Malapposition of Graft-host Interface after Keratoplasty: an Optical Coherence Tomography Study

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Abstract

Background: Previous studies of internal graft-host malappositions have not dealt with the precise ways in which each wound malapposition affected post-keratoplasty visual outcomes. In this study, reviewing our postsurgical keratoconic patients using anterior segment optical coherence tomography (AS-OCT) to evaluate the correlation between characteristics of the graft-host interface (GHI) and visual outcomes was aimed.

Methods: Correlations between characteristics of GHI and the postsurgical visual outcomes, including logarithm of minimum angle of resolution best-corrected visual acuity (logMAR BCVA), spherical equivalent diopter (SE), diopter of spherical power (DS), diopter of cylindrical power (DC), and keratometric astigmatism, were evaluated of 45 eyes (patients).

Results: The graft-host touch (GHT) varied with different alignment patterns. LogMAR BCVA correlated positively with GHT (r=0.32, *P*=0.030) and junctional graft thickness (Tg) (r=0.49, *P*=0.001). SE had positive correlation with frequency of step [F (step)] (r=0.46, *P*=0.001), graft step [F (graft step)] (r=0.40, *P*=0.028), total prevalence of malapposition proportion (Pm) (r=0.35, *P*=0.018), size of malapposition (Sm) (r=0.31, *P*=0.037), Tg (r=0.03, *P*=0.022), disparity between junctional graft and host thickness (|Tg-Th|) (r=0.40, *P*=0.007), and correlated negatively with GHT (r=-0.34, *P*=0.021). Similar results were acquired in DS. Keratometric astigmatism was found to correlate positively with Sm (r=0.30, *P*=0.047).

Conclusion: In keratoconic eyes, corneal keratometric astigmatism increased by 0.017 with Sm. LogMAR BCVA increased by 0.001 with both GHT and Tg. Investigation of the visions for keratoconus patients. Our study might have potential reference value for future technological promotion.

Introduction

Patients with advanced keratoconus usually have quite low vision due to progressive high myopia and irregular astigmatism. Therefore, the primary objective of keratoplasties for these patients should be rebuilding normal corneal curvature and acceptable vision.1.2 Penetrating keratoplasty (PK) and deep anterior lamellar keratoplasty (DALK) are two main surgical treatment options for keratoconus. However the persistence of postoperative ametropia remains the mainly unsolved cause of suboptimal vision outcomes even with progressing ophthalmological operation and examination techniques.3 Approximately 40% of cases experienced astigmatism after corneal transplantations, among which 19% to 38% had high astigmatism (> 5 diopters) and could not be corrected satisfactorily by spectacles or contact lenses.4-7 Since keratoconus usually attacks young and middle-aged people, lifelong satisfying vision should be the ultimate goal of surgical treatment.2,3,5,6,8

Anterior-segment optical coherence tomography (AS-OCT) can penetrate through deeper tissues with a stretched wavelength (1.3 μm) and be safely applied in perioperative stages to obtain cross-sectional images of anterior segments, which is critical for preoperative evaluation and postoperative follow-ups.17 Hence, it had been used to observe alignment patterns of the posterior graft-host junctions after PK. However, reports of similar observations in post-DALK cases were rarely seen.9,10

Until now, the influential factors in postsurgical refraction errors have remained inconclusive due to insufficiency of relevant reports.11 Kaiserman and Bahar11 reported that internal graft-host malappositions were associated with increased postoperative ametropia, astigmatism. However, the precise ways in which each malapposition affected postsurgical visual outcomes were rarely seen.12

The aim of this study was to analyze and quantify the correlations between characteristics of the posterior graft-host interfaces (GHI) and postoperative visual outcomes in keratoconus patients.

Patients And Methods

A retrospective observational cross-sectional study was conducted from March to August 2016 at the Eye & ENT Hospital of Fudan University, Shanghai, China. We reviewed the clinical records of patients who had surgical treatments (PK or DALK). All subjects received comprehensive ophthalmologic examinations including visual acuity, intraocular pressure (IOP), anterior segment photographs, slit-lamp biomicroscopy, and refraction. We strictly selected patients with transparent grafts at the time of enrollment who had no postsurgical complications such as secondary glaucoma, cataract, or iris synechia. According to the widely known Amsler-Krumeich classification, preoperative diagnosis of each subject was grade 4 keratoconus without any associated history of ophthalmic diseases, surgeries, or trauma.13 Written informed consent was obtained from all patients for the participation in the study. This investigation adhered to the tenets of the Declaration of Helsinki and was approved by the Ethics Committee of Shanghai Eye & ENT Hospital of Fudan University.

