Corneal Biomechanics in Refractive Surgery: An Update

Cynthia Roberts, Ph.D.
Professor of Ophthalmology and Biomedical Engineering
Martha G. and Milton Staub Chair for Research in Ophthalmology
The Ohio State University

Egyptian Ophthalmological Society
AAO Symposium
March 28, 2019
Cairo, Egypt

THE OHIO STATE UNIVERSITY
Biomedical Engineering
THE OHIO STATE UNIVERSITY Medical Center

Disclosure

- Travel Funding by STAAR Surgical
- Consultant to Ziemer Ophthalmic Systems AG
- Consultant to Oculus Optikgeräte GmbH
- Advisory Board and Consultant of Optimeyes

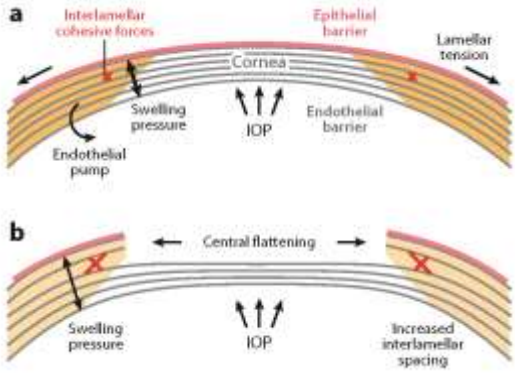
Biomechanical Response in Refractive Surgery

- Stable modification of every treatment outcome
- Unstable decompensation (ectasia)
  - "At risk" cornea pre-operatively
  - Too much tissue altered by surgery

Biomedical Engineering Medical Center

Cynthia J. Roberts, Ph.D.

Biomechanical Response to Refractive Surgery

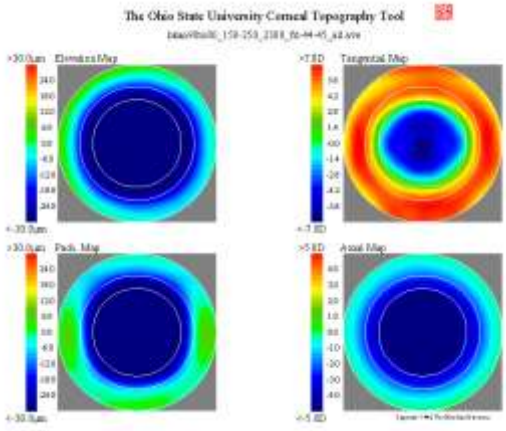


Ruberti JW, Sinha Roy A, Roberts CJ. Corneal Biomechanics and Biomaterials. *Annual Review of Biomedical Engineering*, 2011 Aug 15; Vol. 13, pp. 269-95.

Biomedical Engineering Medical Center

Cynthia J. Roberts, Ph.D.

Composite difference maps for entire Population: Anterior Surface (n=2,380)



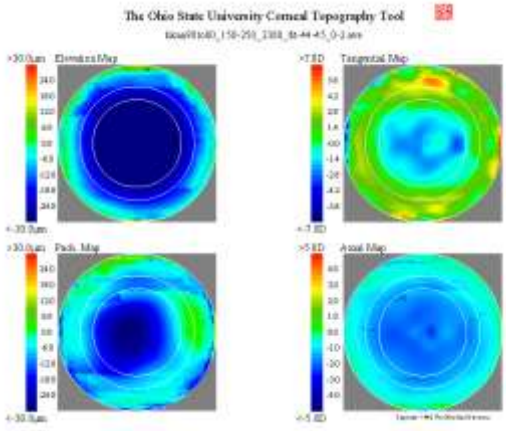
- All regions show statistically significant differences from pre-operative state.
- Although there are areas of increased height and pachymetry in the outer zone, the overall trend of the region as a whole is decreased.

