Anterior Segment Optical Coherence Tomography–Guided Big-Bubble Technique

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Purpose: To evaluate the feasibility of intraoperative anterior segment (AS) optical coherence tomography (OCT) for quantification of the corneal depth reached with the dissecting cannula used for deep anterior lamellar keratoplasty, as well as its correlation with the success rate of big-bubble formation.

Design: Retrospective, noncomparative, interventional case series.

Participants: One hundred consecutive keratoconus patients.

Intervention: Deep anterior lamellar keratoplasty was performed using the big-bubble technique. During surgery, the cannula used for pneumatic dissection was inserted into the peripheral stroma and advanced as deep and far toward the center as believed adequate by the surgeon. Then, after retracting the cannula, AS OCT was performed. The cannula was placed back in position and creation of the big bubble was attempted.

Main Outcome Measures: Stromal depth reached with the cannula tip, success rate in achieving big-bubble formation, and complication rate.

Results: Bubble formation was obtained in 70 of 100 eyes (70%). In all remaining eyes, the procedure was completed by manual deep lamellar dissection. The average depth reached by the cannula tip was 104.3 ± 34.1 μm from the internal corneal surface; the mean value recorded in cases of successful big-bubble formation (90.4 ± 27.7 μm) was statistically lower than that measured in failed procedures (136.7 ± 24.2 μm). In 1 case, corneal perforation occurred during the insertion of the cannula and required conversion to penetrating keratoplasty (PK). In 8 eyes, small microperforations occurred during stromal excision but could be managed conservatively, avoiding conversion to PK. In 2 advanced cones, an incomplete bubble formation was obtained, necessitating manual peripheral stromal removal.

Conclusions: Successful big-bubble formation can be anticipated if pneumatic dissection is attempted at a sufficiently deep level. Although an ideal depth could not be defined, AS OCT allows objective evaluation of the depth reached by the cannula tip used for pneumatic dissection. The AS OCT findings may confirm the decision to proceed with air injection. It is possible that cannula repositioning based on the AS OCT depth may improve the success rate for big-bubble formation.

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Deep anterior lamellar keratoplasty (DALK) has become popular as an alternative to penetrating keratoplasty (PK) for the treatment of keratoconus and other corneal stromal diseases in the presence of healthy endothelium. Most importantly, in contrast to PK, with DALK, the host endothelium is preserved, thus eliminating the risk of endothelial rejection. Finally, DALK is an extraocular procedure that allows more rapid wound healing and requires corticosteroid therapy for a shorter period, usually administered only topically.[1–6]

Several authors have shown that visual acuity after DALK can be optimized only when baring of Descemet's membrane (DM) is achieved or only when minimal residual stroma is left in place.[7–9] To do so, most surgeons prefer to use the so-called big-bubble technique, originally reported by Anwar and Teichmann[2] in 2002, who first used air to create a plane of dissection between DM and corneal stroma.

However, the big-bubble technique is still far from being standardized, and its popularity is strongly affected by a steep learning curve, which makes most surgeons still prefer to perform PK because of its technical ease and shorter surgical time. In particular, the creation of the big bubble itself remains the most frustrating step of the entire procedure.[7]

It is commonly accepted that pneumatic dissection of DM from the overlying stroma requires injection of air at a level as close as possible to DM itself. However, to date, a technique for the intraoperative measurement of the depth of the injection cannula has not been described. In addition, the ideal distance between the DM and the injection cannula for the formation of an adequate big bubble has not been identified.

Anterior segment (AS) optical coherence tomography (OCT), a noncontact imaging device that allows high-resolution, cross-sectional images of the AS, recently has been used during surgery for different purposes.[10–13] This technique was used in this study in an attempt to correlate the depth at which air is injected into the stroma with the success rate in creating the big bubble in 100 patients undergoing DALK.

