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Chapter 7

Intraoperative OCT in Lamellar Corneal Transplants (DALK, DSAEK, DMEK)

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Additional information is available at the end of the chapter

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Abstract

An explanation of this new technology, consisting of optical coherence tomography integrated to the microscope in both anterior and posterior lamellar corneal transplants (DALK, DSAEK, DMEK). The advantages of visualizing the different layers of the host and donor cornea, with specific emphasis in the Descemet-stroma interphase, are explained in the written work and captured in the intraoperative images. This technology makes the procedure safer, increases the surgery success rate and consequently improves the postoperative results in the patient. The surgical technique of the lamellar transplants and its benefits are explained. The advantages of this new technology are analyzed, including visualizing the corneal planes, checking the tissue orientation and ensuring the correct execution of critical surgical steps; all of these help in reducing the technical difficulty of the procedure. Likewise, it is explained that by providing direct transurgical visualization in a screen, there is a potential teaching and academic advantage.

Keywords: deep anterior lamellar keratoplasty (DALK), Descemet stripping automated endothelial keratoplasty (DSAEK), Descemet membrane endothelial keratoplasty (DMEK), optical coherence tomography (OCT), lamellar transplant, Descemet-stroma interphase

1. Introduction

We are familiarized with the term *penetrating keratoplasty* (PK), which is a transplant of the full thickness of the cornea. Nowadays, lamellar transplants are widely accepted because of its many advantages like a decreased probability for immunologic rejection, higher resistance

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to trauma, anatomic integrity maintenance, better refractive stability, a quicker rehabilitation and a surgery with fewer risks. Anterior lamellar transplants have evolved into the deep anterior lamellar keratoplasty (DALK), which is the substitution of the entire stroma while maintaining the recipient's Descemet membrane and endothelium. Endothelial transplants have also seen a wide range of changes throughout the years. In the present day, the most widely performed techniques are Descemet stripping automated endothelial keratoplasty (DSAEK), in which the recipient's endothelium and a thin layer of posterior stroma are replaced, and Descemet membrane endothelial keratoplasty (DMEK), in which only the Descemet and endothelium are replaced. Even though lamellar transplants have a wide array of advantages, these techniques are not always offered by the ophthalmologist due to the complexity and the difficult learning curve of the surgical technique, which requires a precise dissection of the corneal anatomic layers. The use of a transurgical optical coherence tomography (OCT) may help the surgeon to visualize the corneal layers and hence increase the rate of success in lamellar transplants.

2. Historical background

2.1. DALK

The firts anterior lamellar keratoplasty was performed in 1905 [1]. In the second half of the twentieth century [1], PK became the surgical gold standard to treat the majority of the axial diseases in the cornea. Meanwhile in Colombia at the start of the 1950s, José Barraquer et al. began dissecting two-thirds of the stroma in both the donor and the recipient's cornea [2], but the technique did not gain popularity due to the poor final visual acuity in patients due to irregularities of the interphase.

Beginning in 1984, Eduardo Arenas Archila created the term *deep anterior lamellar keratoplasty* (DALK) by using intrastromal air to dissect the corneal tissue [3]. This technique has evolved over time, and currently surgical techniques achieve the complete separation of the stroma-Descemet interphase with few risks, maintaining the integrity of the Descemet with no stromal residue, which is extremely important to reach a high-quality visual acuity.

In 2002, Anwar developed the *Big Bubble* technique, which is the most widely used one nowadays [2]. This technique allows the separation of the corneal stroma and Descemet with an injection of air into the deep stroma with a #30 cannula after a partial trepanation (80% deep), in this way modifying Archila's technique [4]. The key step in this procedure is the correct injection of air into the recipient's pre-Descemet space to facilitate the removal of the stromal tissue. This technique has been widely accepted worldwide due to its easy reproducibility and high success rate. Nevertheless, it has a steep learning curve that has slowed its adoption [5]. In 2012, Ghanem describes the *pachy-bubble* technique, in which he used transurgical pachymetry to penetrate 90% of the corneal thickness with a diamond scalpel to reach with the air the pre-Descemet space with a higher success rate [6].

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2.2. DSAEK

In 1956, Tillen introduced the concept of replacing the corneal endothelium by describing the first case of a posterior lamellar keratoplasty [7]. He described how he performed a lamellar dissection of the recipient's cornea and afterward inserted the donor's endothelium to the anterior chamber, suturing it to the recipient's cornea and finally injecting air to apply pressure on the donor endothelium. In 1980, Barraquer modified this technique and trepanated the posterior stroma and sutured to it a posterior lenticule from the donor [8].

Melles is credited with the current success of the endothelial transplant and with the concept of posterior lamellar keratoplasties through a posterior approach [8]. He was the first surgeon to successfully place an endothelial graft to the recipient's stroma without the use of sutures, which allowed better visual results. The procedure was adapted, modified and popularized by Price, which named it *Descemet stripping endothelial keratoplasty* (DSEK). Gorovoy modified this technique by dissecting the donor cornea with a microkeratome, hence the name *descemet stripping automated endothelial keratoplasty* (DSAEK) and is nowadays the most popular technique for endothelial transplants. With the wide acceptance of these techniques, eye banks have begun offering precut donor tissue, facilitating the procedure for surgeons into a one-step procedure.

2.3. DMEK

In 2002, Melles introduced the concept of DMEK [9]. He reported a simpler method for dissecting the stroma of the recipient, by just removing the Descemet and endothelium and placing the endothelium graft behind the recipient's stroma and injecting air into the anterior chamber to hold the graft in place.