Roberts CJ, Mahmoud AM. Topographic Changes after Excimer Laser Refractive Surgery, in: Kılıç A, Roberts CJ (eds). *Corneal Topography: from Theory to Practice*, Amsterdam: Kugler Publications; 2013:239-270.

Biomedical Engineering | Medical Center

Cynthia J. Roberts, Ph.D.

Composite Anterior Difference Maps Myopic Correction < 2 D



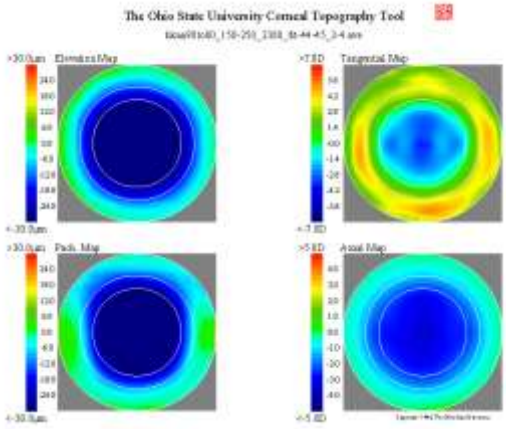
- n = 25
- All regions except outer elevation zone show statistically significant differences from pre-operative state.

Roberts CJ, Mahmoud AM. Topographic Changes after Excimer Laser Refractive Surgery, in: Kılıç A, Roberts CJ (eds). *Corneal Topography: from Theory to Practice*, Amsterdam: Kugler Publications; 2013:239-270.

Biomedical Engineering | Medical Center

Cynthia J. Roberts, Ph.D.

Composite Anterior Difference Maps Myopic Correction from 2 to 4 D

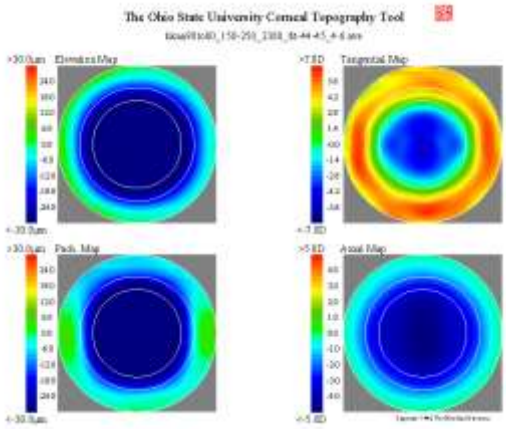


- n = 321
- All regions show statistically significant differences from pre-operative state.

Roberts CJ, Mahmoud AM. Topographic Changes after Excimer Laser Refractive Surgery, in: Kılıç A, Roberts CJ (eds). *Corneal Topography: from Theory to Practice*, Amsterdam: Kugler Publications; 2013:239-270.

Biomedical Engineering | Medical Center

Composite Anterior Difference Maps Myopic Correction from 4 to 6 D

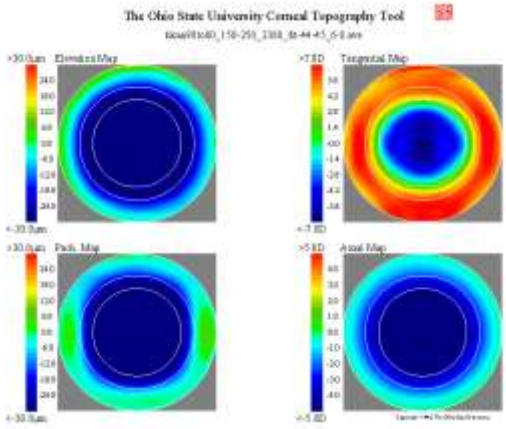


- n = 635
- All regions show statistically significant differences from pre-operative state.

Roberts CJ, Mahmoud AM. Topographic Changes after Excimer Laser Refractive Surgery, in: Kılıç A, Roberts CJ (eds). *Corneal Topography: from Theory to Practice*, Amsterdam: Kugler Publications; 2013:239-270.

