Considerations in Corneal Transplantation and Impact on Contact Lens Fitting

Loretta Szczotka-Flynn OD, PhD
Australian Graft Registry

trends in keratoplasty techniques
Full Thickness

PK

Slide courtesy of George Rossenwasser MD
Partial Thickness

DALK

Slide courtesy of George Rossenwasser MD
Advantages of DALK over PK

• Retained Recipient Endothelium: no late endothelial cell loss
• Safer procedure: no open sky
• No endothelial rejection
• Patient off steroids in matter of weeks, not years
• Sutures can be removed in only weeks after surgery
• Less risk of rupture in future
• Especially great procedure for Atopic pts, Downs syndrome pts, vascularized recipient rim eyes
Disadvantages of DALK to PK

• Less percentage of eyes attain BCVA of 20/20 with DALK than PK eyes, but an equal percentage of 20/25
• DALK is much more technically demanding than PK and takes more O.R. time
• Graft failure rates the same between DALK and PK, i.e. no advantage
Epithelial Rejection

- May look like post-EKC keratitis

S/P DALK
In our practice, DALK is rare

• In specialty contact lens practices, KC patients are retained in contact lenses until very advanced disease
  • Cornea is thinned, scarred prior to transplant
  • Hydrops with residual scarring which dictates PK
• Usually prevents successful DALK, therefore PK is still usually the required procedure
Figure 2. Kaplan-Meier survival plots of observed penetrating corneal grafts (penetrating) and deep anterior lamellar keratoplasty (DALK) procedures performed from 1996 through 2013 for keratoconus. The numbers on the plot represent the number of grafts at risk in each stratum. The differences between the curves are significant at $P<0.001$ (log-rank test). Penetrating grafts for keratoconus fared significantly better than DALK procedures for the same indication over the same era.
Endothelial Keratoplasty: Multiple names and acronyms

- PLK: Posterior Lamellar Keratoplasty (Melles)
- DLEK: Deep Lamellar Endothelial Keratoplasty (Terry)
- DSEK: Descemets Stripping Endothelial Keratoplasty (Price)
- DSAEK: Descemets Stripping with Automated Endothelial Keratoplasty (Gorovoy)
- DMEK: Descemets Membrane Endothelial Keratoplasty (Melles)
- DMAEK: Descemets Membrane Automated Endothelial Keratoplasty (Price)
DLEK/DSEK/DSAEEK
-variations on a theme

DLEK: Pocket dissected in corneal stroma – Bed stromal fibers exposed

DSEK/DSAEEK: No pocket or dissection
Smooth recipient bed

Slide courtesy of Mark Terry MD
Interface fluid resolves without intervention

1 day post-DSAEK
UCVA=20/200

1 week post-DSAEK
UCVA=20/200

3 weeks post-DSAEK
UCVA=20/100

2 months post-DSAEK
+1.25 + 1.00 x 25 = 20/40
UCVA=20/60

Slide courtesy of Mark Terry MD
EK v.s. Conventional PK
Australian Graft Registry

• 2012; Australian Graft registry data published their annual report
  • 8 year follow-up data on PK and EK for pseudophakic bullous keratopathy or FECD.
• Graft survival for PK:
  • 94% at one year, 88% at two years, 74% at four years, and 51% at six years.
• Graft survival EK:
  • 77% at one year and 70% at two years.
• Mean and median survival:
  • PK
    • Mean 63.51 months, median 84 months (seven years).
  • EK
    • Mean 27.60 months, median 38 months (3.2 years)
Australian Graft Registry
EK vs PK graft survival
Better one, or better two?

Slide courtesy of George Rossenwasser MD
EK vs PK

- Cochrane review Dec 2014:
- No difference in best corrected visual acuity (BCVA)
- Irregular astigmatism was worse in PK
- Endothelial cell loss greater following EK
  - EK had 50% of ECD compared to PKP at 12 months
- DMEK VA potentially best (80% better than 20/25 at 1 year, Price group)
- Adverse Events:
  - graft dislocation, acute IOP elevation, primary donor failure more common in EK
  - wound and suture-related problems more common in PK
  - no important difference in rate of endothelial rejection episodes between groups
Corneal Endothelial Rejection

- (Ali) Khoudadoust line
- Donor class I and II MHC Ag +/- minor
- Contact with T-cell
- Macrophages (eg Langerhans cells) present Ag
- Inflammatory cells attack the tissue
- KP on the donor, not the recipient