3. Indications

3.1. DALK

The DALK procedure is the technique of choice for many diseases in the anterior stroma of the cornea such as [8]:

- keratoconus and other ectasias
- postsurgical corneal ectasia
- partial thickness leukoma
- anterior corneal dystrophies

3.2. DSAEK/DMEK

The indications to perform an endothelial transplant are those that implicate an endothelial dysfunction such as [8]:

- postsurgical bullous keratopathy
- Fuchs dystrophy
- posterior polymorphous corneal dystrophy
- corneal transplant rejection
- traumatic endothelial dysfunction
- iridocorneal endothelial syndrome

4. Advantages

4.1. DALK

The advantages of performing DALK corneal transplants are [1] as follows:

- no immunologic endothelial rejection
- extra-ocular procedure
- higher transurgical safety
- higher resistance to traumatic injuries (**Figure 1**)
- endothelium preservation
- less postsurgical use of steroids
- better refractive stability

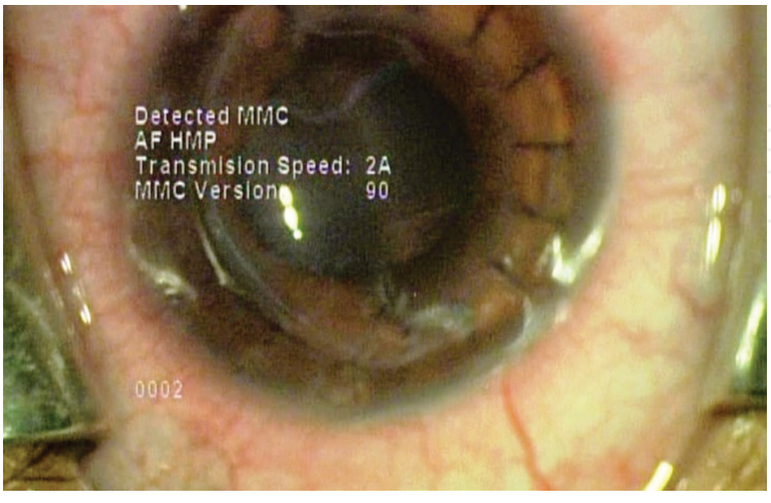


Figure 1. Wound dehiscence in a patient with DALK surgery. The patient received an ocular trauma 1 month postsurgery and eight stitches broke, yet the Descemet remained intact without aqueous humor leakage.

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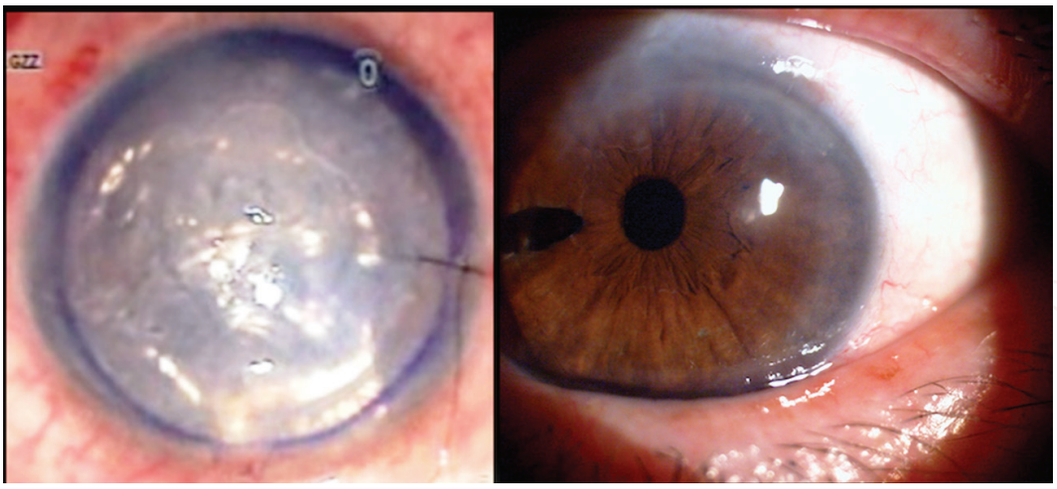


Figure 2. Clinical photographs of an endothelial transplant. On the left a photograph taken at the end of the surgery and on the right the same eye 12 months later.

4.2. DSAEK/DMEK

The advantages of performing endothelial transplants are [8] as follows:

- lower immunologic rejection rate
- less transurgical risks
- small incision
- less sutures or absence of them
- less complications related to ocular surface
- preservation of the corneal innervation
- preservation of the anatomic integrity of the cornea
- visual acuity recovery is faster, more stable and more predictable (**Figure 2**)

5. Surgical technique

5.1. DALK

Nowadays, due to its elevated success rate, the authors use the pachy-bubble technique, which will be described here.

The technique begins with a partial trepanation of 80% of the corneal thickness and an average diameter of 8 mm. Afterward, an ultrasound pachymeter is utilized to measure the corneal thickness in MXII, at a distance of 3 mm from the visual axis. The diamond scalpel is

calibrated for 90% of the pachymetric measurement and a 4-mm incision is performed in this area. Air is injected into the anterior chamber, which will help verify the formation of the big bubble. A specially designed cannula is inserted and moved through the pre-Descemet plane until the visual axis is reached. It is in this zone were air will be injected. Afterward, the stroma is perforated to reach the stroma-Descemet interphase, which is now full of air (**Figure 3**). The stroma is removed and the donor cornea (with no endothelium) is sutured with nylon 10–0.

It is important to mention that to achieve an adequate Descemet detachment, the air injection should be very deep, unfortunately leading to an increased perforation risk [2]. This step continues to be the most challenging part of the surgery.

If the injection of air is too superficial or if it remains in the medium stroma, it will usually disseminate laterally without detaching the Descemet and will give the cornea a diffuse-white appearance. When this happens, the surgeon must try to inject the air deeper or change to a manual dissection (layer by layer) technique, which frequently leads to perforation. This technique is a challenge in advanced keratoconus with a severe corneal thinning or scarring and has a reserved success rate when there are dense corneal opacities due to the bad depth visibility [6].