Biomedical Engineering | Medical Center

Composite Anterior Difference Maps Myopic Correction from 6 to 8 D

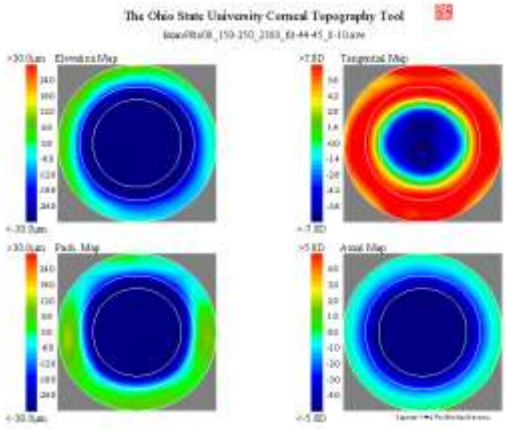


- n = 622
- All regions show statistically significant differences from pre-operative state.

Roberts CJ, Mahmoud AM. Topographic Changes after Excimer Laser Refractive Surgery, in: Kılıç A, Roberts CJ (eds). *Corneal Topography: from Theory to Practice*, Amsterdam: Kugler Publications; 2013:239-270.

Biomedical Engineering

Composite Anterior Difference Maps Myopic Correction from 8 to 10 D

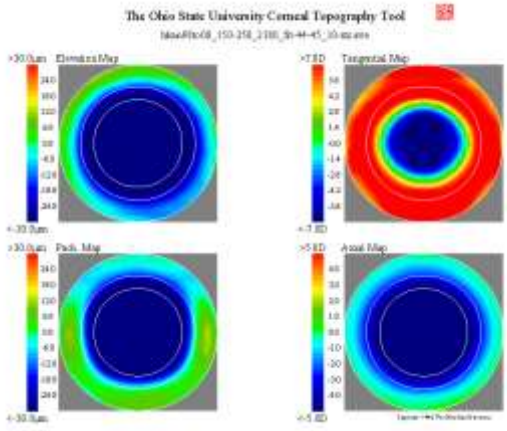


- n = 465
- All regions show statistically significant differences from pre-operative state.
- Note area of increased pachymetry in outer zone is larger, although trend of whole region remains decreased.

Roberts CJ, Mahmoud AM. Topographic Changes after Excimer Laser Refractive Surgery, in: Kılıç A, Roberts CJ (eds). *Corneal Topography: from Theory to Practice*, Amsterdam: Kugler Publications; 2013:239-270.

Biomedical Engineering

Composite Anterior Difference Maps Myopic Correction for > 10 D



- n = 311
- All regions except outer pachymetry show statistically significant differences from pre-operative state.
- Area of central decreased curvature is diminished.

Roberts CJ, Mahmoud AM. Topographic Changes after Excimer Laser Refractive Surgery, in: Kılıç A, Roberts CJ (eds). *Corneal Topography: from Theory to Practice*, Amsterdam: Kugler Publications; 2013:239-270.

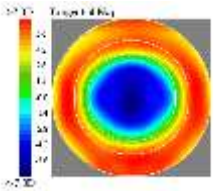
Biomedical Engineering

Medical Center

Cynthia J. Roberts, Ph.D.

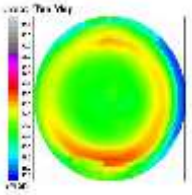
Stable Biomechanical Response

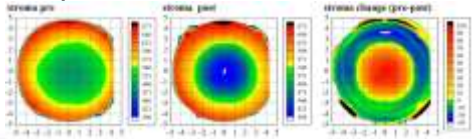
- Central Flattening
  - Flap in LASIK
  - Ablation
  - Lenticule removal



Average LASIK difference map (n=2,380)

- Paracentral/peripheral increase in curvature (red ring)
  - Spherical aberration induction
  - Decrease in post-op functional optical zone
- Peripheral increase in thickness





Biomedical Engineering

Medical Center

Reinstein DZ, et al. Arc-scanning very high-frequency digital ultrasound for 3D pachymetric mapping of the corneal epithelium and stroma in laser in situ keratomileusis. J Refract Surg. 2000;16:414-430.

