Rapidly Changing Landscape of Refractive Technology

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Abstract:

TGLASIK, TEPRK, SMILE, LIKE, LIRIC, LAL, EDOF, SAO, or my!! If you don't know what all these acronyms mean, then this course is for you! Refractive technology is ever evolving with a veritable alphabet soup of new procedures and lenses. This lecture will teach about today's newest technologies and what's to come in the near future. We will cover cornea and lens based procedures, discuss considerations for myopic, hyperopic, astigmatic, and presbyopic correction, IOL lens optics, new devices for visual simulation, and the importance of myopia control in the concept of comprehensive refractive management.

Course Learning Objectives:

1. Understand excimer and femtosecond laser technologies used in cornea based refractive surgery
2. Understand lens technologies used in lens based refractive surgery
3. Discuss new advances in refractive surgery and upcoming treatments and diagnostics under development

Outline:

1. General refractive landscape
    a. Correction for everything
        i. Myopia
        ii. Hyperopia
        iii. Astigmatism
        iv. Presbyopia
            1. Irregular Astigmatism?
    b. Temporary
        i. Glasses
        ii. Contact lenses
        iii. Orthokeratology
    c. Permanent
        i. Surgery
            1. Method
                a. Add
                b. Subtract
                c. Replace
                d. Remodel
            2. Surgical site
                a. Cornea
                b. Lens
2. Vision Council 2019 report
    a. Percentage of patients undergoing refractive surgery is increasing

        i. Pandemic mask factor
3. Who are ideal refractive candidates
    a. Contact lens abusers
        i. Reduced risk of MK
    b. Contact lens failures
    c. Athletes
4. Refractive management and surgery across a lifetime
    a. Spectacle and contact lens free vision possible at all ages
        i. Sub 18
            1. Non-surgical for peds
                a. Orthokeratology
        ii. 18+
            1. Cornea based option overview
                a. Excimer based
                b. Femtosecond based
            2. Lens-based option
                a. Pseudophakic IOL
                b. Phakic ICL
5. Brief overview of clinical optics
    a. Refractive anatomy
        i. Cornea
        ii. Lens
        iii. Axial length
    b. 2 refractive surgery targets
        i. Cornea
        ii. Lens
6. Advances in technology have led to the treatments we see today
    a. Significant work in diagnostics to improve evaluation of patients
        i. Why care?
            1. Rule out corneal based surgery
                a. Possibility of iatrogenic disease
                    i. Alternative surgical options
                        1. Lens-based refractive surgery
                b. Forgo elective surgery all together
            2. Follow up more frequently
7. Surgical management
    a. History and origin of modern refractive surgery
        i. Jose Barraquer
            1. Father of modern refractive surgery
                a. Proposed that the term refractive keratoplasty
                    i. Keratomileusis
                    ii. Keratophakia
            2. Procedure evolution

a. Radial keratotomy
    i. First by hand
        1. LRI for astigmatism
            a. Evolve to femtosecond laser
        2. Radial keratotomy for myopia and astigmatism
b. Excimer laser
    i. Data input
        1. Wavefront optimized
        2. Wavefront guided
        3. Topography guided
c. Thermal
    i. Conductive keratoplasty
        1. Radiowave to create collagen shrinkage
        2. FDA approval
            a. Hersh et al 2002
d. Femtosecond laser
    i. Flap
    ii. Lecticule

8. Cornea-based refractive surgery
    a. Laser
        i. First application of laser in health care was ophthalmology
            1. Light amplification by stimulated emission of radiation
                a. First application was used in retina
                    i. L'Esperance et al 1968
                        1. Pulsed ruby
                            a. Commercially available in 1971
            2. First application to the cornea
                a. Excimer laser
                    i. Ablation of corneal tissue
                        1. No collateral tissue damage
                    ii. FDA approval
                        1. Hersh et al 1996
                            a. Myopia
                b. Femtosecond laser
                    i. Cavitations principle to separate tissue
                        1. FDA approval 2000
                            a. Lamellar flaps
                        2. FDA approval 2007
                            a. Myopia
    b. Modern surgical approach
        i. Excimer laser
            1. Early development

