What’s The Kraze with Total Keratometry?

2022 Southern Eye Congress, July 21-24, 2022

KAMRAN M. RIAZ, MD
CLINICAL ASSOCIATE PROFESSOR
DIRECTOR OF MEDICAL STUDENT RESEARCH
CATARACT, CORNEA, EXTERNAL DISEASE AND REFRACTIVE SURGERY
DEAN MCGEE EYE INSTITUTE, UNIVERSITY OF OKLAHOMA
KAMRAN-RIAZ@DMEI.ORG

Financial Disclosures

- I have no financial interests in this lecture or any information discussed therein

- Unrelated Disclosures:
  - Bausch & Lomb – Speaker
  - CorneaGen – Speaker
  - ImmunoGen, Ambrx – Consultant

Acknowledgments

- David L. Cooke, MD – Great Lakes Eye Care, St. Joseph, MI
- David A. Murphy, MD – Research Fellow, DMEI

Med Students

- Aiker Khan, MS4 – OU College of Medicine
- Deanna Dang, MS4 – OU College of Medicine
- Michael Heath, MS4 – OU College of Medicine
- Raj Patel, MS4 – OU College of Medicine
- Jacob Rogers, MS4 – OU College of Medicine
Objectives

- To introduce and summarize developments in corneal power measurements – total keratometry (TK)
- To discuss applications of TK in 5 commonly-encountered patient populations

Introduction: Keratometry and TCP

- Keratometry (K) uses the keratometric index (e.g., 1.375) to estimate the corneal power from measurements of the anterior corneal surface only
- The posterior cornea is like the dark side of the moon
  - Posterior cornea is a minus-powered lens

What is the refractive power (Ds) of the back surface of the cornea?

\[ D_s = \frac{n' - n}{r} \]

- \( n' \) (cornea) = 1.37
- \( n \) (water, aqueous) = 1.33
- \( r \) = radius of curvature of the cornea = 7mm

\[ 1.37 - 1.33 = 0.04 \text{ D} \]

1.37 - 1.33 = 5.7 D

+6.7D or -5.7D ???
Introduction: Keratometry and TCP

- Keratometry (K) uses the keratometric index (e.g., 1.3375) to estimate the corneal power from measurements of the anterior corneal surface only.
- The posterior cornea is like the dark side of the moon.
- Scheimpflug devices (e.g., Pentacam) can measure posterior corneal surface. Now we can combine the anterior and posterior corneal power into the total corneal power (TCP).
- Sounds good, right? We are measuring more accurately??
- TCP is typically lower than K values [1-4].


TCP: K value is falsely lower-than-real

\[ P = A - 0.9K - 2.5L \]

Risk of myopic surprise
Corneal Power Measurements with Optical Biometry

- Corneal Power Measurements: Assumed measurement of posterior cornea based on Gullstrand ratio \( \rightarrow \) more "inaccuracy" in steep/flat K eyes, which often occur independently and concurrently with short/long AXL eyes.
- Posterior corneal astigmatism: usually contributes ATR astigmatism.
  - Range from -0.26 to -0.78D1.
  - How does ATR contribute to the measured corneal astigmatism?
    - Negative: may decrease the WTR of the total corneal astigmatism.
    - Additive may add to the ATR of the total corneal astigmatism.
  - How to measure posterior corneal curvature?
    - Indirect measurements: nomograms (Baylor, Abulafia-Koch) vs IOL formulas (online, Barrett, etc.).
    - Direct measurement: Scheimpflug device, Fundus Images, SS-OCT (Total K on IOL Master 700).


Total Keratometry (TK)

- The IOL Master 700 (Carl Zeiss Meditec AG, Jena, Germany) is a swept-source OCT (SS-OCT) biometer that uses.
  - Telecentric keratometry for anterior keratometry measurements.
  - SS-OCT acquired pachymetry to define a toric posterior surface model for posterior corneal measurements.
  - The resulting total keratometry (TK) value offers the surgeon a measurement of the anterior and posterior corneal radii that can potentially be used for more accurate IOL calculations.
  - TK does not differ from standard K in most normal K range unoperated eyes and post-eximer laser surgery eyes.
  - But TK and TCA values are NOT interchangeable [1].
  - Allows surgeons to use TK values compatible with established IOL formula constants.


TK on IOL Master 700

Some evidence that TK works well for post-refractive eyes, but still unclear for virgin eyes, especially for extreme flat/steep Ks.
Is TK Better? Well...

- Depends on the study and what it looked at
  - Regular Eyes
    - Conventional K and TK similar, trend towards better outcomes with TK (60 eyes) 1
    - TK works better with formulas optimized for it, such as Barrett TK 7
  - Presbyopia Correcting IOLs
    - TK may help improve outcomes of toric tri-focal IOLs 1
    - However, conventional K is better than TK in MFIOLs 2
  - Post-Laser Vision Correction
    - TK can help better measure corneal power in post-SMILE patients 6
    - TK doesn’t make existing post-LASIK formulas (ASCRS website) better; Barrett True-K with conventional K worked best. FOC data no informative results; TK makes maps better.
    - TK used with customized post-LASIK formulas (ie, TK with TK) is superior (Barrett is author) 8
    - TK can make some existing formulas (not optimized for post-LASIK) better, such as Evo and maps (author was developer of Evo) 9
  - Bottom line: we’re not sure how much TK helps and in which eyes it helps

Where Can TK Potentially Help?

- At this time, no convincing evidence that TK helps improve outcomes in “normal” eyes
  - Normal range AL
    - Normal range Ks (especially without previous laser vision correction)
  - For ~90% of most cataract surgeries, TK values may not help “that” much
  - Approximately 0.25D difference on most eyes between K and TK values
    - Barrett TK Universal II (built into IOLM): requires no additional surgeon effort
    - Not worth inputting TK values manually into online-formula websites for “normal” eyes

Where Can TK Potentially Help?

