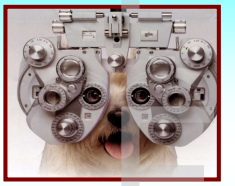
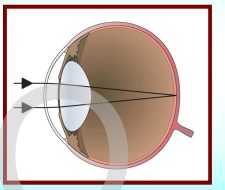
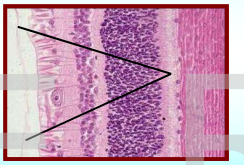
THE EYE IS A POORLY- DESIGNED OPTICAL INSTRUMENT



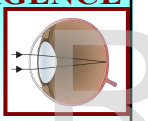
Ron Ofri DVM, PhD, DECVO
Koret School of Veterinary Medicine
Hebrew University of Jerusalem, ISRAEL

THE "PURPOSE" OF AN EYE?



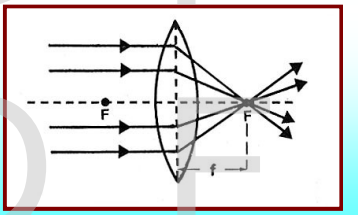


BENDING/REFRACTION/VERGENCE OF LIGHT....



... IS MEASURED IN DIOPTERS

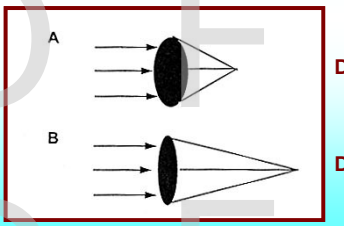
D = 1 / f



VERGENCE OF LIGHT

AMOUNT OF VERGENCE IS DETERMINED BY LENS CURVATRUE

f=10 cm



D= 1/0.1 = 10D

f=20 cm

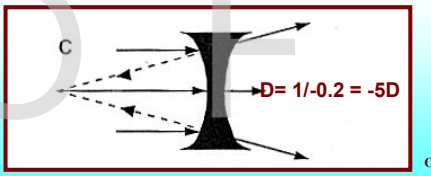
D= 1/0.2 = 5D

Ofri R, 2013

VERGENCE OF LIGHT

- POSITIVE CONVERGENCE IN CONVEX LENS (real image)
- VERGENCE MAY BE NEGATIVE IN CONCAVE LENS (virtual image)

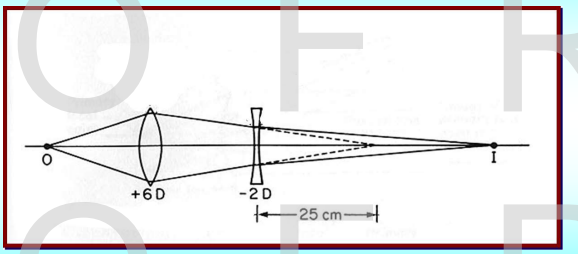
f=-20 cm



D= 1/-0.2 = -5D

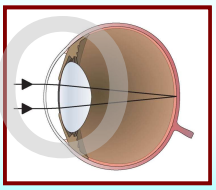
Ofri R, 2013

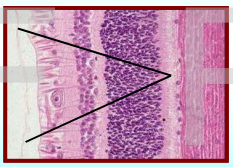
VERGENCE OF LIGHT



AAO Basic & Clinical Science Course 1991

THE "PURPOSE" OF AN EYE





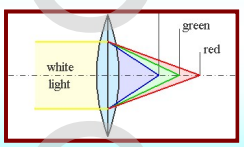
Hermann von Helmholtz, 1821-94

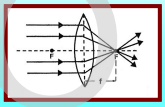
Inventor of the ophthalmoscope

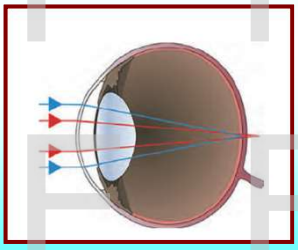
"If an optician should try to sell me an instrument possessing such faults, I would feel justified in using the most severe language with regard to the carelessness of his work and return the instrument under protest."

