Accepted Manuscript

An analysis of factors influencing quality of vision after big-bubble deep anterior lamellar keratoplasty in keratoconus

Sepehr Feizi, MD, MSc, Mohammad Ali Javadi, MD, Hossein Mohammad-Rabei, MD

PII: S0002-9394(15)00706-0

DOI: 10.1016/j.ajo.2015.11.018

Reference: AJOPHT 9547

To appear in: *American Journal of Ophthalmology*

Received Date: 22 September 2015

Revised Date: 9 November 2015

Accepted Date: 9 November 2015

Please cite this article as: Feizi S, Javadi MA, Mohammad-Rabei H, An analysis of factors influencing quality of vision after big-bubble deep anterior lamellar keratoplasty in keratoconus, *American Journal of Ophthalmology* (2015), doi: 10.1016/j.ajo.2015.11.018.

Abstract

Purpose: To identify causes of reduced visual acuity and contrast sensitivity after big-bubble deep anterior lamellar keratoplasty (DALK) in keratoconus.

Design: Prospective interventional case series.

Methods: This study included 36 eyes in 36 patients with keratoconus who underwent DALK using the big-bubble technique. A bare Descemet membrane was achieved in all cases. Univariate analyses and multiple linear regression were used to investigate recipient-, donor-, and postoperative-related variables capable of influencing the postoperative quality of vision, including best-spectacle corrected visual acuity (BSCVA) and contrast sensitivity.

Results: The mean patient age was 27.7±6.9 years old, and the patients were followed for 24.6±15.1 months postoperatively. The mean postoperative BSCVA was 0.17±0.09 LogMAR. Postoperative BSCVA ≥ 20/25 was achieved in 14 eyes (38.9%), whereas a BSCVA of 20/30, 20/40, or 20/50 was observed in 15 eyes (41.7%), six eyes (16.6%), and one eye (2.8%), respectively. Preoperative vitreous length was significantly associated with postoperative BSCVA (β=0.02, P=0.03). Donor-recipient interface reflectivity significantly influenced scotopic (β=-0.002, P=0.04) and photopic (β=-0.003, P=0.02) contrast sensitivity. The root mean square of tetrafoil was significantly negatively associated with scotopic (β=-0.25, P=0.01) and photopic (β=-0.23, P=0.04) contrast sensitivity. Recipient age, keratoconus severity, donor-related variables, recipient trephination size, and graft and recipient bed thickness were not significantly associated with postoperative visual acuity or contrast sensitivity.

Conclusion: Large vitreous length, higher-order aberrations, and surgical interface haze may contribute to poor visual outcomes after big-bubble DALK in keratoconus.

An analysis of factors influencing quality of vision after big-bubble deep anterior lamellar keratoplasty in keratoconus

Short running title: Quality of Vision after Deep Anterior Lamellar Keratoplasty

Sepehr Feizi, MD, MSc[1], Mohammad Ali Javadi MD[2], Hossein Mohammad-Rabei MD[3]

1- Assistant Professor of Ophthalmology, Ophthalmic Research Center, Shahid Beheshti University of Medical Sciences, Tehran, Iran.

2- Professor of Ophthalmology, Ophthalmic Research Center, Shahid Beheshti University of Medical Sciences, Tehran, Iran.

3- Associate Professor of Ophthalmology, Ophthalmic Research Center, Shahid Beheshti University of Medical Sciences, Tehran, Iran.

Corresponding author: Sepehr Feizi, Ophthalmic Research Center, Labbafinejad Medical Center, Boostan 9 St., Pasdaran Ave., Tehran 16666, Iran.

Fax: +98-21-2256-2138

Tel: +98-21-2258-4733 or 2259-1616

e-mail address: sepehrfeizi@yahoo.com

Introduction

Different techniques for lamellar keratoplasty have evolved over time to achieve visual outcomes comparable to those of penetrating keratoplasty (PK). Among these techniques, deep anterior lamellar keratoplasty (DALK), in which a maximal depth of corneal stroma is removed, has gained popularity for its management of corneal stromal pathologies not involving the endothelium.[1-5] Several studies have reported that visual function results are related to the type of donor-recipient interface that is accomplished with DALK. It has been demonstrated that when the recipient corneal stroma is removed down to the Descemet membrane, the optical quality of the interface is excellent and comparable to that achieved through PK and that when layers of stroma are left adherent to the Descemet membrane, quality of vision is inferior to that achieved by PK.[6,7] However, we have encountered patients whose best spectacle-corrected visual acuity (BSCVA) is not good, even when a bare Descemet membrane is achieved intraoperatively and the transparency of the donor cornea as well as the donor-recipient interface appears to be excellent postoperatively. In addition, some patients have reported limitations to their vision despite good corrected visual acuity.

Multiple factors can limit post-DALK visual performance, including lower- and higher-order aberrations and light scatter caused by the surgical interface or the use of low-quality grafts. The relative contributions of these factors in degraded visual performance after big-bubble DALK are poorly understood. Our study was designed to investigate, for the first time, the influence of donor-, recipient-, and postoperative-related variables on quality of vision (visual acuity and contrast sensitivity) after anatomically successful big-bubble DALK in keratoconus.

Materials and Methods

In this prospective interventional case series, patients who underwent big-bubble DALK between January 17, 2008 and March 5, 2014 for moderate (mean keratometry 48-55 D) or advanced (mean keratometry >55 D or immeasurable keratometry) keratoconus were included. Indications for surgery included contact lens intolerance and poor corrected visual acuity. Ethics Committee approval was obtained from the Ophthalmic Research Center, which is affiliated with Shahid Beheshti University of Medical Sciences, Tehran, Iran, to conduct this prospective study and the study adhered to the tenets of the Declaration of Helsinki. Informed consent was obtained from all participants after the purpose of the study was explained.

The inclusion criteria required an uncomplicated postoperative course (absence of a double anterior chamber, graft rejection, graft opacity, interface haze or wrinkling, cataract development, or raised intraocular pressure) and a minimum follow-up of one year. Exclusion criteria were any ocular comorbidity (such as amblyopia and strabismus), neurologic problems, systemic diseases, or the taking of any medication that may affect visual acuity or contrast sensitivity. Eligible participants were enrolled on a consecutive attendance basis.

