Double-Docking Technique for Femtosecond Laser-Assisted Deep Anterior Lamellar Keratoplasty

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Purpose: To describe a new and safe surgical technique of deep anterior lamellar keratoplasty (DALK) using the femtosecond laser (FSL) and intraoperative optical coherence tomography (iOCT) for surgical management of corneal thinning and/or opacities. The technique was coined the double-docking procedure for DALK (DD-DALK).

Methods: FSL-integrated iOCT was used for direct visualization and calibration to perform precise anterior lamellar and side cuts for the removal of the anterior stroma. Air was then injected in the residual posterior stroma to detach Descemet membrane [big-bubble (BB) formation]. Returning the residual posterior stroma into the docked position, a cylindrical vertical cut was made with the FSL to securely open the BB roof. Next, the stromal roof of the BB was removed with forceps leaving Descemet membrane intact, followed by a lamellar corneal graft.

Results: Anterior stroma resection, BB formation, and residual stromal resection were achieved in every case without perforation. The curved applanation surface helped to limit the formation of folds on the posterior stroma (ie, advanced thinning).

Conclusions: DD-DALK is a reproducible and safe procedure for surgical management of corneal thinning and/or opacities. The precision of stromal cuts made by the FSL and iOCT guidance for air injection increases success in DD-DALK preparation.

Key Words: deep anterior lamellar keratoplasty, keratoplasty, femtosecond laser, keratoconus, cornea

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Deep anterior lamellar keratoplasty (DALK) is increasingly used in keratoplasty cases to preserve the endothelial layer (opaque or irregular stroma).[1,2] In such cases, it supersedes penetrating keratoplasty; however, reproducibility is dependent on the level of experience of the surgeon. The surgical challenge involves complete removal of the stroma without inflicting endothelial cell loss or Descemet membrane (DM) injury. The big-bubble (BB) technique[3] was developed to address this need, and, to date, has been associated with better visual outcomes[4] compared with partial stromal removal.

In view of the potential gains that can be obtained with the femtosecond laser (FSL) in terms of quality, reproducibility, and safety of stromal corneal cuts, it should provide a useful surgical aid in DALK. However, to date, visual outcomes after FSL-assisted lamellar anterior keratoplasty has been limited by poor quality of the stromal interface, particularly when lamellar cuts were performed deep in the stroma[4,5] or made through corneal opacities.

Two additional potential aids within the FSL platform are the curved cornea–laser interface and integrated intraoperative coherence tomography (iOCT) within the FSL platform. iOCT allows in vivo real-time imaging of the stromal microstructure, improving guidance. Combining the FSL with the BB technique[6] has been described previously; however, a significant risk of DM perforation remained when opening the BB roof. In the procedure described in this study, referred to as the double-docking technique (DD-DALK), we used a modern FSL device with intraoperative iOCT guidance and also modified the standard surgical technique to optimize the stability afforded by the curved suction cup. The aim of this study was to examine the possible benefits of this modified surgical technique during DALK with respect to safety and reproducibility. In this study, we report our experience of FSL-assisted DALK, first in the ex vivo experimental setting and then during DALK surgery in patients.

MATERIALS AND METHODS

Surgeries were performed under general anesthesia by one experienced corneal surgeon at the Rothschild Ophthalmic Foundation (Paris, France). Informed consent was obtained from all patients before surgery. The study met all criteria of the Declaration of Helsinki and was approved by the ethics committee.

The Victus FSL platform (Bausch + Lomb; Bridgewater, NJ) was located in the operation theater; for every step

TABLE 1. Parameters Used to Configure Victus FSL Platform

Parameters	First Docking; Lamellar and Side Cuts*	Second Docking; Residual Stromal Cut
Diameter (mm)	8.2†	6.5–8
Depth (μm)	TP >300 μm: 60% TP; TP <300 μm: 50% TP	300
Space between spots (μm)	5.4	5
Space between raster (μm)	5.4	2
Energy (μJ)	0.750	2

*Side cuts were vertical straight cuts.
†The same diameter was used for lamellar and side cuts.
TP, thinnest point.

of surgery, the patient lay on the FSL platform's patient bed that was swiveled to perform steps under an operating microscope (Lumera 700; Zeiss, Germany) with iOCT (Rescan; Zeiss, Germany).