Some of the disadvantages of this type of transplant are its steep learning curve and its longer surgical time compared to a PK [1]. In many countries, including Mexico, this technique does not have a widespread use secondary to its difficulty and longer time requirements. Nowadays, even a skilled surgeon performs with a risk of perforation between 10 and 30% [10].

The DALK procedure has some complications including [1]:

- Descemet membrane rupture
- double anterior chamber
- loss of endothelial cells secondary to air/gas
- interphase opacities or irregularities

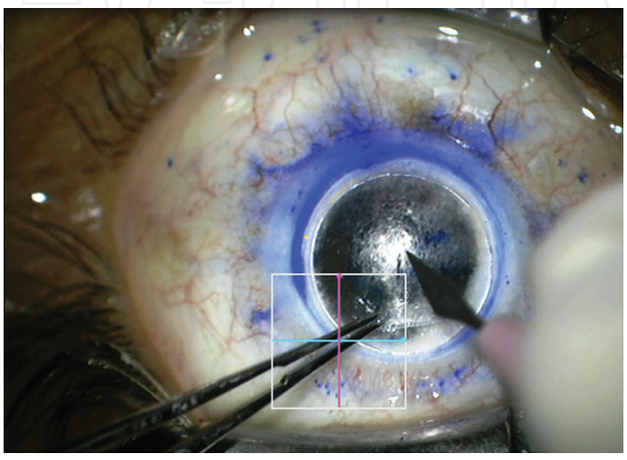


Figure 3. Perforation of the corneal stroma in a DALK corneal transplant.

- detritus, hemorrhage, vascularization, microbial infections and epithelial growth in the interphase
- pupillary block glaucoma secondary to injected air in anterior chamber
- recurrence of the stromal corneal dystrophy
- Difficulty in re-epithelization

5.2. DSAEK

There are many variations to the original endothelial transplant DSAEK technique. The one used by the authors is described here.

The donor cornea is prepared using a Moria microkeratome adapted to an artificial anterior chamber. The ideal thickness is between 90 and 120 μm. Afterward, the donor cornea is trepanated with an average diameter of 8.25 mm.

Once the donor tissue is obtained, surgery begins by inserting an anterior chamber maintainer. Trypan blue solution is inserted to the anterior chamber for better visualization of the Descemet membrane. A circular descemetorhexis is performed with a diameter of 8.25 mm. A 2-mm incision is done on the temporal limbus and a 4-mm incision on the nasal limbus. An iridotomy is performed on the meridian at six o´clock and the donor tissue is inserted through the nasal incision using a Busin glide or any other type of injector designed for this purpose. The temporal incision is used for the instrument used to help during the insertion of the donor tissue. Finally, the anterior chamber is filled with air for adequate fixation of the graft.

The DSAEK procedure has some complications including:

- lack of adherence of the donor tissue
- foldings or tears in the donated tissue
- inverted positioning of the tissue
- endothelial dysfunction secondary to surgical trauma
- pneumatic pupillary block

The most reported complication in endothelial transplants is the lack of adherence of the donor tissue to the recipient's stroma. The key to reducing the dislocation is a meticulous reconstruction of the wound (so that there is no leakage of aqueous humor) and complete removal of fluid from the interphase. Whenever a graft is dislocated, it can be accommodated once again with air injections; nevertheless, this may cause damage to the endothelial cells.

5.3. DMEK

The DMEK technique used by the authors is described below.

To obtain the donor tissue, the Blister technique is used, a technique developed by Eric Abdullayev (Manager of Clinical Development and Innovations at Lions Eye Institute for

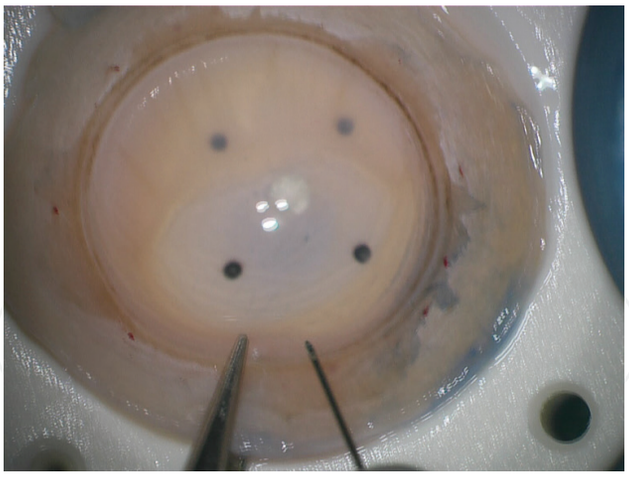


Figure 4. Blister technique for the isolation of corneal Descemet-endothelium prior to a DMEK surgery.

Transplant and Research, Tampa, Florida, USA). In this technique, balanced saline solution is injected to achieve separation of the Descemet membrane (**Figure 4**). Currently, it is possible to get the tissue prepared and preloaded by the staff of some eye banks, which facilitates the procedure and eliminates the risks of tissue preparation in the operating room.

Once the donor tissue is obtained, surgery is performed on the recipient, initiating with the introduction of trypan blue to improve Descemet visualization, then the circular descemetorhexis of an average of 8.25 mm is performed. The Descemet can be extracted using the irrigation-aspiration piece of the phacoemulsification equipment, through a previously performed 3 mm incision. An iridectomy is performed in MVI, and the donor tissue is introduced and unfolded with delicate hydraulic and pressure-counter-pressure maneuvers, finally introducing the air/gas in the anterior chamber once the correct unfolding of the graft has been ensured. The eye must be completely sealed with or without sutures.