Slide courtesy of George Rossenwasser MD
NIH Funded Large Scale Studies on Corneal Transplantation

• Collaborative Corneal Transplant Studies (CCTS)
• Cornea Donor Study (CDS)
• Corneal Preservation Time Study (CPTS)

• Collectively explored in association with graft success:
  • Tissue/histocompatibility matching (CCTS)
  • ABO blood type matching (CDS)
  • Donor age (CDS)
  • Donor Preservation Time (CPTS)
Cornea Preservation Time Study (CPTS): Multi-Center Prospective Clinical Trial following DSAEK

• NEI grant support: U10EY012358 and U10EY020798
CPTS Organization

- CWRU
  - Jonathan Lass MD (Study Chair)
  - Loretta Szczotka OD, PhD (Director, Coordinating Center)
  - Beth Ann Benetz, MA (Director, Cornea Image Analysis Reading Center)
- Jaeb Center for Health Research
  - Allison Ayala MS, Director Data Management and Analysis Center
  - Roy Beck MD, PhD
  - Robin Gal MSPH
- National Eye Institute
  - Maryann Redford DDS, MPH
Cornea Preservation Time Study Clinical Sites
US surgeons reluctant to use donor tissue beyond 7-8 days from death to surgery

Limited clinical studies in the United States using donor corneas for PK or EK with extended time out to FDA-approved time in storage of 14 days for Optisol GS at 4°C and none for recently released Life 4°C

Excellent, but uncontrolled, experience with exported tissue internationally with use of tissue beyond 7 days
Preservation Time
Domestic vs International

![Histogram showing preservation time for domestic and international cases. The x-axis represents days from preservation to surgery, and the y-axis represents the percent of cases. The bars are colored orange for domestic (N=15972) and blue for international (N=2121).]
Why Cornea Preservation Time and a multicenter prospective randomized clinical trial: Threats to the Donor Pool

- Increased demand:
  - Aging population
  - Increasing numbers of Fuchs’ dystrophy cases being operated on at earlier stage with EK
- Loss of younger donors: restrictions on coroners cases, social history restrictions
- Donor tissue loss with tissue preparation for EK (DSAEK, DMAEK, DMEK)
- Risks to the donor pool from emerging infection (e.g. West Nile Virus)
- Greater regulations and need for more extensive and time consuming testing requirements related to increasingly impaired donor pool (Van Meter et al. *Int J Eye Banking 2013*)
Endothelial keratoplasty growth in the United States but no multi-center analysis of performance and factors for success

- Nearly quadruple growth in the United States since 2006
- Represents 38% of all keratoplasties and 83% of keratoplasties performed for endothelial failure (34,874 cases)
- Data on graft success and cell loss restricted to single site, high volume surgeons
- No multi-center studies on performance and comparison of techniques, complications and postop management on graft success and cell loss

EBAA Statistical Report 2014

CPTS with secondary analyses can get us the data
Cornea Preservation Time Study
Objectives

• To determine if the 3-year graft failure rate following DSAEK performed with donor corneas with a preservation time of 8 to 14 days is non-inferior to the failure rate when donor corneas with a preservation time of 7 or fewer days are used.

• To determine if the central corneal endothelial cell density 3 years after DSAEK is related to preservation time.

• To evaluate donor, recipient, operative and postoperative factors on graft failure and endothelial cell density three years following DSAEK.
Cornea Preservation Time
Advantages of extending beyond 7-8 days

- Improve efficiency of tissue evaluation and distribution and reduce need for export
- Change attitudes about longer preservation time among surgeons and patients
- Meet anticipated greater demand for tissue with an aging population
- Respond to future threats to the donor pool related to increase domestic demand and emerging infections
Cornea Preservation Time Study (CPTS)
Donor criteria

- Any FDA-approved intermediate storage medium up to 14 days at 4°C (Optisol GS, Life 4°C)
Cornea Preservation Time Study (CPTS)
Donor criteria

• Met current EBAA standards

• Donor age at death 10 to 75 years

• Corneas suitable for EK (eye bank prepared according to normal procedure for the surgeon or surgeon-prepared)

• Eye bank determined minimum ECD at time of screening of ≥ 2300 cells/mm² and no upper limit

• Death to preservation time: <20 hrs if body refrigerated or eyes on ice within 10 hours of death and ≤10 hrs if not refrigerated for both groups