Cynthia J. Roberts, Ph.D.

Percentage increase in central corneal strain (stretch)

to an intraocular pressure change from 15 to 15.5mmHg

	90 µm	160 µm
LASIK Flap	9%	32%
Sidecut Only	9%	33%
Delamination Only	5%	5%

Knox Cartwright NE, Tyrer JR, Jaycock PD, Marshall J. Effects of Variation in Depth and Side Cut Angulations in LASIK and Thin-flap LASIK Using a Femtosecond Laser: A Biomechanical Study. J Refract Surg. 2012;28:419-425.

Theoretical vs Clinical Studies

ORIGINAL ARTICLE

Comparison of biomechanical effects of small-incision lenticule extraction and laser in situ keratomileusis: Finite-element analysis

Abhijit Sinha Roy, PhD, William J. Dupps Jr, MD, PhD, Cynthia J. Roberts, PhD

BIOMECHANICS

Contralateral Eye Comparison of SMILE and Flap-Based Corneal Refractive Surgery: Computational Analysis of Biomechanical Impact

Biomechanical Comparison

- Less severing of anterior lamellae in SMILE
- Greater maintenance of integrity of anterior portion of stroma in SMILE
- Greater stress in the residual stromal bed in LASIK than SMILE

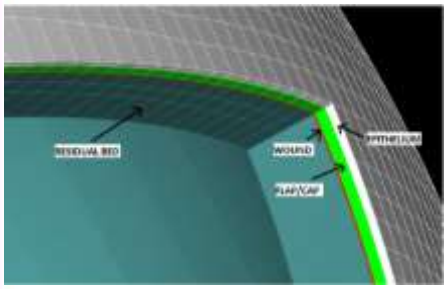
Sinha Roy A, Dupps WJ, Roberts CJ. "Comparison of Biomechanical Effects of Small Incision Lenticule Extraction (SMILE) and Laser in situ Keratomileusis (LASIK): A Finite Element Analysis Study." *J Cataract Refract Surg* 2014; 40:971-980.

Biomedical Engineering

Medical Center

Cynthia J. Roberts, Ph.D.

Flap vs Cap Contralateral Study



- 10 eyes of 5 patients
- SMILE in one eye
- FLEx in fellow eye
- Patient-specific Inverse Finite Element Analysis
- Forward analysis at elevated IOP

Seven, Vahdati, Pedersen, Vestergaard, Hjortdal, Roberts, Dupps. Contralateral-Eye Comparison of Small Incision Lenticule Extraction and Flap-Based Corneal Refractive Surgery: Computational Analysis of Biomechanical Impact. JRS 2017; 33:444-453.

Biomedical Engineering

Medical Center

Cynthia J. Roberts, Ph.D.

Inverse Finite Element Modeling

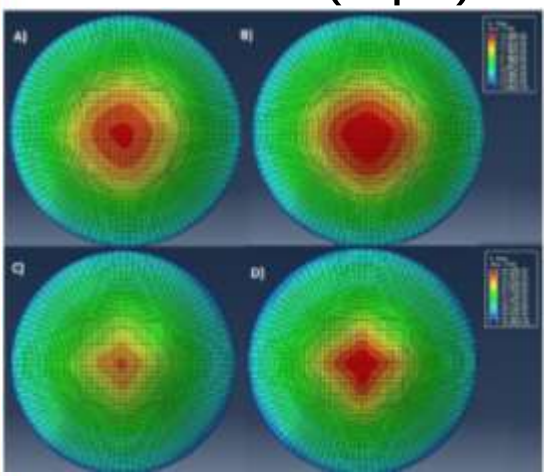
- Build Model with Pre-op Tomography
- Post-op Tomography is target
- Iterate Model biomechanical parameters until post-op tomography is achieved within a small error limit