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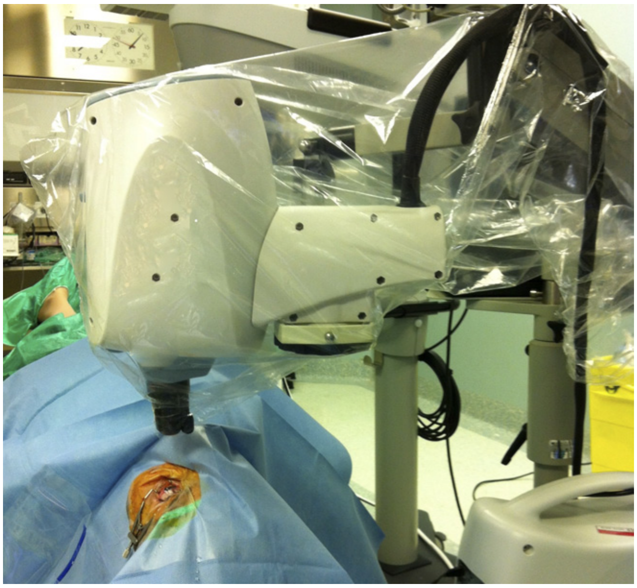

Figure 1. Photograph showing the surgical setup: the anterior segment optical coherence tomography device is mounted on a swinging arm, which can be used to obtain the required scans of the patient's cornea under sterile conditions.

Patients and Methods

All the charts were reviewed of patients with keratoconus, who were intolerant to spectacle or contact lens correction, or both and who were included in a retrospective clinical study undertaken at our institution from January 2010 through April 2012. The study followed the tenets of the 1964 Declaration of Helsinki and was approved by the local ethics committee (University of "Magna Graecia," Catanzaro, Italy); detailed informed consent was provided by all patients undergoing DALK. Keratoconus had been diagnosed based on slit-lamp findings (corneal ectasia, Fleischer ring, and Vogt striae) and was confirmed by corneal topography. No value of minimum corneal thickness was considered too low for inclusion in the study. Exclusion criteria were the coexistence of other ocular pathologic features, presence or history of acute corneal hydrops, and previous corneal surgery. Intraoperative and postoperative complications, as well as secondary interventions, were recorded.

Before surgery, every patient underwent a complete ophthalmologic evaluation, including slit-lamp examination, both Snellen uncorrected visual acuity and best spectacle-corrected visual acuity, refraction, tonometry, funduscopy, and corneal topography (Pentacam Scheimpflug imaging system; Oculus, Wetzlar, Germany). Before surgery, the thinnest corneal point was determined by AS OCT (i-Vue; Optovue, Inc., Fremont, CA), and endothelial cell density was assessed by specular microscopy (EM-3000; Tomey, Germany). In the operating theater, the AS OCT device was mounted on a customized mobile table with a flexible arm (Fig 1); the caliper measuring tool software was used to measure the distance between the dissection plane and the DM, thus providing a value of the residual corneal thickness (Fig 2D).

Statistical analysis was performed using a basic statistical package (Microsoft Excel for Mac 2011, version 14.2.2; Microsoft, Redmond, WA). A Student t test was used for comparison of variables, with a P value less than 0.05 considered statistically significant. Normally distributed values were reported as mean ± standard deviation.

Surgical Procedure

All patients received peribulbar anesthesia with a mixture of lidocaine hydrochloride 2% and bupivacaine hydrochloride 0.5%. Deep anterior lamellar keratoplasty was performed in all cases by the same surgeon (V.S.) using the classic big-bubble technique described by Anwar and Teichmann,[2] with the only exception of