SURGICAL TECHNIQUE: All corneal transplantations were performed by skilled anterior segment surgeons (X.J.J., Z.Z.R. et al.) from our hospital who have more than 20 years' corneal surgery experience. Fresh full-thickness cornea materials preserved and provided by the local eye bank were used. All surgeries were performed under both retrobulbar and peribulbar anaesthesia, with complete akinesia of the eyeballs together with eyelids. PKs were performed using standard techniques. The diameter of each recipient bed (7.50 mm to 8.25 mm) was decided according to preoperative AS-OCT examinations. The donor was excised to the same diameter as the recipient using a manual trephine system. Intraocular viscoelastic injections (VISCOAT®; Alcon Laboratories Ltd, Ft. Worth, TX) were applied to protect corneal endothelium of grafts. The graft was secured to the host bed using 12 or 16 interrupted 10-0 nylon non-absorbable surgical suture (USIOL, Inc.; Lexington, KY), according to the surgeon's preference. At the end of each operation, anterior chamber was restored by saline injection and the watertightness of corneal wound was carefully checked. To perform DALK, the diameter range (7.50 mm to 8.25 mm) of host bed was similar to that in PK procedures. After a partial trephination of approximately 50% of the host corneal stroma and manual stripping of the superficial stromal layer, pneumatic pressure was used to detach the Descemet's membrane (DM) from the deep stroma by injecting sterile air into the latent space between these two adjacent corneal microstructures with a 30-gauge needle. Air injection would produce a dome-shaped bubble that could be seen under the surgical microscope. Corneal stromal tissue above the “bubble” was manually dissected with scissors and spatula until a complete exposure of DM underneath was achieved. The same-size donor cornea without DM and endothelium was then sutured to the recipient using a 12- or 16-bite interrupted suturing technique.

INSTRUMENTS AND METHODS

OCULUS ANALYSIS: Corneal topography images were automatically taken by the system software (OCULUS Keratograph® 5M; OCULUS, Wetzlar, Germany) when the best manual adjustments of eyeball position were acquired by one single ophthalmologist (Z.Y.J). Data from images in which cornea coverage was greater than 70% was used in the following statistical procedures. Each parameter included within the device was an average of three consecutive measurements and was collected by one single examiner (W.D).

AS-OCT IMAGING: Visante™ AS-OCT (Carl Zeiss Meditec, Inc; Dublin, CA), with noninvasive, non-contact infrared light tomography technology was used. The axial scan rate of time-domain Visante™ AS-OCT reaches up to 2000 points per second, and its axial and transverse resolutions are up to 60 μm and 20 μm in its 360-degree scanning of the anterior segment. Each image was acquired just in 0.125 seconds. Subjects were required to remain in sitting position and look straight at a fixation target inside the camera lens with their eyes wide open. Each corneal graft underwent four high-resolution optical sections separated by 45●, representing eight GHI sections (Fig. 1). One scanning axis was placed on the main corneal meridian according to a previously determined direction by OCULUS.
For consistency, OCT images were acquired and interpreted by a single ophthalmologist (Z.Y.J). Based on definitions from a previous report,11 graft-host alignment patterns were classified according to the internal surfaces of the corneal wound as follows: well-apposed junctions (Fig. 2A), step [graft step (Fig. 2B) and host step (Fig. 2C)], protrusion [hill (Fig. 2D) and tag (Fig. 2E)], and gape (Fig. 2F).

STATISTICAL PARAMETERS: Refraction parameters included: logarithm of minimum angle of resolution best-corrected visual acuity (LogMAR BCVA), spherical equivalent diopter (SE), diopter of spherical power (DS), and diopter of cylindrical power (DC). Astig value, included in OCULUS keratometric parameters, represented the keratometric astigmatism in the central 2mm of the cornea. AS-OCT parameters included: mean graft-host touch (GHT), total prevalence of malapposition proportion (Pm), frequency of malapposition (Fm), size of malapposition (Sm), junctional graft thickness (Tg), and junctional host thickness (Th). GHT, representing the graft-host contact area, was defined as: the linear distance between epithelial and endothelial surfaces of the GHI. Pm was defined as the percentage of malappositions in one case. Fm was difined as the percentage of a certain type of malapposition in one case. For protrusion and gape, Sm was defined as the vertical distance between the DM layer and the end of malalignment. For step, Sm was the vertical distance between the DM layers of host and graft. We measured Tg and Th in consideration of the varying initial thicknesses of graft beds. Specifically, an imaginary line was drawn perpendicular to the external and internal sides of the cornea, from the central point of the line where the donor and recipient met. Tg and Th were calculated by measuring the thicknesses both of recipient and donor, each at a point 1 mm away from the meeting point on the external side (Fig. 3). |Tg-Th| represented the absolute disparity value between Tg and Th.

In the current study, GHT, Pm, Sm, Tg, Th, and |Tg-Th| were chosen to describe the characteristics of a postoperative GHI. The post-surgery visual outcomes were assessed by LogMAR BCVA, SE, DS, DC (refractive astigmatism), and Astig value (keratometric astigmatism).

STATISTICAL ANALYSIS: Data were analyzed using SPSS® version 19 (IBM® Corp.; Armonk, NY). All measurements were expressed as mean ± standard deviation (SD). After estimating the normality and homoscedasticity of all the data using the Shapiro-Wilk normality test and Levene test, One-way analysis of variance was used for continuous variables, while ranked data were analyzed by Mann-Whitney U test or Kruskal-Wallis test. The Pearson and the Spearman correlations were employed to assess the relationships between characteristics of GHI and post-surgery visual outcomes. Linear regression analysis was performed to establish equations for visual outcome parameters which showed significant correlation with AS-OCT parameters. Probabilities of less than 5% were considered statistically significant.

