Scleral Lens–Induced Corneal Edema after Penetrating Keratoplasty

Mukesh Kumar, MOpt,1* Rohit Shetty, PhD,1 Pooja Khamar, MS, PhD,1 and Stephen J. Vincent, PhD, FAAO2

SIGNIFICANCE: Modern highly oxygen-permeable nonfenestrated scleral lenses induce approximately 1 to 2% corneal edema after short periods of lens wear in healthy individuals. This study investigated the magnitude and regional variation in scleral lens-induced central corneal edema after penetrating keratoplasty.

PURPOSE: The purpose of this study was to examine the magnitude and regional variation in corneal edema after a short period of scleral lens wear in post–penetrating keratoplasty eyes and a control group of eyes with healthy corneas.

METHODS: Nine post–penetrating keratoplasty eyes (nine participants; mean age, 32 years) were fitted with highly oxygen-permeable nonfenestrated scleral lenses (Dk 100 × 10−11 cm3 O2 (cm)/(l s) (mmHg)). Central corneal thickness was measured using Scheimpflug imaging before lens insertion and immediately after lens removal (mean wearing time, 6.2 hours). Corneal edema was quantified across the central 6 mm and compared with data obtained from a historical control group of healthy eyes using a similar experimental paradigm.

RESULTS: Post–penetrating keratoplasty eyes exhibited significant corneal edema after lens wear (2.99% [95% confidence interval, 1.13 to 4.85%]) averaged across the central 6 mm (P = .006) and regional variations in edema (P < .001) (greater swelling toward the graft-host junction inferiorly). Compared with healthy eyes, post–penetrating keratoplasty eyes displayed a greater magnitude of corneal edema (by ~3×) and greater variability in the corneal response (by ~2.5×).

CONCLUSIONS: Scleral lens–induced central corneal edema is greater in post–penetrating keratoplasty eyes and varies regionally compared with healthy corneas after short-term wear. Lens design and fitting factors contributing to hypoxic and mechanical corneal stress should be carefully considered for all post–penetrating keratoplasty scleral lens fits to minimize potential graft rejection or failure in the longer-term.

Optom Vis Sci 2020;97:697–702. doi:10.1097/OPX.0000000000001571
Copyright © 2020 American Academy of Optometry

Optical rehabilitation after penetrating keratoplasty is the primary indication for approximately 12 to 20% of scleral lens fits.1–6 Theoretically, scleral lenses are an ideal refractive correction for the post-graft eye because they can correct a high degree of irregular corneal astigmatism, which is common after penetrating keratoplasty,5 and minimize any resultant anisometropia and aniseikonia in unilateral cases.7 Scleral lenses are also extremely stable compared with smaller diameter corneal rigid lenses and, if fitted appropriately, will vault the cornea entirely including the graft-host junction, reducing the potential for mechanical irritation and tissue inflammation during lens wear.

Although the superior stabilization and complete corneal clearance provided by scleral lenses can be particularly useful in cases of a proud or tilted graft, or an elevated graft-host junction, corneal edema related to scleral lens wear remains a significant concern because endothelial cell density decreases postoperatively. For example, previous studies have reported a decrease of 10 to 30% within first the year after surgery and up to 50% after 5 years.8,9 Consequently, persistent scleral lens–induced corneal edema, resulting from mechanical or hypoxic stimuli, may contribute to graft rejection or failure. However, despite these concerns, the majority of research investigating the corneal response to modern scleral lens wear has focused on eyes without anterior segment conditions10–14 or keratoconus.15,16 Collectively, these studies suggest that after short periods of lens wear (8 hours or less), highly oxygen-permeable scleral lenses (≥100 Dk) typically induce 1 to 2% corneal edema over the course of the day in young healthy eyes.

