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High Resolution Optical Coherence Tomography Guided Donor Tissue Preparation for Descemet's Membrane Endothelial Keratoplasty Using Reverse Big Bubble Technique

Florence Cabot^{1,2}, Vardhaman P. Kankariya^{1,4}, Marco Ruggeri², Sonia H. Yoo^{1,2}, Pravin K. Vaddavalli³, Jean-Marie Parel², and George D. Kymionis⁴

¹Anne Bates Leach Eye Hospital, Bascom Palmer eye Institute, University of Miami Miller School of Medicine, Miami, FL

²Ophthalmic Biophysics Center, Bascom Palmer eye Institute, University of Miami Miller School of Medicine, Miami, FL

³LV Prasad Eye Institute Hyderabad, India

⁴Faculty of Medicine, University of Crete, School of Health Sciences, Voutes, Heraklion, Crete, Greece

Abstract

Purpose—To assess the feasibility of High Resolution Spectral Domain Optical Coherence Tomography (HR-SDOCT) to guide donor tissue preparation in Descemet's Membrane Endothelial Keratoplasty (DMEK) using the reverse big bubble technique.

Methods—Three corneo-scleral discs were included in this ex-vivo experimental study. A 27 gauge cannula was introduced into each cornea at the periphery by 3 different surgeons. Each surgeon attempted to achieve the ideal depth (pre-descemetic plane) of the tip of the cannula for air injection to produce the reverse big bubble in order to separate Descemet's membrane (DM) from posterior stroma. A supine OCT system built at the Ophthalmic Biophysics Center of the Bascom Palmer Eye Institute was used to estimate in real-time the depth reached by the tip of the cannula in the posterior stroma during tissue preparation.

Results—After air injection, one successful big bubble was obtained, while each of the other corneo-scleral discs had intrastromal emphysema and DM perforation. On HR-SDOCT evaluations, artifacts were noticed at the tip of the cannula. The successful big bubble demonstrated separation of DM and stroma without intrastromal hyperreflectivity. Emphysema was visualized on the HR-SDOCT as a hyperdense intrastromal area shadowing the posterior structures of the anterior chamber.

Conclusion—HR-SDOCT guided reverse big bubble technique may be a useful method to prepare donor tissue in DMEK. Further improvements in HR-OCT technology are needed to improve this promising technique.

Corresponding author: George D. Kymionis, University of Crete-School of Health Sciences, GR 71 003 Voutes, Heraklion, Crete – Greece, Tel: +30 2810 371800, Fax: +30 2810 394653, kymionis@med.uoc.gr.

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Keywords

Descemet's membrane endothelial keratoplasty; spectral domain optical coherence tomography; donor tissue preparation; intraoperative real-time imaging

Introduction

Recently, lamellar keratoplasties have gained in popularity to treat selectively affected layers of cornea, while preserving the healthy recipient corneal tissue. They demonstrate several advantages over penetrating keratoplasty (PK) such as lower incidence of endothelial graft rejection, better tectonic stability, early steroids discontinuation and faster visual recovery¹. However, the interface between graft and recipient cornea limits optimal visual outcomes compared to penetrating keratoplasty. In Descemet's Stripping Automated Endothelial Keratoplasty (DSAEK), the diseased endothelium of the recipient cornea is replaced by the donor endothelium, Descemet's membrane (DM) and a thin layer of posterior stroma²⁻⁴. Descemet's Membrane Endothelial Keratoplasty (DMEK), in which only the DM-endothelium complex is transplanted onto the recipient cornea, demonstrated advantages over DSAEK procedure which are related to the lack of stromal tissue and may include: better visual quality provided by a near natural interface and a potentially lower incidence of graft rejection⁵.

According to recent reports⁵⁻⁷, the DMEK technique, although providing better results than DSAEK, remains a complicated and time-consuming surgery in which donor preparation is one of the most challenging steps. The purpose of our study was to assess, on donor corneo-scleral discs, the benefit of real time High Resolution Spectral Domain Optical Coherence Tomography (HR-SDOCT) guided air dissection used in reverse big bubble technique for DMEK donor preparation.