Results

- FLEx produced 49% (range 2-87%) greater mean reduction in stromal collagen fiber stiffness within the flap region than contralateral cap region in SMILE
- Lower stresses and deformations within residual stromal bed in SMILE eyes

Seven, Vahdati, Pedersen, Vestergaard, Hjortdal, Roberts, Dupps. Contralateral-Eye Comparison of Small Incision Lenticule Extraction and Flap-Based Corneal Refractive Surgery: Computational Analysis of Biomechanical Impact. JRS 2017; 33:444-453.

Residual Stromal Bed von-Mises Stresses (Mpa) for Subject 1



A) SMILE at 15mmHg
B) FLEx at 15mmHg

C) SMILE at 30mmHg
D) FLEx at 30mmHg

Red is greater stress

Seven, Vahdati, Pedersen, Vestergaard, Hjortdal, Roberts, Dupps. Contralateral-Eye Comparison of Small Incision Lenticule Extraction and Flap-Based Corneal Refractive Surgery: Computational Analysis of Biomechanical Impact. JRS 2017; 33:444-453.

Biomedical Engineering Medical Center

Cynthia J. Roberts, Ph.D.

SMILE/LASIK Summary

SMILE offers biomechanical advantages over LASIK

However, <u>strongest cornea is pre-op cornea</u>!

Biomedical Engineering Medical Center

Cynthia J. Roberts, Ph.D.

Biomechanics of LASER Refractive Surgery

- PRIMARY EFFECT IS THE **AMOUNT OF TISSUE REMOVED** TO GENERATE REFRACTIVE EFFECT
- Secondary effect is location of tissue removal, whether at the surface, under a flap or under a cap

Biomedical Engineering Medical Center

Cynthia J. Roberts, Ph.D.

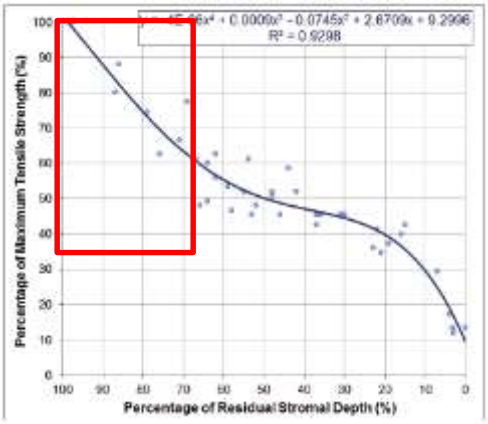
"At Risk" Cornea

- Corneas identified as "at risk" by pre-operative screening tools may indicate an underlying biomechanical abnormality.
- This biomechanical abnormality OVERCOMES biomechanical advantages with SMILE

Biomedical Engineering Medical Center

Cynthia J. Roberts, Ph.D.

Depth Dependence of Corneal Tensile Strength



Randleman JB, Dawson DG, Grossniklaus HE, McCarey BE, Edelhauser HF. Depth-dependent cohesive tensile strength in human donor corneas: implications for refractive surgery. J Refract Surg. 2008;24:S85-89.

Biomedical Engineering Medical Center

Cynthia J. Roberts, Ph.D.

CAUTION

- **DO NOT PERFORM SMILE IF YOU SUSPECT AN "AT-RISK" CORNEA!**
- **If you would NOT perform LASIK, do NOT perform SMILE!**

Biomedical Engineering Medical Center

Cynthia J. Roberts, Ph.D.

Summary

- Any incisional/ablative/femtosecond disruption that cuts tension bearing lamellae will generate a biomechanical response.
- Changing surface shape via corneal biomechanics will change visual outcomes!

Thank you!

Biomedical Engineering Medical Center
Cynthia J. Roberts, Ph.D.