The Optics of Contact Lenses

IAO/COS
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No financial disclosures.

Why do we see better with CL's vs. glasses?

Because:

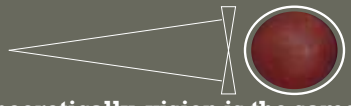
A. We don't; we just look better in CL's.
B. The coating on CL's doesn't scratch when I clean them like glasses do.
C. CL's are thinner than glasses.
D. A CL wearer is always looking through the optical center of the lens.
E. There are fewer aberrations with a CL.

2

Why do we see better with CL's vs. glasses?

Answer:

A. We don't; we just look better in CL's.



- Theoretically, vision is the same with glasses and CL's
  - Full correction not always used with SCL's (uncorrected cylinder)

3

Why do we see better with CL's vs. glasses?

- Early studies comparing acuity with spectacles vs. scl or rigid cl's
  - Hard lenses: 16% one line increase; 55% no change; 28% one line decrease
    - 88% no change with OR
  - Soft lenses: 8% one line increase; 24% no change; 61% one line decrease
    - 67% no change with OR
  - No change/increase by one line 2:1 with hard over soft cl

Wechsler S. Visual acuity in hard and soft contact lens wearers: a comparison. J AOA 1978. 49(3) 251-256.

4

Why do we see better with CL's vs. glasses?

Answer:

A. We don't; we just look better in CL's.

- Improved self perception
  - Adolescent and Child Initiative to Encourage Vision Empowerment (ACHIEVE) study
    - Spectacles vs. SCL wear
    - Self perception with SCL improved for:
      - Physical appearance
      - Athletic competence
      - Social acceptance

Walline, J et al. Randomized trial of the effect of contact lens wear on self-perception in children. Optom Vis Sci. 2009 Mar;86(3):222.32.

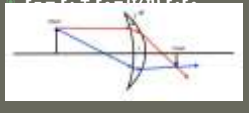
5

Why do we see better with CL's vs. glasses?

Answer:

A. We don't; we just look better in CL's.
B. The coating on CL's doesn't scratch when I clean them like glasses do.
C. CL's are thinner than glasses.

- Equivalent power formula
  - $F_{eq} = F_1 + F_2 - (t/n) F_1 F_2$



6

Why do we see better with CL's vs. glasses?

- **Spectacle magnification**
  - Axial myopia = spec >> cl
  - Axial hyperopia = spec >> cl
  - Refractive myopia << spec < cl
  - Refractive hyperopia >> spec > cl
- **Unencumbered field of view**
  - CL closer to eye's entrance pupil.
  - High ametropia: improved VF with CL

Benjamin WJ. Optical phenomena of contact lenses. Clinical Contact Lens Practice. 2005 Lippincott. Chap 7A. p157

7

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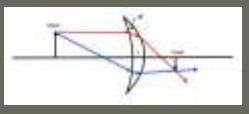
B. The coating on CL's doesn't scratch when I clean them like glasses do.
C. CL's are thinner than glasses.
D. **A CL wearer is always looking through the optical center of the lens.**

- Optical center moves with the eye
- Optic zone



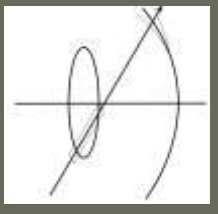
8

Lens Aberrations: ABC's

- Low order aberrations
  - Sphere, cylinder
- Higher order aberrations
- When considering off-axis rays
  - A=Astigmatism of Oblique Incidence
  - B=Barrel/pincushion distortion
  - C=Coma/Chromatic aberration
  - S=Spherical aberration

9

Lens Aberrations: ABC's



Astigmatism of Oblique Incidence

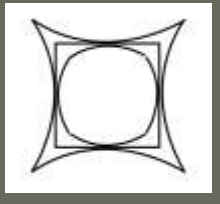
- Oblique rays encounter different radii of curvature at front/back lens surfaces
  - Essentially creates sphero-cylinder along path traveled
  - Result: astigmatic image with two line foci
  - Curved image = curvature of field