Several recent case series have highlighted potential corneal complications associated with scleral lens wear after penetrating keratoplasty. Guillen et al.17 observed moderate epithelial edema in a unilateral graft patient after several months of successful lens wear, which was attributed to mechanical and hypoxic factors after extended periods of wear; the lens exhibited superior central touch on the graft tissue and was relatively thick (~600-μm thickness) because of the moderate hyperopic astigmatic refractive error. This complication resolved by reducing wearing time and alleviating the corneal bearing. Transient epithelial macrocysts have also been observed in corneal grafts in association with corneal edema,18 which typically resolve shortly after lens removal, and do not appear to have any long-term adverse effects on comfort or vision. These macrocysts have been hypothesized to originate from both hypoxic and mechanical factors (negative pressure or suction forces) in combination with alterations in epithelial tissue adhesion after corneal surgery.

Scheir et al.19 also reported on 26 post–penetrating keratoplasty eyes fitted with scleral lenses, 15% of which failed, presumably because of a significantly reduced (unmeasurable) endothelial cell count. In this case series, which included other ocular conditions in addition to penetrating keratoplasty, unsuccessfully fitted eyes (50% of which were post–penetrating keratoplasty) displayed approximately 18% edema after 2 hours of lens wear. For these
unsuccessful fits, the lens oxygen permeability was either 85 or 141 Dk, the average central corneal clearance was approximately 500 μm, and the average lens thickness was 290 μm. These case series suggest that scleral lens–induced corneal edema in post–penetrating keratoplasty eyes may be due to several factors including compromised endothelial function, lens over wear, mechanical stress (lens bearing or suction forces), or hypoxic stress (a thick lens or post-lens fluid reservoir).

To date, only one study has quantified the magnitude of scleral lens–induced corneal edema in post–penetrating keratoplasty eyes (Bhattacharya and Mahadevan. Contact Lens Spectrum, October 2018). This retrospective analysis reported approximately 4% corneal swelling after 6 hours of lens wear averaged across five different corneal locations but were derived from contact A-scan ultrasound measurements. Consequently, the aim of this study was to accurately measure the regional variations in corneal edema after a short period of scleral lens wear in eyes that had undergone penetrating keratoplasty and to compare these data to a historical data set of corneal edema measured in young healthy eyes using the same instrumentation and experimental approach.

METHODS

Post–penetrating Keratoplasty Group

This study was approved by the Narayana Nethralaya Institutional Review Board and adhered to the tenets of the declaration of Helsinki. Written informed consent was obtained from all participants. An overview of the study participants is provided in Table 1. Nine participants (mean age, 32 years [95% confidence interval, 26 to 38 years]; five females and four males) were recruited, and nine eyes (six right, three left eyes) were included in the analysis. One participant had bilateral corneal grafts, but the left eye was randomly selected for inclusion in the analysis. Participants were recruited from patients who presented to the contact lens clinic for a scleral lens fitting because of reduced visual function. All participants had undergone penetrating keratoplasty (five full-thickness penetrating keratoplasty and four deep anterior lamellar keratoplasty) because of advanced keratoconus at least 2 years prior (range, 2.0 to 17.7 years) and were unsatisfied with or unable to tolerate soft or corneal rigid gas-permeable lenses.

The study was conducted on 2 days separated by 1 to 2 weeks. An ophthalmic screening examination was conducted on day 1 to ensure that participants were suitable for inclusion in the study with no contraindications to contact lens wear. Potential participants with active anterior segment disease or contraindications to contact lens wear were excluded from participation (e.g., ocular allergy or eyelid disease). Keracare (Acculens, Denver, CO) scleral diagnostic contact lenses were then used to determine the optimal fitting trial lens. These are nonfenestrated lenses made from roflufocon D (oxygen permeability, 100 Dk; center thickness, 250 μm). A trial set of 10 lenses was used with overall diameters of 15.9 and 16.4 mm, with all lenses having a standard symmetric landing zone design. The overall diameter was selected to ensure the lens extended at least 2 mm beyond the limbus. A single experienced examiner performed all lens assessments in accordance with the manufacturer’s fitting guide. Scleral lenses were inserted with preservative-free saline and sodium fluorescein, without an air bubble present, and assessed using a slit-lamp biomicroscope. The scleral lens was selected to provide approximately 250 to 300 μm of central corneal clearance. Once this central fit was achieved (based on slit lamp evaluation of the fluid reservoir relative to the center lens thickness), the lens-conjunctiva relationship was assessed using the slit lamp to ensure an appropriate fit without changes in the conjunctival vasculature. After an adequate fit was obtained, the lens was allowed to settle for 60 minutes and was reexamined using the slit lamp to check that the lens remained centered and free from air bubbles.