• Slit lamp examination with normal endothelial appearance
Study Participant Eligibility Criteria

- Sample size: 1330 eyes followed for 3 years
- Candidate for DSAEK due to:
  - Fuchs’ Dystrophy (FECD)
  - Pseudophakic/aphakic corneal edema uncomplicated
- Between 30 - <91 years w/ minimum life expectancy of 3 years and at least one eligible eye
- DSAEK chosen as procedure to facilitate recruitment and minimize sample size
- Second eye allowed, if qualified and surgery no earlier than 6 weeks after first eye—will receive other PT donor
- DMEK not included because procedure still in evolution and limited data on dislocation and failure rate in larger surgical community
- AC IOLs, tube shunts, and other higher risk conditions (synechiae, uncontrolled glaucoma) are excluded to enable predicted failure rate influencing sample size
CPTS Corneal Recipient Stroma Clarity and Graft Failures: Primary Endpoint Measure at 3 years
Grading Scale for Endothelial Keratoplasty

Clear  Equivocal  Cloudy

Clear  Equivocal  Cloudy

Clear, Szczotka-Flynn, et al Cornea 2015
CPTS Classification for Graft Failure

Primary donor failure

Graft rejection failure

Early Failure

Non-rejection failure

Refractive/visual failure

Courtesy of George Rosenwasser and Mark Terry
CPTS Graft Rejection Classification

Definite

**Mild:** presence of one or more of the following signs:
- one to five KP
- increase in aqueous cells with less than a 10% increase in total corneal thickness ultrasonically from the previous visit

**Severe:** presence of one or more of the following signs:
- more than five KP
- cells in the stroma,
- a 10% or greater increase in total corneal thickness ultrasonically from the previous visit,
- a clinically apparent decrease in stromal clarity,
- endothelial rejection line,
- or both increased corneal thickness by 10% or greater from the previous visit and increased aqueous cells

Courtesy of M. Terry
CPTS Graft Rejection Classification Possible/Probable

- Clinically apparent stromal edema impacting stromal clarity with inflammation (keratic precipitates, aqueous cells, ciliary injection) without an endothelial rejection line in a previously clear graft
- OR any of the following:
  - Possible presence of a new KP with difficulty distinguishing between KP vs. pigment

Courtesy of A. Aldave
CPTS Secondary Measure
Central ECD at 3 years

- Obtaining screening image and ECD from eye bank but not CIARC analyzed
- Postcut image or image obtained prior to shipping for surgeon cut sent to CIARC
- Clinical sites sending images at 6 months, 1, 2, and 3 years for analysis by CIARC
- Dual grading and adjudication process by variable frame analysis to determine ECD
CPTS evaluation of donor, recipient, operative and postoperative factors on graft failure and ECD three years following DSAEK

- Late Complications
  - Rejection
  - Failure/Regraft
  - Epithelial ingrowth
  - Interface opacity
  - Trauma

Courtesy of G. Rosenwasser and M. Terry
CPTS status

- Recruitment began in April 2012 and concluded in April 2014
- 1604 eyes consented from 1174 participants
- 1330 surgeries in 1090 patients completed including 240 bilateral cases
- Recipients
  - Median age of 70
  - 90% white, 60% women
  - 94% FECD, 6% PBK
  - 52% phakic preop
  - 18% hx of diabetes

- DSAEK being performed at earlier stage of FECD
  - 53% grade 6
  - 29% grade 5
  - 19% grade 4 and below
Collaborative Corneal Transplantation Studies

• Between 1986 and 1989, CCTS Group conducted two controlled, double-masked studies addressing donor-recipient histocompatibility matching.

• After 3 years of patient follow-up, participants that received corneal transplants with well-matched antigens did not fare significantly better than those with a poor match.
  • Each patient group had similar rates of initial immune reactions, graft rejection, and graft failure due to rejection or other causes.
  • However, the researchers did note that CCTS patients who were compatible with the donor's blood type had a better outcome than unmatched patients.