10

Lens Aberrations: ABC's

Barrel/pincushion Distortion

- Image forming rays from the corners go through peripheral lens.
- Increased power in the periphery magnifies or minifies corner more than sides
  - Plus lens = pin cushion
  - Minus lens = barrel distortion



11

Lens Aberrations: ABC's

Chromatic aberration

- Prism disperses light into spectral components
  - Blue refracted more than red
  - Creates chromatic interval
  - Basis for duochrome test
- ABBE value of spectacle lenses: higher # = less CA
  - Glass (1.523) = 59; CR-39 (1.49) = 58; Polycarbonate (1.58) = 30

Coma

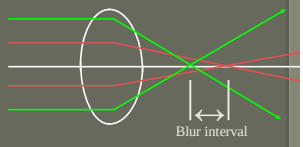
- Off-axis peripheral rays create comet-shaped deformity to non-axial portions of the image

12

Lens Aberrations: ABC's

Spherical aberration

- Peripheral rays subject to increased prismatic effect and more power creating blur interval along axis
- Reduced, physiologically in the eye, by:
  - Pupil acting as aperture.
  - Flatter peripheral cornea radius of curvature.
  - Slightly higher index of refraction for nucleus of crystalline lens.



13

Why do we see better with GP lenses vs. soft contact lenses?

Because:

A. GP lenses hurt more so you have to get something out of wearing them.
B. You don't; GP lenses move more which degrades the image.
C. They mask astigmatism.
D. There is no water content with GP lenses to degrade the image.

14

Why do we see better with GP lenses vs. soft contact lenses?

Because:

A. GP lenses hurt more so you have to get something out of wearing them.
B. You don't; GP lenses move more which degrades the image.
   - Line of sight stays within optic zone as lens moves
C. They mask astigmatism.
   - GP mask up to 2.50 D cylinder with spherical lenses
   - Hide surface irregularity
   - Fluctuating vision:
     - Poor surface wetting
     - Lens deposits/surface scratches
     - Corneal staining
     - Toric lens rotation
     - GP lens flexure

15

Why are the optics better with GP lenses?

- **Materials**
  - Rigid
    - PMMA
    - Silicone acrylates
    - Flurosilicone acrylates
    - Dehydrated state
    - Hydrophilic surface
  - Soft
    - Hydrogel
    - Silicone hydrogel
    - Hydrated state: up to 70% water content
    - Hydrophilic surface

16

Why do we use minus cylinder for contact lens prescriptions?

Because:

A. An optometrist invented CL's.
B. Minus cylinder was invented first.
C. Mostly near sighted people wear CL's.
D. Optometrists use minus cylinder and they fit more CL's.
E. We should use plus cylinder, after all the cornea is convex.

17

Why do we use minus cylinder for contact lens prescriptions?

BECAUSE:

A. AN OPTOMETRIST INVENTED CL'S.

Theoretical

- da Vinci (1508)
  - CL conceptualized
- Descartes (1636)
  - Scientist
- Young (1801)
  - Described neutralizing cornea
- Herschel (1827)
  - Astronomer/physicist
  - Proposed mold of eye to correct vision

Actual

- Scleral Lenses (glass)
  - A.F.Muller (1887): glassblower
    - Protective shell
  - Fick (1888)
    - Physician; diagnostic fitting; rx
  - Kalt (1888): first?
  - Feinbloom (1936): O.D.; PMMA scleral portion; glass center
  - Obrig (1937): all PMMA
- Corneal lenses
  - Tuohy (1948): technician for Obrig; PMMA corneal lens
- GP materials
  - Gaylord (1971): chemist; assisted by Seidner brothers (OD/engineer)→ Polycon material
- Wichterle/Lim (1951): chemists
  - Led to first scl 1971

18

Why do we use minus cylinder for contact lens prescriptions?

Because:

A. An optometrist invented CL's.
B. Minus cylinder was invented first. (No)
C. Mostly near sighted people wear CL's.
   - Self evident: myopia more debilitating; earlier age of onset; more availability of parameters
   - But, can write hyperopic or myopic Rx in either form
D. Optometrists use minus cylinder and they fit more CL's.
   - CL spectrum 2013 survey: 87% of respondents were OD's
   - 24,000 ophtho in US; 35,000 OD's in US
   - 37 millions cl wearers in US

19

Why do we use minus cylinder for contact lens prescriptions?