Preoperatively, complete ocular examinations, including tests for uncorrected visual acuity (UCVA) and BSCVA using the Snellen acuity chart (expressed in LogMAR notations), slit-lamp examination, tonometry, dilated funduscopy, manifest refraction (when possible), corneal topography (TMS-1 Topographic Modeling System, version 1.61; Computed Anatomy Inc, New York, NY, USA), and vitreous length measurement using A-scan biometry (A/B scan; Sonomed Inc, Lake Success, NY, USA) were performed. All procedures were performed under general anesthesia using the big-bubble technique, as described in detail elsewhere.[8] A bare Descemet membrane was achieved in all cases. For all transplants, we used fresh donor sclerocorneal buttons that were preserved using cold storage. The donor corneas, which were oversized by 0.25 mm, were punched from the endothelial side with a Barron punch (Katena, Denville, NJ, USA) after the donor Descemet membrane was gently stripped off with a dry cellulose sponge or forceps. The recipient stromal bed was completely washed out to remove viscoelastic material and debris before proceeding to graft suturing. A combined suturing technique that consisted of 16-bite single running and 8-bite interrupted nylon sutures (Sharpoint, Angiotech, Vancouver, Canada) was used. Three months after surgery, selective interrupted suture removal was initiated to reduce astigmatism. At the time of the study, all sutures had been removed.

At least 3 months after complete suture removal, postoperative examination was performed. This included analyses of UCVA, BSCVA, manifest refraction, contrast sensitivity, higher-order aberrations (HOAs), and central corneal thickness using confocal microscopy. Orbscan II topography maps (Orbscan II, Bausch & Lomb, Rochester, NY, USA) were used for topographic assessments. Data collected from these maps included postoperative keratometry readings and irregularity index, which was measured at central 3 mm and 5 mm. Data relevant to the donor corneas was retrieved from the Central Eye Bank of Iran, where the donor tissues had been procured.

Contrast sensitivity measurement

Monocular contrast sensitivity was measured using sine-wave gratings at six spatial frequencies [1, 2, 6, 12, 15, and 18 cycles per degree (cpd)] using the Metrovision Moniteur Ophtalmologique "STATphot" program (Metrovision, Pérenchies, France). During the determination of contrast sensitivity, the chart was viewed from a distance of 2 m with correcting glasses in place. After an initial demonstration of the procedure, the contrast threshold was measured for each spatial frequency. All patients were tested under both scotopic and photopic conditions, and the results were expressed as log units of contrast sensitivity. Scotopic and photopic contrast sensitivity were also expressed as the area under the log contrast sensitivity function (AULCSF).[9] This converts contrast sensitivity measures at different spatial frequencies into a single digit, facilitating the evaluation of several explanatory factors that may influence contrast sensitivity.

Wavefront aberration measurement

After measuring contrast sensitivity, cyclopentolate (1%) eye drops were instilled, and when a pupil diameter greater than 6 mm was achieved, the wavefront was measured using a Zywave II aberrometer with Zywave software version 5.2 (Bausch & Lomb, Rochester, NY, USA) in a dark room. This aberrometer was used to calculate HOAs for a 6 mm pupil in terms of Zernike polynomials up to the 5th order. Three measurements were taken for each eye, and the average of the three readings was used to calculate different root mean square (RMS) values, which were expressed in micrometers.

Confocal scan examination

A confocal scan (Confoscan 3.4, Nidek Technologies, Padova, Italy) was used to measure central graft and recipient bed thickness and to quantitatively evaluate the donor-recipient interface. Using three Z-scan graphs in each cornea, central graft thickness (the distance between the epithelial and interface reflectivity peaks) and recipient bed thickness (the distance between the interface and the endothelial reflectivity peaks) were calculated and averaged. The donor-recipient interface was defined as the corneal sublayer located in the posterior stroma that displayed a discontinuity in stromal keratocytes and extracellular matrix architecture. Features of the interface that were evaluated for the purposes of the study included folds, deposits, and reflectivity. Interface reflectivity was calculated as the average of 3 maximum light reflectance unit values (expressed in arbitrary numerical units), which were obtained using Z-scan graphs.

Statistical analysis

The data were analyzed using SPSS statistical software version 21 (IBM Corp., Armonk, NY, USA). Values indicating means and standard deviations, ranges, frequencies and percentages were used to express data. The normal distribution of continuous variables was verified using a Kolmogorov–Smirnov test and a Q-Q plot. Spearman's correlation coefficient was used to analyze the influence of donor features (including age, death-to-preservation time, storage time, stromal status, endothelial cell density, and graft rating), recipient parameters (including age, preoperative mean keratometry and keratometric astigmatism, keratoconus severity, vitreous length, and trephination size), and postoperative outcomes (including follow-up period, spherical equivalent refraction, mean keratometry, keratometric astigmatism, graft irregularity indices measured at central 3 mm and 5 mm, RMS of each HOA, RMS of total HOAs, central graft thickness, recipient bed thickness, and interface reflectivity) on postoperative BSCVA, and scotopic and photopic AULCSF. Variables selected by the Spearman's correlation coefficient based on a 0.05-significance threshold were introduced into a multiple linear regression model to evaluate the simultaneous effect of the variables. A P value <0.05 was considered to be statistically significant. All reported P values are two-sided.

Results

Recipient and donor characteristics

Forty-one eyes of 41 patients with keratoconus who underwent big-bubble DALK were initially enrolled. Five eyes were excluded from the study due to subepithelial graft haziness (n=1), interface haziness (n=1), and interface wrinkling (n=3). Therefore, data of 36 eyes were included for analysis. The mean age of the participants was 27.7±6.9 years old (range, 15 to 41 years old). The mean vitreous length was 16.91±1.28 mm and ranged from 15.22 to 20.59 mm. Moderate keratoconus was observed in 6 eyes (16.7%), whereas 30 eyes (83.3%) had severe keratoconus. The recipient trephination size was 7.75 mm in 8 eyes (22.2%) and 8.0 mm in 28 eyes (77.8%). The mean follow-up duration after corneal transplantation was 24.6±15.1 months (range, 13 to 82 months). All grafts were clear at the final follow-up, and slit-lamp examination showed a clear interface with no visible opacities or wrinkling.