THE EYE IS A POORLY- DESIGNED OPTICAL INSTRUMENT

I. CHROMATIC ABERRATIONS



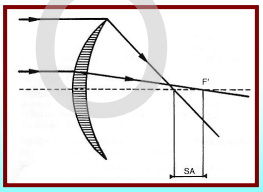


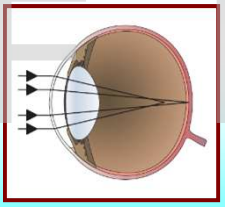


Ofri R, 2013

THE EYE IS A POORLY- DESIGNED OPTICAL INSTRUMENT

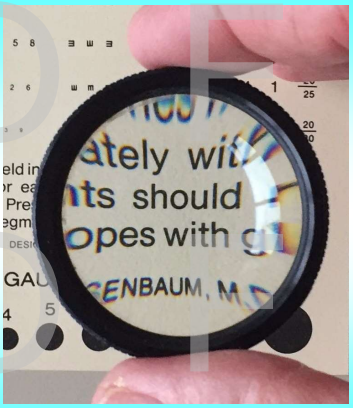
II. SPHERICAL ABERRATIONS





Dictionary of Ophthalmology

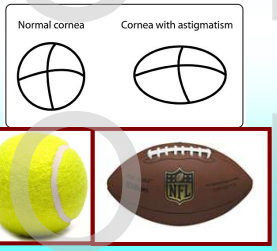
Ofri R, 2013

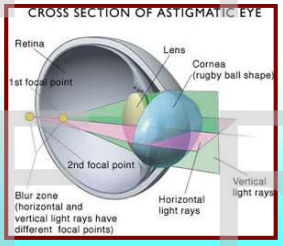


Paul Miller

ASTIGMATISM

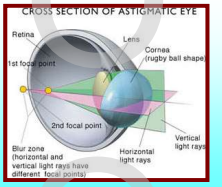
Central corneal curvature varies in different meridians

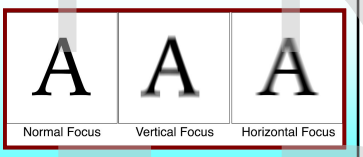




ASTIGMATISM

CONSEQUENCE: The eye has a different refractive error for different visual axes

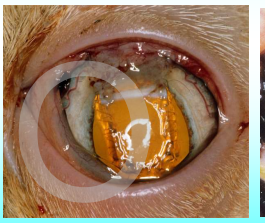




Ofri & Ekesten, 2021

CAUSES OF ASTIGMATISM

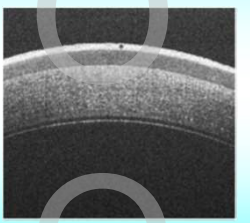
Induced by corneal scarring, edema & SUTURING!!

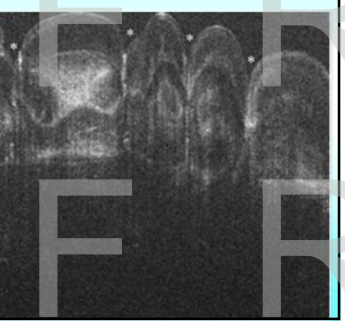


Paul E Miller

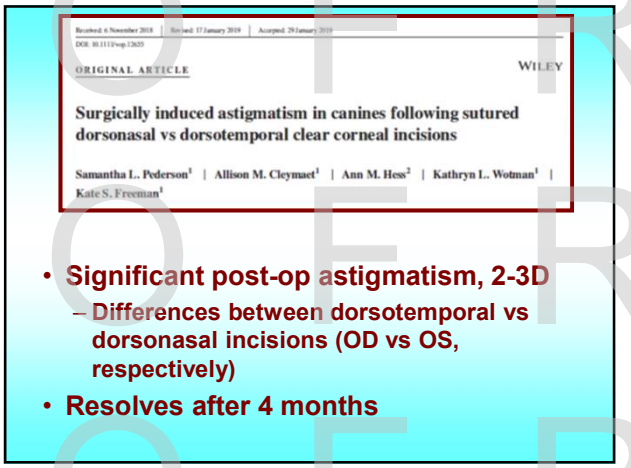
Brian Gilger, Equine Ophthalmology

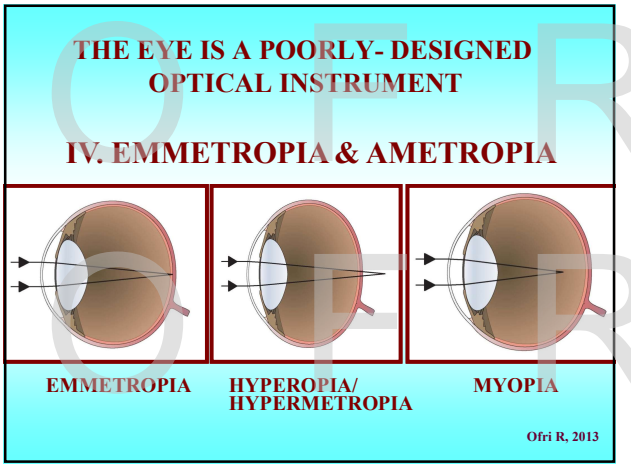
WHO CARES IF WE SUTURE THE CORNEA?!?!