The DMEK procedure has some complications including:

- lack of adherence of the donor tissue
- foldings or tears in the donated tissue
- inverted positioning of the tissue
- endothelial dysfunction secondary to surgical trauma
- pneumatic pupillary block

Currently, the number of surgeons performing DMEK is on the rise because of its better visual acuity results when compared to DSAEK.

6. Overview of optical coherence tomography (OCT)

The OCT is based on the principle of low coherence interferometry to measure distances. A light source is used, typically a superluminescent infrared diode with a wavelength between

830 and 1325 nm. OCT has revolutionized clinical ophthalmology, and its development continues providing opportunities for a better diagnosis and even management of eye diseases. Originally introduced in the 1990´s at the Massachusetts Institute of Technology in 1991 as a technique for noninvasive transverse imaging of biological systems, the image of the retina was the first application of this technology [11]. OCT devices have undergone modifications in their original technique to see and measure anterior segment structures such as the cornea, iris, and the lens [12]. In 1994, Izatt described the use of OCT for the anterior segment with a resolution close to histological level [13]. Since then, it has been used for the diagnosis and



Figure 5. OPMI LUMERA & RESCAN 700 microscope, where OCT images can be observed in real time.



Figure 6. OPMI LUMERA & RESCAN 700 microscope, OCT images can be appreciated for all members of the surgical team.

management of various corneal conditions. Now that it is one of the most important diagnostic tests in ophthalmology, it is natural to use this technology in the operating room, as it provides a unique feedback mechanism in real time and helps facilitate the achievement of surgical objectives.

The authors use the OPMI Lumera® 700 and RESCAN™ microscope from Zeiss (**Figures 5** and **6**), and this microscope includes an integrated OCT system, which optimizes the procedure of deep anterior lamellar keratoplasty and endothelial keratoplasty.

7. Use of transurgical OCT for lamellar transplants (DALK, DSAEK, DMEK)

The application of OCT to lamellar transplant surgery is a useful tool to visualize the tissue planes and depth in the different steps of the surgery. This system optimizes the surgical procedure by letting the surgeon observe high-resolution images both at the eyepiece level of the microscope and at an external screen. By objectively visualizing depth in the different steps of surgery, greater safety is achieved by decreasing the risk of complications and facilitating surgical maneuvers, thereby increasing the success rate.

7.1. DALK

With this new technology, the depth of trepanation can be assessed, avoiding corneal perforations, especially in patients with thickness irregularities, such as keratoconus [14] (**Figure 7**). It is also possible to verify the depth of the cut with the diamond scalpel in the pachy-bubble technique, which is of vital importance to achieve the air injection close to Descemet, avoiding perforation and superficial air injection. Sorcia observed a higher success rate in reaching the pre-Descemet planes when performing DALK pachy-bubble [15]. The measurement of

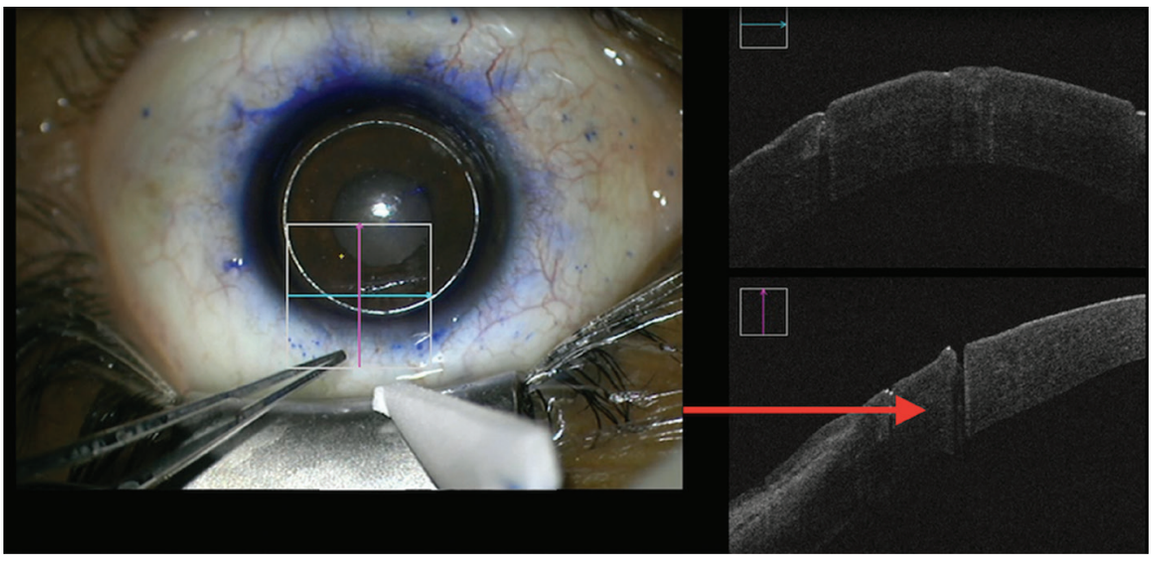


Figure 7. Trepanation depth check (red arrow) by intraoperative OCT.

trepanation seems to be useful to determine if the depth is adequate or there is a need for further dissection to reach the ideal depth for an air injection.

Once air is injected to create the bubble that will separate the Descemet membrane and stroma, OCT images are captured to verify the extent of the dissection, and to check whether it reached the trepanation mark limit. These images will help the surgeon assess if there is risk of perforation or if there exists an inadequate separation of the stroma and the Descemet membrane (**Figures 8–10**).

In cases of poor visibility secondary to injected intrastromal air, the OCT helps to see the extension of the big bubble in the anterior chamber to ensure it is complete and to prevent perforation when removing the stroma (**Figure 11**).