1. Identifying Post-Laser Vision Correction (LVC) Eyes
2. Refractive Outcomes in Post-LVC Eyes
3. Refractive Outcomes in Keratoconus Eyes
4. Refractive Outcomes in Extreme K (non-ectatic, non LVC) Eyes
5. Refractive Outcomes in Combined Phaco-DMEK Eyes
6. Refractive Outcomes in Past Penetrating Keratoplasty Eyes
Identifying LVC Eyes

- We can recognize previous M-LVC during the preoperative examination through accurate history taking, review of prior medical records, and meticulous clinical examination.
- Ancillary diagnostic testing, such as topography, tomography, and anterior segment ocular coherence tomography (AS-OCT), can also help.
- Surgeons can also review optical biometry (OB), as flatter K values combined with long AL are often associated with previous M-LVC.
- But we may miss patients with M-LVC:
  - Poor patient recall, lack of medical records, low amounts of M-LVC treatment
  - Preoperative examiner is not the surgeon, information not conveyed to the surgeon
  - LASIK scar may be subtle and missed
  - PRK has no clinical evidence
- Some surgeons solely utilize biometry measurements and do not have access to topography/tomography.

Identifying LVC Eyes

- Can we use Tk values to detect M-LVC eyes solely using optical biometry?
- We know that M-LVC alters the relationship of ant-poster corneal radii.
- This can be used to calculate the APR or P/A ratio.
- As the APR and P/A values are inversely related, post-M-LVC eyes will have lower APR and higher P/A values, respectively.
- Since TK incorporates posterior corneal measurements, we sought to develop an index to detect M-LVC eyes using only IOLMaster700 measurements.
- We have termed this Cooke-Riai-Wendelstein Index (CRW1).
- The CRW1 Index was tested in several international datasets to assess its accuracy, including a comparison to Rpost/Rant obtained by biometry, three additional corneal imaging devices, and a combined biometry-corneal imaging software program.

Identifying LVC Eyes

- Development of CRW1
  - Six centers – 3 in USA, 3 in Austria
    - Great Lakes Eye Care (St Joseph, MI)
    - Northwestern University (Chicago, IL)
    - Penn State University (Hershey, PA)
    - Hanusch Hospital and satellite (Vienna, Austria)
    - Kepler University Hospital (Linz, Austria)
- Development dataset (DMEI): 10,780 eyes to identify LVC eyes
- Several iterations tested before finalizing CRW1
  - CRW1 formula: to be published
Identifying LVC Eyes

Accuracy of CRW1 compared to Rpost/Rant

In 38,439 eyes, the CRW1 was significantly better than Rpost/Rant (p < 0.001) with notably higher PPV (93% vs 65%) and fewer false positives (180 vs 29). Rpost/Rant had 180 false positives, while CRW1 had only 29 false positives.

Accuracy of CRW1 compared to other methods of detecting M-LVC

CRW1 was better than Pentacam, Veracity, and Galilei Indices Similar to Atlas Pathfinder II software

CRW1: Summary

- CRW1 complements interest in TEK in presenting a method for surgeons to identify post-M-LVC eyes effectively before cataract surgery solely utilizing IOLM700 measurements
- Researchers may use the CRW1 Index to efficiently identify post-M-LVC eyes for research purposes
- CRW1 can be easily incorporated on the printout page of the studied SS-OCT biometer (or, after recalibration, onto another biometer) similar to other metrics, such as the CW-Chord values
- Why CRW1? Future iterations to identify other pathologies (e.g., Fuchs, KCN, previous H-LVC) through IOLM700 measurements
Refractive Outcomes in M-LVC Eyes

TK in M-LVC Eyes

- Previous authors have shown that TK values can make older-generation formulas, such as Haigis, to perform as similar as post-refractive formulas[1]
- Question: Can TK values used with multivariable formulas help improve refractive accuracy in these challenging post M-LVC eyes?
- Or does simply using a formula dedicated for post M-LVC eyes with traditional K values work better?

TK in M-LVC Eyes

- Retrospective review of 130 eyes with previous M-LVC that were measured with SS-OCT biometer for K and TK prior to cataract surgery between 2019-2021
- Previous hyperopic LVC and RK were excluded due to an insufficient number of eyes
- Eyes with a history of trauma, contact lenses, or viation limiting ocular pathology were excluded
- Standard K and TK values were inputted into dedicated post-refractive multivariable formulas with mechanisms for adjusted K values using no prior historical data
- TK values were applied to non-LASIK formulas
- Only IOLcom lens constants were used
- Postoperative refractive outcomes were compared to the predicted outcomes to determine predictive error and percentage of eyes within ±1.00 of targeted outcome
- Refractions done 21-90 days postoperatively with lane-length adjustments

**Results: Post-LVC Formulas with K vs TK**

Newer post-LVC formulas (EVO and BTK) performed best both with K or TK.

- Barrett on IOLM700 should be run in post-LVC mode or use online.
- EVO and Barrett performed better than "old-generation" LVC formulas (Shammas, Haigis).
- Pearl DGS performed consistently hyperopic.
- Feeding Haigis TK makes it better than Haigis-L.

### Post-LVC Formulas with K vs TK

![Image of table showing results for different formulas with K vs TK]

- **Barnett True K** and **EVO-LVC-PK** have similar performance.
- **EVO LVC (K)** and **Barrett True K** have consistent performance.
- **Haigis (TK)** and **Shammas (K)** show differences in performance.