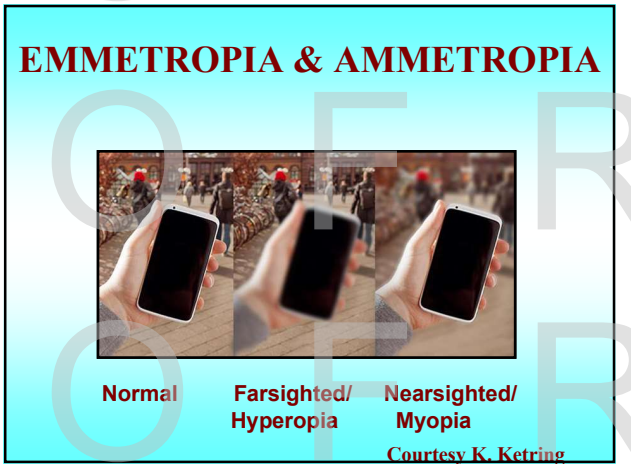




Charnock et al 2022

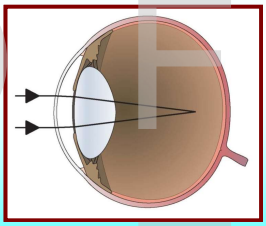

ORIGINAL ARTICLE
WILEY
Surgically induced astigmatism in canines following sutured dorsonasal vs dorsotemporal clear corneal incisions
Samantha L. Pederson | Allison M. Cleymaet | Ann M. Hess | Kathryn L. Wotman | Kate S. Freeman
• Significant post-op astigmatism, 2-3D
– Differences between dorsotemporal vs dorsonasal incisions (OD vs OS, respectively)
• Resolves after 4 months


THE EYE IS A POORLY- DESIGNED OPTICAL INSTRUMENT
IV. EMMETROPIA & AMETROPIA
EMMETROPIA
HYPEROPIA/ HYPERMETROPIA
MYOPIA
Ofri R, 2013


EMMETROPIA & AMMETROPIA
Normal
Farsighted/ Hyperopia
Nearsighted/ Myopia
Courtesy K. Ketring

AMETROPIA

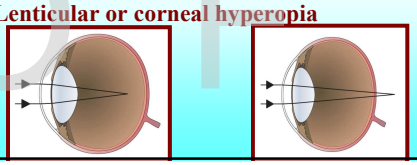
- Defined as -0.5D > refractive error > +0.5D



CAUSES OF AMETROPIA

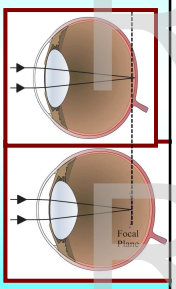
May be the result of insufficient/excessive refractive power in the lens/cornea

- Excessive refractive power: myopia
  - Lenticular or corneal myopia
- Insufficient refractive power: hyperopia
  - Lenticular or corneal hyperopia



CAUSES OF MYOPIA

- May be the result of increased axial length of the eye
- Vitreal elongation is a common cause of myopia
  - ➢Induced in animal models by optical defocus, visual deprivation…
  - ➢Results from juvenile cataract, corneal opacity…



Ofri R, 2013

CANINE MYOPIA

Investigative Ophthalmology & Visual Science, Vol. 33, No. 8, July 1992

Myopia and Refractive Error in Dogs

Christopher J. Murphy,* Karla Zadnik,†‡ and Mark J. Mannis†

Breed	# of eyes studied	Mean refractive error	% of myopic dogs
Rottweiler	28	-1.77 D	64%
Min. schnauzer	16	-0.66 D	50%
Ger. Shepherd (general pop.)	58	-0.86 D	53%
Ger. Shepherd (guide dogs)	106	+0.19 D	19%

All 3 breeds have lenticular myopia

OPTOMETRY AND VISION SCIENCE

ORIGINAL ARTICLE

Ocular Components in Three Breeds of Dogs with High Prevalence of Myopia

Laura A. Williams*, Melissa A. Kubai†, Christopher J. Murphy‡, and Donald O. Mutti§

Breed	# of dogs studied	Mean refractive error	% of myopic dogs
ESS	33	-0.36 D	36.4%
Collie	14	-0.21 D	35.7%
Toy Poodle	36	-1.5 D	63.9%

- **All 3 breeds have lenticular myopia**

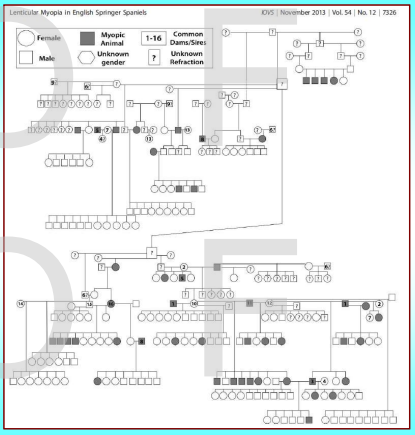
Clinical and Epidemiologic Research

Heritability of Lenticular Myopia in English Springer Spaniels

Melissa A. Kubai,[1] Amber L. Labelle,[1] Ralph E. Hamor,[1] Donald O. Mutti,[2] Thomas R. Famula,[3] and Christopher J. Murphy[4,5]

Investigative Ophthalmology & Visual Science, 2013; 54:7324-8

- Survey of 226 related ESS
  - Median age – 2 months
- Good news – mean refractive error +0.25D
- Bad news – 19% of ESS had lenticular myopia
  - Range -0.5D to -3.5D
  - Genetic effects account for 1/3 of the variability in refractive error, while environment, age, etc. account for 2/3



Naturally Occurring Vitreous Chamber–Based Myopia in the Labrador Retriever

Donald O. Mutti,[1,2] Karla Zadnik,[2] and Christopher J. Murphy[3]

Investigative Ophthalmology & Visual Science, 1999;40:1577-84

- 17/75 (23%) of Labrador retrievers are myopic
  - Range -0.5D to -5.0D
- Myopia due to elongation of vitreous (axial myopia)