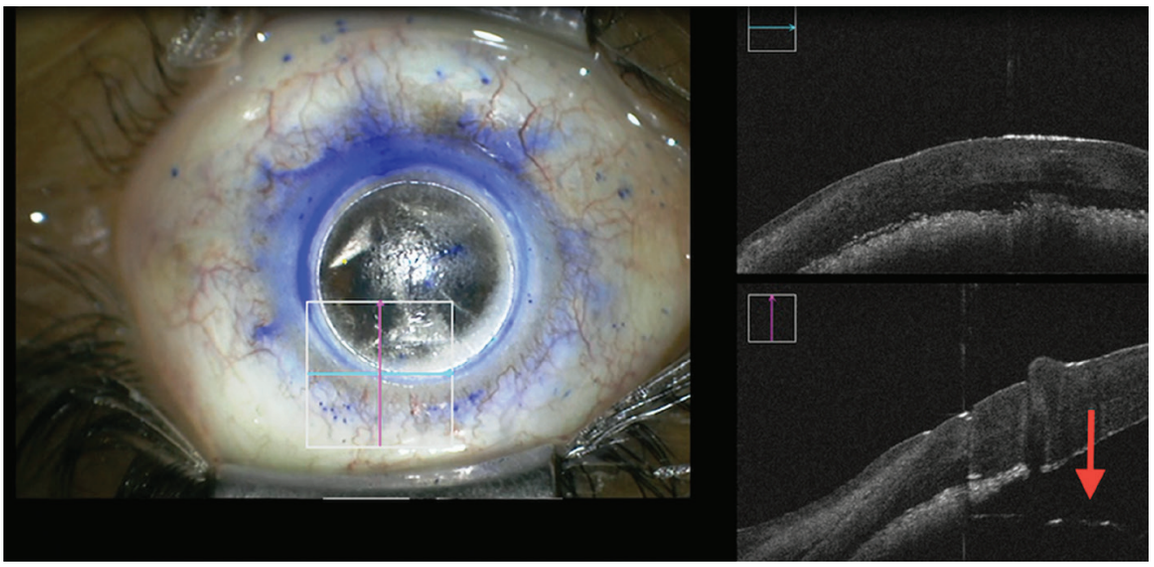


Figure 8. The red arrow points to the Descemet membrane separated from the stroma by air forming the big bubble.

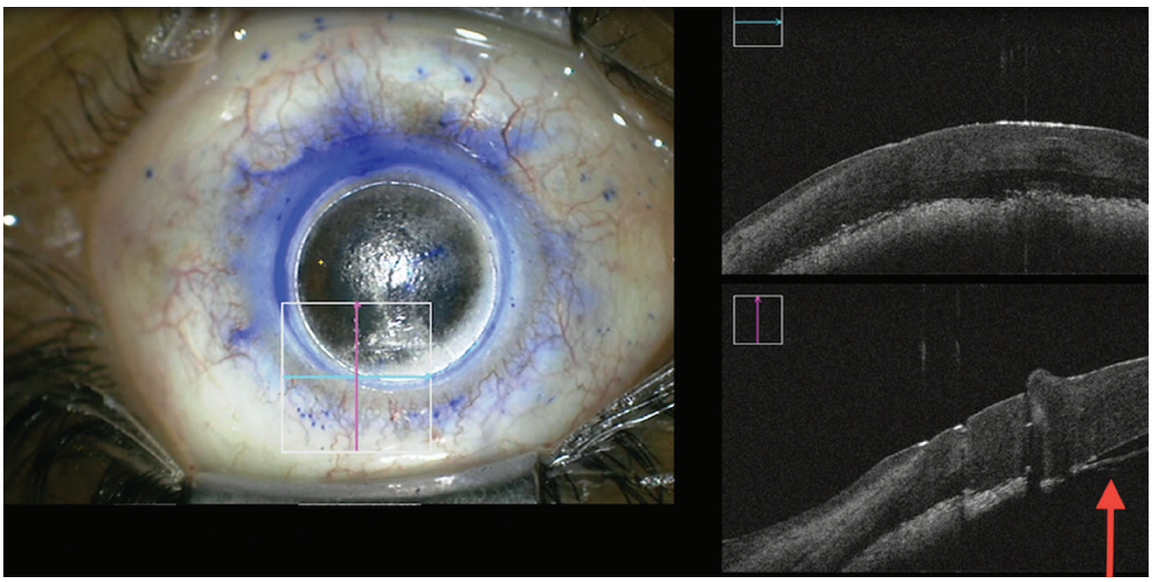


Figure 9. Descemet membrane (red arrow) returning to its original location. This is after the perforation of the stroma.