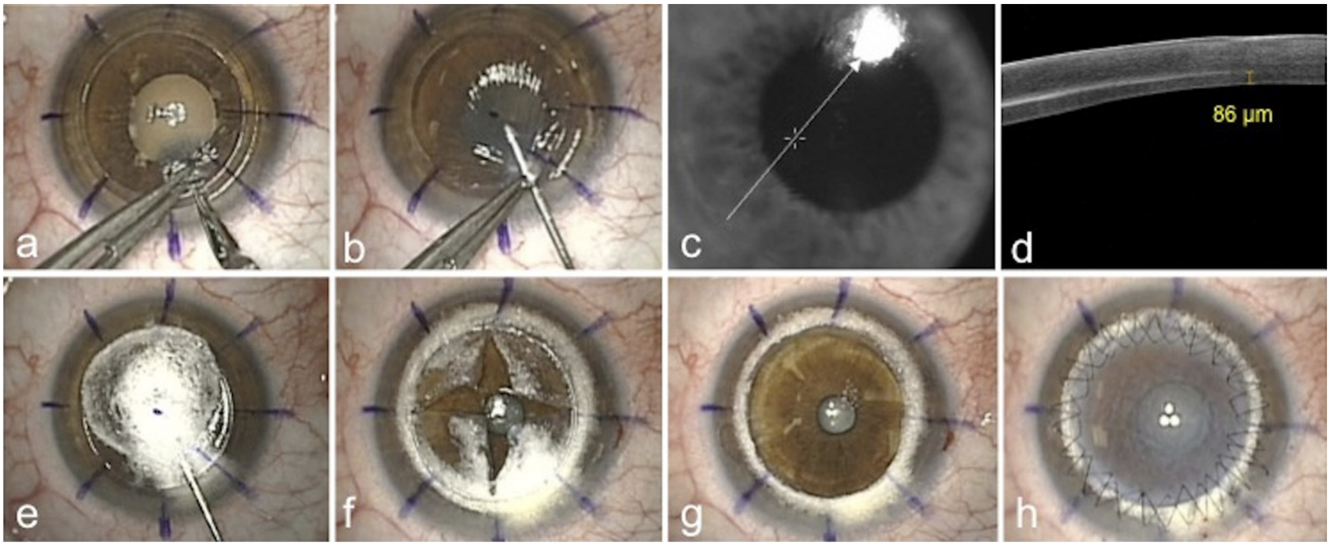

Figure 2. Images showing anterior segment (AS) optical coherence tomography (OCT)–assisted big-bubble surgery. **A,** A pointed spatula is used to create a small corneal pocket. **B,** A blunt 27-gauge cannula is advanced centripetally toward the Descemet's membrane. **C,** The cannula is withdrawn and the AS OCT device is oriented parallel to the corneal tunnel previously created, under guidance of the system's infrared camera. **D,** The stroma depth reached by the cannula tip is measured. **E,** The cannula is inserted again into the same channel and air is injected into the stroma until formation of the big bubble is completed. **F,** After performing a superficial keratectomy, the anterior stroma is split into 4 sections, which (**G**) are excised, exposing the Descemet's membrane completely. **H,** The donor cornea is sutured in place with a double running 10-0 nylon suture.