TABLE 1. Ocular Component Values as a Function of Refractive Status

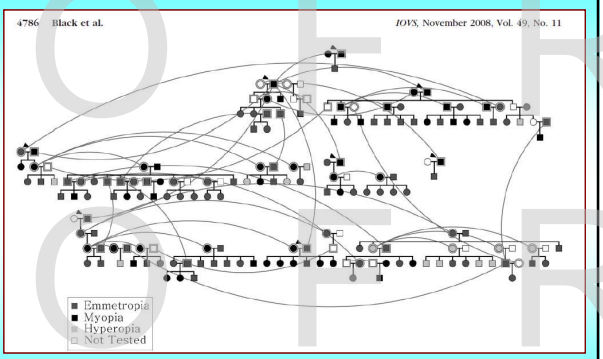
Ocular Component	Nonmyopes (*n* = 50)	Myopes (*n* = 7)	*P*
Vitreous chamber depth (mm)	10.02 ± 0.40	10.87 ± 0.34	<0.0001
Anterior chamber depth (mm)	4.29 ± 0.36	4.16 ± 0.33	0.47
Lens thickness (mm)	7.85 ± 0.51	7.70 ± 0.56	0.26
Keratometer power (D)	36.94 ± 1.98	37.12 ± 2.45	0.67
Equivalent refractive index	1.535 ± 0.027	1.543 ± 0.027	0.55
Anterior lens radius (mm)	7.61 ± 0.55	7.94 ± 0.57	0.23
Posterior lens radius (mm)	8.12 ± 1.29	8.87 ± 0.93	0.14
Equivalent lens power (D)	48.26 ± 3.69	47.00 ± 4.43	0.45

A Canine Model of Inherited Myopia: Familial Aggregation of Refractive Error in Labrador Retrievers

Joanna Black,[1] Sharon R. Browning,[2] Andrew V. Collins,[1] and John R. Phillips[1]

Investigative Ophthalmology & Visual Science, 2008; 49:4784-9

- **Survey of 116 related Labradors in New Zealand**
  - **Mean refractive error -0.4D (!)**
  - **Myopia in 31% of dogs (range -0.5 to -5.38D)**
  - **Coat color and sex not correlated, but dogs from small litters more myopic**
  - **After subtracting effect of litter size, half the variability due to genetics and half to environment**



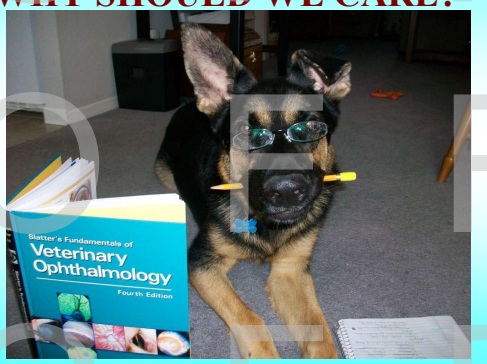
WHY DOES IOVS PUBLISH ABOUT CANINE MYOPIA ?

Myopia is the most common eye disorder in the world![1]

- **USA:** **25% of 12-54 year olds are myopic[2]**
- **Greece:** **37% of 15-18 year olds affected[3]**
- **Singapore:** **80% are myopic by age 18![4]**
- **Huge economic costs**
  - **LASIK, contact lenses, spectacles…**
- **Risk factor for other ocular diseases**
  - **Cataract, glaucoma, retinal detachment…**

[1]Hornbreak and Young, 2009; [2]Vitale et al., 2009; [3]Mavracanas et al., 2000; [4]Rose et al, 2008

WHY SHOULD WE CARE?



THE CANINE REFRACTIVE ERROR

Refractive states of eyes and association between ametropia and breed in dogs

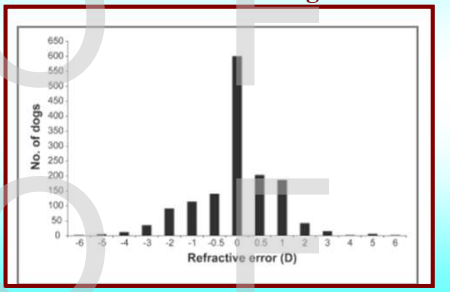
Melissa A. Kubai, BS; Ellison Bentley, DVM; Paul E. Miller, DVM; Donald O. Mutti, OD, PhD; Christopher J. Murphy, DVM, PhD

AJVR, 2008;69:946-951

- Retinoscopy performed in 1440 dogs
  - ➢CERF clinic
- 90 breeds represented
  - ➢16 breeds were represented by ≥ 20 dogs

THE GOOD NEWS…

- Mean refractive error in dogs -0.05D ±1.36D



MORE GOOD NEWS…

- Nine breeds were defined as emmetropic (+0.5D > refractive error > -0.5D) :
  - English springer spaniel, German shepherd, Golden retriever, Siberian husky, Shetland sheepdog, Labrador retriever, Border collie, Samoyed and "other" Terriers (Fox, Scottish, Belgian, Boston, Bull, Tibetan…)

THE NOT-SO-GOOD NEWS

- Even in emmetropic breeds, significant number of dogs were myopes:
  - 22.1% of Labradors
  - 21.7% of ESS
  - 24.4% of GSD
- Range of myopia -0.5 to -5.0 D!!!
- These were usually clustered in subpopulations or entire litters!

