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Short Communication

Surgical Tips for Improving Success Rate of Deep Anterior Lamellar Keratoplasty in Keratoconus

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Abstract

This article aims to provide some personal surgical tips to increase the success rate of deep anterior lamellar keratoplasty (DALK), a very advantageous yet complex procedure for treating keratoconus. The most troublesome surgical step is obtaining a successful pneumatic dissection of the deep stromal tissue, allowing the exposure of a deep cleavage plane. The following tips may aid the trainee surgeon in mastering this step, among others: performing a deep trephination, using intraoperative anterior segment optical coherence tomography and/or femtosecond laser, exploiting the red reflex after pupil dilation, using the ophthalmic viscoelastic device in case of bubble formation failure. Approaches for reducing postoperative astigmatism are employing large-diameter grafts and using intraoperative keratoscopy with digital ring analysis. In conclusion, different tips can shorten the DALK learning curve and help to obtain better results from this surgery. Standardizing this surgical technique is paramount to reduce "human errors" and broaden its range of applicability.

Keywords
Deep anterior lamellar keratoplasty; DALK; surgical tips; keratoconus

1. Introduction

Keratoconus (KC) is an ectatic cornea disease that can determine high irregular astigmatism, thinning of stroma and overlying epithelium and variable amounts of corneal scarring in advanced stages. Traditionally, the mainstay of surgical treatment has been represented by penetrating keratoplasty (PK), an open-sky procedure that may be associated with significant intraoperative (suprachoroidal or expulsive hemorrhage) and postoperative complications (increased endothelial cell loss and immune graft rejection). Deep anterior lamellar keratoplasty (DALK) is a surgical procedure characterized by the selective transplantation of the anterior corneal stroma up to the predescemetic layer or Descemet membrane (DM). The major advantage of this technique stands in the preservation of the healthy endothelium, with the maintenance of globe integrity during surgery and abolished risk of endothelial rejection. This surgical approach has become very popular among cornea surgeons, and several studies have confirmed favorable outcomes, especially in KC patients [1, 2]. However, it is a technically demanding surgical procedure, requiring further operating time and greater surgical skills compared to PK, determining longer learning curves [3].

2. Big Bubble DALK

The gold standard surgical technique for DALK is big bubble (BB) DALK, proposed by Anwar and Teichmann in 2002 [4]. They introduced the practice of injecting a big air bubble with a 27-30 gauge needle attached to a 1 to 3 mL air-filled syringe. The needle was inserted bevel-down into the corneal stroma and advanced in an oblique direction towards the center of the cornea for 2-4 mm, aiming posteriorly towards the DM. Air is then forcefully injected into the deep stroma, causing a separation of the DM from the overlying stroma. Two types of bubbles may form and are referred to as “type 1 BB” and “type 2 BB” [5]. The former is the most common and is an intrastromal dome-shaped, well-circumscribed bubble that forms centrally, expands radially and has white margins. The latter has a thinner wall with clear margins and forms between the stroma and the DM. It originates from the peripheral cornea and extends centripetally. Both bubbles may coexist, creating a “mixed bubble” [6]. Paracentesis of the anterior chamber is then obtained by performing a vertically oriented side port. This aims to reduce local pressure and the risk of complications such as Descemet membrane perforation. Anterior keratectomy is accomplished with a blade, and a sharp knife punctures the bubble. Donor tissue preparation is paramount for a good postoperative visual outcome. It consists in cutting the donor’s cornea with an established-diameter blade. The graft’s DM and the endothelium must be peeled with a dry surgical sponge or tooth-less forceps. Finally, the graft is placed over the host’s bed and secured with corneal suture(s) according to the surgeon’s preference.

3. Personal Surgical Tips

DALK is not universally standardized among cornea surgeons. The following tips are useful to achieve higher success rates [7].

3.1 Tip #1: Deep Trephination

When performing BB DALK, finding a proper depth of air injection (i.e., as close as possible to the DM) is a frequent difficulty. This is crucial to obtain BB formation and may not be straightforward even for surgeons with relative surgical inexperience [7]. However, too deep approaches are associated with DM perforation which may require conversion to PK. Conversely, superficial air injection results in corneal emphysema with bubble failure, causing a significant narrowing of the error margin. Trephination depth should be set to aim for 100 µm short of the thinnest point obtained using anterior segment (AS) optical coherence tomography (OCT) at the 9-mm trephination zone. At this diameter, corneal depth is generally more homogenous when compared to 8 mm diameter, where ectatic corneal tissue is more likely to be present. With this approach, a blunt 27-gauge cannula is inserted at the base of trephination, at a predetermined depth. Although this procedure may seem hazardous, it has significantly reduced accidental perforation requiring conversion to PK (1.2%) [7].

