artifact causing blank superior pachymetry map. (e) Patient with droopy lids. (f) Patient pulling lower lid down. (g) Photographer holding upper lid up. *(Photos a,b,c,d: Debra Cantrell, COA)*

Image Averaging

Figure 15 demonstrates image averaging artifacts. Figure 15a shows a fuzzy looking cornea. The white arrow points to a section where it is easier to see the four images that produced this image on the Visante. Notice the calipers that are used to manually measure the corneal thickness from the surface of the recipient epithelium to the graft-recipient interface, and from the surface of the recipient epithelium to the donor endothelium. The accuracy of the measurements should be questioned because of the image averaging artifact. In Figure 15b, the white arrow points to what looks like a "diced" iris captured on the Visante. If the iris moves while the four images that create this image were captured, they will not line up properly during the image averaging process. The mismatched alignment creates this "diced" iris appearance due to algorithm failure.

Inverted Image

Figure 16 shows a common artifact with SD-OCT technology. The white arrows point to the inverted image artifact that shows when the center of the cornea reaches the top of the 2mm scan box. The image inverts itself and shows up lightly in the background of the image.

Corneal Reflex

When the cross-section is centered on the vertex of the cornea, a vertical white beam appears in the anterior chamber and a small hyper-reflective area appears on the corneal surface on both the Visante and RT-Vue images (Figure 17).[3] When trying to perform corneal pachymetry, it is important to center on the vertex of the cornea to get an accurate pachymetry reading. This artifact can be used as a guide to center the scan.

Conclusions

Both TD and SD anterior segment OCTs are useful for following patients after DSEK surgery. The faster scan speed and higher resolution in the SD-OCT images provided more detailed information about the layers of the cornea, whilst the longer wavelength and the stronger optical power of the TD-OCT technology provided a longer scan length that gives a more complete image of the anterior segment. Artifacts created by anterior segment OCTs were discussed and should now be easily identifiable.

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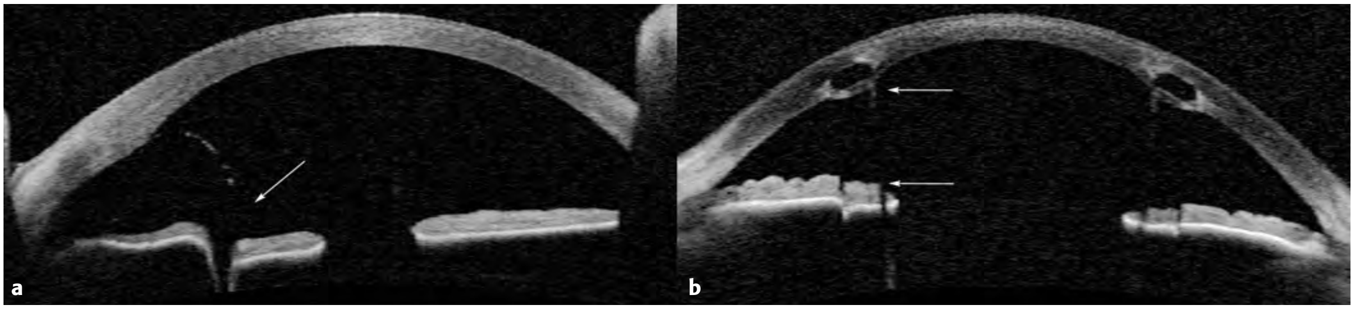

Figure 14: Artifact: Shadowing. Imaged on Visante. (a) Caused by air bubble in anterior chamber. (b) Caused by Intacs *(Addition Technology, Inc., Des Plaines, IL). (Photo: Debra Cantrell, COA)*