Method

Three sclera-corneal discs, which were non suitable for human transplantations, were used in this ex-vivo experimental study. These sclera-corneal discs were collected from the Florida Lions Eyes Bank and were mounted 'endothelial side-up' on a disposable Barron donor punch block (Barron Precision Instruments, Grand Blanc, MI). After achieving sufficient suction, 3 experienced surgeons attempted to produce a pre-Descemetic pneumatic dissection using the reverse big bubble technique with a 27 gauge Fogla cannula (Storz Ophthalmics, Bausch and Lomb, USA) attached to a 5ml syringe filled with air. With the help of an operating microscope, the tip of the cannula was introduced at the corneal periphery just inside the limbus from the endothelial side and then was advanced towards the central cornea through the posterior stroma. Each surgeon attempted to achieve the ideal depth (pre-Descemetic plane) to produce the reverse big bubble in order to separate DM from posterior stroma. Prior to air injection, the operating microscope was removed from the surgical area, the HR-OCT probe was aligned vertically with the corneal button in order to obtain real-time OCT imaging and to evaluate the depth reached by the tip of the cannula and to track its path.

The procedures were imaged using a supine OCT system, built by the Ophthalmic Biophysics Center at Bascom Palmer Eye Institute, which is normally used to image patients in a supine position in an operating room environment⁸. The imaging system combines a modified portable operating microscope with a HR-SDOCT unit (ENVISU C2200, Bioptigen Inc., Morrisville, NC, USA) (Figure 1). The axial resolution of the HR-SDOCT unit is approximately 3 μ m (in tissue) and the axial range is 1.56 mm (in tissue). The modified operating microscope stand is equipped with custom motorized adjustments that provide 5 degrees of freedom. The adjustments are controlled with a remote so that the operator can accurately position the HR SD-OCT probe to the designated area of the anterior segment that needs to be imaged. The working distance between the optics of the hand-held unit and the sample was increased to 60 mm to enable imaging the anterior segment during surgery.

The incidence of big bubble, intrastromal emphysema and perforation obtained by each surgeon was recorded and HR-SDOCT imaging findings were described.

Results

Prior to air injection, the depth of the tip of the cannula into the stroma was visualized in real-time with HR-SDOCT. One DM perforation (corneo-scleral disc 1), one intrastromal emphysema (corneo-scleral disc 2) and one successful big bubble (corneo-scleral disc 3) were observed with the operating microscope and the HR-OCT.

In corneo-scleral disc 1, corneal perforation was suspected under the operating microscope before attempting air injection. This corneal perforation was confirmed by HR-OCT images which showed a discontinuity of the hyperreflectivity at the plane of DM.

In corneo-scleral disc 2, emphysema was observed with the operating microscope as a white opacification and haziness of stroma at the point of injection and was visualized on the HR-SDOCT as a hyperdense intrastromal area shadowing the posterior structures of the anterior chamber (Figure 2). Microbubbles were also found around the hyperdense area suggesting a mixed pattern: emphysema-microbubbles. No focal microdetachments were noted on the HR-SDOCT.

In corneo-scleral disc 3, the tip of cannula was first introduced into the stroma but the posterior stroma was not reached according to the HR-OCT images (Needle at depth 1, Figure 3C). Therefore, the surgeon pushed the needle further to be closer to the Descemet's membrane, guided by the real-time HR-OCT: when the tip of the cannula was noted to be at the pre-descemetic plane (Needle at depth 2, Figure 3D), the surgeon proceeded to intrastromal air injection. HR-SDOCT images showed that the big bubble separated Descemet's membrane and stroma without intrastromal hyperreflectivity (Figure 4).

Discussion

DMEK procedures, although advantageous, are not widely practiced as they present unique challenges at several steps: donor tissue preparation, intraoperative maneuvering of the donor DM-endothelium discs and postoperative patient care. Currently, two techniques have

been described for DMEK donor tissue preparation: peeling the donor endothelium and isolating it from the adjacent stroma, and air-assisted dissection to create a big bubble, as originally described for Deep Anterior Lamellar Keratoplasty (DALK) by Anwar and Teichman⁹⁻¹⁰. This approach has been modified as the reverse big bubble technique in DMEK donor tissue preparation which has been recently described¹¹⁻¹³.

Zarei-Ghanavati *et al.* successfully attempted the reverse big bubble technique on one corneo-scleral disc¹¹. Busin *et al.* used 20 human donor corneo-scleral discs unsuitable for transplantation to test pre-descemetetic pneumatic dissection¹². In their study, complete detachment of Descemet's membrane was achieved in 95% of cases (in 60% of cases, this was achieved with a single injection). Studeny *et al.* performed DMEK on 20 eyes of 18 patients and used the reverse big bubble technique for donor tissue preparation¹³. At one year follow up the rate of endothelial cell loss was 44% compared to the preoperative endothelial cell density. In comparison with manual dissection of donor DM, reverse big bubble technique for DMEK can be done faster, easier and it should reduce the rate of endothelial cell loss.

