We are IntechOpen, the world's leading publisher of Open Access books
Built by scientists, for scientists

6,900
Open access books available

185,000
International authors and editors

200M
Downloads

154
Countries delivered to

Our authors are among the

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

CLARIVATE ANALYTICS
BOOK CITATION INDEX
INDEXED

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Donor Graft Quality Used for Penetrating Keratoplasty and Deep Anterior Lamellar Keratoplasty

Sepehr Feizi

Additional information is available at the end of the chapter

Abstract

Deep anterior lamellar keratoplasty (DALK) has been recently introduced as an alternative to penetrating keratoplasty (PK) for corneal pathologies not involving corneal endothelium. DALK does not rely on donor endothelium and requires less rigid criteria for donor corneal tissue quality. Therefore, it provides a greater availability of donor corneas that do not need perfectly healthy endothelium and high endothelial cell density to be suitable for PK. Furthermore, as lamellar corneal surgery expands the potential use of acellular corneal tissue, long-term preservation techniques are being revisited as a way to increase availability of corneal tissue to alleviate constraints of availability, cost, storage, and transportation in many countries. The recent alterations in the technique of corneal transplantation and hence the type of donor cornea tissues used for each technique, may require eye banks and corneal surgeons to reassess their selection criteria but it is important for any changes to be evidence-based. The purpose of this chapter, therefore, is to present an updated analysis on the type and quality of donor corneas used for PK and DALK, to evaluate the impact of donor and eye bank variables on the suitability of corneas for transplantation and then go on to determine whether any of these donor factors affect clinical outcomes, complications, and graft survivals.

Keywords: corneal transplantation, penetrating keratoplasty, full-thickness keratoplasty, deep anterior lamellar keratoplasty, deep lamellar keratoplasty, maximum depth anterior lamellar keratoplasty, donor corneal quality, graft quality

1. Introduction

Penetrating keratoplasty (PK) is a surgical technique in which the full thickness of the recipient cornea is replaced by donor tissue. Deep anterior lamellar keratoplasty (DALK) is intended to selectively replace the abnormal stroma while preserving the recipient's endothelium in place [1]. Therefore, DALK can eliminate the risk of endothelial graft rejection and has minimal detrimental effect on endothelial cell density [2]. Some investigators report that visual acuity and refractive error following DALK can be similar to those following PK [3-6]. Since the introduction of DALK, many surgeons have been accepting donor corneas with lower quality compared with PK. DALK does not rely on quality of the donor endothelium and requires less strict criteria for donor selection [7]. As a result, long-term preservation techniques are being revisited to increase the availability of donor corneas and subsequently alleviate constraints of availability, cost, storage, and transportation in many countries. This feature is imperative in increasing the availability of corneal grafts in regions where there is shortage of donor corneas [7]. The recent alterations in corneal transplantation techniques and consequently the type of donor cornea tissues employed for each technique may require corneal surgeons and eye banks to reevaluate their donor selection criteria.

There is currently a paucity of evidence for setting an acceptable minimum donor conditions for corneal transplantation, especially for lamellar keratoplasty. According to Eye Bank Association of America standards for human corneal transplantation, minimal endothelial cell count limits, the upper and lower limit of donor age, time intervals from death, enucleation or excision to preservation are left to the discretion of the eye banks [8]. An understanding of the effect of donor variables including age, time interval from death to enucleation and preservation, storage time, and endothelial cell density both on the quality of donor corneas and on posttransplantation outcomes helps to set eye banking standards. To establish the criteria, it is vital to find out the correlation between these donor parameters and the appropriateness of corneas for transplantation as well as between donor parameters and posttransplantation outcomes. This chapter presents an updated analysis on the type and quality of donor corneas used for PK and DALK, assesses the influence of donor and eye-bank factors on the quality of donor corneas, and furthermore determines whether any of these donor factors affect clinical outcomes, complications, and graft survival.