A second study visit was conducted 1 to 2 weeks later using the optimum fitting diagnostic scleral lens determined at the previous fitting visit. Participants who habitually wore contact lenses were advised to discontinue lens wear for at least 10 days before this study visit. Scheimpflug imaging (Pentacam HR; Oculus Optikgeräte GmbH, Wetzlar, Germany) was used to measure central corneal thickness before and immediately after a period of scleral lens wear of at least 4 hours (mean wearing time, 6.2 hours [95% confidence interval, 5.2 to 7.2 hours]; range, 4 to 8.5 hours). Three corneal pachymetry maps were obtained before and after lens wear and exported for analysis using customized software.

Healthy Control Group

To provide a comparison with the corneal swelling observed in young healthy eyes after a short period of scleral lens wear, data

| Participant | Sex | Eye | Age (y) | Graft type | Time since surgery (y) | Back vertex power (D) | Sagittal depth (mm) | Wearing time (h) | Central corneal edema (%) |
|-------------|-----|-----|---------|------------|------------------------|----------------------|-------------------|----------------|--------------------------|
| 1           | M   | R   | 29.6    | PK         | 14.1                   | −8.00                | 5.68              | 5.5            | 0.64                     |
| 2           | M   | R   | 23.8    | DALK       | 4.4                    | −12.00               | 6.30              | 4.0            | 6.25                     |
| 3           | M   | R   | 35.3    | PK         | 7.2                    | −5.00                | 5.41              | 6.5            | 0.29                     |
| 4           | M   | L   | 24.4    | DALK       | 4.0                    | −4.00                | 5.19              | 8.0            | 2.57                     |
| 5           | F   | R   | 26.1    | DALK       | 2.5                    | −4.00                | 5.19              | 5.5            | 2.61                     |
| 6           | F   | L   | 23.4    | DALK       | 2.0                    | −5.00                | 4.91              | 7.3            | 2.47                     |
| 7           | F   | L   | 31.1    | PK         | 4.5                    | −4.00                | 5.19              | 5.2            | 1.01                     |
| 8           | F   | R   | 44.0    | PK         | 5.4                    | −6.00                | 5.59              | 5.1            | 3.90                     |
| 9           | F   | R   | 48.1    | PK         | 17.7                   | −3.00                | 5.00              | 8.5            | 7.18                     |

DALK = deep anterior lamellar keratoplasty; F = female; M = male; PK = full-thickness penetrating keratoplasty.
collected in a previous study\textsuperscript{10} that used a similar repeated-measures design and included 15 young adults with healthy corneas (mean age, 22 years [95% confidence interval, 20 to 24 years]; eight females, seven males) were reanalyzed. In this study, lenses were worn on the left eye only for 8.5 hours (95% confidence interval, 8.4 to 8.6 hours) on average (range, 8.3 to 8.8 hours), and nonfennestrated lenses were made from hexafocon A material (oxygen permeability, 100 Dk; center thickness, 300 μm; diameter, 16.5 mm) with an initial central clearance of 353 μm (95% confidence interval, 287 to 419 μm) based on anterior segment optical coherence tomography. Scheimpflug imaging (Pentacam HR; Oculus) was also used to measure central corneal thickness before and immediately after scleral lens wear with five corneal pachymetry maps obtained at each time point and exported for further analysis using customized software. Previously published data from this cohort\textsuperscript{10} also accounted for the natural diurnal thinning of the cornea (using Pentacam data obtained on a separate day without lens wear to map the natural corneal diurnal variation). However, the current reanalysis of this data only considered the change in corneal thickness immediately after lens removal with no correction for diurnal fluctuations.