### Non-LVC Formulas with K vs TK

![Image of table showing results for different formulas with K vs TK]

- **Hoffer Q** and **K-6** show better performance with TK.
- **T2** and **DGS** show slight improvement with TK.
- **Barrett** shows consistent performance across both K and TK.
- **Holladay 1** and **SRK/T** show minor improvement with TK.

---

All these non-LVC formulas improved with TK values.
Results: Non-LVC Formulas with K vs TK

<table>
<thead>
<tr>
<th>Formula</th>
<th>HRE</th>
<th>IPE</th>
<th>ModE</th>
<th>SD</th>
<th>Max RE</th>
<th>% &lt; 1.5</th>
<th>% &lt; 3</th>
<th>% &lt; 5</th>
<th>% &lt; 7</th>
<th>% &lt; 10</th>
<th>RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evo-(TK)</td>
<td>0.42</td>
<td>0.588</td>
<td>0.605</td>
<td>0.627</td>
<td>2.33</td>
<td>27.7%</td>
<td>52.3%</td>
<td>73.1%</td>
<td>83.1%</td>
<td>0.754</td>
<td></td>
</tr>
<tr>
<td>Kane-(TK)</td>
<td>0.49</td>
<td>0.642</td>
<td>0.620</td>
<td>0.633</td>
<td>2.58</td>
<td>24.6%</td>
<td>48.5%</td>
<td>69.2%</td>
<td>80.8%</td>
<td>0.815</td>
<td></td>
</tr>
<tr>
<td>RBF 3.0</td>
<td>0.52</td>
<td>0.663</td>
<td>0.563</td>
<td>0.627</td>
<td>2.36</td>
<td>20.9%</td>
<td>42.7%</td>
<td>67.3%</td>
<td>80.0%</td>
<td>0.813</td>
<td></td>
</tr>
</tbody>
</table>

- Caution: these popular multivariable formulas performed WORSE when given TK values
- Reason: Not designed to be used for post-LVC eyes

TK in M-LVC Eyes: Recommendations

- despite potential advantages of TK to incorporate posterior corneal measurements, we recommend that surgeons utilize formulas customized for post-LVC eyes.
- Surgeons should utilize dedicated post-refractive formulas with traditional K values.
- Surgeons can utilize either K or TK values for the EVO-LVC and Barrett True K formulas

Refractive Outcomes in Keratoconus Eyes
Background

- Biometry measurements are difficult in KCN eyes,
- Corneal power is often overestimated, resulting in insufficient IOL power and hyperopic surprise [1].
- IOL Calculation assumes a certain ratio of the power of the anterior cornea compared to the posterior cornea, which does not hold true in KCN [2,3] especially with increasing disease severity.
- Standard Biometry assumes anterior and posterior K’s will be equal at visual axis and that the posterior cornea will be ~1.7mm steeper than the anterior cornea.
- Can TK improve predictions in KCN eyes?

TK in KCN Eyes

- 87 KCN Eyes between DMEI and Bascom Palmer (2-center study)
- Formulas studied included Barrett Universal 2 (KCN measured, KCN predicted, and original), Kane (original and KCN), EVO, K-6, SRK/T, Pearl DGS, T2, Holladay 1, Holladay 1 with EKR65, Haigis, and Hoffer Q
- Hill RBF was only able to accept XXX eyes
- IOLCon Lens Constants were used
- Values input into the respective formula websites
- Time from surgery to post-op refraction ranged from 21-180 days
- Post-op refractive outcomes were compared with predicted refracted outcomes to determine mean error, mean absolute error, median absolute error, standard deviation, maximum absolute error, root mean squared error, and % of eyes within +/-0.5D and 1D.

TK in KCN Eyes

All formulas had a better ME with TK compared to K.
All formulas had a better or equal MAE with TK, compared to K (Except Kane KCN MAE was slightly better for K than for TK).