After placement of a disposable suction ring at the sclera–limbal margin and the first docking with a curved laser–cornea interface, parameters of the anterior stromal lamellar cut were set (Table 1) in respect to corneal thickness measured with iOCT. Corneal lamellar cuts and side cuts were performed under real-time iOCT guidance (Figs. 1, 2A, B). Then, the suction ring was removed, and the patient's bed was swiveled to position the patient under the operative microscope with iOCT. The stromal flap was removed with forceps and a spatula (Figs. 2C, D). Then, a 30-gauge needle or a Fontana cannula (Moria, France) was used to pneumodissect DM from the anterior residual stroma (BB formation) (Figs. 2E, F). Afterward, the patient's bed was swiveled under the FSL, a new suction ring was placed and second docking was made (Fig. 2G). The interface of the residual stroma and DM limit was identified with iOCT (Fig. 2G). To remove the residual stroma and to prevent any injury to detached DM, a cylindrical vertical stromal cut was performed from the back to the front of the residual stroma with the FSL platform (Table 1) under iOCT control to visualize DM (Fig. 2G). The suction ring was removed, and the patient's bed was swiveled to reposition the patient under the microscope. The roof of the BB was removed (Fig. 2H), and DM was pushed back using viscoelastic (DuoVisc, Alcon, France) (Fig. 2I). When necessary, the residual posterior stroma was resected with Gabison DALK scissors (Moria, France) (Figs. 2J, K, L). The donor cornea was trephined (diameter 8.25 mm, Moria, France), and the endothelium was peeled off. The graft was placed after removing viscoelastic with Balanced Salt Solution (Alcon, France). The graft was sutured with a simple interrupted stitch of 10-0 monofilament. The postoperative treatment included topical 0.1% dexamethasone instillation and vitamin A ointment application. Several examples are shown in the online video (see Video, Supplemental Digital Content, http://links.lww.com/ICO/A595).

RESULTS

DD-DALK was performed on 18 consecutive patients (Fig. 2; see Video, Supplemental Digital Content, http://links.lww.com/ICO/A595), including 15 cases with keratoconus and 3 with stromal opacities. In all cases, treatment planning of anterior lamellar resection was set according to the thickness at the corneal thinnest point acquired with FSL platform-integrated iOCT. Anterior lamellar stromal resection was successfully achieved in every case without additional cutting, and no perforation occurred. The air dissection technique according to Anwar created a BB in every case, visible on iOCT in the deep stromal location (Fig. 2G). After the second docking, detached DM was observed with iOCT in 17/18 corneas. Compared with ex vivo experimentation, whitening of the posterior stroma induced by air injection in vivo did not always allow the complete section of the cylindrical cut. Therefore, smaller cylindrical keratotomy was intentionally positioned in the clear zone inside the typical white annular area (corresponding to pneumodissected DM detachment). The residual stroma FSL cut could be then resected with scissors after viscoelastic substance injection.

DISCUSSION

The BB technique described by Anwar et al[3] enables wider dissemination of the DALK procedure because it helps to limit the residual stroma that inhibits visual recovery.[4] However, there is a tedious learning curve with this technique.[7] Several modifications aiming at improving success and repeatability have been described, including semiautomated dissection with air injection. The depth of air injection has been correlated with the success of BB formation (around 100 μm above DM).[8,9] Intraoperative OCT or pachymetry-guided incisions were used to perform the deepest stromal insertion of the needle while reducing the rate of DM perforation.[10,11] In

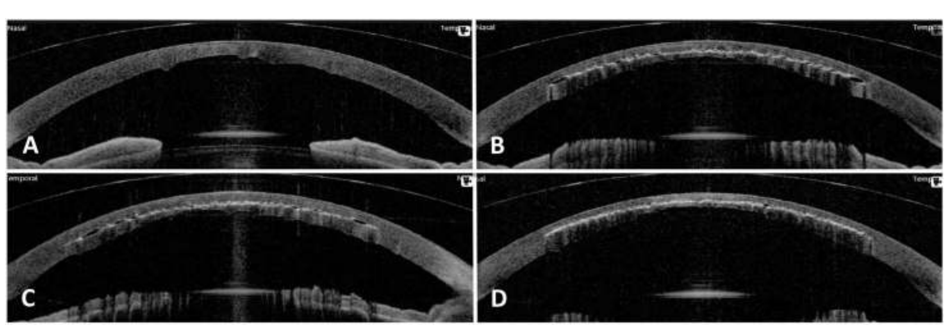

FIGURE 1. FSL-assisted lamellar cut during DD-DALK. A, OCT scan after the first docking. B, C, and D, OCT scans after the lamellar cut.