Results

A total of 360 graft-host sections of 45 eyes (40 male and 5 female) were acquired and analyzed, including post-PK eyes (n=22) and post-DALK eyes (n=23). The average age was 24.04 (±6.82) years and the mean postoperative period was 29.31 (±19.57) months. The postsurgical LogMAR BCVA was 0.36 (±0.25). There were 58.3 (±30.7) % internal graft-host malappositions out of all the GHIs, and the mean GHT was 682.93 (±80.22) μm. The post-surgery period of DALK group was significantly shorter than that in PK group. DALK patients had relatively higher LogMAR BCVA and lower SE and DS values than PK patients. Graft thickness was thinner in post-PK cohort comparing with post-DALK cohort. Correspondingly, |Tg-Th| value in PK group was smaller. Details are listed in Table 1.

Although GHIs had quite smooth epithelial surfaces in all scans, 58.3% of them had malappositions on the internal surface. Of all the internal graft-host interfaces, there were 43.9% steps (122 graft steps and 36 host steps), 11.7% protrusions (33 hills and 9 tags), and 2.8% gapes (10 scans). GHT size varied with alignment types. In summary, comparing with the well-apposition, internal step and gape significantly reduced GHT, while opposite effects were observed in hill and tag patterns (see Table 2).

LogMAR BCVA was found to have a positive correlation with GHT (r=0.030) and Tg (r=0.001), but correlated negatively with frequency of protrusion [F (protrusion)] (r=0.01). SE was found to have a positive correlation with F (step) (r=0.001), F (graft step) (r=0.028), Pm (r=0.018), Sm (r=0.037), Tg (r=0.022), |Tg-Th| (r=0.007), and correlated negatively with GHT (r=0.021). As for DS, very similar results were acquired. We failed to report any relationships between DS and OCT parameters. Astig value, representing keratometric astigmatism, was found to have a very slight positive correlation with Sm (r=0.047). Details are listed in Table 3.

Based on the graft-host characteristics with significant correlations, linear regression equations of most visual outcomes were established except for the one between LogMAR BCVA and F(protrution) (F=3.937, *P*=0.054). Details are listed in Table 4.

Discussion

The persistence of high regular or irregular astigmatism remains major postsurgical problems for keratoconus patients who resort to corneal transplantation therapies. Until now, there were still conflicting opinions about the causes of post-surgery astigmatism, such as small intraoperative trephinations, uneven suture tension, or graft-recipient misalignments.8,10 Limberg et al14 proposed that imprecise graft-host matching might result in astigmatism of about 4–6 diopters.1 It has been reported that preoperative corneal pathology could influence the graft-host apposition patterns.13,15 Kaiserman et al11 reported slight misalignment-associated astigmatism after PK. Jhanji et al16 categorized the alignment patterns as step and ledge, but failed to find any relationships between malappositions and post-surgery visual outcomes, yet they raised a theory that oversize graft would affect the GHI alignment due to curling of the larger graft at the posterior surface. Despite all considerations, the potential relationships between internal graft-recipient misalignment and postoperative refractive error in keratoconic cohorts remain unclear. In the current study, graft and host beds were prepared isometrically in all cases so graft-host disparity was not an issue. Suture tension within one case was proved to be nearly even according to the OCT cross-sectional images, in which post-keratoplasty corneal morphology were quite symmetric.

Referring to lamellar keratoplasty, the GHI manifest as a moderate to high reflective interface in AS-OCT image.18 However, the cutting depth of corneal stroma in our DALK procedure virtually approached the DM layer. Hence, the very little residual stroma make the cross-sectional images using AS-OCT from PK and DALK groups very much alike.18 In our study, PK group had better LogMAR BCVA than DALP group [(0.25±0.24) vs. (0.47±0.20), *P* = 0.002]. Despite the different opinions about the relative merits of these two surgeries for years, there was strong evidence through register of controlled trials suggesting better LogMAR BCVA at ≧ 6 months with PK in a recent systematic review. Our results concurred with this conclusion.9 We found that post-surgery SE and DS were more severe, which might be contributed to the relatively worse keratoconus status and higher degree myopia before surgery.2 Due to longer post-surgery period, thinner Tg was observed in PK group.

In the current study, we found that misalignments of internal GHI existed in both postsurgical groups. This finding was similar to those in previous reports.11,12 Smoothness of anterior GHI can resulted from several factors. First, surgeons can align the epithelial surface of a corneal wound under direct vision during operation. Other factors include suture traction and the powerful regeneration capacity of corneal epithelium. It has been reported that posterior GHI discontinuity exists universally, but existing related studies are very limite.12 Lang et al19 found misalignments of the DM layer in 22 eyes in post-mortem examinations of 25 patients (30 eyes) who had undergone PK. Kaiserman et al11 reported more post-PK internal graft-host malappositions (76.4%) in keratoconic patients compared with those who received corneal transplantations for other corneal diseases (50%). For keratoconic patients, the higher probability of irregular wound healing might be due to uneven thinning of the cornea before surgery. In our study, 58.3% graft-host junctions were misaligned. The major reason for the relatively low incidence of misalignment may be due to the expertise of our experienced surgeons and equal graft-host size. Moreover, unlike previous studies, we enrolled both post-PK and post-DALK patients. The altered healing processes of these two procedures might result in the discrepancy of misalignment rates among studies.20