<table>
<thead>
<tr>
<th>Formula</th>
<th>Mean Error (D)</th>
<th>Mean Absolute Error (D)</th>
<th>Median Absolute Error (D)</th>
<th>Standard Deviation (D)</th>
<th>Maximum Absolute Error (D)</th>
<th>% of eyes within +/-0.5D</th>
<th>% of eyes within +/-1D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrett Universal 2 (KCN measured)</td>
<td>0.73</td>
<td>1.71</td>
<td>1.00</td>
<td>0.20</td>
<td>0.57</td>
<td>32.4%</td>
<td>83.0%</td>
</tr>
<tr>
<td>Barrett Universal 2 (KCN predicted)</td>
<td>0.73</td>
<td>1.71</td>
<td>1.00</td>
<td>0.20</td>
<td>0.57</td>
<td>32.4%</td>
<td>83.0%</td>
</tr>
<tr>
<td>Barrett Universal 2 (original)</td>
<td>0.73</td>
<td>1.71</td>
<td>1.00</td>
<td>0.20</td>
<td>0.57</td>
<td>32.4%</td>
<td>83.0%</td>
</tr>
<tr>
<td>Kane (original)</td>
<td>0.73</td>
<td>1.71</td>
<td>1.00</td>
<td>0.20</td>
<td>0.57</td>
<td>32.4%</td>
<td>83.0%</td>
</tr>
<tr>
<td>Kane (KCN)</td>
<td>0.73</td>
<td>1.71</td>
<td>1.00</td>
<td>0.20</td>
<td>0.57</td>
<td>32.4%</td>
<td>83.0%</td>
</tr>
<tr>
<td>EVO</td>
<td>0.73</td>
<td>1.71</td>
<td>1.00</td>
<td>0.20</td>
<td>0.57</td>
<td>32.4%</td>
<td>83.0%</td>
</tr>
<tr>
<td>K-6</td>
<td>0.73</td>
<td>1.71</td>
<td>1.00</td>
<td>0.20</td>
<td>0.57</td>
<td>32.4%</td>
<td>83.0%</td>
</tr>
<tr>
<td>SRK/T</td>
<td>0.73</td>
<td>1.71</td>
<td>1.00</td>
<td>0.20</td>
<td>0.57</td>
<td>32.4%</td>
<td>83.0%</td>
</tr>
<tr>
<td>Pearl DGS</td>
<td>0.73</td>
<td>1.71</td>
<td>1.00</td>
<td>0.20</td>
<td>0.57</td>
<td>32.4%</td>
<td>83.0%</td>
</tr>
<tr>
<td>T2</td>
<td>0.73</td>
<td>1.71</td>
<td>1.00</td>
<td>0.20</td>
<td>0.57</td>
<td>32.4%</td>
<td>83.0%</td>
</tr>
<tr>
<td>Holladay 1</td>
<td>0.73</td>
<td>1.71</td>
<td>1.00</td>
<td>0.20</td>
<td>0.57</td>
<td>32.4%</td>
<td>83.0%</td>
</tr>
<tr>
<td>Holladay 1 with EKR65</td>
<td>0.73</td>
<td>1.71</td>
<td>1.00</td>
<td>0.20</td>
<td>0.57</td>
<td>32.4%</td>
<td>83.0%</td>
</tr>
<tr>
<td>Haigis</td>
<td>0.73</td>
<td>1.71</td>
<td>1.00</td>
<td>0.20</td>
<td>0.57</td>
<td>32.4%</td>
<td>83.0%</td>
</tr>
<tr>
<td>Hoffer Q</td>
<td>0.73</td>
<td>1.71</td>
<td>1.00</td>
<td>0.20</td>
<td>0.57</td>
<td>32.4%</td>
<td>83.0%</td>
</tr>
</tbody>
</table>
TK in KCN Eyes – including RBF

When excluding many extreme KCN eyes, a number of formulas did well, both with K and TK.

- **Surprise:** standard Kane did better than EKR.
- **Some formulas better with K > TK.**

TK in KCN Eyes – only EKR eyes

In these eyes, KCN formulas did again well.

- **H1 with EKR did very poorly (MAE wise) but had lowest ME.**
- **EKR is a wild card:** some eyes did very well, others VERY bad (~4D surprises!)

TK in KCN Eyes – at least one K > 50D

KCN formulas did very well.

- **Good ole SRK/T did well too!**
TK in KCN Eyes – both K < 50D

- KCN formulas don’t do as well
- Multivariable formulas (EVO, Kane, Barrett, etc) worked with both TK and K values well
- SRK/T did well
- SRK/T does NOT do well

TK in KCN Eyes: Summary

- If both Ks are < 50D, KCN eyes function similar to “normal” eyes and do NOT benefit from KCN-specific formulas
- In these eyes, multivariable formulas with TK did slightly better than K
- If one K is > 50D, KCN-specific formulas work best
- Multivariable formulas with TK did better than K
- Surprisingly, SRK/T works well (tends to run myopic in extreme K eyes)
- Do not use third-generation formulas like H1, HQ, and Haigis for any of these eyes!

Refractive Outcomes in Extreme K (non-ectatic, non LVC) Eyes
TK in Extreme K Eyes: Background

- IOL calculations are known to be inaccurate in eyes with extreme K measurements (K ≥ 48D or ≤ 42D) without ectasia or previous laser vision correction (LVC).
- The assumed anterior-posterior corneal radius ratios may not be valid in extreme K eyes.
- Question: Do TK values provide an improvement in accuracy of IOL calculations over standard K values in these eyes?
- Retrospective chart review of 1889 eyes with extreme K measurements by SS-OCT between 2019-2021.
- 169 eyes met inclusion criteria.
- Ten IOL formulas studied using K followed by TK.

TK in Extreme K Eyes: Results with K

**Table 1B: Extreme K eyes using K values (N = 169)**

<table>
<thead>
<tr>
<th>RMSE Rank</th>
<th>Formula</th>
<th>RME</th>
<th>RMSE</th>
<th>Dac</th>
<th>Max AMC</th>
<th>% ≤ 0.5 D</th>
<th>% ≤ 0.75 D</th>
<th>RMS</th>
<th>N ≥ 169</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>RBF 3.0</td>
<td>0.03</td>
<td>0.349</td>
<td>0.068</td>
<td>2.73</td>
<td>75.6%</td>
<td>92.9%</td>
<td>0.007</td>
<td>169</td>
</tr>
<tr>
<td>2</td>
<td>K6</td>
<td>0.06</td>
<td>0.375</td>
<td>0.087</td>
<td>2.60</td>
<td>76.9%</td>
<td>93.1%</td>
<td>0.009</td>
<td>169</td>
</tr>
<tr>
<td>3</td>
<td>Halo</td>
<td>0.11</td>
<td>0.355</td>
<td>0.131</td>
<td>2.83</td>
<td>74.0%</td>
<td>91.7%</td>
<td>0.024</td>
<td>169</td>
</tr>
<tr>
<td>4</td>
<td>Garnett</td>
<td>0.23</td>
<td>0.159</td>
<td>0.192</td>
<td>2.66</td>
<td>75.5%</td>
<td>91.3%</td>
<td>0.031</td>
<td>169</td>
</tr>
<tr>
<td>5</td>
<td>Pearl DGS</td>
<td>0.42</td>
<td>0.312</td>
<td>0.156</td>
<td>3.02</td>
<td>73.4%</td>
<td>92.5%</td>
<td>0.155</td>
<td>169</td>
</tr>
<tr>
<td>6</td>
<td>Holladay</td>
<td>0.47</td>
<td>0.351</td>
<td>0.154</td>
<td>3.21</td>
<td>73.3%</td>
<td>87.0%</td>
<td>0.177</td>
<td>169</td>
</tr>
<tr>
<td>7</td>
<td>Haigis</td>
<td>0.10</td>
<td>0.374</td>
<td>0.159</td>
<td>3.05</td>
<td>68.0%</td>
<td>86.4%</td>
<td>0.067</td>
<td>169</td>
</tr>
<tr>
<td>8</td>
<td>SRK/T</td>
<td>0.12</td>
<td>0.441</td>
<td>0.210</td>
<td>2.35</td>
<td>65.3%</td>
<td>82.4%</td>
<td>0.087</td>
<td>169</td>
</tr>
<tr>
<td>9</td>
<td>Haigis</td>
<td>0.11</td>
<td>0.400</td>
<td>0.210</td>
<td>3.15</td>
<td>60.4%</td>
<td>82.6%</td>
<td>0.095</td>
<td>169</td>
</tr>
</tbody>
</table>

