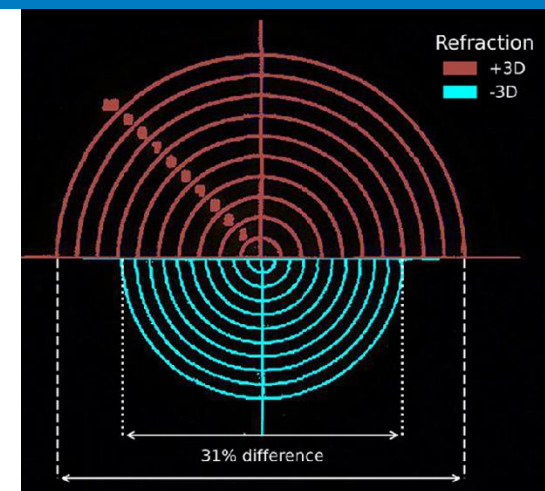


Understanding and correcting for scaling of fundus photographs



Jan-Willem M. Beenakker

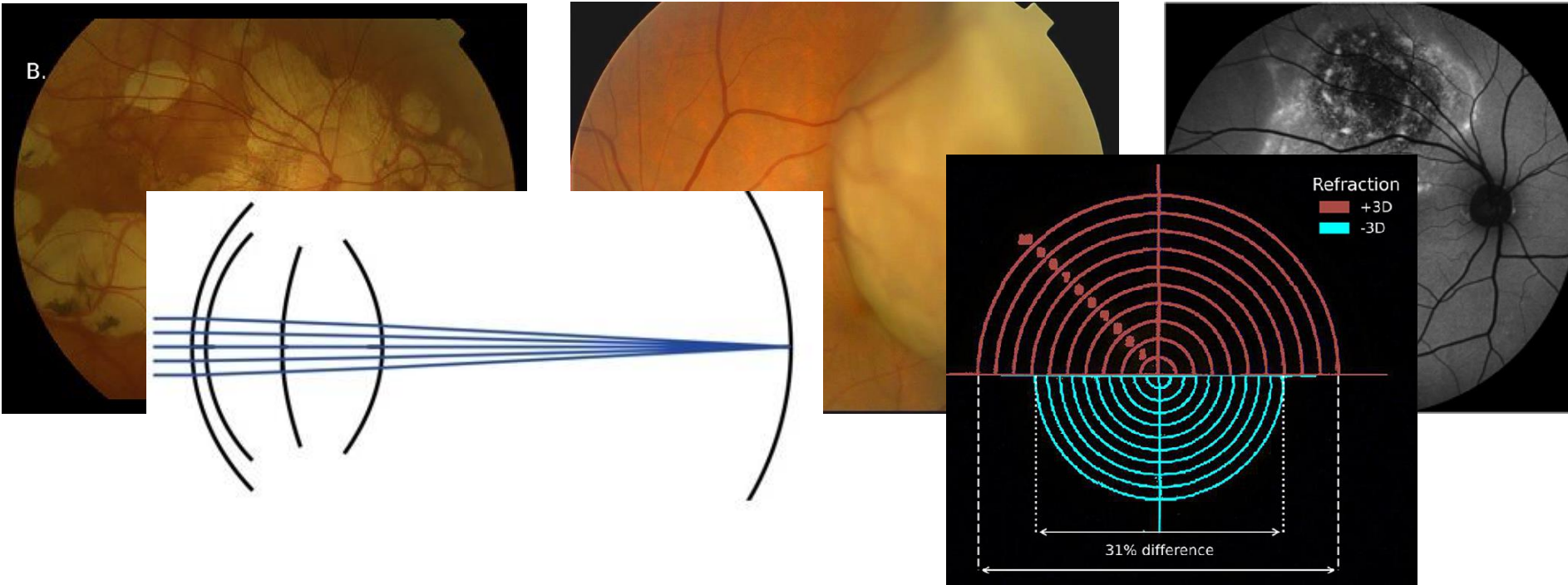
Ophthalmology, Radiology, Radiation Oncology
HollandPTC