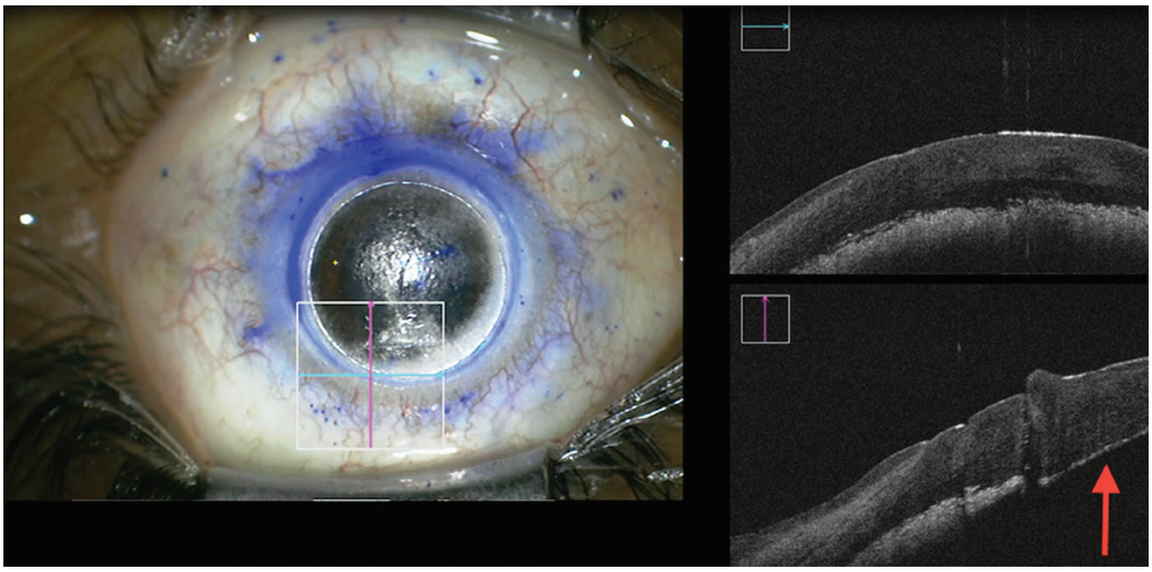


Figure 10. Descemet membrane (red arrow) is completely adhered to the stroma.

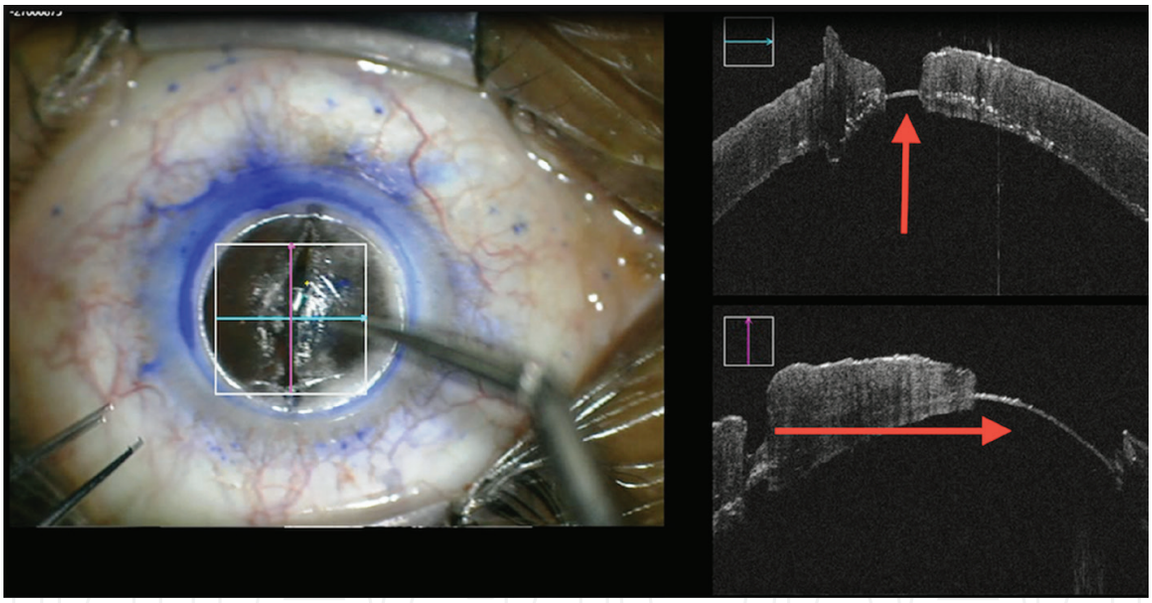


Figure 11. Stromal dissection. The OCT images guide the surgeon to avoid perforation of the Descemet membrane (red arrow).

After the dissection is completed, the surgeon can evaluate if the stroma was completely removed (**Figure 12**). The donor button is allocated and sutured, and the position of both tissues is evaluated. The surgeon should look for irregularities, liquid or air that separates both tissues anywhere. With the OCT system, it is possible to optimize the approximation of graft and host.

7.2. DSAEK/DMEK

When preparing the donor button in the DSAEK transplant, after passing the microkeratome, the residual thickness of the donor can be evaluated with the help of transoperative OCT to guide the surgeon in selecting the ideal blade size for a second cut with the microkeratome [16],