TK in Extreme K Eyes: Results with TK

**Table 1A: Extreme K eyes using TK values (N = 169)**

<table>
<thead>
<tr>
<th>K Rank</th>
<th>TK Rank</th>
<th>Formula</th>
<th>RME</th>
<th>RMSE</th>
<th>Dac</th>
<th>Max AMC</th>
<th>% ≤ 0.5 D</th>
<th>% ≤ 0.75 D</th>
<th>RMS</th>
<th>N ≥ 169</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Kane</td>
<td>0.06</td>
<td>0.277</td>
<td>0.336</td>
<td>0.051</td>
<td>2.83</td>
<td>72.2%</td>
<td>92.0%</td>
<td>0.019</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Williams</td>
<td>0.28</td>
<td>0.186</td>
<td>0.108</td>
<td>2.30</td>
<td>77.6%</td>
<td>90.7%</td>
<td>0.038</td>
<td>169</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>Hill</td>
<td>0.02</td>
<td>0.372</td>
<td>0.010</td>
<td>3.14</td>
<td>79.9%</td>
<td>95.3%</td>
<td>0.008</td>
<td>169</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>RBF 3.0</td>
<td>0.19</td>
<td>0.402</td>
<td>0.156</td>
<td>3.14</td>
<td>71.0%</td>
<td>92.3%</td>
<td>0.014</td>
<td>169</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>Garnett</td>
<td>0.19</td>
<td>0.436</td>
<td>0.136</td>
<td>3.23</td>
<td>71.3%</td>
<td>92.3%</td>
<td>0.014</td>
<td>169</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>Pearl DGS</td>
<td>0.19</td>
<td>0.416</td>
<td>0.151</td>
<td>3.27</td>
<td>71.0%</td>
<td>92.3%</td>
<td>0.009</td>
<td>169</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>Holladay</td>
<td>0.15</td>
<td>0.441</td>
<td>0.154</td>
<td>3.28</td>
<td>64.5%</td>
<td>94.7%</td>
<td>0.005</td>
<td>169</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>Haigis</td>
<td>0.19</td>
<td>0.458</td>
<td>0.164</td>
<td>3.28</td>
<td>66.0%</td>
<td>92.0%</td>
<td>0.010</td>
<td>169</td>
</tr>
<tr>
<td>9</td>
<td>8</td>
<td>SRK/T</td>
<td>0.00</td>
<td>0.438</td>
<td>0.152</td>
<td>2.33</td>
<td>68.0%</td>
<td>93.5%</td>
<td>0.033</td>
<td>169</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>Haigis</td>
<td>0.19</td>
<td>0.604</td>
<td>0.425</td>
<td>0.003</td>
<td>3.37</td>
<td>65.6%</td>
<td>92.0%</td>
<td>0.032</td>
</tr>
</tbody>
</table>
### Difference in ME and RMSE (TK minus K)

<table>
<thead>
<tr>
<th>Formula</th>
<th>ME</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRK/T</td>
<td>0.06</td>
<td>-0.01</td>
</tr>
<tr>
<td>Holladay 3</td>
<td>0.07</td>
<td>0.01</td>
</tr>
<tr>
<td>Evo 2.0</td>
<td>0.07</td>
<td>0.02</td>
</tr>
<tr>
<td>Hoffer Q</td>
<td>0.08</td>
<td>0.02</td>
</tr>
<tr>
<td>Barrett U2</td>
<td>0.08</td>
<td>0.01</td>
</tr>
<tr>
<td>K6</td>
<td>0.08</td>
<td>0</td>
</tr>
<tr>
<td>Kane</td>
<td>0.08</td>
<td>-0.01</td>
</tr>
<tr>
<td>Pearl DGS</td>
<td>0.08</td>
<td>0</td>
</tr>
<tr>
<td>RBF 3.0</td>
<td>0.08</td>
<td>0</td>
</tr>
<tr>
<td>Haigis</td>
<td>0.09</td>
<td>0.03</td>
</tr>
</tbody>
</table>

**Minimal change when using K or TK**

Surprisingly, ME shifts slightly hyperopic when using TK values.

---

### Results: K vs TK in Extreme K Eyes

**Multivariable formulas performed better than third-gen**

K vs TK minimally affected a given formula.