A total of 36 corneoscleral buttons from 36 cadavers, including 31 male and 5 female donors with a mean age of 35.1±15.3 years old (range, 10 to 70 years old), were procured. The donor data are presented in Table 1.

Visual, refractive, and contrast sensitivity outcomes

The mean preoperative UCVA and BSCVA were 1.31±0.30 LogMAR (range, 0.60 to 2.10 LogMAR) and 1.02±0.49 LogMAR (range, 0.48 to 2.10 LogMAR), respectively. These figures were 0.66±0.43 LogMAR (range, 0.0 to 1.50 LogMAR) and 0.17±0.09 LogMAR (range, 0.0 to 0.38 LogMAR), respectively, at the final follow-up. There was a significant increase in postoperative UCVA ($P<0.001$) and BSCVA ($P<0.001$). Postoperatively, a BSCVA ≥ 20/25 was achieved in 14 eyes (38.9%), whereas a BSCVA of 20/30, 20/40, or 20/50 was observed in 15 eyes (41.7%), six eyes (16.6%), and one eye (2.8%), respectively. Preoperative spherical equivalent refractive error, mean keratometry, and keratometric astigmatism were -9.30±5.0 D (range, -17.50 to -5.50 D), 53.53±5.91 D (range, 48.50 to 64.0 D) and 5.88±3.76 D (range, 1.50 to 15.75 D), respectively. Postoperative spherical equivalent refractive error, mean keratometry, and keratometric astigmatism were -3.84±3.56 D (range, -12.88 to +1.38 D), 46.01±3.22 D (range, 40.0 to 53.75 D), and 3.31±2.24 D (range, 0.50 to 9.25 D), respectively ($P<0.05$ for all comparisons with corresponding preoperative values).

Postoperatively, graft irregularity indices measured at the 3 mm and 5 mm zones were 3.09±0.85 D (range, 2.0 to 5.40 D) and 5.46±1.44 D (range, 3.30 to 10.60 D), respectively. The scotopic and photopic contrast sensitivity measured at each spatial frequency is presented in Table 2. The scotopic AULCSF was 1.40±0.18 (range, 1.05 to 1.74) and the photopic AULCSF was 1.41±0.21 (range, 0.99 to 1.74). The wavefront analysis of HOAs is summarized in Table 3.

Confocal scan findings

Mean central corneal thickness was 524.3±62.2 µm (range, 398.0 to 668.0 µm). Mean central graft thickness was 503.0±61.4 µm (range, 370 to 637.4 µm), and recipient bed thickness was 21.8±6.1 µm (range, 10.4 to 31.4 µm). A deep lamellar interface was easily identified in the examined eyes. There were hyporeflective striae in the rear stroma, which represented microfolds, and sheets of moderate to high-reflective amorphous deposits together with scattered high-contrast microdots at the interface area. The mean interface reflectivity value was 118.9±35.2 light reflectance units (range, 60.0 to 196.0 light reflectance units).

Correlations

In the univariate analysis, postoperative BSCVA was significantly associated with preoperative vitreous length (r=0.41, P=0.04), postoperative spherical equivalent refraction (r=-0.39, P=0.03), and the RMS of coma (r=0.52, P=0.02). Scotopic AULCSF was significantly associated with postoperative keratometric astigmatism (r=-0.56, P=0.001), the RMS of coma (r=-0.50, P=0.04), the RMS of tetrafoil (r=-0.62, P=0.006), graft thickness (r=-0.37, P=0.04), and interface reflectivity (r=-0.37, P=0.04). Photopic AULCSF was correlated with postoperative keratometric astigmatism (r=-0.51, P=0.003), the RMS of coma (r=-0.51, P=0.03), the RMS of tetrafoil (r=-0.56, P=0.02), graft thickness (r=-0.37, P=0.04), and interface reflectivity (r=-0.44, P=0.01). The RMS of total HOAs had no correlation with BSCVA (r=0.26, P=0.18) but demonstrated borderline association with scotopic AULCSF (r=-0.37, P=0.048) and photopic AULCSF (r=-0.35, P=0.06). The follow-up period was not correlated with postoperative outcomes including spherical equivalent refraction (r=-0.22, P=0.13), keratometric astigmatism (r=0.19, P=0.58), the RMS of coma (r=0.22, P=0.37), the RMS of tetrafoil (r=0.12, P=0.21), graft thickness (r=0.48, P=0.79), and interface reflectivity (r=0.36, P=0.23). Additionally, the follow-up period had no significant influence on postoperative BSCVA (r=0.03, P=0.82), scotopic AULCSF (r=-0.16, P=0.29), or photopic AULCSF (r=-0.17, P=0.23). Recipient age, preoperative mean keratometry and keratometric astigmatism, keratoconus severity, donor-related variables, recipient trephination size, postoperative mean keratometry, and graft and recipient bed thickness were not significantly associated with visual acuity or contrast sensitivity.

Multiple regression analyses revealed that postoperative BSCVA was significantly associated with preoperative vitreous length (β=0.02, 95% confidence interval [CI]: 0.002 to 0.04, P=0.03) (Figure 1). However, postoperative spherical equivalent refraction (β=0.001, P=0.91) and the RMS of coma (β=0.04, P=0.18) lost their significance in the multiple regression model. Interface reflectivity significantly influenced the scotopic (β=-0.002, 95% CI: -0.005 to 0.0, P=0.04) and photopic (β=-0.003, 95% CI: -0.006 to -0.001, P=0.02) AULCSF (Figure 2). The same analysis showed that the RMS of tetrafoil was significantly negatively associated with the scotopic (β=-0.25, 95% CI: -0.44 to -0.07, P=0.01) and photopic (β=-0.23, 95% CI: -0.44 to -0.01, P=0.04) AULCSF (Figure 3). Scotopic AULCSF was not significantly correlated with postoperative keratometric astigmatism (β=0.003, P=0.91), the RMS of coma (β=-0.06, P=0.38), graft thickness (β=0.001, P=0.60), or the RMS of total HOAs (β=0.005, P=0.14) in multiple linear regression. Similarly, photopic AULCSF was not significantly influenced by postoperative keratometric astigmatism (β=-0.006, P=0.84), the RMS of coma (β =-0.01, P=0.71), or graft thickness (β=-0.09, P=0.27).