3.2 Tip #2: Intraoperative AS-OCT

AS-OCT can be exploited during surgery to ascertain the injection depth, as described elsewhere [8]. After partial trephination, a small corneal pocket is created 1 to 2 mm from the bottom of the trephination. A blunt 27-gauge cannula is advanced toward the DM reaching a plane thought to be deep enough to allow pneumatic dissection. The cannula is withdrawn and an AS-OCT scan is obtained. Based on the acquired images, the surgeon may decide to abort pneumatic dissection if the cannula was inserted too superficially and attempt a second insertion elsewhere to allow successful big-bubble formation. In our experience, the average distance between the cannula tip and the DM, measured during surgery with AS-OCT, was 104.3 ± 34.1 µm. BB formation was achieved in 70% of cases (mean residual thickness 90.4 ± 27.7 µm) [8].

3.3 Tip #3: Red Reflex-Guided BB DALK

Another technique to determine the injection depth is based on the visualization of the residual stroma under the cannula. This was defined as “red reflex-guided BB DALK” and relies on the induction of pharmacological mydriasis before the procedure [9]. After trephination, a blunt spatula is inserted at the base of trephination and advanced 1-2 mm centripetally. A dark line ahead of the spatula tip marks the interface between the endothelium and aqueous; thus, the width of the red zone between the spatula tip and the line corresponds to the thickness of the residual undissected stromal bed. The width of the red zone can be reduced by advancing the spatula downwards until it disappears: this is the desired depth of dissection (Figure 1). This method allowed BB formation in 89.4% of cases; in this group, the mean residual stromal thickness measured intraoperatively with AS-OCT was 63.3 ± 19.2 µm (range, 29-112 µm) [9].

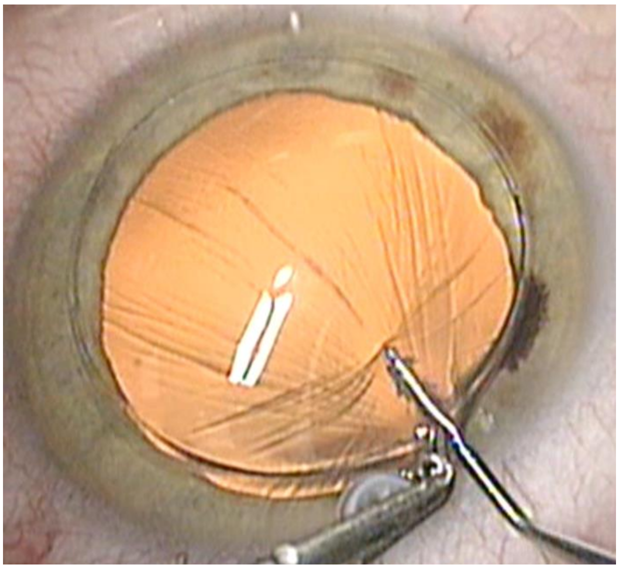

Figure 1 Intraoperative image illustrating the red reflex–guided BB-DALK technique. After advancing the tip of the instrument centripetally tilted downwards, the red zone between the spatula tip and the dark line disappears and only a dark line is visible ahead of the spatula.

3.4 Tip #4: Ophthalmic Viscoelastic Device-Assisted BB DALK

Pneumatic dissection fails in a relatively high number of cases (up to 36%) even in the hands of experienced surgeons. This is more frequent in eyes with milder keratoconus stages than those with more advanced ectasia [6, 10]. A possible approach in the case of corneal emphysema consists of injecting the ophthalmic viscoelastic device (OVD) to obtain a bubble, as reported previously [6, 10]. Briefly, after manual dissection of about 80% of the anterior emphysematous tissue, 0.5 mL to 1.0 mL of OVD is slowly injected via a 27-gauge anterior chamber cannula using the same track from the first injection. The remaining surgical steps do not differ from those of standard BB DALK. As reported, OVD injection successfully creates type 1 BB in most cases (93.33%) [10].