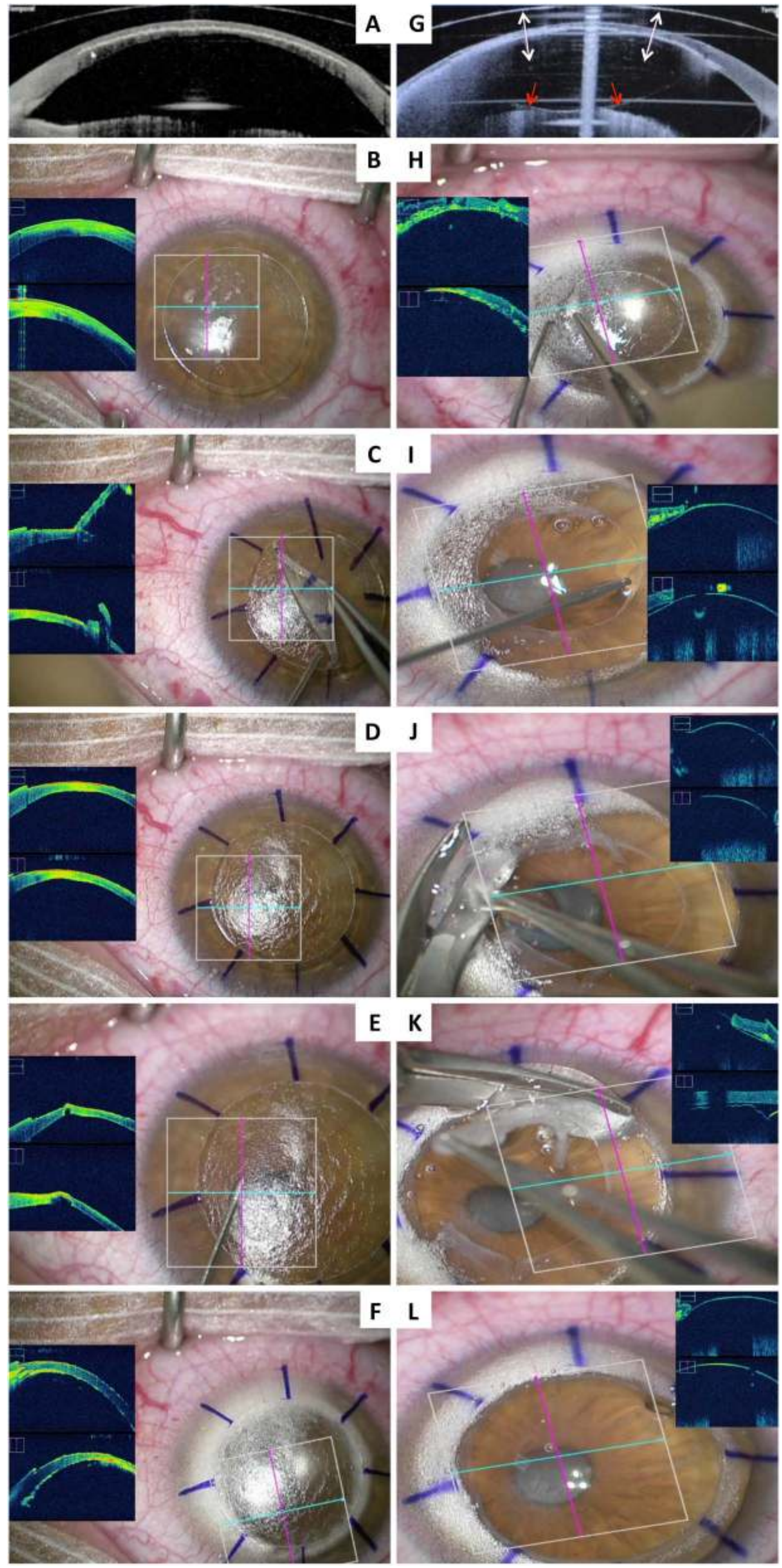

FIGURE 2. FSL-assisted DALK with the double-docking technique (DD-DALK). After the first docking, an FSL-assisted anterior lamellar cut is performed (A). Under an operative microscope with integrated OCT, the lamellar cut is checked (B) and then the anterior stromal lamella is removed using the spatula and forceps (C, D). A 30-G needle is inserted in the residual stroma under OCT guidance (E) and then air is injected to create the BB (F). After the second docking, DM is visible with the FSL-integrated OCT (G, red arrows). The cylindrical vertical cut is set and performed on the residual stroma (G; white arrows indicate the vertical cut setting). Then, the residual stroma is peeled off with forceps (H), and the viscoelastic substance is used to push back DM (I). The residual peripheral stroma is removed using scissors (J, K). The stroma has been fully removed and bare DM was preserved before grafting the donor's anterior stroma (L).

our study, considering the precision of anterior lamellar resection and positioning of the needle under iOCT guidance, we can estimate that air was injected 100 μm above DM. This needle position was effective in achieving a BB in every case and corresponds to the reported relationship between the depth of air injection and success of BB formation.[8,9]

Separately, the FSL was reported as a tool for anterior stroma lamellar resection[6] or for making a deep stromal channel to inject air for BB creation.[6,12] Combining the FSL and real-time iOCT to improve the safety of the DALK procedure was a logical step. However, opening and removal of the stromal roof of the BB remain high-risk surgical steps. FSL-assisted anterior lamellar resection enables a more precise incision depth compared with manual dissection to avoid perforation during this first step, especially in irregular cases such a corneas with keratoconus. Therefore, the DD-DALK technique described in this study represents the final step required to allow widespread adoption of the DALK technique. The curved laser–cornea interface limits the applanation-induced posterior folds, which are traditionally difficult to avoid in very thin corneas. The curved surface allows a more regular FSL-assisted lamellar cut, which reduces the risk of perforation. FSL's real-time iOCT is used to plan and monitor the lamellar cut based on direct real-time visualization of the cornea. In this way, FSL-assisted lamellar cuts have decreased the risk of perforation in cases with irregular stromal thickness such as advanced keratoconus.[13]