Discussion

The purpose of this study was to determine why quality of vision is, in some cases, suboptimal after big-bubble DALK in spite of a clinically clear donor-recipient interface. Previous studies of PK in keratoconus subjects have reported that contrast sensitivity after this type of corneal transplantation is better than it is in keratoconus subjects but not as good as it is in normal subjects.[10,11] The decreases in contrast sensitivity after PK have been mainly attributed to configurational changes at the graft surface, which lead to optical aberrations rather than light scatter.[11] Because of the differences in surgical techniques between PK and DALK, other potential factors, such as intraocular light scatter originating from the donor-recipient interface and the transplantation of low quality donor tissues, can negatively impact post-DALK visual functions.

Among factors related to the recipient, the results of the current study suggest that BSCVA after DALK may be limited as a result of increased vitreous length. In univariate analysis, postoperative refractive error was significantly associated with postoperative BSCVA. When entered into a multiple regression analysis, however, this factor lost its significance. This supports a previous observation that indicated that myopization of keratoconic eyes after DALK was primarily the result of the increased posterior segment length of the globe.[12] Degradation of postoperative visual acuity in eyes with a long vitreous length can be attributed to the minifying effects of high-power spectacles, which can be eliminated by the use of contact lenses. We do not, as a routine practice, correct post-DALK refractive errors with contact lenses. Therefore, in the current study, spectacle-corrected vision is reported to give a better representation of functional vision.

The present study failed to demonstrate any significant association between recipient age and postoperative visual functions, possibly because all participants were between 15 and 41 years old. Furthermore, the severity of keratoconus did not have a negative impact on visual outcomes. This supports the idea that this type of transplantation is equally effective for advanced keratoconus. Using the DALK procedure in keratoconus patients with very steep corneas sometimes induces wrinkling in the Descemet membrane, which results from a mismatch between donor and recipient corneas. This wrinkling can interfere with the quality of vision. It was not possible to determine the effects of Descemet membrane wrinkling on visual function in this study because the presence of this complication led to patient exclusion.

Other factors investigated in the present study were related to the donor. Donor corneas used for DALK do not need to have a perfectly healthy endothelium or high endothelial cell density.[13] Therefore, donor tissues that range widely in quality (from fair to excellent) can be used for transplantation. There is a concern that the use of low quality donors for DALK could potentially degrade quality of vision after surgery. The results of the present study failed to demonstrate any significant associations between donor-related variables and postoperative visual acuity or contrast sensitivity. This observation is consistent with the results of studies by other investigators who have demonstrated no significant correlation between donor factors and final visual acuity after DALK.[14,15] This finding is encouraging because access to sight-restoring keratoplasty in many countries is limited by a shortage of tissue that is suitable for transplantation. Recruiting donor tissues of low quality can help to address the rising demand for donor corneal tissue that can be used in DALK.

The effect of follow-up period on postoperative outcomes was investigated in the current study. The length of follow-up did not significantly influence postoperative visual acuity, refractive error, HOAs, interface reflectivity, and contrast sensitivity. A gradual improvement in postoperative BSCVA has been reported after DALK which can be attributed to remodeling of the remaining recipient stroma over time.[16] In the current study where the corneal stroma was completely removed and a bare Descemet membrane was achieved in all cases, we did not observe any significant correlation between follow-up period and visual outcomes. Postoperative BSCVA demonstrated no significant association with postoperative keratometric astigmatism, irregularity index, HOAs, or interface haze, indicating that these variables did not account for the difference in acuity. These findings are in line with previous studies that have reported no correlation between HOAs and visual acuity after DALK.[17,18] The lack of significant correlation between these factors can be explained by the fact that high-luminance, high-contrast visual acuity is relatively insensitive to variation in HOA magnitude and inconspicuous interface haze.[19]

Contrast sensitivity is a more sensitive measure of visual performance that can identify factors that influence the quality of vision that are not revealed by visual acuity testing.[20] Our results show that the main reasons for decreases in contrast sensitivity after big-bubble DALK were HOAs and interface haze. The most dominant aberration component in our study was trefoil, which was followed by coma, spherical, and tetrafoil, in descending order. Experimental studies have demonstrated that different HOA components have a different impact on vision. Zernike terms that have a greater effect on the central portion of the wavefront, such as coma and spherical aberration, can adversely affect visual performance much more than terms near the edge of the Zernike pyramid, such as trefoil or tetrafoil.[21,22] Our results, however, show that only the RMS of tetrafoil had a significantly negative correlation with contrast sensitivity. This observed association can be explained by peripheral local deformations of the transplanted corneas, which were caused by the formation of irregular scars between the donor and recipient tissues.

Among the different variables assessed by the confocal scan, only the morphologic characteristic of the donor-recipient interface demonstrated a significant correlation with contrast sensitivity. This observation indicates that interface haze can result in a decreased quality of vision even if the recipient stroma is fully excised and no interface haze is detectable upon slit-lamp examination. The exact reason for the increased interface reflectivity observed in some eyes in the current study is not clear. It is possible that debris retained at the interface or an excessive healing response contributed to an increase in reflectivity, which might result in an increase in stray light and a decrease in contrast sensitivity.[23]

There are two limitations in the current study. First, vision testing was conducted with correcting glasses in place. This better reflects visual function in everyday life since the patients routinely use this type of optical correction after DALK. However, the use of rigid-gas permeable contact lens could determine whether the minifying effect of correcting glasses or abnormality of retinal function associated with myopia accounted for the reduced visual acuity. Meanwhile, from the lack of association between vitreous length and postoperative contrast sensitivity, it can be inferred that impaired visual performance was not caused by changes in the retinal function. Second, contrast sensitivity which is a subjective measure was used to evaluate quality of vision. This psychophysical test can be time consuming and requires full patient attention which can hamper the precision of acquired data. Other measurements such as modulation transfer function, Strehl ratio, and objective scatter index allow objective evaluation of optical quality after big-bubble DALK.