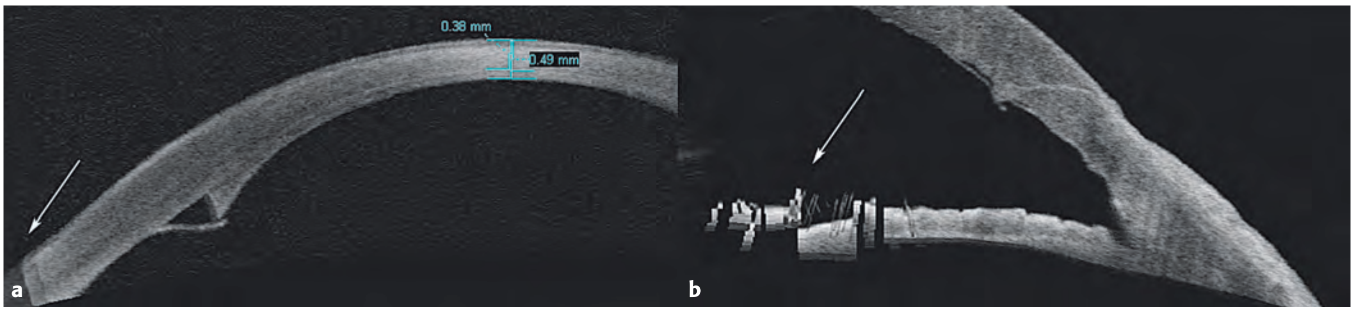

Figure 15: Artifact: Image averaging. Imaged on Visante. (a) Four images misaligned (b) Algorithm failure caused by the iris moving between the four images. *(Photo: Debra Cantrell, COA)*

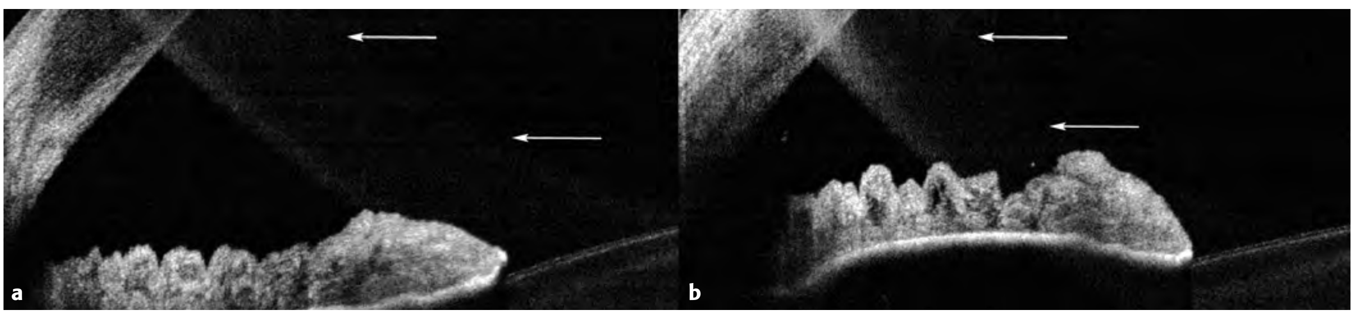

Figure 16: Artifact: Inverted image specific to SD technology. Imaged on RT-Vue. White arrows show the faded inverted image of the central cornea in the background of the image. *(Photos: Carl Denis, CRA)*

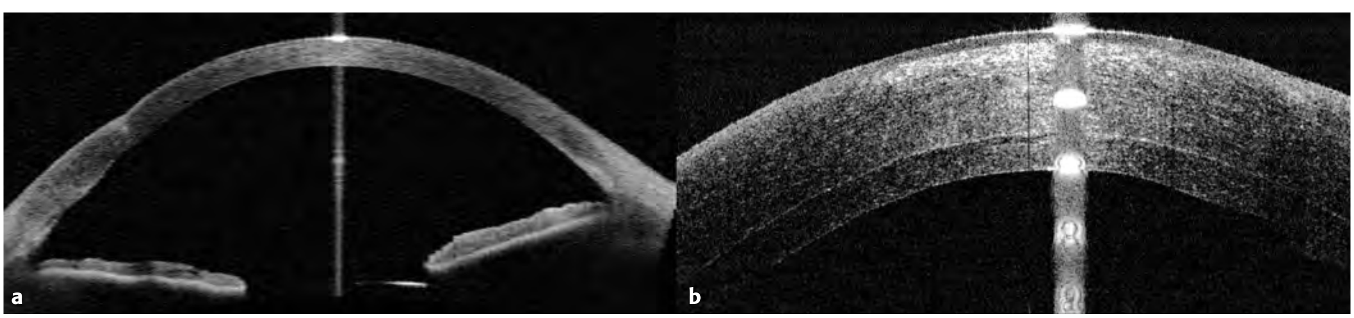

Figure 17: Artifact: Corneal Reflex. When the cross-section is centered on the vertex of the cornea, a vertical white beam appears in the anterior chamber and a small hyper reflective area appears on the corneal surface. (a) on Visante. *(Photo: Rona Lyn Esquejo-Leon, CRA)* (b) on RT-Vue. *(Photo: Bruno Bertoni, CRA, OCT-C; Tamera Davis, CRA)*

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