EVEN WORSE NEWS…

Some breeds have a mean myopic refractive state:

	% myopic	Mean error
Rottweiler	44%	-0.9D
Min. schnauzer	41%	-0.6D
Collie	54%	-0.8D
Toy poodle*	77%	-1.8D

*Up to -6.25D!!!!

- 25.4% of ALL dogs were myopic!
  - 1.5% of dogs were severely myopic (< -4D)

SOME MORE BAD NEWS…

Some breeds have a mean hyperopic refractive state:

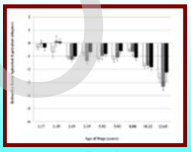
	% hyperopic	Mean error
Aus. shepherd	63%	+1.3D
Bouv. des Flandres	59%	+0.6D
Alaskan malam.*	61%	+1.0D

*Up to +3.25D!!!!

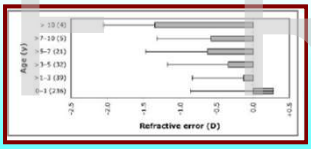
- 8% of all dogs were hyperopic

AGE & THE REFRACTIVE ERROR

- Myopia increases with age
- The association is stronger in females
- The association is especially strong in ESS, Australian shepherd, Bouvier, Collie, GSD & Alaskan malamute
  - Also in Beagles (Maehara *et al*., 2011)



Beagles



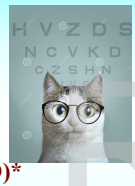
ESS

CATS*

- Kittens < 4M -2.45D
- Adults -0.39D
- Myopia decreases with age in cats, but increases with age in some dog breeds

*Konrade et al. 2012

CATS. Additional factors



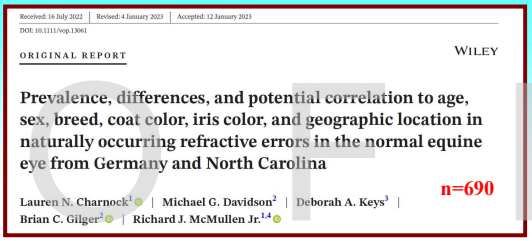
- Coat length*:
  - DSH more likely to be myopic
  - DLH more likely to be emmetropic
- Habitat**:
  - Indoor cats: 75% myopic (mean -0.8D)*
  - Outdoor cats: 88% hyperopic (mean +1.4D)*
  - Changes are lenticular, not vitreal

*Konrade et al., 2012; **Belkin M et al. 1977

HORSES

	Mean error	% emmetropia	% myopia	% hyperopia
Rull-Cotrina et al., 2013 (n = 135)	-0.17 ±0.05D[a]	55	30	15
Grinninger et al., 2010 (n = 159)**	-0.06 ±0.68D	50	25[b]	25
Meister et al., 2018 (n=49)	+ 0.32 ± 0.66D[c]	93	4[d]	3
Bracun et al., 2014 (n=333)	?	84	7[d]	7[e]

[a] 22% astigmatism; [b] prevalence of myopia increases with age; [c] emmetropia defined as ±1D; [d] up to 5D myopia!; [e] up to 5D hyperopia



Received: 16 July 2022 | Revised: 4 January 2023 | Accepted: 12 January 2023

DOI: 10.1111/vop.13061

ORIGINAL REPORT

WILEY

Prevalence, differences, and potential correlation to age, sex, breed, coat color, iris color, and geographic location in naturally occurring refractive errors in the normal equine eye from Germany and North Carolina

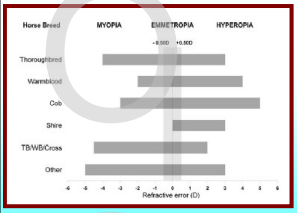
n=690

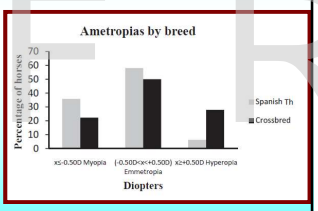
Lauren N. Charnock[1] | Michael G. Davidson[2] | Deborah A. Keys[3] | Brian C. Gilger[2] | Richard J. McMullen Jr.[1,4]

- Emmetropia in 56% of eyes (±0.5D)
- Anisometropia in 12.5% of eyes
  - Difference >1D between eyes
- Error affected by sex, iris color & location
- Error NOT affected by age, breed or coat color

HORSES

- Thoroughbreds tend to be myopic





Bracun et al., 2014 Rull-Cotrina et al. 2013

HOT OFF THE PRESS

- Donkeys are likewise emmetropic
  - 46% of donkeys were emmetropic, comparable to 55% of horses (Rull-Cotrina et al, 2013; Charnock et al, 2022)
- Goats are also emmetropic...

