Data-Driven IOL Calculations
Gerald Clarke, M.D.
Warren Hill, M.D.

Kudos
- Surgeons and Staff at:
  - Florida Eye - Val Zudans, M.D.
  - Chippewa Valley Eye - Tom Harvey, M.D.
  - Montefiore Eye Center, Jimmy Lee, M.D., Rebecca Weiss, Philip Kurochkin, Matthew Nicholas
  - Eye Doctors of Washington, Paul Kang, M.D.
  - Adam Kapelner, Ph.D., Assistant Professor Mathematics, Queens College, NYU
- The Great Ones: Warren Hill, Jack Holladay, Ken Hoffer, Don Sanders, Ketzlaff, Manus Kraft, Wolfgang Haigis, Thomas Olsen, Graham Barnett, and Many More...

Financial Disclosures
- Owns Copyright, CMO - FullMonteData, LLC
- Consultant, Appasamy Associates
- Founder, CEO, ReaLens, Inc.
- Consultant, Research
- The services of MathWorks were provided through a research grant from Haag-Streit, Switzerland.
- The author’s current industry relationships are with:
  - Alcon Laboratories: Consultant, Speaker, Clarity Medical Systems: Consultant, Stockholder, Haag-Streit: Consultant, Speaker, Research, Oculus: Consultant, Research

Einstein:
- As far as the laws of mathematics refer to reality, they are not certain;
- and as far as they are certain, they do not refer to reality.
All Models are Wrong!!

- Main Question: How Wrong?
- Models are Representations of Reality
- Current IOL Calc Models: SRKT, HofferQ, Holladay 1&2, Haigis, Barrett, Olsen

Current Models

- Formula calculations
  - Published – SRK-T, Holladay 1, HofferQ, Haigis
  - Unpublished – Holladay 2, Barrett, Olsen

- Data Driven
  - Computed – Not Calculated
  - Store Large Data Sets & Algorithms
    - On Machine (Biometers – Haag Streit)
    - In Cloud (FullMonte IOL)
  - Future of Our Numeric Specialty

The Problem: Precision

- Colt 0.45
- Walther P.22

The Standard Deviation in all Current Formulas = 0.45 – I want 0.22
The Other Problem: Outliers

- 5% > 1.0 Diopters Pred Error
- 0.1% > 1.0 Diopter Prediction Error

Current Models

- Formula calculations
  - a Single Number
- Data Driven
  - A qualified Number or Probability Distribution
- Future of Our Numeric Specialty

Most Errors outside Sweet Zone

Most Errors outside Sweet Zone

- Short $LOng ACD => Errors
What Do the Best Models Do?

- Predict Well on Unseen (out of sample) Data
- Robust (Don’t Break)
- Handle Multivariable data
- Handle missing data
- Indicate Quality or Probability of Prediction (So Your Brain Machine Can Decide)

Predict Unseen Data

- Single Most important Function of a Model
- How Well Does the Model work on out of Sample (never been seen) data?
Predict Unseen Data

Haigis ELP vs Actual ELP

GRNN ELP vs Actual ELP

MCMC ELP vs Actual ELP
Predict Unseen Data

<table>
<thead>
<tr>
<th></th>
<th>SRKT</th>
<th>HOLL</th>
<th>HAIGIS</th>
<th>Grnn</th>
<th>MCMC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stand</td>
<td>0.45</td>
<td>0.44</td>
<td>0.60</td>
<td>0.40</td>
<td>0.25 –</td>
</tr>
<tr>
<td>Dev</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.35</td>
</tr>
</tbody>
</table>

Predict with MultiVariate Data

- Astigmatism
- Corneal Shape or Aberrations, Anterior and Posterior Cornea, all Meridians
- Pupil Size
- WTW, internal STS

Papa John:

- Better Ingredients = Better Pizza
Ubm Data

Keratomety Data

- Q-Shapefactor (+ Pupil Size) – Hoffer/Savini
- Anterior/Posterior Cornea
- Multiple Zones
- Zernike Aberrations

Good Models Handle Many Variables

- Add New Variables as needed
- Handles Complexity
- Factors (Post Lasik, DSAEK) can bifurcate predictions

Good Model: Robust to Outliers

- All Formulas work reasonably well in central average area
- Predictions Break Down for Long/short eyes/ Extreme Ks
- Machine Learning Models tend to produce predictions that revert to mean
Good Model: Robust to Missing Data

- Important Feature – Not all data can be collected with current biometry/keratometry (Lens Thick)
- MCMC models are re-sizable, dropping or adding variables as needed. Do not Break with holes in data sets. Many Neural Nets can have same features.