• In short, data from the CCTS indicated that matching patient and donor blood types (combined with treating patients with high-dose topical steroids after surgery) may be potentially effective in improving high-risk corneal transplantation.
CORNEA DONOR STUDY
Purpose of the Cornea Donor Study

**Objective:** to determine whether donor age is associated with corneal transplant success in corneal diseases associated with endothelial dysfunction (moderate risk for failure)
Study Design

**Cornea Assignment:**
- Corneas assigned from donor ≥66 and from donor <66 using a random approach without respect to recipient factors

**Masking:**
- Investigator and patient masked to age of donor tissue

**Treatment:**
- Surgery and postoperative care by surgeons’ usual routine

**Study Outcome:**
- Graft failure based on clinical exam during 5 year follow up
Enrollment and Participation

- 1,101 subjects enrolled January, 2000 to August, 2002
  - 11 subjects with ineligible diagnoses
  - 1,090 eligible subjects

- 43 eye banks provided corneas to CDS subjects

- 105 surgeons at 80 sites enrolled subjects
5-Year Graft Success Rates

Similar graft success rates
- Donor Age ≥ 66 years 86%
- Donor Age < 66 years 86%

Difference = 0%
- Limit of one-sided 95% CI = 4%
- Less than pre-specified non-inferiority limit of 8%
Graft Success by Donor Age Group

- Donor Age < 66y: 86%
- Donor Age >= 66y: 47%
5-Year Graft Success by Donor Age
Endothelial Cell Density over 5 Years by Donor Age Group
(only includes subjects with graft success through 5 years)
Percent Endothelial Cell Loss from Baseline to 5 Years

Spearman Correlation Coefficient (95% CI) = −0.20 (−0.30, −0.09)
Conclusions

- 5-yr graft success rate similar with corneas from donors >66 yrs and <66 yrs old
- Suggestion of a slightly higher success rate with very young donors
- Endothelial cell loss is substantial over 5 yrs even with successful transplant
- Slightly greater cell loss in corneas from donors >66 yrs than <66 yrs old
10-Year Graft Success by Donor Age Group

Donor Age 12 to 65 Years
(N=707)

Success Probability

Survival Time (Years)

Donor Age 12 to 65 Years
(N=707)

P = 0.11

Mannis et al Ophthalmology 2013
Median Endothelial Cell Density by Donor Age Group

(only includes subjects with graft success through 10 years)

<table>
<thead>
<tr>
<th>Donor Age</th>
<th>Baseline ECD (cells/mm²)</th>
<th>5-Year ECD (cells/mm²)</th>
<th>10-Year ECD (cells/mm²)</th>
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<tr>
<td>Overall</td>
<td>2695</td>
<td>786</td>
<td>611</td>
</tr>
<tr>
<td>&lt;66 years</td>
<td>2726</td>
<td>870</td>
<td>628</td>
</tr>
<tr>
<td>≥66 years</td>
<td>2617</td>
<td>683</td>
<td>550</td>
</tr>
</tbody>
</table>

Lass et al. Ophthalmology 2013
Corneal Endothelium 10 Years After Keratoplasty

- Bourne et al, 1997, Ophthalmology
  - Endothelial cell loss was 67%
  - endothelial cell density was 958 cells/mm²
  - coefficient of variation was 0.32
  - % hexagonal cells were 56
  - corneal thickness was 580 microns
  - Aphakic eyes had the lowest endothelial cell loss
  - Phakic eyes had the highest endothelial cell loss
  - Eyes with posterior chamber lenses had a greater endothelial cell loss
  - The central endothelial cells of successful corneal transplants five years after keratoplasty form an unstable monolayer with continued accelerated loss of cells and abnormal cellular morphologic features.
  - This process results in fewer endothelial cells remaining on the central graft with an associated increase in stromal swelling and graft failure.
The central endothelial cells of successful corneal transplants five years after keratoplasty form an unstable monolayer with continued accelerated loss of cells and abnormal cellular morphologic features.
CDS Images for a Single Subject over 10 Years

Baseline Donor ECD  2378 cells/mm²
6 month ECD  1864 cells/mm²
1 year ECD  1504 cells/mm²
2 year ECD  982 cells/mm²
3 year ECD  765 cells/mm²
4 year ECD  628 cells/mm²
5 year ECD  568 cells/mm²
7/8 year ECD  584 cells/mm²
10 year ECD  522 cells/mm²
10-15 years after PK

- At 15 years:
  - endothelial cell loss from preoperative donor levels = 71%
  - endothelial cell density ~872 cells/mm²
  - corneal thickness ~590 microns
- Endothelial cell density appears to be unchanged between 10 and 15 years
- However, corneal thickness increases
- mean annual rate of endothelial cell loss from 10 to 15 years after surgery is 0.2 % which is similar to unoperated eyes
- The cumulative probability of developing glaucoma, graft rejection, or graft failure was 20%, 23%, and 28%, respectively
10-15 years after PK