In summary, big-bubble DALK is now considered as the transplantation technique of choice for patients with keratoconus. These patients tend to be young and in their most productive years; therefore, it is important to understand the effect of big-bubble DALK on corneal optical quality. The present study has, for the first time, extensively investigated the factors that can potentially influence the quality of vision after this type of corneal transplantation. Our results reflect the fact that differences in postoperative visual acuity are independent of corneal features and show that the main factor that contributed to decreases in BSCVA was an elongated posterior segment. Optical aberrations and surgical interface haze were the main reasons for deceased contrast sensitivity. The surgical interface was characterized by the presence of reflective particles and amorphous materials, despite achieving a bare Descemet membrane during the surgery. The source of these particles is not understood. A better understanding of the cellular and extracellular matrix changes that occur at the surgical interface after big-bubble DALK is needed.

Acknowledgements/Disclosure

The authors report no funding support or financial disclosures.

References

1- Shimazaki J, Shimmura S, Ishioka M, Tsubota K. Randomized clinical trial of deep lamellar keratoplasty vs penetrating keratoplasty. *Am J Ophthalmol* 2002;134*(2)*:159–165.

2- Funnell CL, Ball J, Noble BA. Comparative cohort study of the outcomes of deep lamellar keratoplasty and penetrating keratoplasty for keratoconus. *Eye (Lond)* 2006;20*(5)*:527–532.

3- Cohen AW, Goins KM, Sutphin JE, Wandling GR, Wagoner MD. Penetrating keratoplasty versus deep anterior lamellar keratoplasty for the treatment of keratoconus. *Int Ophthalmol* 2010;30*(6)*:675–681.

4- Watson SL, Ramsay A, Dart JK, Bunce C, Craig E. Comparison of deep lamellar keratoplasty and penetrating keratoplasty in patients with keratoconus. *Ophthalmology* 2004;111*(9)*:1676–1682.

5- Javadi MA, Feizi S, Yazdani S, Mirbabaee F. Deep anterior lamellar keratoplasty versus penetrating keratoplasty for keratoconus: a clinical trial. *Cornea* 2010;29*(4)*:365–371.

6- Ardjomand N, Hau S, McAlister JC, et al. Quality of vision and graft thickness in deep anterior lamellar and penetrating corneal allografts. *Am J Ophthalmol* 2007;143*(2)*:228–235.

7- Fontana L, Parente G, Sincich A, Tassinari G. Influence of graft-host interface on the quality of vision after deep anterior lamellar keratoplasty in patients with keratoconus. *Cornea* 2011;30*(5)*:497–502.

8- Feizi S, Javadi MA, Jamali H, Mirbabaee F. Deep anterior lamellar keratoplasty in patients with keratoconus: big-bubble technique. *Cornea* 2010;29*(2)*:177–182.

9- Applegate RA, Howland HC, Sharp RP, Cottingham AJ, Yee RW. Corneal aberrations and visual performance after radial keratotomy. *J Refract Surg* 1998;14*(4)*:397–407.

10- Mannis MJ, Zadnik K, Johnson CA, Adams C. Contrast sensitivity after penetrating keratoplasty. *Arch Ophthalmol* 1987;105*(9)*:1220–1223.

11- Pesudovs K, Schoneveld P, Seto RJ, Coster DJ. Contrast and glare testing in keratoconus and after penetrating keratoplasty. *Br J Ophthalmol* 2004;88*(5)*:653–657.

12- Javadi MA, Feizi S, Rastegarpour A. Effect of vitreous length and trephine size disparity on post-DALK refractive status. *Cornea* 2011;30*(4)*:419–423.

13- Shimazaki J. The evolution of lamellar keratoplasty. *Curr Opin Ophthalmol* 2000;11*(4)*:217–223.

14- Feizi S, Javadi MA, Kanavi MR, Javadi F. Effect of donor graft quality on clinical outcomes after deep anterior lamellar keratoplasty. *Cornea* 2014;33*(8)*:795–800.

15- Heindl LM, Riss S, Adler W, Bucher F, Hos D, Cursiefen C. Split cornea transplantation: relationship between storage time of split donor tissue and outcome. *Ophthalmology* 2013;120*(5)*:899–907.

16- Feizi S, Javadi MA, Rastegarpour A. Visual acuity and refraction after deep anterior lamellar keratoplasty with and without successful big-bubble formation. *Cornea* 2010;29*(11)*:1252–1255.

17- Koh S, Maeda N, Nakagawa T, Nishida K. Quality of vision in eyes after selective lamellar keratoplasty. *Cornea* 2012;31*(Suppl 1)*:S45–49.

18- Salvetat ML, Brusini P, Pedrotti E, et al. Higher order aberrations after keratoplasty for keratoconus. *Optom Vis Sci* 2013;90*(3)*:293–301.

19- McLeod SD. Beyond snellen acuity: the assessment of visual function after refractive surgery. *Arch Ophthalmol* 2001;119*(9)*:1371–1373.

20- Rabin J, Wicks J. Measuring resolution in the contrast domain: the small letter contrast test. *Optom Vis Sci* 1996;73*(6)*:398–403.

21- Pepose JS, Applegate RA. Making sense out of wavefront sensing. *Am J Ophthalmol* 2005;139*(2)*:335–343.

22- Calossi A. Corneal asphericity and spherical aberration. *J Refract Surg* 2007;23*(5)*:505–514.

23- Patel SA, McLaren JW, Hodge DO, Baratz KH. Scattered light and visual function in a randomized trial of deep lamellar endothelial keratoplasty and penetrating keratoplasty. *Am J Ophthalmol* 2008;145*(1)*:97–105.