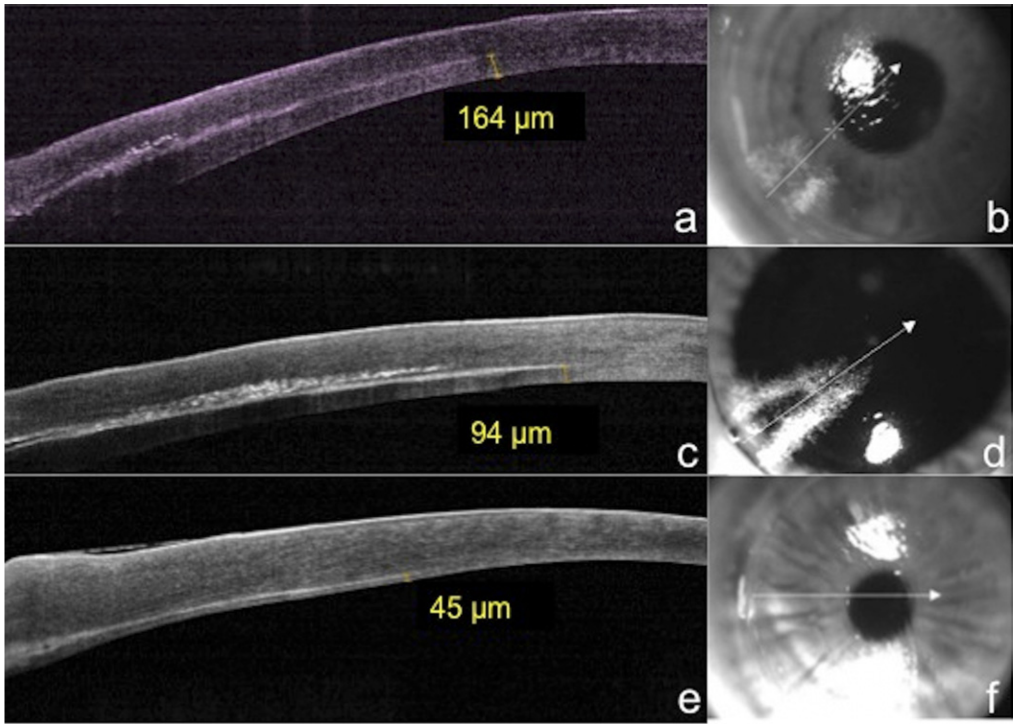

Figure 3. Anterior segment (AS) optical coherence tomography (OCT) images of 3 different patients. **A-B**, The depth reached with the cannula is rather superficial (thickness of underlying stroma, 164 μm), and no bubble could be obtained. **C-D**, The dissection has reached a deeper level, allowing subsequent bubble formation. **E-F**, The cannula progression was stopped before reaching the center of the very ectatic cornea. In this case, the AS OCT image was instrumental in avoiding perforation, which would have occurred if the cannula had been advanced toward the central cornea at the same depth.

using a blunt cannula instead of a sharp needle, as recently proposed by other authors.[14,15]

Initially, a Barron suction trephine (Katena Products, Inc., Denville, NJ) was used to obtain a circular incision of between 8.0 and 8.5 mm in diameter and approximately 70% and 80% of total thickness in depth in the recipient cornea; the peripheral pachymetric map obtained before surgery by means of the Pentacam Scheimpflug imaging system served as a reference. A Melles pointed spatula (D.O.R.C., Zuidland, The Netherlands) was used to create a small corneal pocket advancing 1 to 2 mm (Fig 2A) from the bottom of the partial trephination. A blunt 27-gauge Fogla cannula (Bausch & Lomb Storz Ophthalmics, Milano, Italy) connected with a luer-lock syringe filled with air then was advanced slowly centripetally toward the DM (Fig 2B), reaching a plane thought to be deep enough to allow pneumatic dissection. Progression into the stroma was stopped when the surgeon felt a decrease in tissue resistance, revealing that a deep stromal plane had been reached. The cannula was withdrawn without injecting any air, and an AS OCT scan was obtained with a dedicated instrument mounted on a swinging arm (Fig 1). Before surgery, the entire instrument, including the anterior lens and flexible arm, was sealed within a sterile bag and was taped in the same fashion as previously described.[13] Intraoperative OCT scans were obtained by a single experienced ophthalmologist (A.L.) who optimized focus and scan quality at the monitor; the anterior corneal surface was kept wet while performing AS OCT to improve the quality of the scan obtained. A section parallel to the corneal tunnel previously created (Fig 2C) was obtained, and the thickness of the corneal stroma beneath the end point of the cannula dissection was measured (Fig 2D). To increase the accuracy of measurements, the caliper tool of the system always was aligned perpendicular to the inner and outer corneal profile, rather than simply being positioned vertically. For this reason, depending on the curvature of the measurement site, the caliper alignment may look different, as in Figure 3, without affecting reproducibility. It was not possible to obtain an AS OCT scan of adequate quality with the cannula in position because of both the difficulty in maintaining a steady position and a shadowing effect of the metal onto the underlying stroma. Surgery then was continued by inserting the cannula back into the stroma through the same channel down to its end. This was possible easily in all cases, without encountering any resistance, thus making sure that the same path had been followed. Air was injected into the stroma until a big bubble was formed and reached the trephination edge (Fig 2E). A peripheral side entry was created, and the superficial keratectomy was completed with a crescent knife. Blunt-tipped corneal scissors were used to divide the anterior stroma into 4 sections (Fig 2F), which then were excised, baring the DM completely (Fig 2G).

In all cases in which the big bubble failed to form, a layer-by-layer manual stromal dissection was carried out with a blunt-tipped Melles spatula (D.O.R.C., Zuidland, The Netherlands). No additional air injection was attempted because of the difficulty of effectively injecting air into emphysematous corneal tissue.