...UNLIKE SHEEP, WHO ARE HYPEROPIC

BEWARE OF EXTRAPOLATION, EVEN BETWEEN RELATED SPECIES

SOME MORE SPECIES

Rabbit (New Zealand White)	1.7 D	Herse (2005)
Chicken (Cornell-K)	4.1, 3.7D (4 & 17 weeks old, respectively)	Wahl et al. (2015)
Guinea pig (pigmented)	0.7 D	Howlett & McFadden (2007)
Rat (Norway brown)	4.7, 14.2D (infant & adult, respectively)	Guggenheim et al. (2004)
Mouse (CBL75/6)	-1.5, 4.0D (10 & 102 days old, respectively)	Zhou et al. (2008)

Development of the refractive state in eyes of ostrich chicks (*Struthio camelus*)

Ron Ofri, DVM, PhD; Susan Millodot, B Optom; Ronnie Shimoni, DVM; Igal H. Horowitz, DVM; Ehud Ashash, DVM; Michel Millodot, OD, PhD

Refractive State, Corneal Curvature, Accommodative Range and Ocular Anatomy of the Asian Elephant (*Elephas maximus*)

CHRISTOPHER J. MURPHY,* THOMAS J. KERN,† HOWARD C. HOWLAND‡

Optical Performance of the Penguin Eye in Air and Water

ORIGINAL PAPER

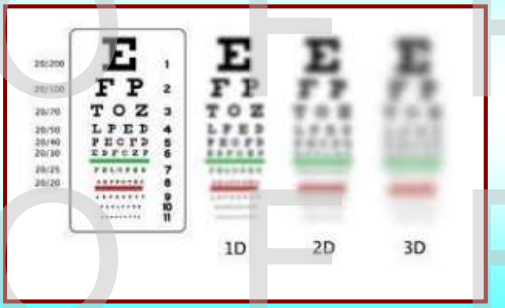
The development of the refractive state in the newborn Thomson gazelle

Vision Research

Corneal topography, refractive state, and accommodation in harbor seals (*Phoca vitulina*)

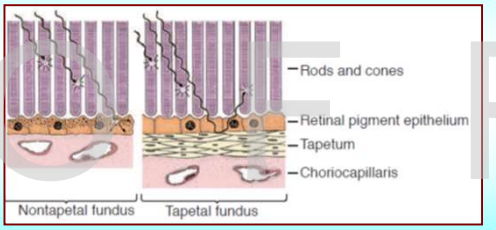
Frederike D. Hanke*, Guido Dehnhardt, Frank Schaeffel, Wolf Hanke

REFRACTIVE ERROR REDUCES VISUAL ACUITY



R Ofri. Fundamentals of Animal Vision. NEW GELATT'S!!!

BUT VISUAL ACUITY IS ALSO REDUCED BY…

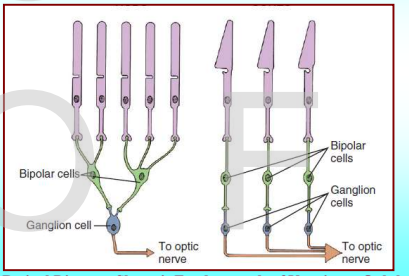


Ofri R. Retinal Diseases. Slatter's Fundamentals of Veterinary Ophthalmology, 2018

…AND BY RETINAL ANATOMY
(Concentration of cones & associated RGCs)

Rod pathway (Converging)

Cone pathway (Non-converging)



Ofri R. Retinal Diseases. Slatter's Fundamentals of Veterinary Ophthalmology, 2018

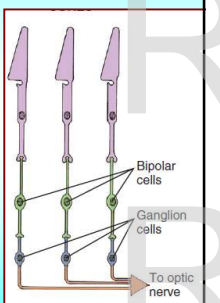
CONE CONCENTRATIONS

HUMANS

- 199,000 cones/mm^2
- 1:1 cone:ganglion cell ratio

CATS

- 27,000 cones/mm^2
- 4:1 cone:ganglion cell ratio

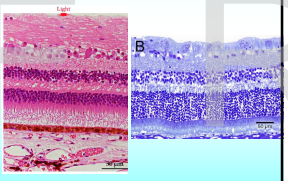


Ofri R. Retinal Diseases. Slatter's Fundamentals of Veterinary Ophthalmology, 2018

VISUAL ACUITY

NUMBER OF GANGLION CELLS

HUMAN	1,200,000
HORSE	500,000
DOG	167,000
CAT	116,000



Human Feline

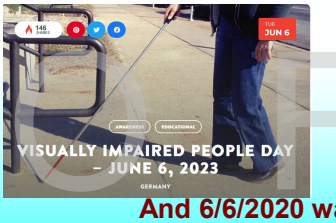
Ofri R et al., 2015

VISUAL ACUITY (Snellen fraction)

HUMAN 6/6 (20/20)

WHICH IS WHY 6/6 IS

"INTERNATIONAL BLINDNESS DAY"



And 6/6/2020 was a

"once in a lifetime" anniversary

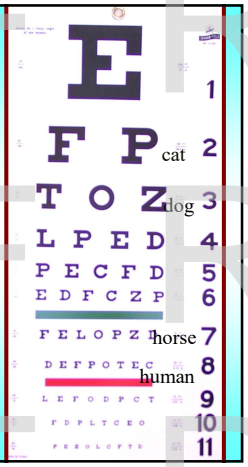
VISUAL ACUITY

(Snellen fraction)

HUMAN	6/6	(20/20)
HORSE	6/10	(20/33)
DOG	6/22	(20/75)
CAT	6/45	(20/150)

- The horse has 0.6 times the acuity of humans, 1.5 times the acuity of dogs, and 3 times that of cats.