In the technique described by Anwar et al,[3] the BB roof is opened with a knife, whereas we perform it with the FSL. The second FSL-assisted cut on the residual stroma is made from the back to the front of the cornea, avoiding DM lesions during cylindrical sectioning; BB roof opening was made only when removing the BB roof with forceps. In this way, it avoids DM injury while it is projected forward when opening the roof with a knife. Moreover, iOCT enables control of the DM position before the second cut to detect incomplete or eccentric BBs and hence to decide whether to complete the BB, to shift the second cut location, or to adapt its diameter. The wide opening of the BB roof enables DM to be pushed back with the viscoelastic substance without applying excessive pressure on DM. After residual stroma removal, the procedure resembles the modified DALK technique that we reported for surgery of descemetoceles.[14] It is advisable to use a cohesive viscoelastic to facilitate its removal.

Further improvements are possible; the diameter of the second cut could be modified as a function of the whitened stroma, as the FSL cuts are suboptimal in the opaque cornea. Optimization of the FSL settings may allow complete removal of the residual stroma with a large diameter to avoid its resection with scissors. Alternatively to manual resection of the residual stroma, the donor cornea could be cut with a mushroom shape to fit the residual posterior stroma. Finding a way to limit stromal opacification during or after air injection could also ease the second penetrating cut. A significant drawback of this technique is the associated cost and its availability in the operating room.

In this pilot study, we show that DD-DALK, although entailing higher costs, is a reproducible procedure. The FSL improves accuracy of corneal cuts and trephination centration. Real-time OCT integrated to the FSL platform was helpful to assess the lamellar dissection depth and to program cylindrical keratotomy of the BB roof. DM rupture was avoided in all cases. This promising procedure merits further investigation in a larger number of cases to assess more thoroughly its safety and efficacy relative to other techniques.

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