The donor cornea was punched from the endothelial side with the Barron donor punch (Katena Products, Inc.) to the same diameter of recipient trephination. The DM with endothelium was stripped off gently with a dry Weck-Cel sponge after staining with 0.06% trypan blue dye (VisionBlue; D.O.R.C., Zuidland, The Netherlands). Surgery was completed with 2 running 10-0 nylon sutures, with 16 corneal bites each (Fig 2H).

Postoperative medication included tobramycin and dexamethasone phosphate 0.1% 4 times daily for 1 month, which was tapered off over 12 weeks, as well as artificial teardrops instilled 4 times daily for 3 months.

Table 1. Baseline Characteristics and Postoperative Measurements after Big Bubble and Manual Deep Anterior Lamellar Keratoplasty

Measures	Big-Bubble Deep Anterior Lamellar Keratoplasty	Manual Deep Anterior Lamellar Keratoplasty	*P* Value*
Age (yrs)	37.8±14.2	33.4±10.6	0.14
Preoperative thinnest point (μm)	373.1±86.2	396.9±56.7	0.17
Preoperative corneal curvature (D)	54.6±7.6	57.2±7.9	0.14
Stroma below cannula (μm)	90.4±27.7	136.7±24.2	<0.01

D = diopters.
Data are expressed as mean±standard deviation.
*Student *t* test.

Results

One hundred eyes of 96 patients were identified at the time of this review (May 2012). The average age±standard deviation at surgery was 36.5±13.3 years, ranging from 16 to 49 years. Sixty patients were women (60%) and 40 were men (40%).

The average preoperative best spectacle-corrected visual acuity was 20/200 (range, counting fingers–20/100). Preoperative mean keratometry was 55.4±7.8 diopters (D), and astigmatism was 4.95±1.95 D (range, 0.75–7.25 D). Average central corneal pachymetry was 380.3±79.0 μm (range, 255–480 μm). The endothelial cell density measured before surgery ranged from 2340 to 2952 cells/mm^2 (mean, 2704 cells/mm^2).

A big bubble was achieved in 70 eyes (70%); 30 eyes required layer-by-layer dissection to reach the DM (because of failed formation of the big bubble). In 1 case, corneal perforation occurred during the initial insertion of the cannula, requiring conversion to PK. In 8 eyes, a small peripheral microperforation occurred during manual dissection, which was completed, however, with no need for conversion to PK. In 2 advanced cones, an incomplete bubble formation was obtained, demanding manual peripheral stromal removal. No other intraoperative or postoperative complications were recorded.

The average distance between the cannula tip and the DM, as measured during surgery with AS OCT, was 104.3±34.1 μm. In the group of patients in whom the big bubble formed, the residual tissue thickness (mean, 90.4±27.7 μm) was significantly lower ($P<0.01$) than that recorded in the group of failed procedures (136.7±24.2 μm). No further significant differences were recorded between the 2 groups in terms of patient age ($P = 0.14$), preoperative corneal curvature ($P = 0.14$), or minimal value of corneal pachymetry ($P = 0.17$). Table 1 lists the main outcomes recorded.

Discussion

In recent years, several techniques of DALK have been proposed in an attempt to remove most of the anterior corneal stroma safely, thus achieving a pre-Descemetic or Descemetic plane of dissection, which is compatible with best visual outcomes.[1,2,4,16–19] Among these methods, the big-bubble technique offers the advantage of a quick exposure of DM or a pre-Descemetic plane, thus eliminating the painstaking manual dissection.[7,8] This method, however, is not widely performed, most likely because of the unpredictability of bubble formation, which may succeed in less than 50% of cases, especially at the beginning of each surgeon's learning curve.[7]

The fundamental step for the formation of a big bubble is the insertion of a needle or blunt cannula into the deep stroma, where tissue adhesion is weakest. In fear of perforating DM, surgeons often stop the insertion at the level of mid rather than deep stroma, and air injection results only in diffuse emphysema of the anterior stroma. To date, no objective intraoperative assessment of the insertion depth of the cannula has ever been performed, thus making impossible a statistical correlation between this variable and the success rate of the big-bubble procedure.