a. Wavelength
2. Stromal ablation
    a. Surface ablation
        i. Photorefractive keratectomy (PRK)
            1. Removal of epithelium followed by ablation
    b. Lamellar dissection
        i. Laser assisted in situ keratomileusis (LASIK)
            1. Flap creation to expose stromal bed followed by ablation
                a. Microkeratome
                b. Femtosecond laser
3. Wavefront optimized
    a. Algorithmic eccentricity to reduce aberrations
4. Wavefront guided
    a. Aberrometry data input to create custom ablation for treatment of total optical aberrations
5. Topography guided
    a. Topography data input to create a custom ablations for smoothing of anterior corneal surface irregularity
6. Tomography guided
    a. Tomography data input to create a surface ablation for total corneal aberrations
        i. Advanced algorithms with anterior and posterior curvature calculations

ii. Femtosecond laser
1. Intrastromal lenticule
    a. Small Incision Lenticule Extraction (SMILE)
        i. Lenticule formed within the anterior stroma and removed

c. Near future procedure
i. LIKE
1. Lamellar flap created
    a. Pre-prepared allograft stromal lenticule laid on bowmans
    b. The flap is then replaced
        i. 8 weeks to stabilize
            1. If needed, the flap is re-lifted and a final touch-up laser correction on the LIKE lenticule is performed.
                a. US clinical trial ongoing
2. Indication
    a. Hyperopia correction of 4+ diopters
        i. Fully reversible procedure
        ii. Large optical zone of 7+ mm

1. Less aberration

ii. Refractive cross-linking
1. Patterned biomechanical change for inducing cornea curvature changes

d. In the lab
i. Dual photon femtosecond laser
1. Sub-cavitation
a. Ionizing tissue, create singlet oxygen
i. Increased tissue strength
1. Guo et al 2016
2. Wang et al 2017
a. Laboratory only

ii. UV ablations
1. Newer power source for faster more precise ablations

9. How well do patients do after LASIK?
a. The PROWL studies = Patient reported outcomes with LASIK
i. Eydelman M, Hilmantel G, Tarver ME, Hofmeister EM, May J, Hammel K, Hays RD, Ferris F 3rd. Symptoms and Satisfaction of Patients in the Patient-Reported Outcomes With Laser In Situ Keratomileusis (PROWL) Studies. JAMA Ophthalmol. 2017 Jan 1;135(1):13-22. doi: 10.1001/jamaophthalmol.2016.4587. PMID: 27893066.
ii. Hays RD, Tarver ME, Spritzer KL, Reise S, Hilmantel G, Hofmeister EM, Hammel K, May J, Ferris F 3rd, Eydelman M. Assessment of the Psychometric Properties of a Questionnaire Assessing Patient-Reported Outcomes With Laser In Situ Keratomileusis (PROWL). JAMA Ophthalmol. 2017 Jan 1;135(1):3-12. doi: 10.1001/jamaophthalmol.2016.4597. PMID: 27893063.
iii. Sugar A, Hood CT, Mian SI. Patient-Reported Outcomes Following LASIK: Quality of Life in the PROWL Studies. JAMA. 2017 Jan 10;317(2):204-205. doi: 10.1001/jama.2016.19323. PMID: 28097345.

10. How do patient do after LASIK in comparison to contact lenses
a. Patient reported outcomes with LASIK vs Contact Lenses
i. Price MO, Price DA, Bucci FA Jr, Durrie DS, Bond WI, Price FW Jr. Three-Year Longitudinal Survey Comparing Visual Satisfaction with LASIK and Contact Lenses. Ophthalmology. 2016 Aug;123(8):1659-1666. doi: 10.1016/j.ophtha.2016.04.003. Epub 2016 May 18. PMID: 27208981.