2. Type and quality of donors used for PK and DALK

Controversy exists regarding the donor corneal tissue quality used for each transplantation technique, especially DALK. When indicated for optical purposes, PK surgeons prefer transplanting donor cornea tissues with quality ranging from good to very good to excellent to provide adequate endothelial cells for a lifelong period. The acceptable conditions for PK donors are donor age varying from 1 to 96 years [9-16], endothelial cell density between 2000 and ≥ 3000 cells/mm^2 [9, 10, 17, 18], death-to-preservation time between 45 minutes and 22.3 hours [11, 14, 15, 19], and storage time up to 14 days in cool-storage media and 4 weeks in organ culture [11-13].

In contrast to penetrating keratoplasty, donors with quality ranging from fair to excellent are employed for DALK [20, 21]. Furthermore, long-term preserved donor tissues completely devoid of cells are also transplanted [22-25]. One DALK study used donor cornea tissues with age between 12 and 72 years, graft rating from fair to excellent, endothelial cell density (ECD) between 1128 and 4255 cells/mm^2, death-to-preservation time up to 56 hours, and storage time up to 13 days in Optisol medium (-4°C) [20]. Another DALK study used donors with the following features: age between 28 and 88 years, ECD between 100 and 3300 cells/mm^2, and storage time up to 35 days in organ culture medium (31°C) [21]. Long-term preserved corneas with mean storage time between 2.7 and 9.6 months are also used for DALK by some surgeons [22-25]. Frequently, lyophilization or chemical agents are used to dehydrate corneas before cryopreservation [22-24]. However, it is possible to employ cryopreservation without dehydration before freezing as indicated by one study [25].

3. Effect of donor and eye-bank variables on endothelial cell density and graft quality

Donor factors such as age, local and systemic diseases, cause of death, and traumatic damages or surgical procedures as well as the storage factors (mainly method of storing, time between death and preservation, and duration of tissue preservation) can influence the final quality of the corneas. The age of donor, time interval from enucleation to corneoscleral disc excision, and time interval in organ culture are the main variables influencing the quality of endothelium [18, 26, 27]. Gavrilov et al [28] reported that the rate of organ-cultured corneas which were inappropriate for PK as a result of inadequate endothelium increased from 13% in donors < 40 years to 32% in donors > 80 years. The Cornea Donor Study revealed a negative correlation between donor age and ECD [29]. Armitage et al [18] revealed that the age of donor and preservation time in organ culture were the main variables which could affect endothelial suitability for PK. The odd of ECD less than 2500 cells/mm^2 was increased with longer preservation time and increasing donor age. Increasing time interval from enucleation to corneoscleral disc excision also increased the likelihood of ECD less than 2500 cells/mm^2, but the overall impact was small and significant only for a time interval greater than 18 hours [18]. Grabska-Libereket al [27] found that the rating of the morphological state of corneas suitable for PK depended mostly on the time between death and preservation, donor's age, cause of death, and duration of preservation. The overall rating of tissues obtained in a very short time after death (to 5 hours) was higher (excellent and very good) compared with corneas removed 8–12 hours after the donor's death. An increasing percentage of endothelial cell loss was observed after 7 days of preservation independent of other factors [27]. One study found that initial ECD was lower and elimination for low ECD was more frequent in donors aged 85 years and above, compared to younger donors [26]. However, after storage in organ culture, very old corneas lost fewer endothelial cells than younger ones resulting in ECD which did not differ at the end of storage [26]. One study measured endothelial cell loss during preservation in organ culture [19]. The donor's gender, age, cause of death, and postmortem interval had

no significant correlation with the percentage of endothelial cell loss. However, the preservation time demonstrated a significant correlation with a loss of 0.07% for each day of preservation [19].

Additionally, the combined effects of cause of death and donor age on ECD were evaluated. It was identified that chronic and long-lasting, severe diseases like cancer reduced ECD to a greater extent as compared to diseases causing a more rapid death. This negative impact of chronic diseases was aggravated by the general reduction in ECD observed with increasing age [30].