Post-keratoplasty alignment patterns could be classified into four basic types: good apposition, step, protrusion and gape. Moreover, graft step and host step are subtypes of step, while hill and tag are subtypes of protrusion.11 Studies have shown that various preoperative corneal pathologies would influenced the wound alignment patterns.11,21 Sung et al12 observed the posterior surface of corneal wounds from 13 post-PK keratoconic eyes with AS-OCT and found 78.8% malapposed junctions, including 22.1% gape, 22.1% protrusion and 34.6% step. Among the 360 graft-host sections confined only to keratoconic eyes in the current study, the most common malapposition was graft step (122 cases, 33.9%). We hold the opinion that pre-operation asymmetrical thinning of cornea in different disease staging caused more graft step, because donors' normal corneal grafts were mostly thicker than the recipient beds that had already thinned.

GHT represented the contact area between graft and recipient bed. Generally, step and gape significantly reduced GHT, while hill increased GHT. In the current study, tag pattern also increased GHT slightly. Since tag is a small piece of DM layer protruding from the corneal wound, while hill is a protrusion of both DM layer and deep corneal stroma.11,12 Hence, we suppose that tag would increase GHT, but only to a very limited extent.

Kaiserman et al11 analyzed 204 post-PK graft-host sections from 27 eyes, and found that Sm correlated negatively with postoperative SE (r=-0.2, P=0.02) and positively with postoperative DC (r=0.26, P = 0.006). Although the correlations were slight, Sm could partly explain the astigmatism and ametropia. Sung et al12 evaluated the characteristics of GHI after PK using AS-OCT and reported that the graft-host thickness disparity, which closely related to the wound alignment state, showed positive correlation with keratometric astigmatism (r=0.56, P<0.01). In our study, various correlations between visual outcomes and characteristics of corneal alignment patterns were specifically evaluated and quantified. Generally, we found the existence of malapposed junctions that decreased GHT would significantly increase the postoperative SE and DS by 0.019 and 0.02, respectively. However, the decreased GHT would lower the LogMAR BCVA by 0.001. There was good reason to suspect that expansion of GHT helped bring greater stability to the corneal wound, which would reduce the postoperative SE and DS. But LogMAR BCVA increased slightly with GHT in some unknown ways and need further exploration. DS significantly increased by 6.139, 5.067, 4.518, 0.017, and 0.027 under the influence of F (step), F (graft step), Pm, Tg, and |Tg-Th|. SE, equal to (DS+1/2 DC), was found to increase by 6.851, 5.428, 5.164, 0.018, 0.019, and 0.031 under the influence of F (step), F (graft step), Pm, Sm, Tg, and |Tg-Th|. Given the above situation, F (step), F (graft step) and Pm seemed to be the factors that most responsible for post-keratoplasty ametropia. Moreover, the relationship between |Tg-Th| and visual outcomes indicates that greater graft-host disparity would lead to more serious ametropia, too. Hence, we assumed that the thinner the recipient bed was, the worse visual outcomes might be. The increase of graft thickness mainly occurs early in the postoperative period because of tissue edema; hence, this could explain the increase of LogMAR BCVA, SE, and DS with Tg, because most cases were observed shortly after operations.

Our study has several limitations. Because it only represented a single-center experience with relatively small-scale subjects, there may be some insignificant statistical conclusions. Next, the study population was restricted to keratoconic patients, so our results might not be applicable to post-keratoplasty cases with other corneal diseases. Moreover, we unavoidably missed some information about the internal GHI, since only eight images were obtained for one eye at a time in a raster scan.

We verified the wide existence of internal graft-host malappositions using AS-OCT and specifically quantified the relationship between GHI characteristics and visual outcomes in post-surgery keratoconic patients for the first time. GHT increased in hill and tag patterns and decreased in step and gape patterns. F (step), F (graft step) and Pm influenced SE and DS positively. Central corneal keratometric astigmatism increased by 0.017 with Sm increase. LogMAR BCVA increased by 0.001 with both GHT and Tg. In conclusion, investigations of the characteristics of GHI would be valuable for explanation of different post-surgery visions for keratoconus patients. Our study has potential reference value for future technological promotion. Further studies are warranted to determine ways of achieving optimal graft-host apposition during surgeries.

Declarations

Ethics approval and consent to participate

Written informed consent was obtained from all patients for the participation in the study. Approval from the Ethics Committee of Shanghai Eye & ENT Hospital of Fudan University was received.

Consent for publication

Not applicable.

Availability of data and materials

All data generated or analyzed during this study are included in this published article.

Competing interest

The authors declare that they have no competing interests.

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Authors’ Contributions

Yujin Zhao (YJZ), Hong Zhuang (HZ) and Jianjiang Xu (JJX) made significant contribution for the design of the study. YJZ and Lijia Tian (LJT) acquired the data and YJZ analyzed and interpreted the data. YJZ drafted the work and Jiaxu Hong (JXH) and JJX revised it critically. JJX performed all the surgeries. All authors read and approved the final version of the manuscript.