Figure captions

Figure 1: Scattergram illustrating the relationship between preoperative vitreous length and postoperative best spectacle-corrected visual acuity (BSCVA) in keratoconic eyes undergoing big-bubble deep anterior lamellar keratoplasty. The regression formula was postoperative BSCVA = -0.176 + 0.021 × preoperative vitreous length (r=0.41, P=0.04). Dotted lines indicate 95% confidence intervals for the regression line.

Figure 2: Scattergrams illustrating the relationships between interface reflectivity (light reflectance units) and postoperative area under the log contrast sensitivity function (AULCSF) in keratoconic eyes undergoing big-bubble deep anterior lamellar keratoplasty. (Left) The relationship between interface reflectivity and scotopic AULCSF; the regression formula was scotopic AULCSF = 1.652 - 0.002 × interface reflectivity (r=-0.37, P=0.04). (Right) The relationship between interface reflectivity and photopic AULCSF; the regression formula was photopic AULCSF = 1.725 -0.003 × interface reflectivity (r=-0.44, P=0.01). Dotted lines indicate 95% confidence intervals for the regression line.

Figure 3: Scattergrams illustrating the relationships between postoperative root mean square (RMS) of tetrafoil and postoperative area under the log contrast sensitivity function (AULCSF) in keratoconic eyes undergoing big-bubble deep anterior lamellar keratoplasty. (Left) The relationship between the postoperative RMS of tetrafoil and scotopic AULCSF; the regression formula was scotopic AULCSF = 1.0608 - 0.269 × RMS of tetrafoil (r=-0.62, P=0.006). (Right) The relationship between the postoperative RMS of tetrafoil and photopic AULCSF; the regression formula was photopic AULCSF = 1.618 - 0.255 × RMS of tetrafoil (r=-0.56, P=0.02). Dotted lines indicate 95% confidence intervals for the regression line.

Table 1: Data corresponding to the donor corneas transplanted into patients with keratoconus who underwent big-bubble deep anterior lamellar keratoplasty

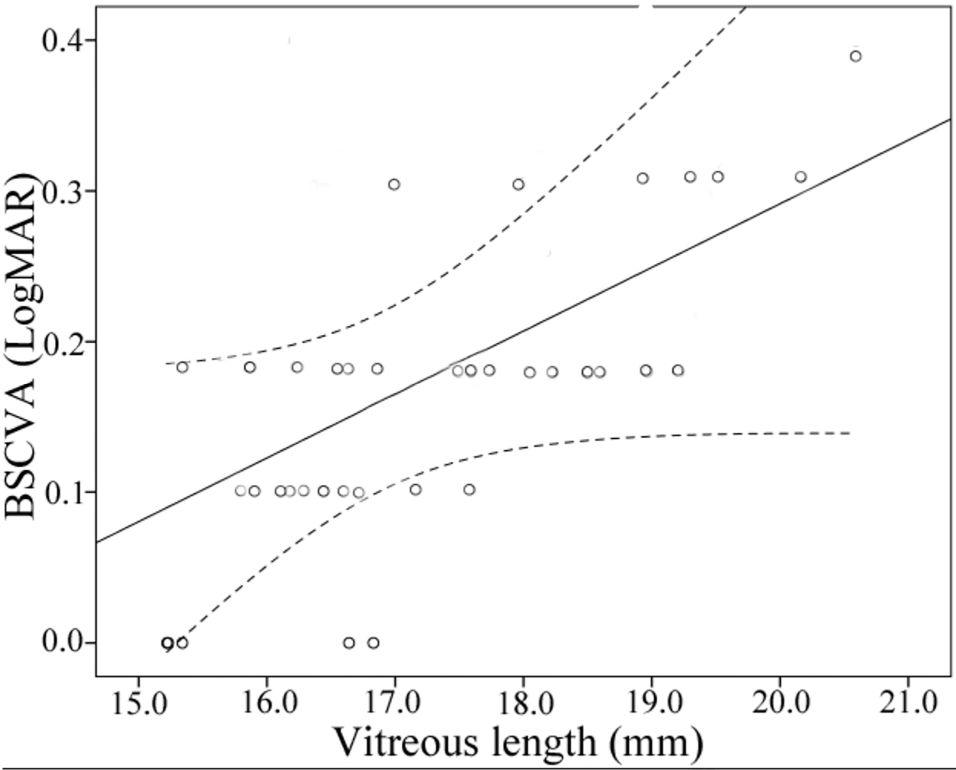
Death-to-preservation time	N (%)
<24 h	10 (27.8)
24-48 h	26 (72.2)
Storage time (days)	Mean ± Standard deviation (range)
	3.2±2.9 (0 to 11)
Stroma status	N (%)
Clear	26 (72.2)
Cloudiness	10 (27.8)
Endothelial cell density (cells/mm^2)	Mean ± Standard deviation (range)
	2803.1±629.6 (1128 to 3890)
Graft rating	N (%)
Excellent	9 (25.0)
Very good	12 (33.3)
Good	8 (22.2)
Fair	7 (19.5)

Table 2: Postoperative scotopic and photopic contrast sensitivity (mean ± standard deviation, range) in patients with keratoconus who underwent big-bubble deep anterior lamellar keratoplasty