Disclosure

Our institute receives research support from

- Philips Healthcare
- RaySearch Laboratories
- Varian Medical Systems
- MacroMedics

Fundusphotography



Content

1. Optics of fundus photography
2. The Bennet-Litmann correction
3. The PAROS method
4. How to do this practically
5. Pitfalls and limitations

WET van SNELLIUS

$$n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$$

n_1

n_1

n_2

n_2

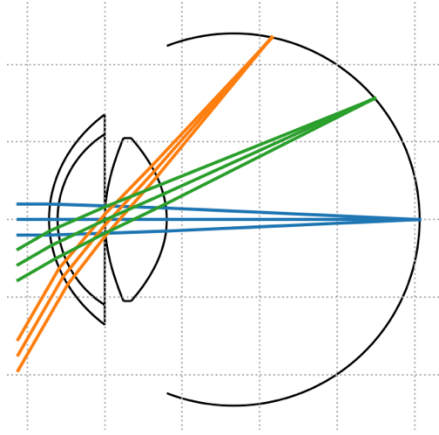
θ_1

θ_2

-licht verandert van richting bij
de overgang naar een ander medium-

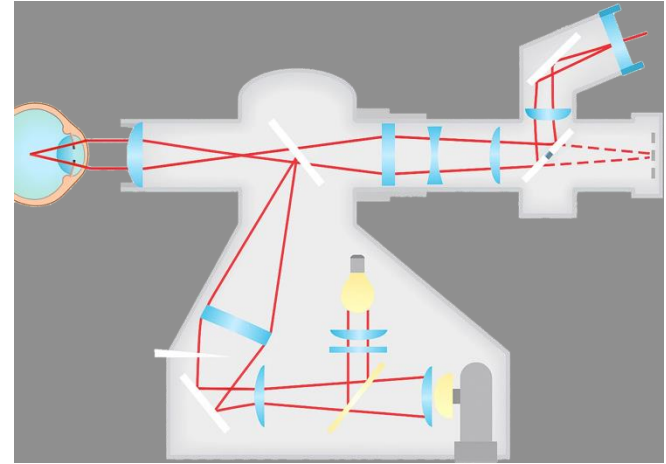
WILLEMHOOD SNEL VAN ROYEN (1600-1676)

Optical principles of fundus photography



Eye

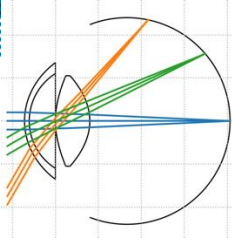
Optics varies between subject
Most parameters can be measured



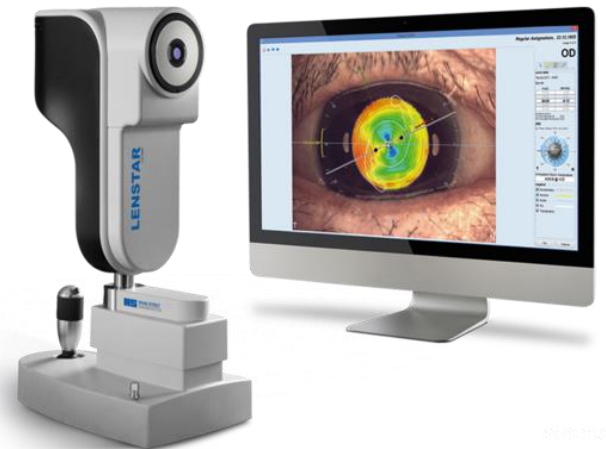
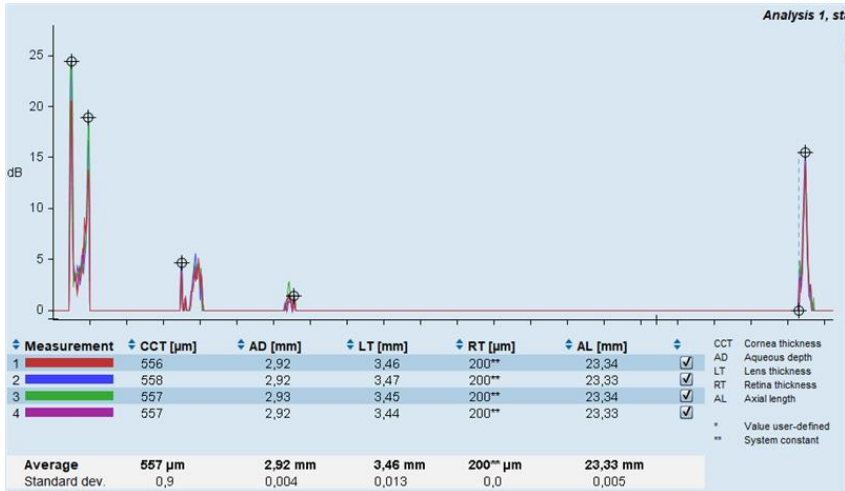
Camera