4. Effect of donor and eye-bank variables on clinical outcomes, complications, and graft survivals following PK

Donor and eye-bank variables have an impact on epithelium-related problems following PK [11, 15, 31-33]. Death-to-preservation time and total storage time were significantly associated with an increased prevalence of epithelial defects on day 1 or hurricane and filamentary keratopathy [11, 15]. Kim et al [31] outlined that the degree of epithelial defect had a statistically significant association with the time interval from preservation to surgery. Borderie et al [32] reported that death-to-storage time, storage time, and deswelling time significantly influenced the graft reepithelialization time in univariate analysis. In multiple regression, however, none of the donor variables significantly influenced the graft reepithelialization time. As for the surface keratopathy 1 week following PK, Mannis et al [33] observed no correlation between this complication and donor age, death-to-preservation time, preservation-to-surgery time, and the donor epithelial status. Therefore, only immediately postoperative epithelium-related complications such as filamentary keratitis and persistent epithelial defects correlate with longer death-to-harvest time and longer storage time.

In addition to donor endothelial status, graft corneal surface is a determinant for the success of corneal transplantation in the postoperative period. Although the donor cornea is ultimately resurfaced by the recipient's epithelium, an intact donor epithelium on postoperative day 1 implies a smoother course after corneal transplantation. An instable graft surface can lead to poor visual acuity due to an irregular tear film interface, discomfort, permanent damage to Bowman's layer, subepithelial scarring, and even infectious keratitis [11].

Another widely investigated correlation is the effect of donor and eye-bank variables on postoperative ECD which yielded contradicting results. Langenbucher et al [13] reported no significant association between the annual endothelial cell loss and the donor age as well as postmortem interval. However, the storage time had a statistically significant correlation with the annual endothelial cell loss. Parekh et al [19] reported postmortem interval ≥ 10 hours tends to have a higher percentage of endothelial cell loss than < 10 hours of interval at both 1 year and 3 years postoperatively. Postoperative higher ECD values were significantly associated with higher baseline ECD and younger donor age in one study [34]. When the follow-up period

was extended to 10 years, the study group observed that the donor age influenced ECD, although this finding was primarily influenced by a small group of the youngest donors (12 to < 34 years of age) that had the least cell loss and the best graft survival [34]. Lass et al [10] observed that younger age and female gender of the donor had a significant correlation with higher ECD over time. However, cause of death and time interval from death to preservation or to surgery failed to demonstrate any significant association with changes in ECD during follow-up [10]. One study found a statistically significant negative influence of postmortem time and donor age on chronic loss of endothelial cell density after PK for keratoconus [35]. Because endothelial cell graft attrition takes place at an accelerated rate [36], a higher initial endothelial cell density of the donor tissue can improve long-term graft survival [34]. Older donor age and longer storage time are more likely to be associated with lower ECD but, as long as the ECD is greater than a given minimum at the time of corneal transplantation, these parameters will have insignificant influence on long-term graft survival. The Cornea Donor Study results indicate that donor age is not an important factor in most penetrating kerato-plasties performed for endothelial disease [37]. Therefore, functional and cellular results of PKs are not dramatically influenced by very old donor age and the very elderly should not be deemed off limits for corneal procurement.

Despite contradictory results of studies evaluating the effect of donor and eye-bank variables on postoperative ECD and morphology, the majority of studies showed that donor preservation method and time, donor age, cause of death, and preoperative donor ECD and/or morphometric measures (coefficient of variation and hexagonality) had no influence on overall graft failure [12, 14, 26, 38-41]. However, one study reported that preoperative risk factors for developing late endothelial failure included low ECD and older donor age [16]. Authors from the Cornea Donor Study observed that grafts from donors aged between 66 and 75 years that met the eligibility criteria of their study had a 5-year graft survival rate, comparable to grafts from younger donors [9]. However, higher donor age was significantly associated with lower graft success during a longer follow-up period [37].