This study used AS OCT during surgery for this purpose and obtained images that could be used for objective evaluation, as shown in Figure 3. Based on these measurements, it was determined that the mean stromal level reached by the cannula in eyes with a successful big bubble was significantly deeper (90.4±27.7 μm vs. 136.7±24.2 μm; $P<0.01$) than that reached in eyes with failure to obtain the big bubble.

No significant difference was recorded between age, recipient corneal thinnest point as measured by means of AS OCT, or preoperative topographic keratometry readings and probability of a successful big-bubble procedure. That only one surgeon operated on all eyes included in this study could represent a bias because a tendency toward deeper insertion can be hypothesized during the learning curve. However, no statistically significant difference was found between early and late cases regarding the depth of the dissection plane achieved. Also, there were 16 failed bubbles among the first 50 cases and 14 in the last 50 cases. That the surgeon had previous experience with the big-bubble technique is the most probable explanation for this.

Interestingly, in 3 eyes, the big bubble could be obtained even when air was injected at a substantially more superficial stromal level (between 148 and 171 μm from the internal corneal surface). This indicates that additional variables also may play a role in facilitating pneumatic dissection of DM. In particular, it is conceivable that the pressure at which the air is injected also may be correlated with the probability of big-bubble formation, and standardization of this parameter, although difficult to obtain, could contribute to a substantial improvement in the technique.

However, in 2 eyes, air injection at a depth of 96 and 82 μm was not successful in achieving the big bubble. The most plausible explanation for this was the presence of deep scar tissue, visible both with the slit lamp and on AS OCT examination in both eyes, most probably resulting from healed ulceration secondary to traumatic contact between ectatic cornea and a hard contact lens.

The identification of an ideal cannula depth, beneath which the DM is expected to be exposed by pneumatic dissection in a very high percentage of cases, as well as its accurate measurement by AS OCT, may prove instrumental in improving the consistency of the big bubble technique and in flattening the surgical learning curve. The purpose of this study was to try to correlate the depth of cannula insertion with the success rate of big-bubble formation, not to establish a new technique to increase the success rate itself. However, based on these results, the surgeon may decide to abort pneumatic dissection when the site of cannula insertion is found to be superficial and instead attempt a secondary insertion to reach a plane deep enough to allow successful big-bubble formation. Because good-quality scans can be achieved in fewer than 30 seconds (including the time required for proper scan alignment), AS OCT scans likely can be repeated until the cannula is placed in the desired plane. This compares favorably with the results of a previous study using a handheld device, which was unstable and therefore difficult to handle.[13] Further studies would be required to demonstrate whether the current approach can increase significantly the rate of successful pneumatic dissection.

A further step forward could be made if the instrument could be mounted onto the operating microscope and used in real time during surgery. However, present limitations include the impossibility of using both devices simultaneously (and the consequent need to switch from the microscope to the AS OCT instrumentation), the standardization of the scan alignment with the patient's cornea, as well as the shadowing effect of the metallic cannula. These limits may be overcome in the future with new technological developments and the use of plastic cannulas that are transparent on ultrasound.

To the best of our knowledge, no alternative quantitative methods have been described to date that successfully help the surgeon to detect the plane reached with the cannula during surgery and consequently provide potential to improve the reproducibility of the big-bubble procedure. A femtosecond laser-assisted big-bubble technique was described recently, with the goal of standardizing the depth of the dissection plane.[15] Wide application of the femtosecond laser-assisted technique, however, would be expected to be limited by reduced accuracy of these devices when performing deep dissections and by the high cost and limited availability of the femtosecond laser. Finally, although this study included only eyes with transparent keratoconic corneas, the AS OCT–guided big-bubble technique also could be used in patients with nontransparent corneas that cannot be operated on by relying on visual clues.

Further studies with a larger number of patients operated on by different surgeons are required to confirm this initially positive experience with the use of intraoperative AS OCT to assist in big-bubble formation. Ideally, these studies will investigate further the ideal depth of cannula placement for pneumatic dissection, as well as the effect that this may have on the success of the procedure.

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Footnotes and Financial Disclosures

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