Data Analysis

Raw corneal pachymetry data from each participant, at each time point (pre–lens wear and post–lens wear), were exported for further analysis. All left eye maps were rotated around the vertical midline so that all data were oriented as right eyes. Using custom written software, the series of maps obtained for each participant were averaged for each time point. The averaged pre–lens wear pachymetry map for each individual was then subtracted from the averaged post–lens wear pachymetry map to generate thickness difference maps. Statistical analyses were restricted to data from within the central 6 mm of each scan to ensure that any areas of missing data associated with upper eyelid position were excluded.

Statistical analyses were performed using SPSS version 25 (IBM Corp., Armonk, NY). For both the post–penetrating keratoplasty and healthy control data sets, repeated-measures ANOVA was used to examine the effect of time (pre–lens wear vs. post–lens wear), region (six 0.5-mm annuli from the center to the periphery with radii of 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 mm), and zone (eight 45° zones, 0 to 45°, 45 to 90°, 90 to 135°, 135 to 180°, 180 to 225°, 225 to 270°, 270 to 315°, and 315 to 360°). Fig. 1 displays the regions and zones considered in the analyses. The region by zone interaction was also examined using a repeated-measures ANOVA after calculating the change in corneal thickness over time (post–lens wear minus pre–lens wear thickness). Bonferroni-corrected post hoc comparisons were used to investigate any significant main effects or interactions. Normality was assessed using the Kolmogorov-Smirnov test, and degrees of freedom were adjusted using the Greenhouse-Geisser correction to prevent type I errors if the assumption of sphericity was violated.

RESULTS

Post–penetrating Keratoplasty Group

As anticipated, corneal thickness significantly increased after lens wear, by 2.99 (95% confidence interval, 1.13 to 4.85%) averaged across the central 6 mm (F\textsubscript{15,1} = 13.72, P = .006). Fig. 2 displays the average corneal pachymetry measured across the central 6 mm before lens wear, after lens removal, and the difference (post–lens wear minus pre–lens wear). No statistically significant variation in corneal edema was observed between zones when averaged across regions (F\textsubscript{9,9} = 1.99, P = .07) or between regions when averaged across zones (F\textsubscript{9,9} = 2.04, P = .09). A significant region by zone interaction was observed (F\textsubscript{9,35} = 2.59, P = .001), indicating that, within zones 5 (180 to 225°), 6 (225 to 270°), and 8 (315 to 360°), the magnitude of corneal edema varied across the regions (typically more edema in the further from the center of the cornea). The significant post hoc comparisons for the zone by region interaction are displayed in Table 2.

Healthy Control Group

Corneal swelling was observed after lens wear (0.88% [95% confidence interval, 0.20 to 1.56%], F\textsubscript{15,1} = 7.97, P = .01). However, there was no main effect of region (F\textsubscript{15,5} = 0.72, P = .61), zone (F\textsubscript{15,7} = 0.68, P = .69), or a region by zone interaction (F\textsubscript{15,35} = 0.60, P = .97), indicating a relatively uniform change in corneal thickness across the central 6 mm. Fig. 3 displays the average corneal pachymetry difference maps for the healthy control group and the post–penetrating keratoplasty group to highlight differences in the magnitude and uniformity of the corneal edema between the two cohorts. Both the magnitude (mean) and variability (standard deviation) of corneal edema in the post–penetrating keratoplasty group were greater than those of the control group as expected. Because the confidence interval is influenced by the sample size, the mean corneal edema and 95% confidence interval were also calculated from a random selection of nine eyes from the healthy control group, which gave a mean ± standard deviation corneal swelling of 0.89 (95% confidence interval, 0.16 to 1.62%) across the central 6 mm. Based on these data, the post–penetrating keratoplasty group exhibited approximately three times more corneal edema.
edema (based on the mean) and approximately 2.5 times more variability (confidence interval) compared with the control group.