Two studies reported the effect of donor age on visual outcomes. Gain et al [26] found no significant difference between the two groups (donors younger than 85 years and donors aged 85 years and older), in terms of visual acuity and astigmatism. Halliday et al [42] found no significant correlation between the time taken to reach a postoperative acuity of 6/12 and the age of donor. One study reported that donor age, ABO compatibility, and other donor factors were not associated with graft rejection [43]. Younger donor age, however, was found to be a risk factor for graft rejection (but not for graft failure) by three other studies [26, 40, 44].

5. Effect of donor and eye-bank variables on clinical outcomes, complications, and graft survivals following DALK

DALK does not rely on donor endothelial cells and less strict criteria can be used for donor graft quality. Therefore, it increases the availability of donor tissues that do not require high-

quality endothelium to be appropriate for PK. Borderie et al [21] evaluated the effect of donor variables on the result of different anterior lamellar keratoplasty techniques in a heterogeneous group of corneal disorders with normal endothelium. The age of donor was the only factor which influenced visual rehabilitation postoperatively; visual acuity was significantly lower in recipients who received corneas from donors > 80 years [21]. Heindl et al [45] did not observe any significant association between donor storage time intervals and visual results one year following DALK. However, the use of low quality donors for DALK could cause epithelium-related complications more frequently, besides more edematous alterations of the graft necessitating a closer follow-up immediately after surgery. Feizi et al [20] observed that graft rating and preservation-to-surgery time had a significant correlation with the presence of graft stromal edema and epithelial defects on postoperative day 1 following DALK. Suture-related complications, graft rejection episodes, graft clarity, visual acuity, and refractive outcomes at the final follow-up examination were found to have no correlations with any donor or eye-bank factors [20]. Therefore, low quality donors can provide good visual acuity and refractive outcomes with complication rates comparable to those achieved after the use of good quality donors following DALK.

The two main techniques for storing corneas are organ culture and hypothermia [46, 47]. Since lamellar corneal transplantation makes it possible to use acellular corneal tissue, long-term preservation methods have emerged as a means to provide a greater availability of corneal tissue to alleviate constraints of availability, cost, storage, and transportation in many countries. The results of several studies indicate that cryopreserved corneal tissues can successfully substitute for fresh grafts in DALK using the big-bubble technique. Five studies concluded that long-term cryopreserved donors can provide similar visual results comparable to fresh corneal tissues following DALK [22, 23, 25, 48, 49]. Another advantage of long-term preservation of the cornea by lyophilization and chemical glycerin-dehydration is to eliminate cells such as epithelium, keratocytes, and antigen-presenting cells and create the acellular biological materials [22, 50]. As such, acellular corneal tissues may significantly reduce or even eliminate the incidence of graft rejection after lamellar keratoplasty [22, 23, 25]. Complications such as persistent epithelial defects, filamentary keratitis, and suture-related complications were more likely to occur when such a low quality graft was transplanted [25].

6. Conclusions

Although both donor and eye-bank variables have effects on the quality of donor corneas, and post-PK outcomes and complications, these effects would be little provided that the minimum selection criteria set by eye banks are respected. DALK makes it possible to transplant corneas with low quality and allows using the long-term methods of storage. Because epithelial defects and stromal edema are more frequently encountered, closer follow-up visits are required when a low-quality graft is transplanted.

Author details

Sepehr Feizi[*]

Address all correspondence to: sepehrfeizi@yahoo.com

Ophthalmic Research Center and Department of Ophthalmology, Labbafinejad Medical Center, Shahid Beheshti University of Medical Sciences, Tehran, Iran

References

[1] Terry MA. The evolution of lamellar grafting techniques over twenty-five years. Cornea 2000;19: 611-616.