---

### TK in Extreme K Eyes: Summary

- TK values did not significantly improve the performance of a given formula when using TK or K values.
- Multivariable formulas with either K or TK perform slightly better than third-generation formulas in these eyes.
IOL calculations are challenging in eyes undergoing combined cataract surgery and DMEK with a near-universal tendency for more-than-intended hyperopic refractive outcomes. This is primarily due to inaccuracy of corneal measurements secondary to corneal pathology causing 1) alterations of the posterior corneal curvature and 2) increased corneal thickness from corneal edema. Previously, we have relied on adjustment factors, such as targeting additional myopia (approx. -0.75 to -1.00D) to compensate for postoperative hyperopic shift and achieve a plano refractive target. We sought to study whether using K or TK values with a given formula would lead to more accurate refractive results.

**TK in Phaco-DMEK Eyes**

- Retrospective review of 83 eyes in 62 patients that underwent concurrent cataract surgery and DMEK between 2019-2021.
- 9 formulas studied include Barrett Universal 2.0, Evo 2.0, K-6, Kane, Pearl DGS, Holladay 1, Hoffer Q, SRK/T, and Haigis (using both K and TK values).
- Only IOLcon lens constants were used.
- Values were inputted into the respective formula websites.
- Formulas were additionally tested by internally increasing the IOL power by 1.00 D ("adjusted formula").
- Refractions were done 30-120 days postoperatively with adjustments for lane length.
- Postoperative refractive outcomes were compared with predicted refractive outcomes to determine the mean error (ME), mean absolute error (MAE), standard deviation, and percentage of eyes within ±0.25, ±0.5, ±0.75, and ±1.00D of the targeted outcome.
TK in Phaco-DMEK Eyes

<table>
<thead>
<tr>
<th>MAE SD MedAE MaxAE RMS-PE ±0.50 D (%)</th>
<th>±1.00 D (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAE SD MedAE MaxAE RMS-PE ±0.50 D (%)</td>
<td>±1.00 D (%)</td>
</tr>
<tr>
<td>MAE SD MedAE MaxAE RMS-PE ±0.50 D (%)</td>
<td>±1.00 D (%)</td>
</tr>
<tr>
<td>MAE SD MedAE MaxAE RMS-PE ±0.50 D (%)</td>
<td>±1.00 D (%)</td>
</tr>
<tr>
<td>MAE SD MedAE MaxAE RMS-PE ±0.50 D (%)</td>
<td>±1.00 D (%)</td>
</tr>
<tr>
<td>MAE SD MedAE MaxAE RMS-PE ±0.50 D (%)</td>
<td>±1.00 D (%)</td>
</tr>
<tr>
<td>MAE SD MedAE MaxAE RMS-PE ±0.50 D (%)</td>
<td>±1.00 D (%)</td>
</tr>
<tr>
<td>MAE SD MedAE MaxAE RMS-PE ±0.50 D (%)</td>
<td>±1.00 D (%)</td>
</tr>
<tr>
<td>MAE SD MedAE MaxAE RMS-PE ±0.50 D (%)</td>
<td>±1.00 D (%)</td>
</tr>
</tbody>
</table>

All 9 formulas are better with K than for TK.

Lower MAE values with multivariable formulas and SRK/T using K.

Barrett worst MV formula.

TK in Phaco-DMEK Eyes: adjust IOL 1D

As an example, if Cooke K6 predicted an +11.00 D IOL would give a -0.50 D final refraction, we would advise that surgeons use a +12.00 D IOL (increase the IOL power by 1.00 D) to obtain the desired refraction of -0.50 D.

Why Did TK Perform Poorly?

• Normal cornea
• Edematous cornea – posterior flattening
  • Ant K gives less negative than expected
  • Measured PK value falsely skews the TK

• After DMEK, posterior corneal steepening occurs → hence TK value is worse than K value.
• “Better to remain ignorant” of the posterior cornea in phaco-DMEK eyes.
• Studies now to predict postoperative corneal flattening to improve IOL power calculations.
TK in Phaco-DMEK Eyes: Summary

- Accuracy remains challenging in these eyes
- For all formulas, the prediction accuracy of K is higher than that of TK
- Multivariable formulas (excluding Barrett) are the most accurate
- Using an IOL power +1.00 higher with all formulas further improve the chances of postoperative refractive accuracy

Refractive Outcomes in Post-Penetrating Keratoplasty Eyes

- IOL calculations remain challenging in patients who have undergone prior corneal transplant surgery (penetrating keratoplasty [PKP]) primarily due to inaccuracy in corneal measurements, significant/irregular astigmatism, or corneal pathology
- While not as common, surgeons may encounter situations where they have to perform cataract surgery after previous PKP
- There is a scarcity of literature or guidelines regarding formula choice in these patients. Most surgeons utilize routine formulas with additional myopia targeted.
- Question: Since K measurements in these eyes are often inaccurate, does using TK improve refractive accuracy?
- 22 eyes with previous PKP ≥ 13 met inclusion criteria

TK in Post-PKP Eyes: Background

- IOL calculations remain challenging in patients who have undergone prior corneal transplant surgery (penetrating keratoplasty [PKP]) primarily due to inaccuracy in corneal measurements, significant/irregular astigmatism, or corneal pathology
- While not as common, surgeons may encounter situations where they have to perform cataract surgery after previous PKP
- There is a scarcity of literature or guidelines regarding formula choice in these patients. Most surgeons utilize routine formulas with additional myopia targeted.
- Question: Since K measurements in these eyes are often inaccurate, does using TK improve refractive accuracy?
- 22 eyes with previous PKP ≥ 13 met inclusion criteria
Results – K values