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Tables

TABLE 1. Descriptive Statistics of Post-keratoplasty Parameters

	Post-keratoplasty Mean (SD)	Post-PK Mean (SD)	Post-DALK Mean (SD)	*P*
Age (Years)	24.04 (6.82)	25.82 (7.29)	22.35 (6.00)	.088
surgery period (Months)	29.31 (19.57)	38.18 (22.91)	20.82 (10.54)	.003
IOP (mmHg)	17.94 (1.47)	18.13 (1.29)	17.74 (1.68)	.838
LogMAR BCVA	0.36 (0.25)	0.25 (0.24)	0.47 (0.20)	.002
SE (diopter)	-2.90 (4.53)	-4.59 (4.74)	-1.29 (3.75)	.013
DS (diopter)	-0.74 (4.22)	-2.35(4.55)	0.81 (3.29)	.010
DC (diopter)	-4.32 (2.58)	-4.47(2.64)	-4.19 (2.57)	.720
GHT (µm)	682.93 (80.22)	686.50 (102.09)	679.52 (52.84)	.778
Pm (%)	58.3 (30.7)	54.5 (30.5)	62.0 (31.2)	.421
Sm (µm)	119.56 (78.63)	113.36 (80.50)	125.48 (78.12)	.611
Tg (µm)	666.67 (81.06)	617.31(61.77)	713.87 (68.82)	<.0001
Th (µm)	638.58 (64.34)	646.41 (83.40)	631.09 (38.98)	.431
|Tg-Th|(µm)	68.49 (57.35)	50.45 (55.61)	85.74 (54.68)	.038
Astig value (diopter)	0.39 (4.40)	0.05 (4.35)	0.72 (4.53)	.618

netrating keratoplasty; DALK=deep anterior lamellar keratoplasty; SD=standard deviation; IOP=intraocular ure; LogMAR BCVA= logarithm of minimum angle of resolution best-corrected visual acuity; SE= spherical ent diopter; DS= diopter of spherical power; DC= diopter of cylindrical power; GHT= mean graft-host touch; otal prevalence of malapposition proportion; Sm= size of malapposition; Tg= junctional graft thickness; Th= junctional host thickness.

TABLE 2. Prevalence and Size of Various Types of Apposition of the Internal Graft-host Interface

	Number of junctions	Fm (%)	GHT mean (SD), range (µm)	Sm mean (SD), range (µm)	GHT comparison *P*
on	150	41.7	682.42 (133.89), 470~1450	-	-
	158	43.9			
	122	33.9	658.28 (137.62), 480~1870	198.68 (77.58), 80~680	.074
	36	10.0	662.50 (131.40), 490~1040	236.44 (81.44), 110~480	<.0001
	42	11.7			
	33	9.2	819.09 (120.73), 530~1190	184.24 (50.87), 100~310	<.0001
	9	2.5	696.67 (155.72), 510~1010	234.44 (70.38), 160~380	<.0001
	10	2.8	600 (167.59), 440~910	285 (188.81), 170~800	<.0001

of malapposition; GHT= mean graft-host touch; SD= standard deviation; Sm= size of malapposition;

nation and one-way analysis of variance were used.

TABLE 3. Correlation Analysis between Graft-host Characteristics and Visual Outcome Parameters

	SE correlation index (*P*)	LogMAR BCVA correlation index (*P*)	DS correlation index (*P*)	DC correlation index (*P*)	Astig value correlation index (*P*)
	0.46 (0.001)	0.24 (0.113)	0.46 (0.002)	0.12 (0.427)	0.22 (0.142)
p)	0.40 (0.028)	0.33 (0.075)	0.41 (0.024)	0.03 (0.859)	-0.01 (0.973)
p)	0.37 (0.160)	-0.16 (0.565)	0.37 (0.157)	0.15 (0.582)	0.09 (0.739)
n)	-0.29 (0.055)	-0.38 (0.010)	-0.29 (0.051)	0.04 (0.820)	0.09 (0.578)
ll)	-0.36 (0.186)	0.01 (0.969)	-0.27 (0.332)	-0.32 (0.242)	-0.22 (0.432)
g)	0.58 (0.134)	-0.42 (0.297)	0.58 (0.134)	-0.25 (0.552)	0.41 (0.310)
	0.07 (0.860)	-0.14 (0.720)	-0.13 (0.724)	0.14 (0.724)	0.41 (0.272)
	-0.34 (0.021)	0.32 (0.030)	-0.38 (0.010)	0.00 (0.989)	0.02 (0.908)
	0.35 (0.018)	0.08 (0.609)	0.32 (0.027)	0.12 (0.451)	0.13 (0.395)
	0.31 (0.037)	0.14 (0.377)	0.28 (0.061)	0.17 (0.253)	0.30 (0.047)
	0.03 (0.022)	0.49 (0.001)	0.33 (0.025)	0.10 (0.502)	0.09 (0.538)
	0.05 (0.741)	-0.04 (0.779)	0.07 (0.647)	-0.05 (0.735)	0.11 (0.483)
	0.40 (0.007)	0.10 (0.522)	0.36 (0.015)	0.21 (0.165)	0.25 (0.102)

equivalent diopter; LogMAR BCVA= logarithm of minimum angle of resolution best-corrected visual

opter of spherical power; DC= diopter of spherical power; GHT= mean graft-host touch; Pm= total

malapposition proportion; Sm= size of malapposition; Tg= junctional graft thickness; Th= junctional

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Spearman correlations were used.