DISCUSSION

This is the first study to provide a detailed examination of the central corneal response to short-term scleral lens wear after penetrating keratoplasty. The main findings from this experiment were that post-penetrating keratoplasty eyes exhibited significant corneal edema (2.99% [95% confidence interval, 1.13 to 4.85%] averaged across the central 6 mm), which varied regionally. In particular, in the majority of inferior corneal regions examined (5, 6, and 8), the magnitude of edema was typically greater further from the center of the cornea (i.e., toward the graft-host junction) (Table 2). In comparison with the control group of young healthy eyes, post-penetrating keratoplasty eyes exhibited approximately three times more edema and approximately 2.5 times more variability in response (after accounting for differences in sample sizes).

TABLE 2. The mean difference in corneal edema and 95% confidence interval for statistically significant Bonferroni-corrected post hoc comparisons from the repeated-measures ANOVA (zone by region interaction) for the post-penetrating keratoplasty group

| Zone | Region (1) | 1     | 2     | 3     | 4     | 5     |
|------|------------|-------|-------|-------|-------|-------|
|      |            |       |       |       |       |       |
| 5    | 2          | 0.40  | (−0.36 to 1.16) |       |       |       |
| 180–225° | 3       | 0.86  | (−0.37 to 2.09) | 0.46  | (−0.02 to 0.93) |       |
|       | 4          | 1.32  | (−0.02 to 2.66) | 0.92  | (0.29–1.54)† | 0.46  | (0.22–0.69)† |
| Inferotemporal | 5      | 1.66  | (0.43–2.89)* | 1.26  | (0.58–1.93)† | 0.80  | (0.25–1.35)† | 0.34  | (−0.05 to 0.73) |       |
|       | 6          | 1.90  | (0.73–3.08)† | 1.50  | (0.59–2.41)† | 1.04  | (0.07–2.02)† | 0.59  | (−0.29 to 1.47) | 0.25  | (−0.27 to 0.76) |
| 6    | 2          | 0.43  | (−0.24 to 1.10) |       |       |       |
| 225–270° | 3       | 1.06  | (−0.28 to 2.40) | 0.63  | (−0.06 to 1.33) |       |
|       | 4          | 1.82  | (−0.17 to 3.82) | 1.39  | (0.01–2.78)* | 0.76  | (0.05–1.47)* |
| Inferotemporal | 5      | 2.54  | (0.00–5.08) | 2.11  | (0.16–4.07)* | 1.48  | (0.17–2.79)* | 0.72  | (0.09–1.35)* |       |
|       | 6          | 2.93  | (0.04–5.82)* | 2.50  | (0.17–4.83)* | 1.87  | (0.13–3.60)* | 1.11  | (−0.05 to 2.27) | 0.39  | (−0.24 to 1.02) |
| 8    | 2          | −0.07 | (−0.46 to 0.32) |       |       |       |
| 315–360° | 3       | 0.11  | (−0.38 to 0.61) | 0.18  | (−0.07 to 0.43) |       |
|       | 4          | 0.61  | (−0.04 to 1.26) | 0.68  | (0.04–1.32)* | 0.50  | (0.06–0.94)* |
| Inferonasal | 5      | 1.34  | (0.28–2.39)* | 1.41  | (0.27–2.54)* | 1.22  | (0.18–1.27)* | 0.73  | (0.18–1.27)* |       |
|       | 6          | 1.93  | (0.44–3.42)* | 2.00  | (0.39–3.62)* | 1.82  | (0.34–3.31)* | 1.32  | (0.23–2.42)* | 0.60  | (0.01–1.19)* |