- Refraction/retinoscopy
  - Dry (non-cycloplegic)
    - Control accommodation by keeping both primary meridians "fogged" with plus lenses
    - Neutralize most plus meridian with spheres; need minus cylinder to neutralize second meridian
  - Wet (cycloplegic)
    - Accommodation temporarily eliminated by drops
    - Over minus during retinoscopy = easier to see 'With Motion'
- Cornea = convex; all eyes are plus powered
  - Gullstrand's schematic eye: 60 D overall power
  - Fit GP to least minus/flattest meridian; creates minus cylinder tear layer to correct plus cylinder error
    - Back surface toric scl
  - Minus cylinder = back lens surface (concave)
  - Plus cylinder = plus lens surface (convex)

20

Why is the power different from glasses to contact lenses?

Because:

A. Some people make errors when ordering.
B. It just depends on what they refracted to that day.
C. The tear layer under the CL changes the power.
D. Myopic people need more power in CL's.
E. The vertex distance between glasses and the cornea changes the required power.

21

Why is the power different from glasses to contact lenses?

Because:

A. Some people make errors when ordering.
   - Easy to make transposition errors going from plus to minus cylinder
   - -3.25+1.75x075 → -1.50-1.75x165
   - Error: 0.00+1.25x180; use plano
   - Error: -4.25+0.00x180; use 'sph'
   - Error: use 3 digits for axis → x005 not x5
   - Can you have axis 007? Phoropter leveled; scale
B. It just depends on what they refracted to that day. Huh?

22

Why is the power different from glasses to contact lenses?

- Convert prescription to minus cylinder form.
- Drop cylinder power (when refractive equals corneal cylinder).
- Adjust for vertex power if sphere power ≥ ±4.00 D
- No tear layer for scl
- Compensate for tear layer:
  - If BC (D)>flat K: plus tear layer, add minus (SAM)
  - If BC (D)< flat K: minus tear layer, add plus (FAP)

23

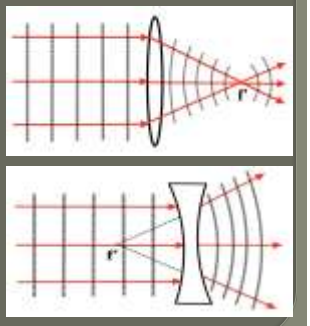
from glasses to contact lenses?

- Keratometry
  - OD 43.75/45.50@105 (+1.75x105)
- Accurate refraction
  - OD -4.50+1.50x110 20/20
  - Trial 9.4 diam; 7.63 BC; -3.00
    - 7.63 mm = 44.25 D
  - Convert: -3.00-1.50x020
  - Drop cylinder
  - VD adjustment: None
  - Tear layer adjustment: -0.50
  - Final lens power: -3.50

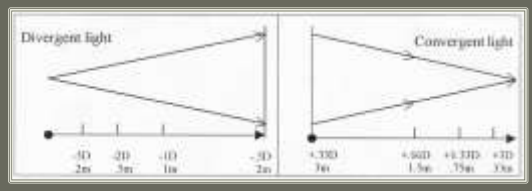
24

Vergence of Light

- **Divergence**
  - Negative
  - Minus vergence
  - Moving away from its origin
- **Convergence**
  - Positive
  - Plus vergence
  - Moving toward its focus
- **Parallel**
  - Zero vergence



25



Diopters – reciprocal in meters of distance from wave front to focal point

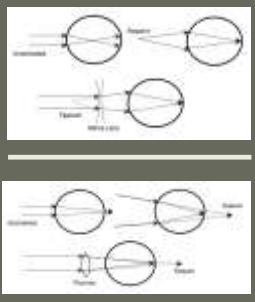
$\frac{1m}{X}$ or $\frac{100cm}{X}$ or $\frac{40"}{X}$

$\frac{1}{-1m} = -1\ D = \frac{100}{-100\ cm}$ $\quad\quad$ $\frac{1}{+.33\ m} = +3\ D = \frac{100}{+33\ cm}$