Brooks DE



LEGAL BLINDNESS

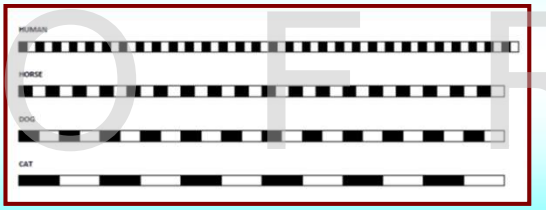
Cat	6/45	20/150
Legal blindness	6/60	20/200
Rabbit	6/60	20/200
Cow	6/105	20/350
Rat	6/150	20/500
Aphakic dog	6/240	20/800
Mouse	6/300	20/1,000
Menace response	6/6,000	20/20,000

AT THE OTHER END OF THE SCALE…

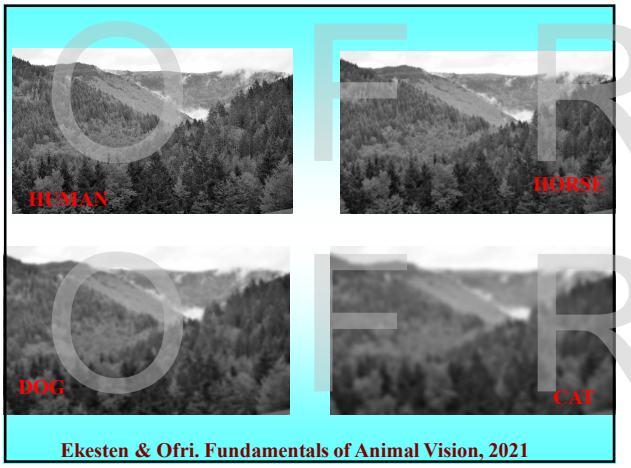
- American kestrel 6/4 (20/13) (Gaffney& Hodos, 2003)
- Brown falcon 6/2.5 (20/8) (Reymond L, 1987)
- Wedge-tailed eagle 6/1.3 (20/4.3) (Reymond L, 1985)
  - Cat – 6/45 (20/150) or 3% of the eagle's acuity!

VISUAL ACUITY

(Cycles/degree, OR Minutes of arc/phase)



Ekesten & Ofri. Fundamentals of Animal Vision, 2021

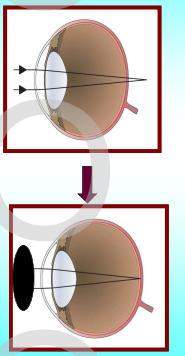


Ekesten & Ofri. Fundamentals of Animal Vision, 2021

THIS IS TERRIBLE!!

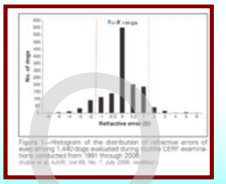
CAN WE IMPROVE THIS WITH GLASSES?

No! Glasses focus light

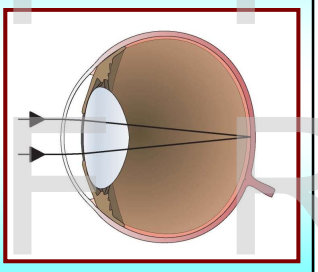


Ofri & Eksten. Optics & Physiology of Vision. 2021

MOST ANIMALS ARE ±1D EMMETROPIC

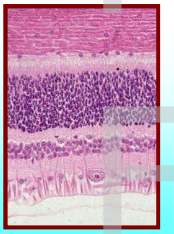


Kuabai MA et al, 2008



Ofri & Eksten 2021

Because of retinal anatomy & tapetum even emmetropic animals have low visual acuity



CONCLUSIONS. I.
MYOPIA AFFECTS A SIGNIFICANT NUMBER OF DOGS

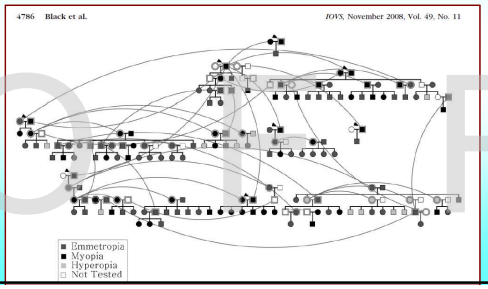
	% myopic	Mean error
Rottweiler	44%	-0.9D
Min. schnauzer	41%	-0.6D
Collie	54%	-0.8D
Toy poodle*	77%	-1.8D

*Up to -6.25D!!!!