TABLE 4. Linear Regression Analysis of Visual Outcomes

Abbreviations

PK: Penetrating keratoplasty; DALK: Deep anterior lamellar keratoplasty; AS-OCT:

Dependent variable (Y)	Independent variable (X)	F (*P*)	Constant α (*P*)	Regression coefficient β (*P*)	Linear regression equation
SE (diopter)	F (step)	12.705 (0.001)	-5.850 (<.0001)	6.851 (.001)	Y=6.851X-5.850
	F (graft step)	8.552 (0.005)	-4.708 (<.0001)	5.428 (0.005)	Y=5.428X-4.708
	GHT	5.782 (0.021)	10.391 (0.069)	-0.019 (0.021)	Y=-0.019X+10.391
	Pm	6.001 (0.018)	-5.912 (<.0001)	5.164 (0.018)	Y=5.164X-5.912
	Sm	4.617 (0.037)	-5.046 (<.0001)	0.018 (0.037)	Y=0.018X-5.046
	Tg	5.631 (0.022)	-15.588 (0.006)	0.019 (0.022)	Y=0.019X-15.588
	|Tg-Th|	8.064 (0.007)	-5.501 (<.0001)	0.031 (0.007)	Y=0.031X-5.501
LogMAR BCVA	F (protrution)	3.937 (0.054)	--	--	--
	GHT	5.015 (0.030)	-0.312 (0.309)	0.001 (0.030)	Y=0.001X-0.312
	Tg	13.215 (0.001)	-0.615 (0.028)	0.001 (0.001)	Y=0.001X-0.615
DS (diopter)	F (step)	12.384 (0.001)	-3.459 (0.001)	6.319 (0.001)	Y=6.319X-3.459
	F (graft step)	8.597 (0.005)	-2.427 (0.005)	5.067 (0.005)	Y=5.067X-2.427
	GHT	7.284 (0.010)	12.948	-0.02 (0.010)	Y=-0.02X+12.948

			(0.015)		
	Pm	5.209 (0.027)	-3.374 (0.013)	4.518 (0.027)	Y=4.518X-3.374
	Tg	5.395 (0.025)	-12.336 (0.018)	0.017 (0.025)	Y=0.017X-12.336
	|Tg-Th|	6.491 (0.015)	-2.564 (0.009)	0.027 (0.015)	Y=0.027X-2.564
Astig value (diopter)	Sm	4.174 (0.047)	-1.598 (0.176)	0.017 (0.047)	Y=0.017X-1.598

SE= spherical equivalent diopter; LogMAR BCVA= logarithm of minimum angle of resolution best-corrected visual acuity; DS= diopter of spherical power; GHT= mean graft-host touch; Pm= total prevalence of malapposition proportion; Sm= size of malapposition; Tg= junctional graft thickness

Anterior-segment optical coherence tomography; GHI: Graft-host interfaces; LogMAR BCVA: Logarithm of minimum angle of resolution best-corrected visual acuity; SE: Spherical equivalent diopter; DS: Diopter of spherical power; DC: Diopter of cylindrical power; GHT: Graft-host touch; Tg: Junctional graft thickness; Th: Junctional host thickness; Fm: frequency of malapposition; F(step): Frequency of step; F(graft step): Frequency of graft step; Pm: Total prevalence of malapposition proportion; Sm: Size of malapposition; |Tg-Th|: Disparity between junctional graft and host thickness; IOP: intraocular pressure; DM: Descemet’s membrane; SD: Standard deviation