26

Farpoints

- **Point conjugate to the retina with accommodation relaxed**
  - Emmetropia = infinity
  - Myopia = in front of eye
  - Hyperopia = behind eye
    - Correcting ametropia is moving far point to infinity



27

Effectivity

- **Effective power of lens changes if vertex distance changes**
  - Lens moved away from eye effectively acts like more plus power (or less minus power)
  - Lens moved toward the eye effectively acts like less plus power (or more minus power)
- **Formula: $F_x = F_o/(1-dF_o)$**
  - d measured in meters
  - Positive if lens moved away from eye
  - Negative if lens moved closer to eye

28

Effectivity

- **A patient is properly corrected with a +5.00 D lens 15mm from the cornea. What power is needed if this lens is fit 25mm from the cornea?**

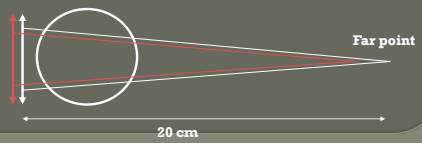
$F_x = 100/21cm = +4.76D$

$F_x = +5/1-(-.01)(+5) = +4.76D$

What would the power be if this lens were fit as a contact lens?

$F_x = 100/18.5cm = +5.41D$

$F_x = +5/1-(.015)(+5) = +5.41D$



29

Effectivity

- **A patient is properly corrected with a -5.00 D lens 15mm from the cornea. What power is needed if this lens is fit 25mm from the cornea?**

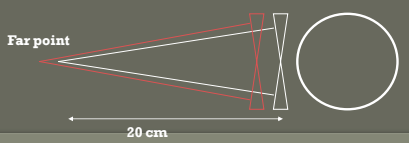
$F_x = 100/19cm = -5.26D$

$F_x = -5/1-(-.01)(-5) = -5.26D$

What would the power be if this lens were fit as a contact lens?

$F_x = 100/21.5cm = -4.65D$

$F_x = -5/1-(.015)(-5) = -4.65D$

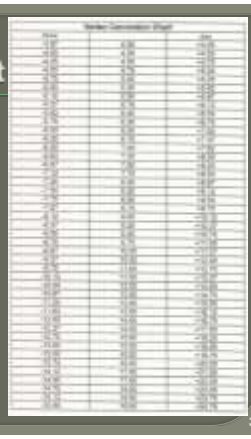


30

Vertex conversion chart

- Converting from spectacle plane to cornea plane
- Always relatively more plus at corneal plane

$$\frac{-10}{1-(0.013)(-10)} = -8.87$$



31

Why is the power different from glasses to contact lenses?

- **Effectivity**
  - Less cylinder if high minus
  - More cylinder if high plus

-12.00+3.00x090

+12.00+3.00x090

32

Why do we use soft toric lenses frequently but toric GP rarely?

Because:

A. **You can only correct low amounts of astigmatism with contact lenses.**
B. **Soft toric lenses are better for you.**
C. **Toric GP lenses hurt.**
D. **Toric GP are hard to make.**

* 37 million CL wearers in the US
* 2013 fits and refits: 66% SH; 24% hydrogel; 8% GP; 2% hybrid
* 24% soft toric; 5% spherical GP; approx 2% toric GP

* Nichols, JJ. Contact Lenses 2013 Annual Report. CL Spectrum. January

33

Why do we use soft toric lenses frequently but toric GP rarely?

Because:

A. **You can only correct low amounts of astigmatism with contact lenses.**
   - Frequent replacement scl torics: 0.75/1.25/1.75/2.25 cylinder powers
   - Custom powers to 10 D cylinder in SCL or GP
B. **Soft toric lenses are better for you.**
   - Higher complications with scl; better optics with GP
C. **Toric GP lenses hurt.**
   - Lens awareness improves with adaptation.
D. **Toric GP are hard to make.**

34

Why do we use soft toric lenses frequently but toric GP rarely?