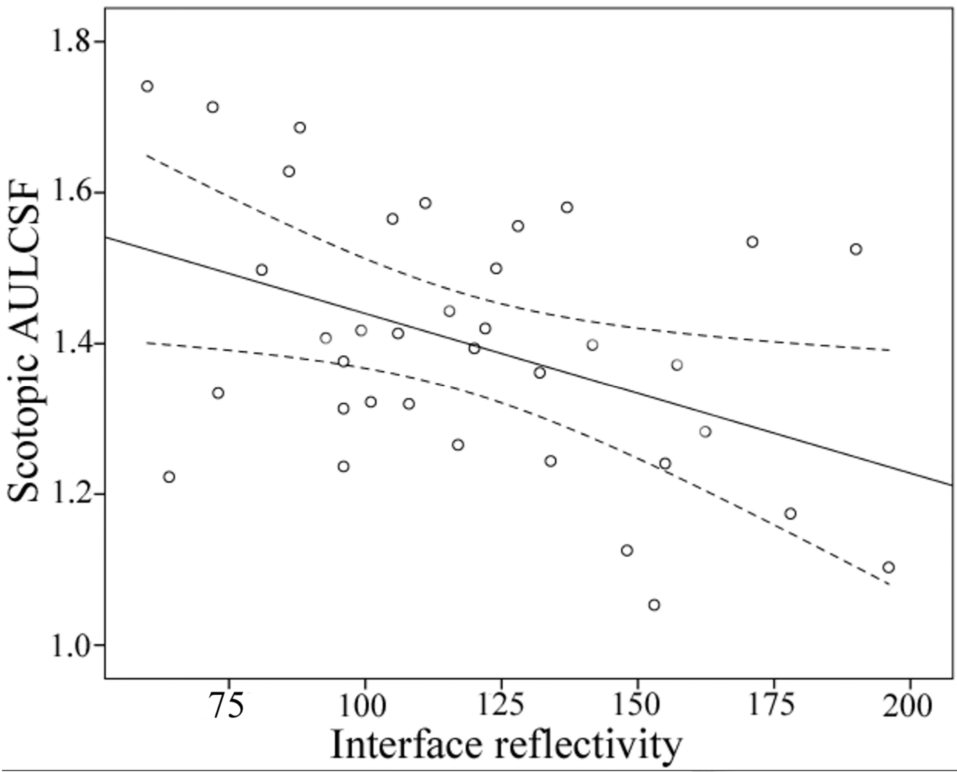
Spatial frequency	Scotopic contrast sensitivity (decibels)	Photopic contrast sensitivity (decibels)
1 cycle/degree	16.50±2.45 (11.0 to 19.0)	16.44±2.37 (10.0 to 19.0)
2 cycles/degree	17.31±3.96 (8.0 to 23.0)	17.19±4.15 (7.0 to 22.0)
3 cycles/degree	17.19±4.72 (11.0 to 26.0)	17.28±5.24 (8.0 to 26.0)
6 cycles/degree	14.53±5.0 (6.0 to 24.0)	14.16±5.70 (5.0 to 24.0)
12 cycles/degree	8.38±5.12 (2.0 to 21.0)	9.28±5.46 (2.0 to 21)
20 cycles/degree	4.66±3.31 (2.0 to 15.0)	5.78±3.59 (2.0 to 14.0)

Table 3: Postoperative root mean squares of higher-order aberrations in patients with keratoconus who underwent big-bubble deep anterior lamellar keratoplasty

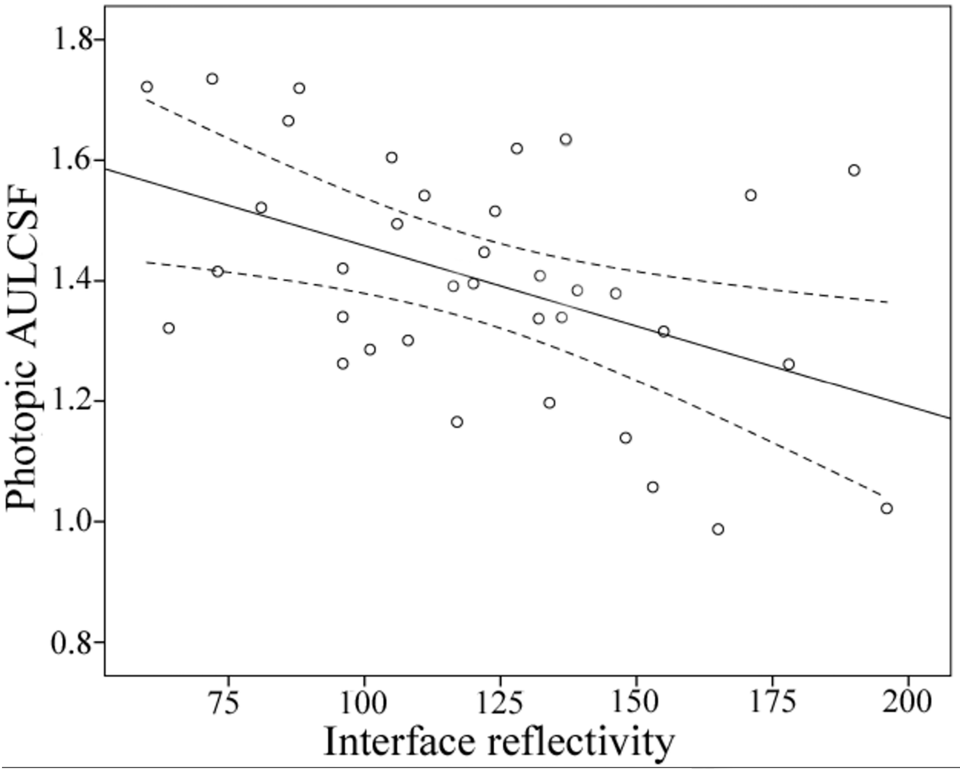
Higher-order aberration	Mean ± standard deviation (µm)	Range (µm)
Trefoil	1.44±0.76	0.58 to 3.03
Coma	1.17±0.64	0.08 to 2.70
Spherical	0.84±0.47	0.20 to 2.07
Tetrafoil	0.54±0.37	0.07 to 1.44
Secondary astigmatism	0.20±0.18	0.01 to 0.77
Pentafoil	0.13±0.14	0.0 to 0.49
Third order	1.99±0.76	0.95 to 3.37
Fourth order	1.11±0.46	0.31 to 2.19
Fifth order	0.18±0.17	0.0 to 0.58
Total	2.20±0.75	0.76 to 3.82