Bold font designates significance. *P < .05. †P < .01.
A previous retrospective analysis (Bhattacharya and Mahadevan. Contact Lens Spectrum, October 2018) of scleral lens–induced corneal edema after penetrating keratoplasty used a very similar sample (10 eyes from 9 patients; mean age, 34 years) but a less oxygen-permeable scleral lens material (oxygen permeability, 85 Dk; initial clearance, 200 to 300 μm). Averaged across five corneal regions examined, 4% edema was observed after 6 hours of lens wear: central, 1.8%; superior, 9.3%; nasal, 3.6%; inferior, 6.6%; and temporal, −1.0% (i.e., 1.0% thinning temporally). This overall magnitude of change (4%) is similar to that observed in the current study (2.99% [95% confidence interval, 1.13 to 4.85%]), with the level of edema slightly less in the current study potentially because of the lens material with higher oxygen permeability (or possibly differences in corneal endothelial function). Regional variations were substantially different compared with the current study, and this may be related to the use of an ultrasonic pachymeter in Bhattacharya and Mahadevan’s study; during the time taken to capture 10 repeated ultrasound measurements per region examined, the cornea would have deswelled to some extent. Contact ultrasound also requires the use of a topical anesthetic, which can influence corneal thickness,20 and measuring the exact same corneal location before and after lens wear would be extremely difficult and examiner dependent. Despite these experimental differences, both studies indicate that scleral lens–induced corneal edema can vary substantially regionally, consistent with clinical observations that patches of edema are common in the post-graft cornea and the predominant complications that arise when fitting contact lenses to these eyes are neovascularization and edema at the graft-host junction.21

The major limitations of the current study include the small sample size, which makes it difficult to generalize these results to all post–penetrating keratoplasty eyes. A standard spherical landing zone was also used for all participants. If significant tear exchange occurred during lens wear because of landing zone misalignment, this may contribute to an underestimation of the true extent of corneal edema in an optimally aligned lens that creates a sealed system. Endothelial cell density was not measured in these participants and would provide further insights to the corneal response after scleral lens wear; however, endothelial function has long been linked with corneal edema, and Smith et al.22 have established a strong negative correlation between endothelial cell count and corneal edema after overnight scleral lens wear in healthy eyes. The use of a historical healthy control group with a range of uncontrolled experimental variables is also a potential limitation (e.g., differences in participant age and lens parameters) but does provide a reliable comparison across the central 6 mm because of the use of the same instrument and analysis procedures. Although the post–penetrating keratoplasty group and the control group had different mean wearing times (6.2 hours compared with 8.5 hours, respectively), scleral lens–induced corneal edema appears to plateau after approximately 90 minutes of lens wear, at least in healthy eyes.12 In addition, there was no association observed between wearing time and central edema in the post–penetrating keratoplasty group (r = 0.12, P = .78). Other differences between the two groups include the scleral lens thickness and the initial thickness of the post-lens fluid reservoir. Using a resistance in series approach to estimate the oxygen transmissibility of the combined scleral lens and post-lens fluid reservoir for each group, assuming an oxygen permeability of 80 for the fluid reservoir,23 and using the following parameters: for the post–penetrating keratoplasty group, central lens thickness of 250 μm; lens oxygen permeability, 100; and initial apical clearance, 275 μm; and for the control group, central lens thickness, 300 μm; lens oxygen permeability, 100; and initial apical clearance, 353 μm provide an oxygen transmissibility of 16.8 Dk/t for the post–penetrating keratoplasty group and 13.5 Dk/t for the control group. Given that the oxygen transmissibility of the scleral system was slightly greater for the post–penetrating keratoplasty group compared with the control group, the changes observed in the post–penetrating keratoplasty group can likely be attributed to the ocular condition (i.e., endothelial function) rather than any differences in the scleral lens parameters, wearing time, or fit between the cohorts.