- **Spherical GP neutralizes corneal cylinder**
- **Residual astigmatism = refractive cylinder minus corneal cylinder**
  - Examples

K's: 41.00/42.25@090 (+1.25X090)
Rx: -4.50+1.25X090
RA = (+1.25X090) – (+1.25X090) = (+0.00X090) — Spherical GP or toric SCL

K's: 43.50/44.25@090 (+0.50X090)
Rx: -3.25+2.25X090
RA = (+2.25X090) – (+0.50X090) = (+1.75X090) — Toric SCL or GP front toric

K's: 42.50/45.50@090 (+3.00X090)
Rx: -5.50+4.50X090
RA = (+4.50X090) – (+3.00X090) = (+1.50X090) — Toric SCL or Bitoric GP

35

Why do we use soft toric lenses frequently but toric GP rarely?

- **Keratometry**
  - OD 43.75/45.50@105 (+1.75x105)
- **Accurate refraction**
  - OD -4.50+1.50x110 20/20
  - Trial 9.4 diam; 7.63 BC; -3.00
    - 7.63 mm = 44.25 D
  - Convert: -3.00-1.50x020
  - Drop cylinder
  - VD adjustment: None
  - Tear layer adjustment: -0.50
  - Final lens power: -3.50
- **Front toric**
  - Specify spherical BC
  - Specify desired sph-cyl rx
    - Applied to front surface
    - Prism in lens; orientation mark
- **Bi-toric**
  - Apply fitting paradigm to each primary meridian
  - Can verify 2 base curves on radiuscope and 2 powers on lensometer

36

What can prism do in a contact lens?

A. Prism in CL's corrects diplopia just like it does in glasses.
B. Prism in CL's can improve the eyes posture in an accommodative esotropia.
C. Prism in CL's can make a crossed eye look straight.
D. Prism in CL's can weight the CL to hold it in position.

37

Prism

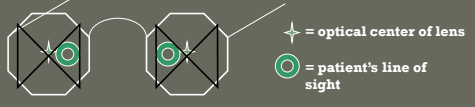
- Definition of a prism diopter
  - One prism diopter displaces light one centimeter at one meter
  - How much will a 5^{Δ} prism displace an object at 40cm?
    - 1 pd = 1cm/1m => 5pd = X/0.4m => X = 2cm
- Prentice's Rule
  - Amount of prism equals distance from optical center times power along that meridian

38

Prism in glasses

- Calculate the horizontal prismatic effect of decentered -6.00 D lenses for a patient with a pupillary distance of 56 mm when the distance between optical centers is 68 mm.

Pt is viewing 68 – 56 = 12/2 = 6mm In with each eye
OD: Δ = 0.6 (-6) = 3.6^{Δ} BI
OS: Δ = 0.6 (-6) = 3.6^{Δ} BI Total = 7.2^{Δ} BI



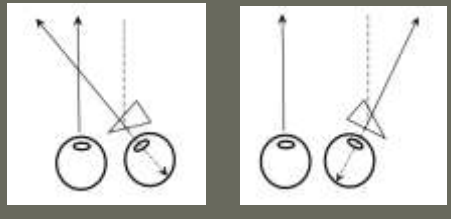
39

What can prism do in a contact lens?

A. Prism in CL's corrects diplopia just like it does in glasses.
  - Prismatic effect depends on where you look through an optical lens (same for glasses or CL)
  - SCL essentially centered over visual axis with little movement
    - No displacement = no prism
  - GP lens will create prism based on lens movement
    - But small amounts; lens moves with the eye; often equal rx
  - Prism to weight toric lens
    - May notice vertical imbalance if toric in one eye or significant anisometropia

40

Exotropia: corrected with BI
Esotropia: corrected with BO
Hypertropia: corrected with BD



Esotropia Exotropia

41

What can prism do in a contact lens?

A. Prism in CL's corrects diplopia just like it does in glasses.
B. Prism in CL's can improve the eyes posture in an accommodative esotropia.
  - Lateral prism: no way to maintain position
  - Minus spectacles cause BI effect at near
    - More esophoric = decreased convergence demand
    - Offset by less accommodative demand (less acc-conv)
    - CL's: no effect on convergence; accommodate more
  - Plus spectacles cause BO effect at near
    - More exophoric = increased convergence demand
    - Offset by more accommodative demand (more acc-conv)
    - CL's: no effect on convergence; accommodate less

42