11. Lens-based refractive surgery
a. Harold Ridley
i. Father of modern IOL
1. Discovered PMMA inert in eye
a. Developed PMMA IOL

ii. Procedure evolution

1. Phacoemulsification
2. Small incision
    a. Foldable IOL
3. Femtosecond laser

iii. Implant evolution
1. Optical profiles

b. Intraocular procedures
i. Phakic ICL
1. Maintains crystalline lens
    a. Maintains accommodation
2. Multiple placements of lens
    a. Anterior chamber
        i. Iris claw
            1. Seldom used
    b. Posterior sulcus

ii. Pseudophakic IOL
1. Removes crystalline lens
    a. No accommodation
        i. No pathology
            1. Refractive lens exchange
        ii. Crystalline lens pathology
            1. Cataract
            2. Dysfunctional lens syndrome
2. Capsular bag
    a. If zonula damage or capsular lens is sutured into place
3. Same as cataract surgery
    a. Small incision
    b. Capsulorhexis

iii. Femtosecond laser-assisted surgery
1. Precision
2. Repeatability
3. Less energy

iv. Lens options
1. IOL technology
    a. Monofocal
    b. Toric
    c. Presbyopic
        i. Refractive
        ii. Defractive
        iii. EDOF
        iv. Small aperture
    d. Light adjustable
2. ICL technology

a. Monofocal
b. Toric

v. Adjunctive procedures
1. Phakic ICL
a. Pre-op peripheral iridotomy
i. Prevent IOP increase
1. New lenses contain an aqueous pass-through
2. Pseudophakic IOL
a. MIGS
b. Iris Implant
i. Iris defects
ii. Intracapsular vs sutured in

c. Newest additions
i. Small aperture
1. Principles of KAMRA but without biocompatibility issues
a. Phase 3
i. European Multicenter
ii. Distance
1. 90% 20/20 or better
iii. Intermediate
1. 66% 20/20 or better
iv. Near
1. 23% 20/20 or better
b. US approval in 2022
2. Favorable outcomes in irregular corneas
a. 2 line or more improvements at all distances

ii. Light adjustable
1. Electromagnetically activated polymer
a. Ability to correct vision post surgery without additional surgery
i. Lock in refractive treatment
ii. Future polymer will have unlimited lock and unlock

12. New treatment for both lens and cornea
a. Laser-Induced Refractive Index Correction (LIRIC)
i. Low-energy, high-repetition-rate femtosecond laser
ii. Fresnel lens patterns to correct presbyopia, myopia, hyperopia, astigmatism, and higher-order aberrations.
1. Cornea = intrastromal
2. IOL = intraoptic
3. Contact lens = intra material
a. OUS studies underway

13. FAQ

a. What happens if the refractive target is missed?
    i. Enhancements
        1. After PRK
            a. PRK
        2. After LASIK
            a. Relift flap and ablate
            b. PRK surface ablation
        3. After SMILE
            a. PRK surface ablation
        4. After lens based refractive surgery
            a. Cornea based refractive surgery is key to refining vision

14. Presbyopia
    a. Considerations
        i. Classification
            1. Chang DH, Waring GO 4th, Hom M, Barnett M. Presbyopia Treatments by Mechanism of Action: A New Classification System Based on a Review of the Literature. Clin Ophthalmol. 2021;15:3733-3745
                a. Interventions
                    i. Varying Refractive Power Over Time
                        1. Topical therapy
                            a. Ciliary muscle contraction
                            b. Dissolved disulfide bonds
                        2. Scleral relaxation
                        3. Accommodating IOL
                    ii. Varying Refractive Power Across the Visual Field
                        1. Multifocal spectacles
                    iii. Varying the Refractive Power Between Eyes
                        1. Static anisometropia
                            a. Monovision
                    iv. Varying the Refractive Power Across a Range of Distance
                        1. Pseudoaccommodation
                            a. EDOF
                            b. Small aperture
                            c. Refractive, and diffractive optics
        ii. Preserve natural accommodation?
            1. Elimination based with RLE
                a. Maintain corneal based procedures and phakic IOL
        iii. Presence of pathology
            1. Cataract
    b. Cornea based treatment
        i. Current