<table>
<thead>
<tr>
<th>Formula</th>
<th>MRE</th>
<th>MAM</th>
<th>MaxMAE</th>
<th>SD</th>
<th>MaxAE</th>
<th>% +/- 0.5D</th>
<th>% +/- 1.0D</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-C</td>
<td>0.41</td>
<td>0.688</td>
<td>0.814</td>
<td>0.706</td>
<td>1.19</td>
<td>46.2%</td>
<td>84.6%</td>
<td>0.702</td>
</tr>
<tr>
<td>DOR  (K)</td>
<td>0.48</td>
<td>0.708</td>
<td>0.792</td>
<td>0.720</td>
<td>1.53</td>
<td>30.8%</td>
<td>69.2%</td>
<td>0.829</td>
</tr>
<tr>
<td>T2 (K)</td>
<td>0.42</td>
<td>0.752</td>
<td>0.749</td>
<td>0.794</td>
<td>1.38</td>
<td>30.8%</td>
<td>69.2%</td>
<td>0.860</td>
</tr>
<tr>
<td>DOR (K)</td>
<td>0.48</td>
<td>0.724</td>
<td>0.735</td>
<td>0.763</td>
<td>1.65</td>
<td>38.5%</td>
<td>69.2%</td>
<td>0.879</td>
</tr>
<tr>
<td>Barrett (K)</td>
<td>0.53</td>
<td>0.767</td>
<td>0.785</td>
<td>0.773</td>
<td>1.50</td>
<td>38.5%</td>
<td>61.5%</td>
<td>0.912</td>
</tr>
<tr>
<td>hallway 1</td>
<td>0.48</td>
<td>0.715</td>
<td>0.716</td>
<td>0.757</td>
<td>1.47</td>
<td>38.5%</td>
<td>69.2%</td>
<td>0.838</td>
</tr>
<tr>
<td>hallway (K)</td>
<td>0.48</td>
<td>0.752</td>
<td>0.749</td>
<td>0.794</td>
<td>1.38</td>
<td>30.8%</td>
<td>69.2%</td>
<td>0.860</td>
</tr>
<tr>
<td>Hags (K)</td>
<td>0.76</td>
<td>0.856</td>
<td>0.970</td>
<td>0.795</td>
<td>1.81</td>
<td>38.5%</td>
<td>53.8%</td>
<td>1.013</td>
</tr>
<tr>
<td>Hags (T)</td>
<td>0.78</td>
<td>0.852</td>
<td>0.895</td>
<td>0.731</td>
<td>1.45</td>
<td>38.5%</td>
<td>69.2%</td>
<td>1.034</td>
</tr>
<tr>
<td>Hager (K)</td>
<td>0.76</td>
<td>0.882</td>
<td>1.000</td>
<td>0.786</td>
<td>1.84</td>
<td>38.5%</td>
<td>53.8%</td>
<td>1.068</td>
</tr>
<tr>
<td>Hager (T)</td>
<td>0.75</td>
<td>0.857</td>
<td>0.735</td>
<td>0.795</td>
<td>2.04</td>
<td>30.8%</td>
<td>69.2%</td>
<td>1.073</td>
</tr>
<tr>
<td>SKRT (K)</td>
<td>-0.05</td>
<td>0.102</td>
<td>0.660</td>
<td>1.422</td>
<td>3.64</td>
<td>46.2%</td>
<td>61.5%</td>
<td>1.367</td>
</tr>
</tbody>
</table>

~40% of eyes were within 0.5D. Not normal eyes. TK values helped slightly
Many newer MV formulas couldn’t run all eyes

Results - TK

<table>
<thead>
<tr>
<th>Formula</th>
<th>MRE</th>
<th>MAM</th>
<th>MaxMAE</th>
<th>SD</th>
<th>MaxAE</th>
<th>% +/- 0.5D</th>
<th>% +/- 1.0D</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-C</td>
<td>0.41</td>
<td>0.688</td>
<td>0.814</td>
<td>0.706</td>
<td>1.19</td>
<td>46.2%</td>
<td>84.6%</td>
<td>0.702</td>
</tr>
<tr>
<td>DOR  (K)</td>
<td>0.48</td>
<td>0.708</td>
<td>0.792</td>
<td>0.720</td>
<td>1.53</td>
<td>30.8%</td>
<td>69.2%</td>
<td>0.829</td>
</tr>
<tr>
<td>T2 (K)</td>
<td>0.42</td>
<td>0.752</td>
<td>0.749</td>
<td>0.794</td>
<td>1.38</td>
<td>30.8%</td>
<td>69.2%</td>
<td>0.860</td>
</tr>
<tr>
<td>DOR (K)</td>
<td>0.48</td>
<td>0.724</td>
<td>0.735</td>
<td>0.763</td>
<td>1.65</td>
<td>38.5%</td>
<td>69.2%</td>
<td>0.879</td>
</tr>
<tr>
<td>Barrett (K)</td>
<td>0.53</td>
<td>0.767</td>
<td>0.785</td>
<td>0.773</td>
<td>1.50</td>
<td>38.5%</td>
<td>61.5%</td>
<td>0.912</td>
</tr>
<tr>
<td>hallway 1</td>
<td>0.48</td>
<td>0.715</td>
<td>0.716</td>
<td>0.757</td>
<td>1.47</td>
<td>38.5%</td>
<td>69.2%</td>
<td>0.838</td>
</tr>
<tr>
<td>hallway (K)</td>
<td>0.48</td>
<td>0.752</td>
<td>0.749</td>
<td>0.794</td>
<td>1.38</td>
<td>30.8%</td>
<td>69.2%</td>
<td>0.860</td>
</tr>
<tr>
<td>Hags (K)</td>
<td>0.76</td>
<td>0.856</td>
<td>0.970</td>
<td>0.795</td>
<td>1.81</td>
<td>38.5%</td>
<td>53.8%</td>
<td>1.013</td>
</tr>
<tr>
<td>Hags (T)</td>
<td>0.78</td>
<td>0.852</td>
<td>0.895</td>
<td>0.731</td>
<td>1.45</td>
<td>38.5%</td>
<td>69.2%</td>
<td>1.034</td>
</tr>
<tr>
<td>Hager (K)</td>
<td>0.76</td>
<td>0.882</td>
<td>1.000</td>
<td>0.786</td>
<td>1.84</td>
<td>38.5%</td>
<td>53.8%</td>
<td>1.068</td>
</tr>
<tr>
<td>Hager (T)</td>
<td>0.75</td>
<td>0.857</td>
<td>0.735</td>
<td>0.795</td>
<td>2.04</td>
<td>30.8%</td>
<td>69.2%</td>
<td>1.073</td>
</tr>
<tr>
<td>SKRT (K)</td>
<td>-0.05</td>
<td>0.102</td>
<td>0.660</td>
<td>1.422</td>
<td>3.64</td>
<td>46.2%</td>
<td>61.5%</td>
<td>1.367</td>
</tr>
</tbody>
</table>