CORNEAL ENDOTHELIUM AND POSTOPERATIVE OUTCOMES 15 YEARS AFTER PENETRATING KERATOPLASTY

By Sanjay V. Patel BMBS, David O. Hodge MS, and William M. Bourne MD

\[
ECD = ECD_0 + qe^{kt}
\]

\(ECD_0 = 3634.6\) (se=0.1747, P=0.05)

\(k=0.0038\) (se=0.0012, P=0.04)

\(q=1422.8\) (se=220.7, P=0.003)

\(t=1294.5\) (se=212.6, P=0.003)

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**Figure 4.** Cumulative probability (Kaplan-Meier) of having at least one rejection episode. *P < 0.05 vs all other diagnoses, log rank test*
DSEK vs. SMAS PKP Endothelial Cell Loss

EK vs PK for endothelial cell density

Figure 2. Median endothelial cell density as a function of time for incision widths of 3.2 mm and 5.0 mm used with Descemet’s stripping automated endothelial keratoplasty.
“The histopathologic findings in grafts with low ECD suggest that the remaining endothelial cells are unstable, stressed, and vulnerable.”
Oxygen-deficient metabolism and corneal edema

B.K. Leung, J.A. Bonanno, and C.J. Radke

• “......the processes by which hypoxia controls corneal thickness reside primarily at the endothelium”
How can a cornea remain clear with 40% of its ECD?

- **Requirements:**
  - maintain barrier integrity at low density
  - fluid pump activity
    - Is likely gradually reduced as ECD declines

- Take FECD as an example. The two main functions of the endothelium, barrier and water pump, follow different courses of decline. The barrier function depends on the ability of endothelial cells to fully cover the stromal surface and to maintain cell to cell tight junctions, and both appear to be intact until end stage disease in FECD. A study suggests that FECD endothelial cells are capable of migration and division to fully populate a stromal surface despite a reduced ability to control stromal water content.
For PKs, I always first consider corneal lens fitting

- “Fit” the corneal contour
- Graft shape dictates RGP design
Waring’s 5 Post-PK shapes:

Originally Classified on Axial Data

- Prolate 31%
- Oblate 31%
- Mixed (Prolate & Oblate) 17.8%
- Asymmetric 8.7%
- Steep to Flat 13.5%
Late Stage Astigmatism after PK for KC

<table>
<thead>
<tr>
<th>Patient</th>
<th>Center</th>
<th>Date of PK</th>
<th>Size of donor button</th>
<th>Recipient Bed</th>
<th>Baseline Astigmatism</th>
<th>Late stage astigmatism</th>
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<tr>
<td>1*</td>
<td>CWRU</td>
<td>11-1985</td>
<td>7.5 mm</td>
<td>7.5 mm</td>
<td>-3.10 X 005</td>
<td>-12.4 X 163</td>
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<tr>
<td>2*</td>
<td>UIC</td>
<td>04-1987</td>
<td>8.0 mm</td>
<td>7.7 mm</td>
<td>-1.06 X 006</td>
<td>-13.00 X 050</td>
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<tr>
<td>3</td>
<td>CWRU</td>
<td>10-1979</td>
<td>8.5 mm</td>
<td>8.5 mm</td>
<td>-5.00 X 110</td>
<td>-8.00 X 113</td>
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<tr>
<td>4*</td>
<td>CWRU</td>
<td>03-1989</td>
<td>8.0 mm</td>
<td>8.0m</td>
<td>-3.50 X 030</td>
<td>-19.37 X 024</td>
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<td>5</td>
<td>CWRU</td>
<td>12-1980</td>
<td>NA</td>
<td>NA</td>
<td>-4.80 X 003</td>
<td>-8.12 X 178</td>
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<td>6</td>
<td>CWRU</td>
<td>04-1992</td>
<td>7.25 mm</td>
<td>7.0 mm</td>
<td>-4.96 X 130</td>
<td>-12.00 X 115</td>
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<td>7</td>
<td>CWRU</td>
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<td>NA</td>
<td>NA</td>
<td>-5.75 X 016</td>
<td>-8.50 X 012</td>
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<tr>
<td>8</td>
<td>UIC</td>
<td>03-1991</td>
<td>8.25 mm</td>
<td>7.75 mm</td>
<td>-2.75 X 020</td>
<td>-13.75 X 035</td>
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<td>9</td>
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<td>7.5 mm</td>
<td>-7.88 X 179</td>
<td>-16.50 X 002</td>
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<td>10</td>
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<td>07-1992</td>
<td>8.0 mm</td>
<td>8.0 mm</td>
<td>-1.62 X 180</td>
<td>-12.37 X 030</td>
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<tr>
<td>11</td>
<td>UIC</td>
<td>05-1979</td>
<td>7.5 mm</td>
<td>7.5 mm</td>
<td>-2.50 X 055</td>
<td>-8.64 X 176</td>
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<tr>
<td>12</td>
<td>UCLA</td>
<td>1979</td>
<td>NA</td>
<td>NA</td>
<td>-3.25 X 060</td>
<td>-7.50 X 017</td>
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</table>
**Example:**  
**Initial PK: 11-1985**  
All sutures removed 04-1986