1. High eccentricity ablation
    a. Reinstein
2. Blended vision
    a. Reinstein binocularity studies
    b. Limitation
3. Synthetic inlays
    a. Methods
        i. Raindrop (ReVision Optics)
            1. FDA approval 2016
                a. Center near (hyperprolate)
        ii. Flexivue microlens (Presbia)
            1. Clinical trial
                a. Center distance
        iii. KAMRA (AcuFocus)
            1. FDA approval 2016
                a. Pinhole
    b. Failure of inlays
        i. Biocompatibility issues
            1. Inlays block glucose from the posterior and oxygen from anterior
            2. May cause haze, regression, need for prolonged corticosteroids, glare, halo, dimness, corneal melt, interface deposits and material buildup
                a. Raindrop FDA recall
                b. Flexivue microlens clinical trial abandoned
                c. KAMRA generally not used
        ii. Multiple cases of haze and complications documented
        iii. All inlays are in line of sight = visually impactful complications

ii. Future

1. Corneal tissue inlays
    a. Theoretically enhanced biocompatibility
    b. Presbyopic inlays based on SMILE Lenticule transfers studies
        i. Jacob et al. = PEARL = Hyper Prolate Shape
            1. Pocket insertion
        ii. Lui et al
            1. Allograft vs Xenograft vs Decellularized Xenograft
                a. Placed under a flap

i. Well tolerated with De-cell Xeno and Allo
ii. Haze with Xeno lasting 6 months
iii. Banking SMILE tissue in US fraught with issues
1. How to overcome it?
a. Sterilized allogeneic corneal tissue
2. Commercially prepared corneal tissue inlays and onlays of sterilized allogeneic corneal tissue
a. Femtosecond laser shaped
b. Single cornea = multiple lenticules
c. 2-year shelf life
d. Phase 2 Study
i. Multicenter EU
ii. Highly effective and safe
iii. Binocular
iv. No loss of UCVA
v. 2 line improvement in UCIVA
vi. 5 line improvement in UCNVA
1. US Phase 3 coming soon

15. Myopia
a. Myopia
i. Prevalence by age (Theophanous 2018)
1. 5 to 7: 15%
2. 8 to 10: 33%
3. 11 to 13: 49%
4. 14 to 16: 56%
ii. Pre-myopia and predictors of myopia (Zadnik 2015)
1. Myopia onset
iii. Annual progression rates
1. School-aged children (Donovan 2013)
2. Young to middle-aged adults (Lee 2020)
b. Considerations in refractive surgery
i. Level of myopia
1. Concern in lens-based
a. Retinal detachment
b. Myopic maculopathy
2. Concern in cornea based
a. Iatrogenic ectasia
ii. Why utilize treatments to slow myopia progression?
1. Important to refractive surgery
a. Improved outcomes at lower levels
b. Less chance of complications

c. Primary management strategies
    i. Walline et al in 2020
        1. Soft lens: dual focus, multifocal, custom
        2. Orthokeratology: standard, custom
            a. Bullimore et. al in 2020
        3. Low dose atropine: concentrations
            a. ATOM
            b. ATOM
            c. LAMP
d. Pediatric cornea-based refractive surgery?
    i. An ongoing study in the US

16. Diagnostics
    a. Diagnostics used to evaluate a refractive candidate
        i. Refraction
            1. Level of error
                a. Spherical
                    i. High plus or high minus
                b. Cylinder
                    i. High cyl
                    ii. Axis orientation
                c. Add power
                    i. Reinstein monovision study
            2. Review of refraction study
                a. Chung et al 2020
                    i. Average axis orientation: oblique or ATR
                    ii. Cyl (refractive or K) > 1.5D should be worked up
            3. Review of retinoscopy study
                a. Al-Mahrouqi et al 2019
                    i. Compare retinoscopy to Pentacam BAD D-value findings ≥2.69.
                    ii. The results to assess the validity and reliability.
                    iii. Retinoscope is sensitive for detection even in early KC
        ii. Topography
            1. Reflection based = anterior surface only
                a. Utility
                    i. Corneal curvature evaluation
                        1. KC or surface?
                            a. Mires matter
                        2. Is is KC?
                            a. Rabinowitz et al
                                i. K (Central and Apical) > 47D
                                ii. IS > 1.4D

iii. Skew (SRAX) > 20deg if >1.5DD

ii. Clinical pearl:

1. Symmetry is key!
2. Look out for tear film
    a. Treat and repeat

iii. Tomography metrics

1. Full corneal metrics
    a. Corneal curvature and elevation
        i. Anterior and posterior
        ii. Motlagh et al
            1. Curvature (Axial Map)
                a. Same metrics apply
            2. Elevation (Posterior >20>Anterior >15)
            3. Pachymetry (<500)
                a. Examples
        iii. Li et al
            1. Epithelial doughnut pattern
                a. Apical epithelial thinning and peripheral thickening
                b. Max to min thickness: ~20μm
                    i. Examples
    b. Global pachymetry
        i. Concept of residual stromal bed
    c. Anterior chamber depth and posterior chamber sulcus
        i. ICL candidacy
    d. Clinical pearl:
        i. Topo rules apply to anterior maps
        ii. Adds posterior surface and global pachymetry!
            1. Focal elevations
            2. Thickness gradients

iv. Aberrometry

1. Full visual system aberrations
    a. Li et al and Kosaki et al
    b. Higher-order aberrations
        i. Vertical COMA is the predominate aberration
            1. Followed by Trefoil
    c. Normal vs Suspect vs KC
        i. <0.2 vs ~0.2-0.3 vs >0.3
            1. Examples
2. Clinical pearl:
    a. Sensitive but nonspecific!!
    b. The cornea or internal!?

        c. Coma and trefoil!
v. Ocular Scatter
    1. Similar to aberrations but quality of focus vs distortion of focus
        a. Full visual system scatter
            i. Stable
                1. Opacity
            ii. Dynamic increase
                1. Tear film
    2. Clinical pearl:
        a. Sensitive but nonspecific!!
        b. The cornea or internal!?
vi. Biomechanics
    1. Roberts et al and Dupps et al
        a. Corneal resistance factor (CRF): Rebound
        b. Corneal hysteresis (CH): Elasticity (less important)
            i. Factors are not sensitive and specific enough to differentiate subclinical from normal
                1. Newer devices exist internationally
                    a. Scheimpflug waveform
                        i. Global weakness
    2. Cases
        a. Normal shape but super weak
    3. Clinical pearl:
        a. Poor diagnostic value on its own
        b. Low corneal resistance
            i. Fast deformation
vii. Biometry
    1. Corneal keratometry
    2. Axial length
        a. Anterior chamber depth
        b.
    3. Axial myopia
        a. Evaluate risk
viii. Genetic testing
    1. Assess risk before physical manifestation
        a. Corneal dystrophy
            i. Monogenic
                1. Positive or negative
        b. Keratoconus
            i. Polygenic
                1. Risk score
        c. Continuously under development
ix. Combine testing

1. Clinical pearl:
    a. Combine for most accurate
    b. Think like glaucoma
        i. More findings = more risk
            1. Healthy patients = good outcomes
    c. Suspicious or borderline findings?
        i. Monitoring
            1. Worsening of the aforementioned metrics overtime = progression
                a. Cornea
                    i. Refer for treatment with CXL
                b. Lens
                    i. Refer for cataract

b. Future diagnostics
    i. Several devices in development
        1. Brillouin
            a. Focal weakness
        2. Elastography
            a. Depth weakness
    ii. Finite element analysis
        1. Simulation based on multiple data points
            a. Used to predict outcomes
                i. Guide surgical decision making
    iii. Visual simulations
        1. VR based
            a. Simulate vision with MF
        2. Adaptive Optics
            a. Deformable mirror to simulate optics
    iv. Task distance trackers
        1. Understand your patients need prior to surgery