~40% of eyes were within 0.5D. Not normal eyes. TK values helped slightly
Many newer MV formulas couldn’t run all eyes

Ranked by RMSE

<table>
<thead>
<tr>
<th>Formula</th>
<th>MRE</th>
<th>MAM</th>
<th>MaxMAE</th>
<th>SD</th>
<th>MaxAE</th>
<th>% +/- 0.5D</th>
<th>% +/- 1.0D</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-C (K)</td>
<td>0.41</td>
<td>0.688</td>
<td>0.814</td>
<td>0.706</td>
<td>1.19</td>
<td>46.2%</td>
<td>84.6%</td>
<td>0.702</td>
</tr>
<tr>
<td>DOR (T)</td>
<td>0.48</td>
<td>0.708</td>
<td>0.792</td>
<td>0.720</td>
<td>1.53</td>
<td>30.8%</td>
<td>69.2%</td>
<td>0.829</td>
</tr>
<tr>
<td>T2 (K)</td>
<td>0.42</td>
<td>0.752</td>
<td>0.749</td>
<td>0.794</td>
<td>1.38</td>
<td>30.8%</td>
<td>69.2%</td>
<td>0.860</td>
</tr>
<tr>
<td>DOR (K)</td>
<td>0.48</td>
<td>0.724</td>
<td>0.735</td>
<td>0.763</td>
<td>1.65</td>
<td>38.5%</td>
<td>69.2%</td>
<td>0.879</td>
</tr>
<tr>
<td>Barrett (K)</td>
<td>0.53</td>
<td>0.767</td>
<td>0.785</td>
<td>0.773</td>
<td>1.50</td>
<td>38.5%</td>
<td>61.5%</td>
<td>0.912</td>
</tr>
<tr>
<td>hallway 1 (K)</td>
<td>0.48</td>
<td>0.715</td>
<td>0.716</td>
<td>0.757</td>
<td>1.47</td>
<td>38.5%</td>
<td>69.2%</td>
<td>0.838</td>
</tr>
<tr>
<td>hallway (K)</td>
<td>0.48</td>
<td>0.752</td>
<td>0.749</td>
<td>0.794</td>
<td>1.38</td>
<td>30.8%</td>
<td>69.2%</td>
<td>0.860</td>
</tr>
<tr>
<td>Hags (K)</td>
<td>0.76</td>
<td>0.856</td>
<td>0.970</td>
<td>0.795</td>
<td>1.81</td>
<td>38.5%</td>
<td>53.8%</td>
<td>1.013</td>
</tr>
<tr>
<td>Hags (T)</td>
<td>0.78</td>
<td>0.852</td>
<td>0.895</td>
<td>0.731</td>
<td>1.45</td>
<td>38.5%</td>
<td>69.2%</td>
<td>1.034</td>
</tr>
<tr>
<td>Hager (K)</td>
<td>0.76</td>
<td>0.882</td>
<td>1.000</td>
<td>0.786</td>
<td>1.84</td>
<td>38.5%</td>
<td>53.8%</td>
<td>1.068</td>
</tr>
<tr>
<td>Hager (T)</td>
<td>0.75</td>
<td>0.857</td>
<td>0.735</td>
<td>0.795</td>
<td>2.04</td>
<td>30.8%</td>
<td>69.2%</td>
<td>1.073</td>
</tr>
<tr>
<td>SKRT (K)</td>
<td>-0.05</td>
<td>0.102</td>
<td>0.660</td>
<td>1.422</td>
<td>3.64</td>
<td>46.2%</td>
<td>61.5%</td>
<td>1.367</td>
</tr>
</tbody>
</table>
TK in Post-PKP Eyes: Summary

- Very small number of eyes that met inclusion criteria
- TK results were not statistically better than K results
- While we recommend K6 (with K or with TK) as having the best performance across all studied eyes, we also note the strong performance of Kane and EVO, with the caveat that these formulas may not compute all eyes, so surgeons should be prepared to utilize other formulas.

Our Recommendations for TK

- TK values can help detect previous M-LVC eyes (CRW1 Index)
- Post M-LVC Eyes
  - Use dedicated post M-LVC formulas with traditional K values
  - TK helps improve the EVO-LVC and Barrett True K formulas
- KCN Eyes
  - Both Ks are < 50D: multivariable formulas with TK did better than K; KCN-specific formulas did not help
  - If one K is > 50D, KCN-specific formulas (either with K or TK) work best; SRK/T works well
- Extreme K Eyes
  - TK didn’t help much; multivariable formulas > older formulas
- Phaco-DMEK Eyes
  - Do NOT use TK values; better to use IOL1D up > K values
- Post-PKP Eyes
  - TK did not help much; multivariable formulas > older formulas

THANK YOU