[2] Morris E, Kirwan JF, Sujatha S, Rostron CK. Corneal endothelial specular microscopy following deep lamellar keratoplasty with lyophilised tissue. Eye (Lond) 1998; 12(Pt 4): 619-622.

[3] 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: 527-532.

[4] Amayem AF, Hamdi IM, Hamdi MM. Refractive and visual outcomes of penetrating keratoplasty versus deep anterior lamellar keratoplasty with hydrodissection for treatment of keratoconus. Cornea 2013; 32: e2-e5.

[5] 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: 1676-1682.

[6] Javadi MA, Feizi S, Yazdani S, Mirbabaee F. Deep anterior lamellar keratoplasty versus penetrating keratoplasty for keratoconus: a clinical trial. Cornea 2010; 29: 365-371.

[7] Shimazaki J. The evolution of lamellar keratoplasty. CurrOpinOphthalmol 2000; 11: 217-223.

[8] Eye Bank Association of America. Medical Standards. Washington: EBAA, 2011: 1-46.

[9] Gal RL, Dontchev M, Beck RW, Mannis MJ, Holland EJ, Kollman C, Dunn SP, Heck EL, Lass JH, Montoya MM, Schultze RL, Stulting RD, Sugar A, Sugar J, Tennant B, Verdier DD. The effect of donor age on corneal transplantation outcome results of the cornea donor study. Ophthalmology 2008; 115: 620-626. e6.

[10] Lass JH, Beck RW, Benetz BA, Dontchev M, Gal RL, HollandEJ, Kollman C, Mannis MJ, Price F, Raber I, Stark W, Stulting RD, Sugar A. Baseline factors related to endo-

thelial cell loss following penetrating keratoplasty. Arch Ophthalmol 2011; 129: 1149-1154.

[11] Feiz V, Mannis MJ, Kandavel G, McCarthy M, Izquierdo L, Eckert M, Schwab IR, Torabian S, Wang JL, Wang W. Surface keratopathy after penetrating keratoplasty. Trans Am OphthalmolSoc 2001; 99: 159-168.

[12] Patel SV, Diehl NN, Hodge DO, Bourne WM. Donor risk factors for graft failure in a 20-year study of penetrating keratoplasty. Arch Ophthalmol 2010; 128: 418-425.

[13] Langenbucher A, Nguyen NX, Seitz B. Predictive donor factors for chronic endothelial cell loss after nonmechanical penetrating keratoplasty in a regression model. Graefes Arch Clin Exp Ophthalmol 2003; 241: 975-981.

[14] Gogia V, Gupta S, Titiyal JS, Panda A, Pandey RM, Tandon R. A preliminary descriptive analysis of Corneal Transplant Registry of National Eye Bank in India. Cont Lens Anterior Eye 2014; 37: 111-115.

[15] Van Meter WS, Katz DG, White H, Gayheart R. Effect of death-to-preservation time on donor corneal epithelium. Trans Am OphthalmolSoc 2005; 103: 209-222.

[16] Nishimura JK, Hodge DO, Bourne WM. Initial endothelial cell density and chronic endothelial cell loss rate in corneal transplants with late endothelial failure. Ophthalmology 1999; 106: 1962-1965.

[17] Bertelmann E, Pleyer U, Rieck P. Risk factors for endothelial cell loss post-keratoplasty. Acta Ophthalmol Scand 2006; 84: 766-770.

[18] Armitage WJ, Jones MN, Zambrano I, Carley F, Tole DM. The suitability of corneas stored by organ culture for penetrating keratoplasty and influence of donor and recipient factors on 5-year graft survival. Invest Ophthalmol Vis Sci 2014; 55: 784-791.

[19] Parekh M, Salvalaio G, Ferrari S, Frigo AC, Griffoni C, Grassetto A, Ruzza A, Camposampiero D, Ponzin D. Effect of postmortem interval on the graft endothelium during preservation and after transplantation for keratoconus. Cornea 2013; 32: 842-846.