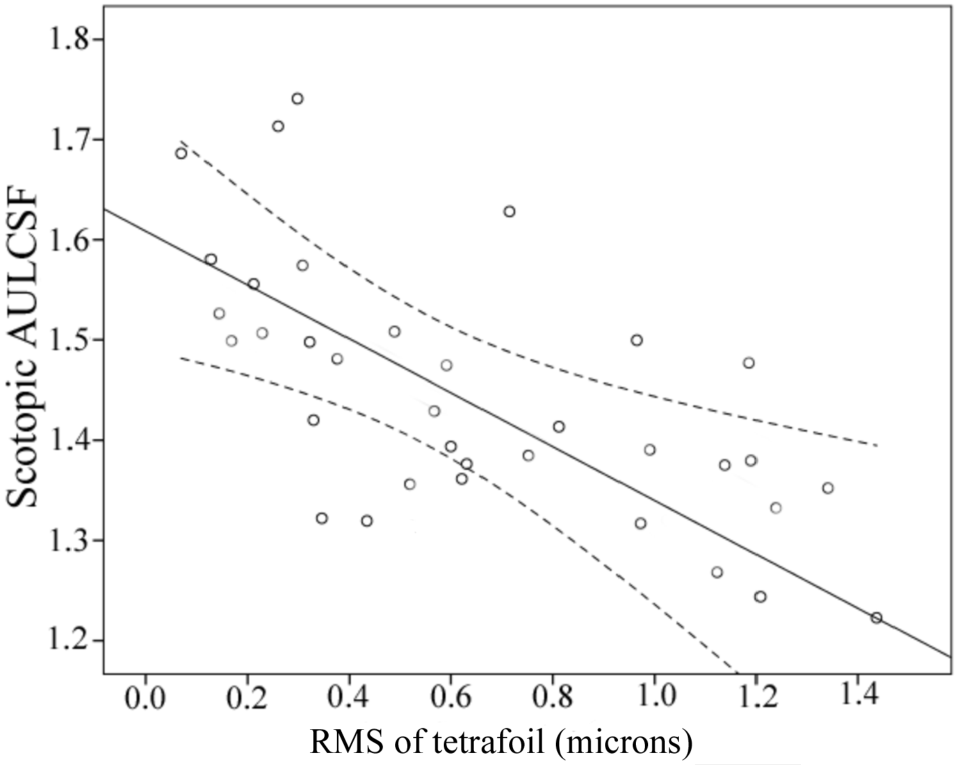


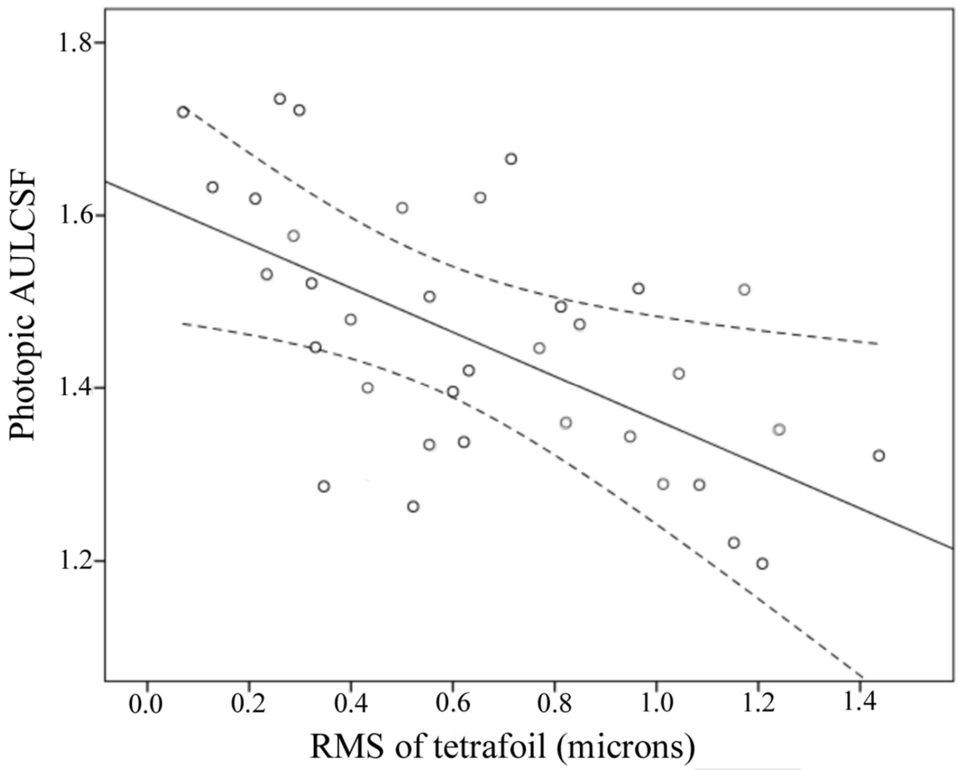
BSCVA (LogMAR)
0.4
0.3
0.2
0.1
0.0
15.0
16.0
17.0
18.0
19.0
20.0
21.0
Vitreous length (mm)



1.8
1.6
1.4
1.2
1.0
Scotopic AULCSF
75
100
125
150
175
200
Interface reflectivity


1.8
1.6
1.4
1.2
1.0
0.8
Photopic AULCSF
75
100
125
150
175
200
Interface reflectivity


1.8
1.7
1.6
1.5
1.4
1.3
1.2
Scotopic AULCSF
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
RMS of tetrafoil (microns)



1.8
1.6
1.4
1.2
Photopic AULCSF
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
RMS of tetrafoil (microns)

Sepehr Feizi, MD, MSc, graduated from Islamic Azad University, Tehran in 2000. After completion of his residency in 2004 and anterior segment fellowship in 2008 at Shahid Beheshti University of Medical Sciences Tehran, he joined the Anterior Segment Service at Labbafinejad Hospital, which is affiliated with Shahid Beheshti University of Medical Sciences. He masters in medical education. He is now Assistant Professor at the Department of Ophthalmology, Labbafinejad Medical Center. Research interests include corneal transplantation.

Mohammad Ali Javadi, MD, graduated from Tehran University of Medical Sciences in 1978. After completion of his residency in 1982 at the same university and anterior segment fellowship in 1984 at Shahid Beheshti University of Medical Sciences Tehran, he joined the Anterior Segment Service at Labbafinejad Hospital as a faculty member. He is now chairman of the Department of Ophthalmology, Shahid Beheshti University of Medical Sciences and director of the Central Eye Bank of Iran.