HR-OCT has been utilized as a valuable diagnostic tool for retinal as well as anterior segment evaluation¹⁴. It has been used to assess postoperative outcomes of various corneal and refractive procedures such as flap thickness in Laser in situ Keratomileusis (LASIK), donor lenticular position after DSAEK¹⁵ *etc.* Recently, utilization of intraoperative HR-OCT has been described to assist lamellar keratoplasties. Indeed, in 2010, Knecht *et al.* used an intraoperative Fourier Domain OCT during DSAEK¹⁶. This technology enabled to assess the quality of attachment and the location of the donor button in the recipient cornea. The host-donor interface was visualized in details and they found that donor adherence can occur in spite of residual interface space. Scorcia *et al.* used HR-OCT to assist intrastromal air injection in DALK¹⁷. The SD-OCT imaging performed in this study enabled visualization of the path taken by the tip of the needle after it was removed from the cornea. They performed SD-OCT imaging of DALK with the i-Vue OCT system (Optovue, Inc., Fremont, CA) on 100 keratoconic eyes with encouraging results: "Big bubble formation" was obtained in 70 % of cases¹⁷.

In our study, HR-OCT real-time imaging of the tissue preparation enabled us to visualize the insertion of the cannula into the posterior stroma. Despite some artifacts due to reflections produced by the tip of the cannula, HR-OCT helped the surgeon to visualize the tip and the track of the cannula into the corneal stroma. Real-time SDOCT imaging may further help in surgical manoeuvres to achieve the optimum pre-Descemetetic plane with the cannula tip. Future studies with a larger sample size are needed to assess the benefits of real-time OCT imaging for donor tissue preparation in DMEK. Nevertheless, our experiments showed that HR-SDOCT imaging of emphysema (stromal hyper-reflectivity shadowing the posterior structures of the anterior chamber) and big bubble (two separated corneal structures, no hyper-reflectivity) helped the surgeons to determine whether the complete pneumatic pattern was achieved or not. The limitations of this technique may include: suboptimal visualization of deep corneal structures in case of emphysema and artifacts related to the metallic nature of the needle and cannula.

In conclusion, HR-SDOCT assisted reverse big bubble technique is feasible and, after improvements, may help in optimizing success of DMEK donor tissue preparation.

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FIGURE 1.

Supine high resolution Optical Coherence Tomography (HR-OCT). The hand-held probe of a commercial HR-OCT system is mounted on a modified operation microscope stand, which is equipped with motorized adjustments to accurately position the OCT scan to the designated area of the anterior segment.

FIGURE 2.

High Resolution Optical Coherence Tomography (HR-OCT) in corneo-scleral disc **A.** Visualization of the white opacified stroma demonstrating intrastromal emphysema (white arrows). **B.** Corresponding HR-OCT image of intrastromal emphysema: heterogenous hyper-reflective areas (white triangles) in corneal stroma with associated shadowing of the underlying structures. The hyporeflexive areas (white arrows) show the multiple micro air bubbles which are created when intrastromal emphysema occurs.

FIGURE 3.

High Resolution Optical Coherence Tomography (HR-OCT) in corneo-scleral disc 3: introduction of the needle in the stroma. **A.** The real-time HR-OCT scan was acquired along the length of the needle. The asterisk shows the segment of the outer needle and the black triangle shows part of the inner needle, that will be visualized on image C and D. **B.** Schematic representation of the insertion of the needle in the stroma in 2 steps: in the first attempt the tip of the needle is not close enough to Descemet's membrane, depth 1 (image C), the needle is then pushed closer to the Descemet's membrane, depth 2 (image D). **C.** HR-OCT imaging of the needle at depth 1: the needle tip is far from the Descemet's membrane; the en-face image generated with the volumetric OCT data showing the needle is reported on the side. **D.** HR-OCT imaging of the needle at depth 2, the needle is very close to the Descemet's membrane, the surgeon is ready to inject the air to obtain the separation of the Descemet's membrane from the underlying stroma.

FIGURE 4. High Resolution Optical Coherence Tomography (HR-OCT) in corneo-scleral disc 3: reverse big bubble acquisition. **A.** Visualization of the reverse big bubble. **B.** Thin hyper-reflective layer (Descemet's membrane) separated from underlying stroma.