Figures

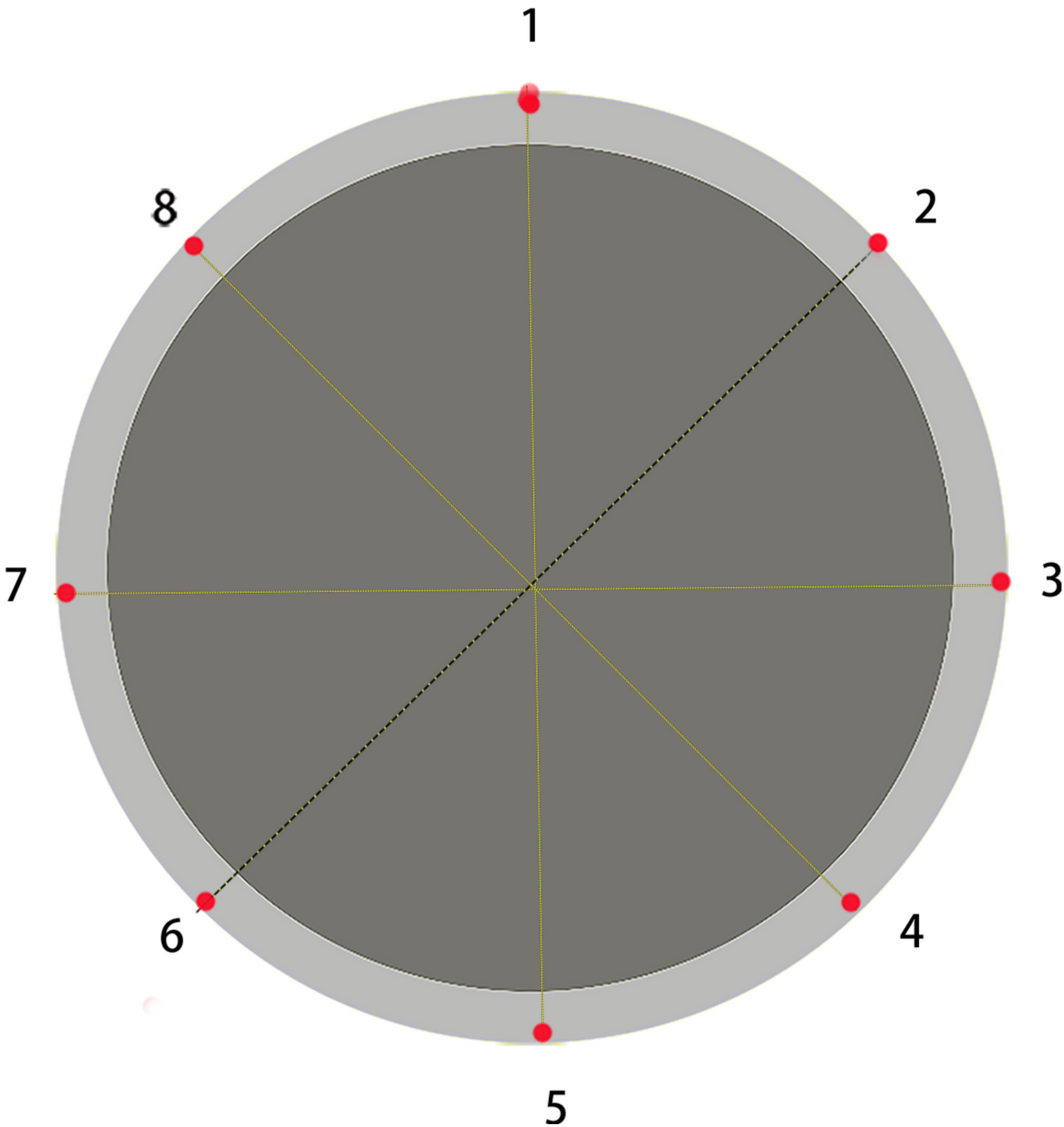

Figure 1

Schematic diagram depicting the 8 corneal GHI (red spots) sections in font view.