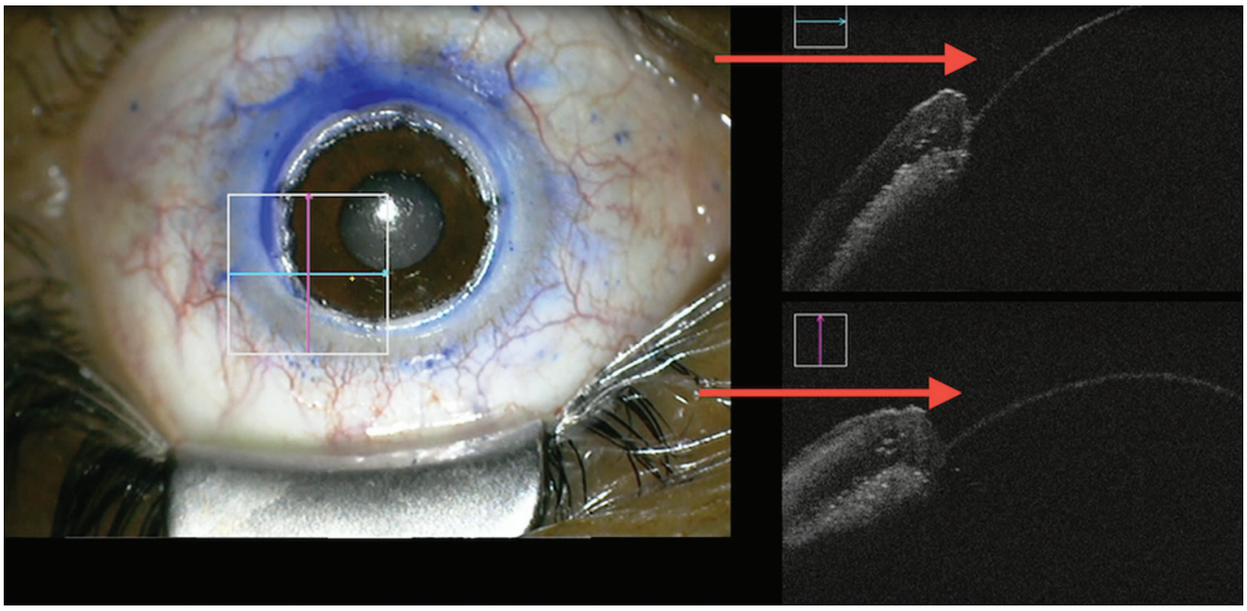


Figure 12. Descemet membrane without any stromal tissue.

in case a thinner donor button is required. Even in cases where the microkeratome is passed once, transoperative OCT evaluates the thickness of the donor cornea and helps to select the ideal size of the blade.

With the transurgical OCT, the state of the donor graft can be observed. In the case of precut grafts for DSAEK, the precut lines are visualized in the corneal images, as well as defects or detritus on the endothelial surface, although these changes have no clinical importance [17]. In the case of DMEK, in addition to showing the space between the endothelium-stroma interphase, another use of transurgical OCT is to prevent cases where the donor button is inverted in the anterior chamber [17].

In donor grafts for DMEK surgery, partial detachments of the Descemet membrane can be observed. Other defects and detritus can also be observed. Therefore, transoperative OCT is an excellent alternative to observe the state of the donor tissue.

In cases where the surgeon's vision is obstructed, for example with corneal edema in a bullous keratopathy, the use of transurgical OCT can help with decision-making inside the operating room [13]. In cases with opaque or edematous corneas, the visualization of the Descemet is difficult, and transurgical OCT can help with its visualization and descemetorhexis. The remaining Descemet membrane can be identified in the case of fibrous or scarred corneas [16]. In this case, transurgical OCT also helps to monitor the insertion and unfolding of the graft, since it can inadvertently have an inverse configuration and result in a failed surgery. With this, the surgeon may ensure an adequate deployment and orientation of the graft, especially in the case of the DMEK surgery in which the graft is much thinner than that of DSAEK (**Figure 13**).

Traditionally, the graft-recipient interphase is reviewed in the slit lamp or in the microscope, but with transoperative OCT, additional information is provided to the surgeon regarding the manipulation of the graft and the final interphase between the graft recipient (**Figure 14**), which can influence the postoperative results.

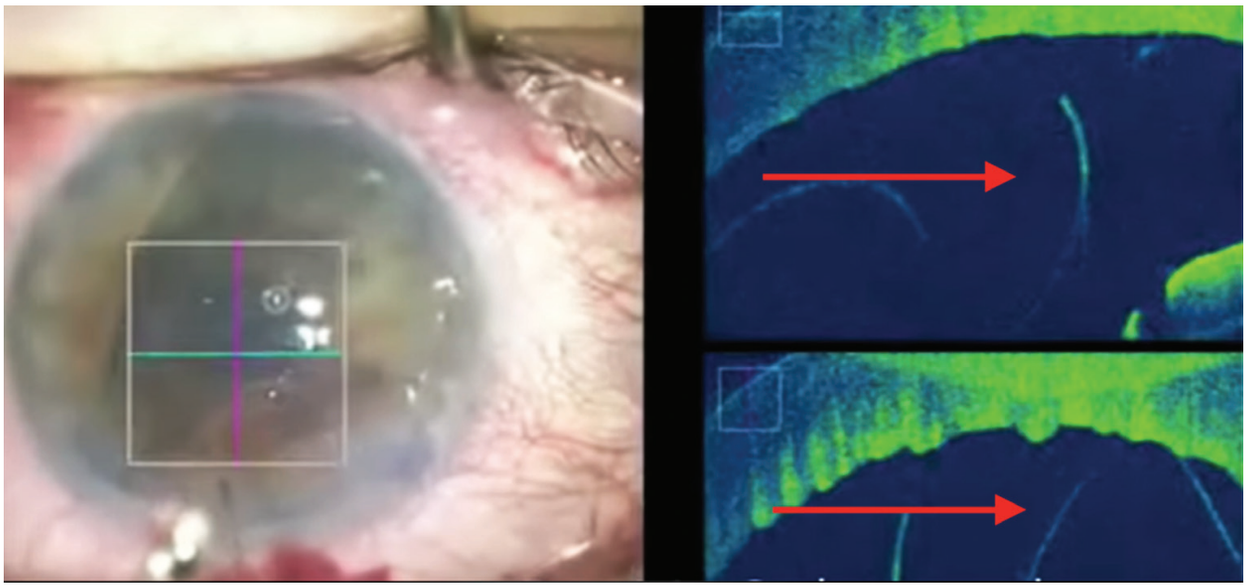


Figure 13. Unfolding of endothelial tissue (red arrow) in DMEK, verifying the tissue orientation. Courtesy of Zeiss.