3.5 Tip #5: Femtosecond Laser – Assisted BB DALK

Another method to improve bubble formation's success concerns using femtosecond laser (FSL). This laser has been used to create precise intracorneal incisions that guide cannula insertion and pneumatic dissection [11]. In our experience, FSL-assisted BB DALK was carried out using the Victus FSL platform (Bausch & Lomb, Bridgewater, NJ, USA) which integrated real-time AS-OCT images into its platform. FSL was used to obtain both the intrastromal pocket (1.70 µJ of cutting energy, 1.7 mm in length, 4.6 mm in width at 80% depth from the superior cornea) and the intersecting circular lamellar side cut (0.90 µJ of cutting energy, 9.0 mm diameter, 65 µm above the endothelium). A blunt spatula was inserted through the intrastromal channel and advanced tangentially maintaining the same depth of the entrance plane. A blunt 27-gauge Fontana cannula (Model J2641.58, E. Janach, Como, Italy) was inserted after spatula removal and pneumatic dissection were attempted. FSL-assisted cuts were successfully created in all cases and pneumatic dissection led to type 1 bubbles in all 11 eyes (100%).

3.6 Tip #6: Large Diameter Grafts

Increasing graft size improves postoperative visual outcomes by minimizing refractive astigmatism [12]. Large diameter DALKs have shown better visual outcomes at higher levels of Snellen best corrected visual acuity, without an increased risk of immune rejection and graft failure. In detail, with regards to refractive astigmatism, 9.0 mm DALK presented significantly lower cylinders compared to 8.0 mm DALK, and the percentage of eyes with refractive astigmatism <4.0D was significantly lower in 9.0 mm DALK (90%) than in 8.0 mm DALK (72%) [12]. Moreover, the use of larger grafts was not associated with increased rates of corneal neovascularization or suture-related complications, and the rate of immune rejection rates was not higher compared to standard 8.0 mm DALK. Furthermore, in the case of DM macro perforations, conversion to a 2-piece mushroom PK is possible with a higher safety profile than conventional large-diameter PK. Thanks to the large anterior lamellar and the minimal endothelial replacement, this option provides excellent outcomes in terms of visual acuity with a low risk of immune endothelial rejection [13].

3.7 Tip #7 Management of Type 2 Bubble

Type 2 bubble forms between the posterior stroma and the DM; this is reasonably explained by the presence of micro-fenestrations in the deep stroma's periphery, allowing air passage in the unwanted cleavage site [14]. Type 2 bubble is fragile because the tough stromal tissue does not cover the DM. For this reason, when type 2 bubble forms, DM bearing is a delicate phase of the surgery as macro perforations may be inadvertently induced, requiring conversion to PK [5, 15].

Type 1 bubble more frequently occurs in younger patients with milder stages of KC (i.e., higher pachymetric values and lower K-mean); instead, posterior corneal surface involvement is considered a risk factor for type 2 bubble formation. Deep stromal scarring may possibly damage the pre-Descemetic layer, causing air dispersion at the level of DM [6]. In our experience, manual layer-by-layer dissection should be followed by limited removal of the type 2 bubble roof within the central 4.0 mm, leaving a 4.0 to 5.0 mm peripheral stromal crown of manual dissected tissue [14]. Little evidence in the literature regarding the best approach to manage type 2 bubbles exists. In one interventional case series the authors highlighted that the best approach involves manual stromal dissection either searching for an incomplete type 1 bubble or down to clear the pre-Descemetic stroma [16]. According to others, the process can be aided by the use of OVD. In particular, after manual dissection to a depth devoid of microbubbles (i.e. the pre-Descemetic layer), the bubble ceiling is perforated and OVD is injected into the cavity. This separates its floor allowing a safe removal of the central 4 mm of pre-Descemetic tissue [17].