Whereas the current study examined the short-term response to lens wear after penetrating keratoplasty, others have investigated...
scleral lens success over longer periods of lens wear. Severinsky et al. retrospectively reviewed clinical records of 36 post-penetrating keratoplasty eyes fitted with scleral lenses (oxygen permeability, 125 Dk; mean center thickness, 300 μm; and target settled central clearance, 200 to 300 μm) with a mean follow-up time of 5 years. More than 10 hours of lens wear per day was achieved in 75% of eyes, and 6 to 10 hours in 18%. During this follow-up period, 30% of eyes had at least one episode of graft rejection, and corneal edema was observed in 6% of eyes; however, only four eyes ultimately ceased lens wear because of corneal decompensation, graft rejection, or end-stage glaucoma. Clearly, chronic mechanical or hypoxic stress may contribute to graft failure; however, the majority of these patients had successful visual rehabilitation with reasonable wearing times. The authors instructed their patients to remove their scleral lenses every 6 hours to increase oxygen delivery to the cornea and remove the stagnant post-lens fluid reservoir, which may have contributed to their relatively low failure rate. Other retrospective analyses examining scleral lens wear after penetrating keratoplasty report a dropout rate up to 35%2,5,25; however, this often includes discontinuation of lens wear due to handling issues rather than corneal complications alone.

Although the magnitude of scleral lens-induced corneal edema observed in post-penetrating keratoplasty eyes was substantially greater than the control eyes, practitioners must consider the risk-benefit ratio in such cases (i.e., long-term complications associated with corneal edema versus potential visual gains and improvement in quality of life). Practitioners should aim to minimize any potential hypoxic and mechanical corneal stress when fitting post-penetrating keratoplasty eyes with scleral lenses. This may be achieved by increasing the scleral lens material’s oxygen permeability (however, minimal benefits are seen in healthy eyes increasing beyond 100 Dk),26 minimizing lens thickness (although this is influenced by the required back vertex power and can increase lens flexure),27,28 and reducing the thickness of the post-lens fluid reservoir.29 Alternatively, reducing wearing time or incorporating a period of lens removal throughout the day may reduce the magnitude of corneal edema and related visual sequelae. Fenestrated scleral lenses may also be a viable option when fitting post-penetrating keratoplasty eyes because of their lower corneal clearance, altered tear exchange, and reduced suction forces. In conclusion, post-penetrating keratoplasty eyes fitted with scleral lenses exhibit more corneal edema and greater variability in the corneal response compared with healthy eyes after a short period of lens wear. Further longer-term studies are required to determine corneal characteristics of post-penetrating keratoplasty eyes that may potentially contraindicate scleral lens wear.