- 25.4% of ALL dogs were myopic!
  - ➢ 1.5% of dogs were severely myopic (< -4D)

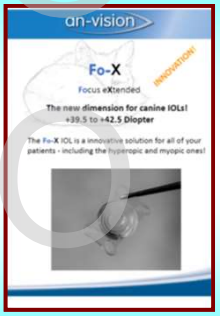
CONCLUSIONS. II.

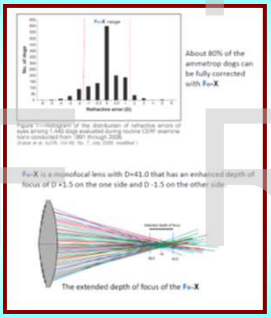
- Myopia is an inherited problem in many breeds



CAN WE CHANGE THINGS?
I. CATARACT SURGERY
WHEN IMPLANTING IOL's, WE USE THE "ONE SIZE FITS ALL" APPROACH

OR MAYBE….





Refractive error outcomes of 3 IOL types following cataract surgery in dogs
(M Kaminsky et al., ACVO 2022)

Or in the future…

…hopefully you can calculate the IOL power needed to restore emmetropia and grab it from your drawer.

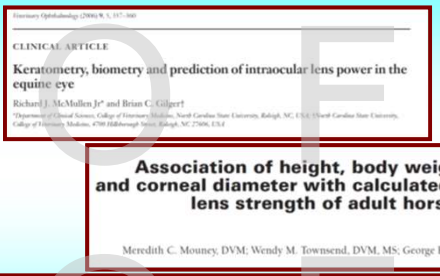
All you need is a keratometer & A-mode ultrasound (and a selection of IOL's ☺)

$$Pe = \frac{1336\ (4r - L)}{(L - C)(4r - C)}$$

Binkhorst formula

$$Pe = \frac{N}{L - C} - \frac{NK}{N - KC}$$

Retzlaff formula


CLINICAL ARTICLE

Keratometry, biometry and prediction of intraocular lens power in the equine eye

Richard J. McMullen Jr* and Brian C. Gilger†

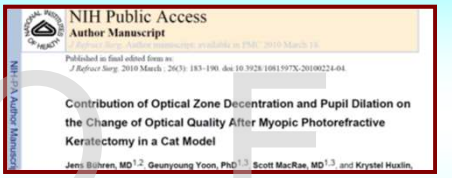
Association of height, body weight, age, and corneal diameter with calculated intraocular lens strength of adult horses

Meredith C. Mouney, DVM; Wendy M. Townsend, DVM, MS; George E. Moore, DVM, PhD

Biometry, keratometry, and calculation of intraocular lens power for the bald eagle (*Haliaeetus leucocephalus*)*

Sonia E. Kuhn,* Diane V. H. Hendrix,* Michael P. Jones,* Daniel A. Ward,* Katherine H. Baine* and Stephen R. Franklin†

Or in the more distant future



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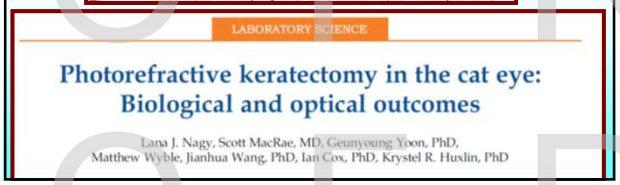
Contribution of Optical Zone Decentration and Pupil Dilation on the Change of Optical Quality After Myopic Photorefractive Keratectomy in a Cat Model

Jens Bühren, MD[1,2], Geunyoung Yoon, PhD[1,3], Scott MacRae, MD[1,3], and Krystel Huxlin,

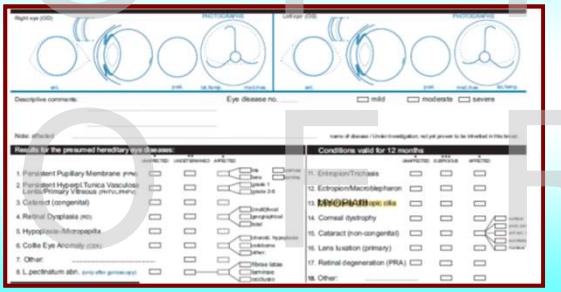


LABORATORY SCIENCE

Photorefractive keratectomy in the cat eye: Biological and optical outcomes

Lana J. Nagy, Scott MacRae, MD, Geunyoung Yoon, PhD, Matthew Wyble, Jianhua Wang, PhD, Ian Cox, PhD, Krystel R. Huxlin, PhD

CAN WE CHANGE THINGS?
II. BREEDING ADVICE



CAN WE CHANGE THINGS?
III. DIAGNOSING YOUR PATIENTS

Next time a 12 year old dog comes to your clinic complaining of decreased vision, and your ophthalmic exam is normal…

DO YOU…

- **Refer to CT/MRI?**
  - Limited availability
  - Thousands of $$
  - Anesthesia
- **Refer to neurology?**
  - CSF tap & anesthesia, hundreds of $$
  - Do you have a nearby specialist?
- **Do an ERG?**
  - Cost of instrument
  - Anesthesia/sedation
  - Requires at least 30 min of your time, hundreds of $$

OR??