Good Models -> How good is my prediction?

- Quality of Prediction
- Assumptions underlying Predictions
  - SRKT - assumes non-imaginary ACD
  - Haigis - assumes ELP Linear to ACD + AXL
  - MCMC models assume data at least T-distributed (Fat Tails)
How good is my prediction?

Your Learning Machine (Intellect)

- Can decide to use the model's predictions or not

Algorithms of Machine Learning

- Big Data (Google-plex)
- Machine Learning Competitions
- Amazon Machine Learning Service
Algorithms of Machine Learning

- Continuous Predictors: (vs Classifiers)
- Linear and Non-Linear Regression
- GRNN $\rightarrow$ Neural Nets
- Support Vector Machines
- Genetic Algorithms
- MCMC predictions

Linear and Non-Linear regression

Non-Linear regression

Neural Nets

Warren Will Discuss
General Regression Neural Nets

Support Vector Machines

Markov Chain Monte Carlo MCMC Techniques

Bayesian Prediction

When an MCMC method is used, "walkers" move around randomly. At each point where a walker steps, the integrand value at that point is counted towards the integral. The walker then may make a number of tentative steps around the area, looking for a place with a reasonably high contribution to the integral to move into next.

Theorem: MCMC can converge to a final probability distribution.

Bayes Principles

Predictions with Assumptions
Bayesian Inference

Most Likely Outcome

Prior

Evidence

Tree Models

Traversing Trees
a billion times

Practical Matters
Does It Work?

- Clinical Studies
- Continually refine Results
- Track Outcomes
Clinical Results 2013 Dr. Val Zudans

Prospective Trial - Used MCMC Guided IOL Selection (FMG) vs SRKT
Chose IOL +/-0.25 diopters in Direction of MCMC Predicted Formula (good Bayesian Decision)
N=93
Results
Reduced StdDev from 0.44 (SRKT) to 0.36 (FMG)
Significant – at pvalue = 0.05478
FMG better predictor 53 times – versus 21 for SRKT, 18 equal
90% of Eyes within 0.50 diopters of intended refraction
61% of Eyes within 0.25 diopters of intended refraction

Clinical Results 2015 Drs. Clarke, Lee, Kapelner

<table>
<thead>
<tr>
<th>Lens Model</th>
<th>N Patients</th>
<th>Mean Average Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>SofTeoHD</td>
<td>1638</td>
<td>0.326</td>
</tr>
<tr>
<td>TecnisZ9002</td>
<td>1147</td>
<td>0.287</td>
</tr>
<tr>
<td>SN60WF</td>
<td>361</td>
<td>0.258</td>
</tr>
<tr>
<td>TecnisZM8000</td>
<td>470</td>
<td>0.251</td>
</tr>
<tr>
<td>TecnisZMB000</td>
<td>454</td>
<td>0.365</td>
</tr>
<tr>
<td>TecnisZHC000</td>
<td>383</td>
<td>0.303</td>
</tr>
<tr>
<td>AcrysofRestorSN6A</td>
<td>201</td>
<td>0.343</td>
</tr>
<tr>
<td>SofteoCarat1B</td>
<td>172</td>
<td>0.307</td>
</tr>
<tr>
<td>SofteoCarat1A</td>
<td>172</td>
<td>0.334</td>
</tr>
<tr>
<td>SofteoCarat1D</td>
<td>155</td>
<td>0.334</td>
</tr>
<tr>
<td>AkreosAOMI60</td>
<td>120</td>
<td>0.333</td>
</tr>
<tr>
<td>other</td>
<td>187</td>
<td>0.563</td>
</tr>
</tbody>
</table>

The IOL Power Calculation Process...

1. Get Patient History
   - Refractive Surgery
   - Dry Eyes, Corneal Disease
   - Contact Lens wear
   - Gotchas!
2. Send Data from LenStar or IOLMaster to Cloud (fullmonteiol.com)
3. Use The Probability Estimates to Pick Your IOL
4. Collect Postop Data, to Refine A Constant, C- Constant, Haigis Vectors

Back to the Future

- Predict Astigmatism – Use total Corneal Astigmatism – Incorporate Ray-Tracing and aberrometry
- Femto AKs – Better Nomograms
- Groups (Factors)
  - Post Lasik/RK
  - DMEK, DSAEK
  - Lasik – all Flavors
Thanks for your attention

Gerry@fullmonteiol.com
www.FullMonteiol.com

Smartest Guy in the Room