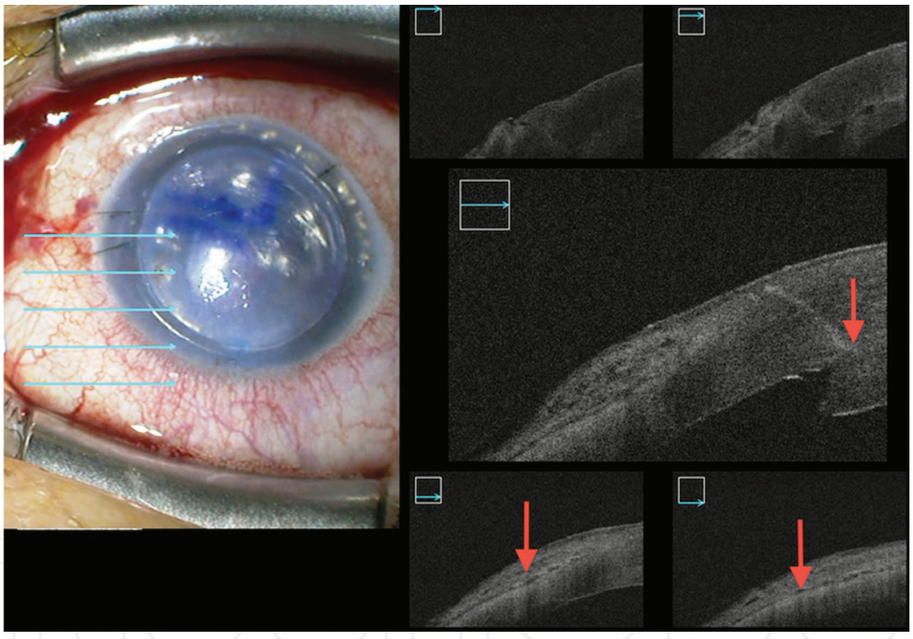


Figure 14. Verification of complete apposition of the donor tissue to the recipient bed, without any space between.

The use of OCT has proved to be useful in detecting any residual space in the interphase at the end of DSAEK surgery. In 2010, Knecht published the first use of transurgical OCT in DSAEK and demonstrated serially the decrease of fluid in the interphase [16], doing manual measurements of the interphase's area of greatest amplitude (between the graft and the recipient). Hallahan correlated the transurgical interphase with the fluid measurements between the graft and the receiver and found that the greater the fluid measurements, the greater the risk for disinsertion and lack of graft adherence in the postoperative period [18].

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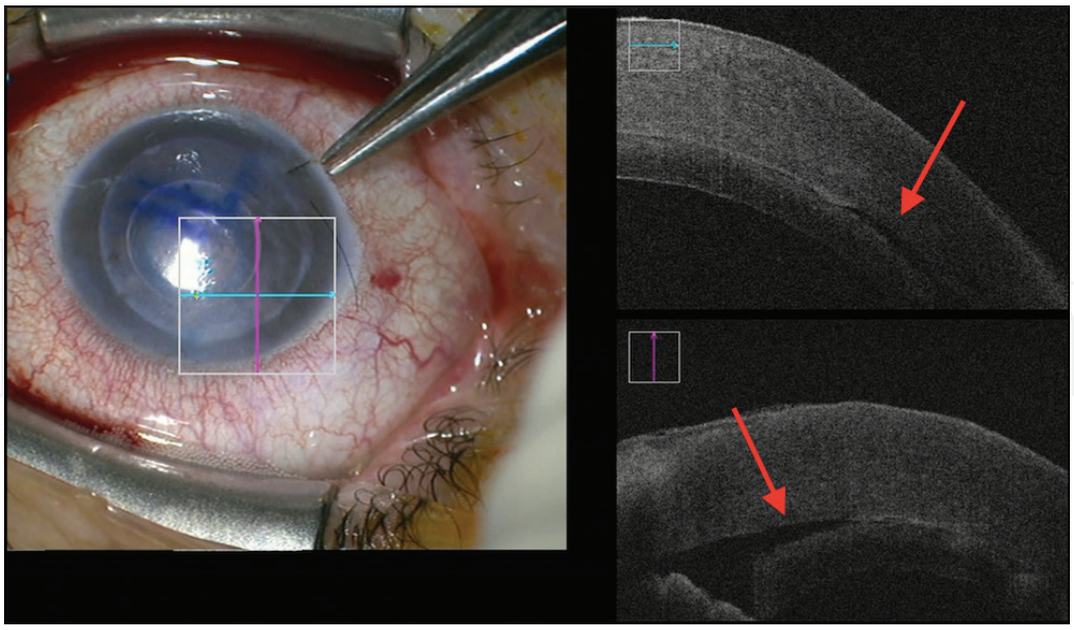


Figure 15. Lack of apposition between donor and recipient tissues, which indicates that additional maneuvers must be performed to achieve correct placement.

If there is an incomplete apposition of the donor lenticule, various maneuvers can be performed such as corneal massage or air tamponade in the anterior chamber to ensure the complete elimination of the fluid between the stroma-Descemet interphase (**Figure 15**). Transoperative OCT helps in determining the efficacy of these maneuvers [16].

A study to determine the feasibility and usefulness of transoperative OCT reported that it indeed helped in decision-making and demonstrated that additional maneuvers were required; this was based on images obtained by OCT in 41% of DSAEK cases. Transoperative OCT revealed persistent fluid in 19% of the cases where the surgeon believed the graft was completely adhered to the stroma. Another finding was that it was indeed adhered in 47% of the cases where the surgeon believed the graft was not completely adhered, therefore reducing the need for further unnecessary surgical manipulation. Transoperative OCT has the potential advantage of decreasing the duration of the surgical event, as well as minimizing graft dislocations [19].

8. Conclusion

The use of this new transoperative OCT technology optimizes the identification of the corneal layer planes by providing a cross section with high-resolution images. These can be observed in real time both in the surgeon's microscope and in an external screen that can be observed by all the staff in the operating room, providing a valuable academic tool. By providing a direct visualization of the critical steps in lamellar transplants (DALK, DSAEK, DMEK), there is an increase in the procedure's safety, it decreases the learning curve of the surgeon in training

and facilitates the work of the experienced surgeon by providing detailed visual information in each surgical step, optimizing the decision-making and reducing the surgical event time.

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