[20] Feizi S, Javadi MA, Kanavi MR, Javadi F. Effect of donor graft quality on clinical outcomes after deep anterior lamellar keratoplasty. Cornea 2014; 33: 795-800.

[21] Borderie VM, Sandali O, Basli E, Goldschmidt P, Laroche L. Donor tissue selection for anterior lamellar keratoplasty. Cornea 2013; 32: 1105-1109.

[22] Chen W, Lin Y, Zhang X, Wang L, Liu M, Liu J, Ye Y, Sun L, Ma H, Qu J. Comparison of fresh corneal tissue versus glycerin-cryopreserved corneal tissue in deep anterior lamellar keratoplasty. Invest Ophthalmol Vis Sci 2010; 51: 775-781.

[23] Li J, Yu L, Deng Z, Wang L, Sun L, Ma H, Chen W. Deep anterior lamellar keratoplasty using acellular corneal tissue for prevention of allograft rejection in high-risk corneas. Am J Ophthalmol 2011; 152: 762-770. e3.

[24] Bonci P, Della Valle V, Bonci P, Lodi R, Russo A. Deep anterior lamellar keratoplasty with dehydrated, 4 °C-stored, and rehydrated lenticules. Eur J Ophthalmol 1990; 21: 368-373.

[25] Javadi MA, Feizi S, Javadi F, Kanavi MR, Ghasemi H, Karimdizani S, Mirbabaee F. Deep anterior lamellar keratoplasty using fresh versus cryopreserved corneas. Ophthalmology 2014; 121: 610-611.

[26] Gain P, Thuret G, Chiquet C, Rizzi P, Pugniet JL, Acquart S, Colpart JJ, Le Petit JC, Maugery J. Cornea procurement from very old donors: post organ culture cornea outcome and recipient graft outcome. Br J Ophthalmol 2002; 86: 404-411.

[27] Grabska-Liberek I, Szaflik J, Brix-Warzecha M. The importance of various factors relating to the morphological quality of corneas used for PKP by the Warsaw Eye Bank from 1996 to 2002. Ann Transplant 2003; 8: 26-31.

[28] Gavrilov JC, Borderie VM, Laroche L, Delbosc B. Influencing factors on the suitability of organ-cultured corneas. Eye (Lond) 2010; 24: 1227-1233.

[29] Sugar A, Gal RL, Beck RW, Ruedy KJ, Blanton CL, Feder RS, Hardten DR, Holland EJ, Lass JH, Mannis MJ, O'Keefe MB. Baseline donor characteristics in the cornea donor study. Cornea 2005; 24: 389-396.

[30] Krohn J, Høvding G. The influence of donor age and cause of death on corneal endothelial cell density. Acta Ophthalmol Scand 2005; 83: 746-750.

[31] Kim T, Palay DA, Lynn M. Donor factors associated with epithelial defects after penetrating keratoplasty. Cornea 1996; 15: 451-456.

[32] Borderie VM, Touzeau O, Bourcier T, Allouch C, Laroche L. Graft reepithelialization after penetrating keratoplasty using organ-cultured donor tissue. Ophthalmology 2006; 113: 2181-2186.

[33] Mannis MJ, Zadnik K, Miller MR, Marquez M. Preoperative risk factors for surface disease after penetrating keratoplasty. Cornea 1997; 16: 7-11.

[34] Lass JH, Benetz BA, Gal RL, Kollman C, Raghinaru D, Dontchev M, Mannis MJ, Holland EJ, Chow C, McCoy K, Price FW, Sugar A, Verdier DD, Beck RW. Donor age and factors related to endothelial cell loss 10 years after penetrating keratoplasty: Specular Microscopy Ancillary Study. Ophthalmology 2013; 120: 2428-2435.