3.8 Tip #8 Intraoperative Keratoscopy

Post-operative astigmatism is strongly dependent on suture positioning and tensioning. A validated approach involves applying 2 running, 10-0 nylon sutures of 16 bites each. Intraoperatively, keratoscopy can be used to evaluate suture tension and to guide their adjustment, until the ring reflected on the cornea is deemed regular by the surgeon. Postoperative astigmatism therefore depends on the surgeons' subjective judgment of circularity with a lack of objective and reliable metrics. To cope with this subjective evaluation, the public domain software ImageJ 1.51 s (National Institutes of Health, Bethesda, MD) was used to digitally analyze the circle produced from intraoperative keratoscopic images [18]. The software provides a roundness value of 1 to indicate a perfect circle; as the value approaches 0, it indicates an increasingly elongated shape. With this approach, we observed that a 0.93 value of roundness or greater produced keratometric astigmatism <3D (sensitivity 70.3%; specificity 61.0%). Moreover, keratometric astigmatism was strongly correlated with refractive astigmatism in the postoperative evaluations, suggesting a possible correction with lenses.

4. Discussion

The field of corneal transplantation has undergone an important paradigm shift from conventional PK to lamellar keratoplasty able to selectively remove the diseased tissue. DALK allows the retention of healthy endothelium while reducing the overall invasiveness of the procedure compared to PK. Yet, this approach suffers from limitations related to its technical complexity. The major difficulty is obtaining bubble formation, which is crucial to reaching a deep cleavage plane. For this reason, developing practical suggestions to address the major issues surgeons encounter has become paramount.

The aim is to make DALK a more standardized procedure to ensure greater replicability of the surgery and predictability of its outcomes. This would make DALK more accessible to cornea surgeons that still prefer to perform PK.

Air injection at the proper depth is deemed by many as the most complex part of the surgery because this is often guided by the surgeon’s subjective sensations (feeling of tissue resistance during cannula advancement in the stroma). Tactile subjectiveness can be overcome in different ways. Thanks to a deep trephination using preoperative AS-OCT images as a reference, the surgeon should only proceed horizontally towards the corneal center to obtain a pneumatic dissection. AS-OCT is also helpful intraoperatively in finding the correct site of bubble formation. In our experience, this approach was very practical, as OCT scans can be achieved quickly, allowing the surgeon to repeat the maneuver until the desired plane of injection is reached. Also FSL DALK can be an advantageous (yet expensive) technique for improving the reproducibility and overall success of the procedure.

As previously mentioned, bubble failure leads to corneal emphysema, with a whitish appearance and a softened consistency. In such cases, the surgeon may instinctively attempt a novel air injection, either using the same track or creating a new one. In the first case, air will keep escaping via the same path as the first injection (through the peripheral cornea, the trabecular meshwork and into the anterior chamber), with a further bubble failure. The second approach is often difficult due to the altered tissue and poor visualization, with an overall high risk of DM perforation. OVD represents another opportunity to obtain a bubble, before proceeding with layer-by-layer manual dissection. Because of this substance's high viscosity and surface tension, OVD finds its way into the spaces of small air-induced detachments, making them coalesce into a single bubble. As described, OVD injection has a high success rate; however, in case of failure manual dissection should be attempted with some additional challenges due to the reduced transparency and roughness of the OVD-injected tissue. Indeed, infiltration of the OVD in the thin, acellular layer of collagen causes intraoperative opacification and leads to hyperreflectivity of the stromal interface in densiometric analysis and consequently decreased vision until 6 months post-operatively [19].

Digital analysis of intraoperative keratoscopy can aid surgeons in evaluating astigmatism at the end of the surgery. Nevertheless, other variables can affect measurements and deserve consideration, including intraocular pressure, epithelial irregularities, graft swelling and lid speculum tension. To cope with these aspects, it is paramount to cover the cornea with a thin meniscus of fluid and remove the graft epithelium when its poor quality affects the regularity of keratoscopy rings.

In conclusion, surgeons can implement different tips to shorten DALK learning curve and to obtain better results from this surgery. Standardizing this surgical technique is paramount in reducing "human errors" as much as possible and broadening its range of applicability.

Author Contributions

Conceptualization: Andrea Lucisano, Giuseppe Giannaccare, Vincenzo Scorcia, Costanza Rossi, Massimiliano Borselli; Writing-original draft preparation: Costanza Rossi, Massimiliano Borselli, Giuseppe Giannaccare, Andrea Lucisano, Vincenzo Scorcia, Rossella Spena; Writing—review and editing: Costanza Rossi, Andrea Lucisano, Giuseppe Giannaccare, Massimiliano Borselli, Vincenzo Scorcia, Rossella Spena; All authors have read and agreed to the published version of the manuscript.

Competing Interests

The authors have declared that no competing interests exist.

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