REFERENCES

1. Pullum KW, Buckley RJ. A Study of 530 Patients Referred for Rigid Gas Permeable Scleral Contact Lens Assessment. Cornea 1997;16:612–22.
2. Tan D, Pullum K, Buckley R. Medical Applications of Scleral Contact Lenses: 1. A Retrospective Analysis of 343 Cases. Cornea 1995;14:121–9.
3. Visser ES, Van der Linden BJ, Otten HM, et al. Medical Applications and Outcomes of Bitangential Scleral Lenses. Optom Vis Sci 2013;90:1078–85.
4. Visser ES, Visser R, Van Lier HJ, et al. Modern Scleral Lenses Part I: Clinical Features. Eye Contact Lens 2007;33:13–20.
5. Pullum KW, Whiting MA, Buckley RJ. Scleral Contact Lenses: The Expanding Role. Cornea 2005;24:269–77.
6. Henein C, Nanavaty MA. Systematic Review Comparing Penetrating Keratoplasty and Deep Anterior Lamellar Keratoplasty for Management of Keratoconus. Cont Lens Anterior Eye 2017;40:3–14.
7. Vincent SJ, Fadel D. Optical Considerations for Scleral Contact Lenses: A Review. Cont Lens Anterior Eye 2019;42:598–613.
8. Culbertson WW, Abbott RL, Forster RK. Endothelial Cell Loss in Penetrating Keratoplasty. Ophthalmology 1982;89:600–4.
9. Lass JH, Benetz BA, Gal RL, et al. Donor Age and Factors Related to Endothelial Cell Loss 10 Years After Penetrating Keratoplasty: Specular Microscopy Ancillary Study. Ophthalmology 2013;120:2428–35.
10. Vincent SJ, Alonso-Caneiro D, Collins MJ, et al. Hypoxic Corneal Changes Following Eight Hours of Scleral Contact Lens Wear. Optom Vis Sci 2016;93:293–9.
11. Lafosse E, Romin DM, Esteve-Taboada JJ, et al. Comparison of the Influence of Corneo-scleral and Scleral Lenses on Ocular Surface and Tear Film Metrics in a Presbyopic Population. Cont Lens Anterior Eye 2018;41:122–7.
12. Vincent SJ, Alonso-Caneiro D, Collins MJ. The Time Course and Nature of Corneal Oedema during Sealed Minisceral Contact Lens Wear. Cont Lens Anterior Eye 2019;42:49–54.
13. Tan B, Tse V, Hyun Y, et al. Effects of Scleral-lens Oxygen Transmissibility on Corneal Thickness: A Pilot Study. Cont Lens Anterior Eye 2019;42:366–72.
14. Vincent SJ, Alonso-Caneiro D, Collins MJ. Corneal Changes Following Short-term Minisceral Contact Lens Wear. Cont Lens Anterior Eye 2014;37:461–8.
15. Esen F, Toker E. Influence of Apical Clearance on Mini-scleral Lens Settling, Clinical Performance, and Corneal Thickness Changes. Eye Contact Lens 2017;43:230–5.
16. Soeters N, Visser ES, Imhof SM, et al. Scleral Lens Influence on Corneal Curvature and Pachymetry in Keratoconus Patients. Cont Lens Anterior Eye 2015;38:294–7.
17. Guillon NC, Godfrey A, Hammond DS. Corneal Oedema in a Unilateral Corneal Graft Patient Induced by High Dk Mini-scleral Contact Lens. Cont Lens Anterior Eye 2018;41:458–62.
18. Nguyen LT, Yang D, Vien L. Case Series: Corneal Epithelial Macrocysts in Scleral Contact Lenses Post-penetrating Keratoplasty. Optom Vis Sci 2018;95:616–20.
19. Scheer MJ, Ibrahim K, Winokur J, et al. Treatment Limitations with PROSE (Prosthetic Replacement of the Ocular Surface Ecosystem): One Centers Experience. Eye Contact Lens 2019;45:315–7.
20. Fernandez-Garcia P, Cerviño A, Quiles-Guiñuau L, et al. Corneal Thickness Differences between Sexes After Oxybuprocaine Eye Drops. Optom Vis Sci 2015;92:89–94.
21. Daniel R. Fitting Contact Lenses After Keratoplasty. Br J Ophthalmol 1976;60:263–5.
22. Smith GT, Mireskandari K, Pullum KW. Corneal Swelling with Overnight Wear of Scleral Contact Lenses. Cornea 2004;23:29–34.
23. Michaud L, van der Worp E, Braezaau D, et al. Predicting Estimates of Oxygen Transmissibility for Scleral Lenses. Cont Lens Anterior Eye 2012;35:266–71.
24. Severinsky B, Behrman S, Frucht-Pery J, et al. Scleral Contact Lenses for Visual Rehabilitation After Penetrating Keratoplasty: Long Term Outcomes. Cont Lens Anterior Eye 2014;37:196–202.
25. Ortenberg I, Behrman S, Garaisy W, et al. Wearing Time as a Measure of Success of Scleral Lenses for Patients with Irregular Astigmatism. Eye Contact Lens 2013;39:381–4.
26. Dhallu SK, Huarte ST, Bilkhu PS, et al. Effect of Scleral Lenses Oxygen Permeability on Corneal Physiology. Optom Vis Sci 2020;97:669–75.
27. Vincent SJ, Alonso-Caneiro D, Kricancic H, et al. Scleral Lens Thickness Profiles: The Relationship between Average and Centre Lens Thickness. Cont Lens Anterior Eye 2019;42:55–62.
28. Vincent SJ, Kowalski LK, Alonso-Caneiro D, et al. The Influence of Centre Thickness on Minisceral Lens Flexure. Cont Lens Anterior Eye 2019;42:63–9.
29. Fisher D, Collins MJ, Vincent SJ. Fluid Reservoir Thickness and Corneal Edema during Open-eye Scleral Lens Wear. Optom Vis Sci 2020;97:683–9.