[35] Böhringer D, Reinhard T, Spelsberg H, Sundmacher R. Influencing factors on chronic endothelial cell loss characterised in a homogeneous group of patients. Br J Ophthalmol 2002; 86: 35-38.

[36] Armitage WJ, Dick AD, Bourne WM. Predicting endothelial cell loss and long-term corneal graft survival. Invest Ophthalmol Vis Sci 2003; 44: 3326-3331.

[37] Mannis MJ, Holland EJ, Gal RL, Dontchev M, Kollman C,Raghinaru D, Dunn SP, Schultze RL, Verdier DD, Lass JH,Raber IM, Sugar J, Gorovoy MS, Sugar A, Stulting

RD, Montoya MM, Penta JG, Benetz BA, Beck RW. The effect of donorage on penetrating keratoplasty for endothelial disease: graftsurvival after 10 years in the Cornea Donor Study. Ophthalmology 2013; 120: 2419-2427.

[38] Lass JH, Sugar A, Benetz BA, Beck RW, Dontchev M, Gal RL, Kollman C, Gross R, Heck E, Holland EJ, Mannis MJ, Raber I, Stark W, Stulting RD. Endothelial cell density to predict endothelial graft failure after penetrating keratoplasty. Arch Ophthalmol 2010; 128: 63-69.

[39] Benetz BA, Lass JH, Gal RL, Sugar A, Menegay H, Dontchev M, Kollman C, Beck RW, Mannis MJ, Holland EJ, Gorovoy M, Hannush SB, Bokosky JE, Caudill JW. Endothelial morphometric measures to predict endothelial graft failure after penetrating keratoplasty. JAMA Ophthalmol 2013; 131: 601-608.

[40] Inoue K, Amano S, Oshika T, Tsuru T. Risk factors for corneal graft failure and rejection in penetrating keratoplasty. Acta Ophthalmol Scand 2001; 79: 251-255.

[41] Chang SD, Pecego JG, Zadnik K, Danneffel MB, Mutti DO, Mannis MJ. Factors influencing graft clarity. Cornea 1996; 15: 577-581.

[42] Halliday BL, Ritten SA. Effect of donor parameters on primary graft failure and the recovery of acuity after keratoplasty. Br J Ophthalmol 1990; 74: 7-11.

[43] Stulting RD, Sugar A, Beck R, Belin M, Dontchev M, Feder RS, Gal RL, Holland EJ, Kollman C, Mannis MJ, Price F, Stark W, Verdier DD. Effect of donor and recipient factors on corneal graft rejection. Cornea 2012; 31: 1141-1147.

[44] Palay DA, Kangas TA, Stulting RD, Winchester K, Litoff D, Krachmer JH. The effects of donor age on the outcome of penetrating keratoplasty in adults. Ophthalmology 1997; 104: 1576-1579.

[45] 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: 899-907.

[46] Armitage WJ. Developments in corneal preservation. In: Reinhard T, Larkin F (eds), Cornea and External Eye Disease. Berlin: Springer, 2008: 101-109.

[47] Armitage WJ, Easty DL. Factors influencing the suitability of organ-cultured corneas for transplantation. Invest Ophthalmol Vis Sci 1997; 38: 16-24.

[48] Farias R, Barbosa L, Lima A, Mayumi E, Lourenço A, De Freitas D, Allemann N, Vieira L. Deep anterior lamellar transplant using lyophilized and Optisol corneas in patients with keratoconus. Cornea 2008; 27: 1030-1036.

[49] Chau GK, Dilly SA, Sheard CE, Rostron CK. Deep lamellar keratoplasty on air with lyophilised tissue. Br J Ophthalmol 1992; 76: 646-650.

[50] Li J, Shi S, Zhang X, Ni S, Wang Y, Curcio CA, Chen W. Comparison of different methods of glycerol preservation for deep anterior lamellar keratoplasty eligible corneas. Invest Ophthalmol Vis Sci 2012; 53: 5675-5685.