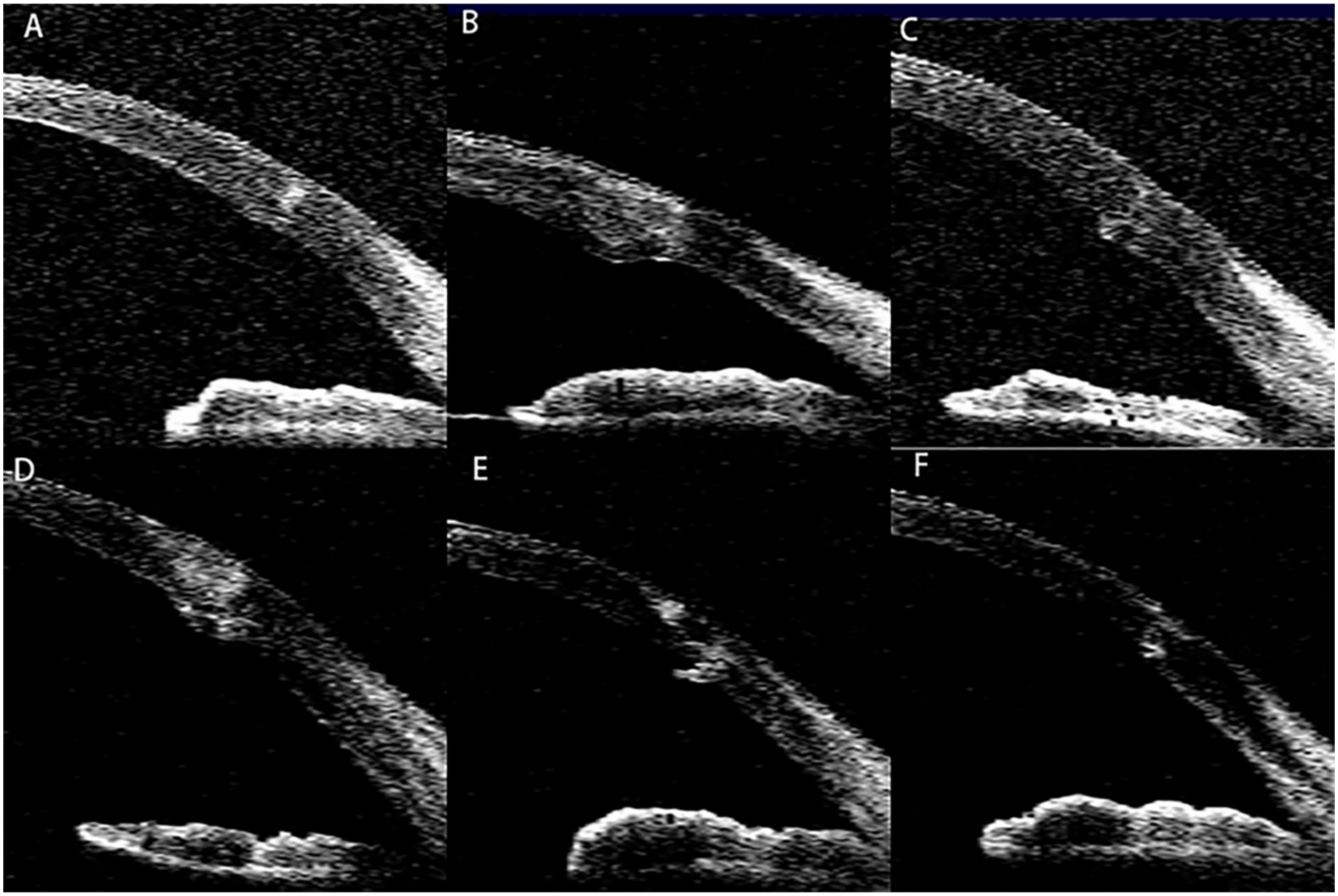

Figure 2

Graft-host Alignment Patterns Using AS-OCT. (A) well-apposed junction; (B) graft step pattern; (C) host step pattern; (D) hill pattern; (E) tag pattern; (F) gape pattern.

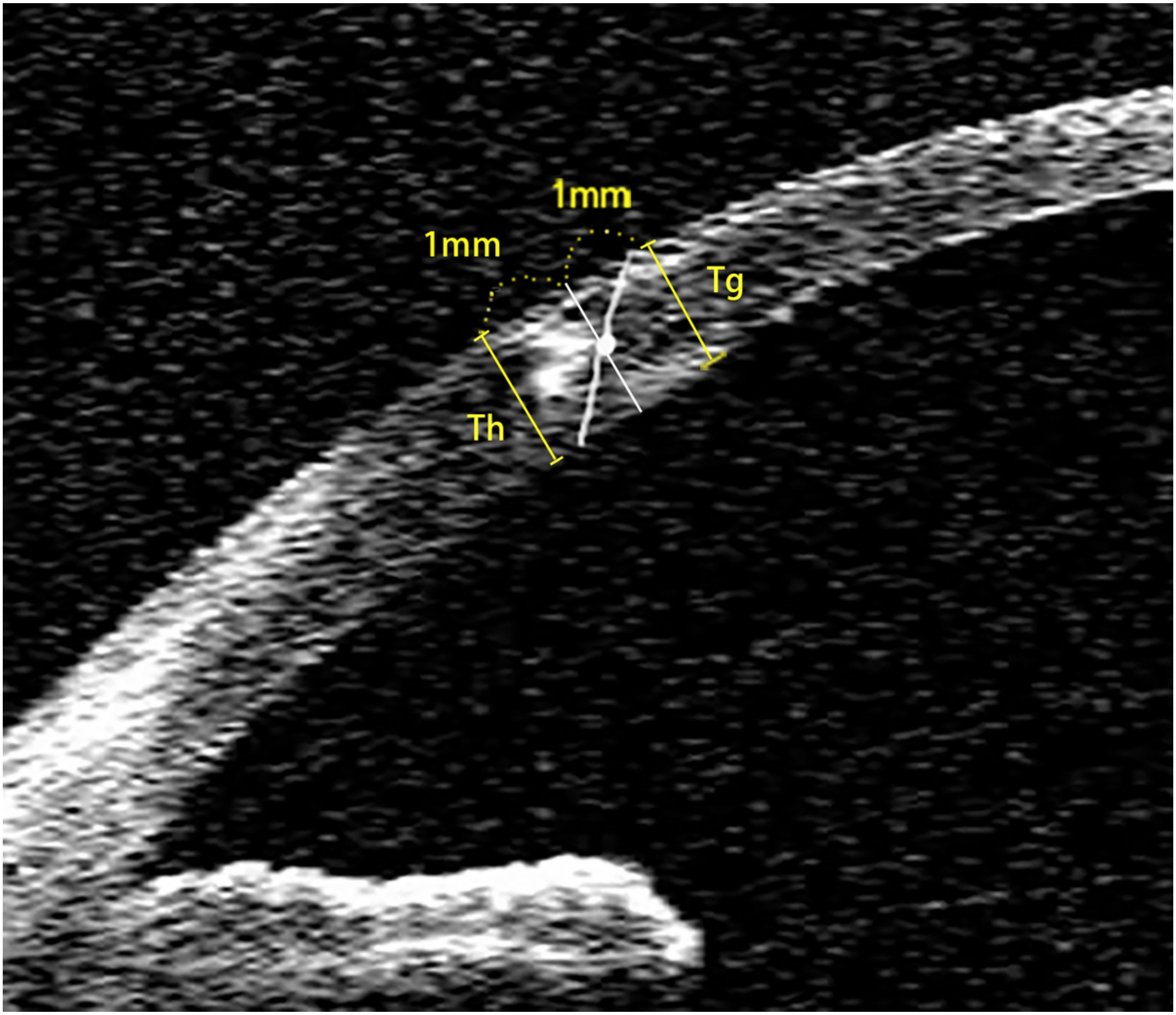

Figure 3

Measurements of graft and host thickness at the corneal wound interface.