<table>
<thead>
<tr>
<th>Date</th>
<th>Corneal astig.</th>
<th>Manifest refraction</th>
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<tbody>
<tr>
<td>05-1987</td>
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<td>-5.00 –3.75 X 015 (20/20)</td>
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<tr>
<td>11-1988</td>
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<td>06-1992</td>
<td>-2.50 X 005</td>
<td>-6.50 –2.75 X 180 (20/20)</td>
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<td>04-1993</td>
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<td>-6.00 –2.50 X 011 (20/20)</td>
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<td>09-1994</td>
<td>-3.50 X 007</td>
<td></td>
</tr>
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<td>09-1996</td>
<td></td>
<td>-6.00 –3.75 X 160 (20/20)</td>
</tr>
<tr>
<td>Date</td>
<td>Keratometric astigmatism</td>
<td>Manifest refraction</td>
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<tr>
<td>---------</td>
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<tr>
<td>07-1999</td>
<td>-12.4 X 163</td>
<td>-5.00 –11.50 X 159</td>
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<td>01-2001</td>
<td></td>
<td>-7.00 –15.00 X 150 (20/30)</td>
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</table>
Scleral Lens Considerations after transplant

• Monitor for excessive corneal swelling as a sign of endothelial cell stress

• Examples in Keratoconus:
  • CLAE, 2015 In Press, Soeters, Visser et al
    • Scleral lenses flatter corneal curavature
    • 2.5 % corneal swelling
Hypoxia, transplants, and scleral lenses

Holden/Mertz criteria for daily wear for central cornea: $24 \times 10^{-9}$
Harvitt–Bonanno criteria for the limbal area: $35 \times 10^{-9}$
Scleral Lens Considerations to Avoid Hypoxia

- Jaynes, Edrington, Weissman, CLAE 2014

Fig. 1. Predicted scleral GP entrapped tear layer oxygen tension (in mmHg) as a function of tear layer thickness (in microns) for three example scleral lenses of DK (100 or 140 Fatt units) and lens thickness values (microns).
Scleral Lens Considerations to Avoid Hypoxia

Thin tear layer, 150 microns

Thick tear layer, 350 microns

Figure 4. The mean and standard deviation values of corneal swelling induced by two different scleral lens fitting in a cohort of eight subjects fitted randomly with a post lens tear film thickness of 150 µm and with a post lens tear film thickness of 350 µm.
18.2 Scleral Lens

6.75 mm/3D reverse  18.2mm OAD  -14.00  Optimum Extra
18.2 mm scleral

6.75 mm/3D reverse   18.2mm OAD   -14.00   Optimum Extra
18.2 Scleral Lens
Corneal-Scleral Lens

- Traditional edge lift
- Landing Zone inside limbus
- Light touch over apex

Specifications:
- 6.5 mm
- 15.0 mm OAD
- -16.00
- Menicon Z
- Std. edge
Corneal-Scleral Lens
Scleral vs Corneal-Scleral

Dk/t=2.16
For Dk=100

Dk/t=25.5
For Dk=165
Dk/t at limbus
scleral vs corneo-scleral

Dk/t=22.5
For Dk=100

Dk/t=49.6
For Dk=165
PK eyes fit with piggybacks
Predicted Tear Oxygen Tensions

## Tear Oxygen Tension beneath piggyback lens systems

<table>
<thead>
<tr>
<th>RGP Dk/t</th>
<th>SCL Dk/t</th>
<th>Open eye pO₂</th>
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<tbody>
<tr>
<td>15</td>
<td>10</td>
<td>0</td>
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