Complex (unknown) design
Constant between subjects

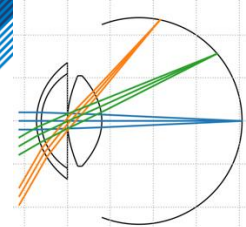
The eye



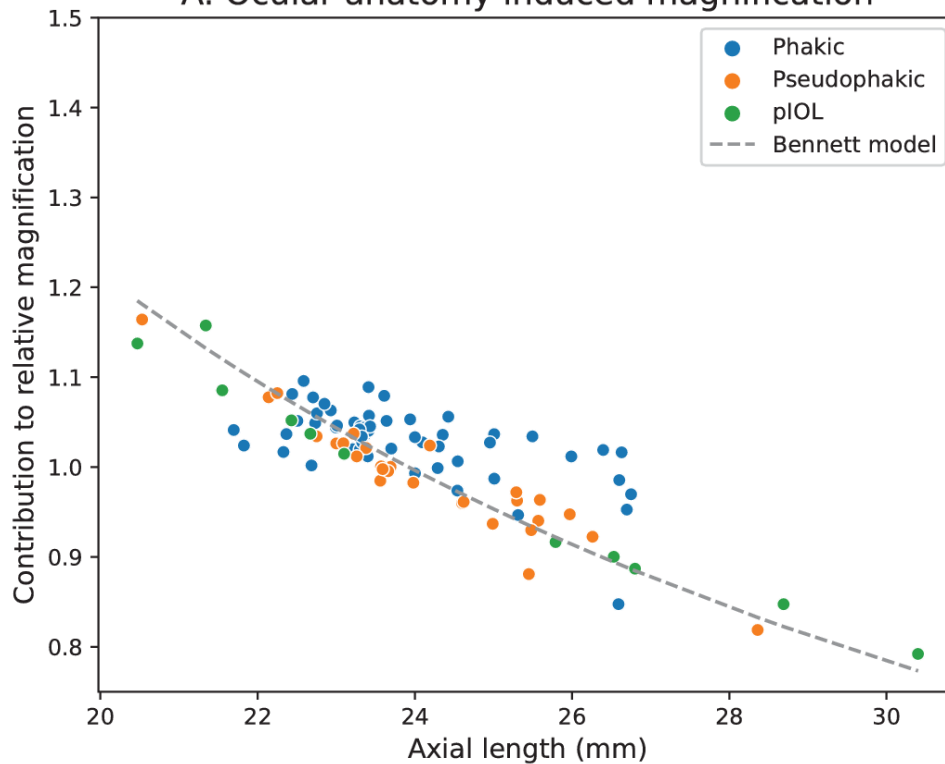
- Distances and curvatures can be quite accurately determined similar to IOL calculation
- Refractive indices cannot be measured but varies little between patients and has a minor impact



Impact of axial length

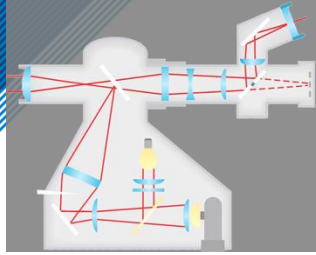


A. Ocular anatomy induced magnification

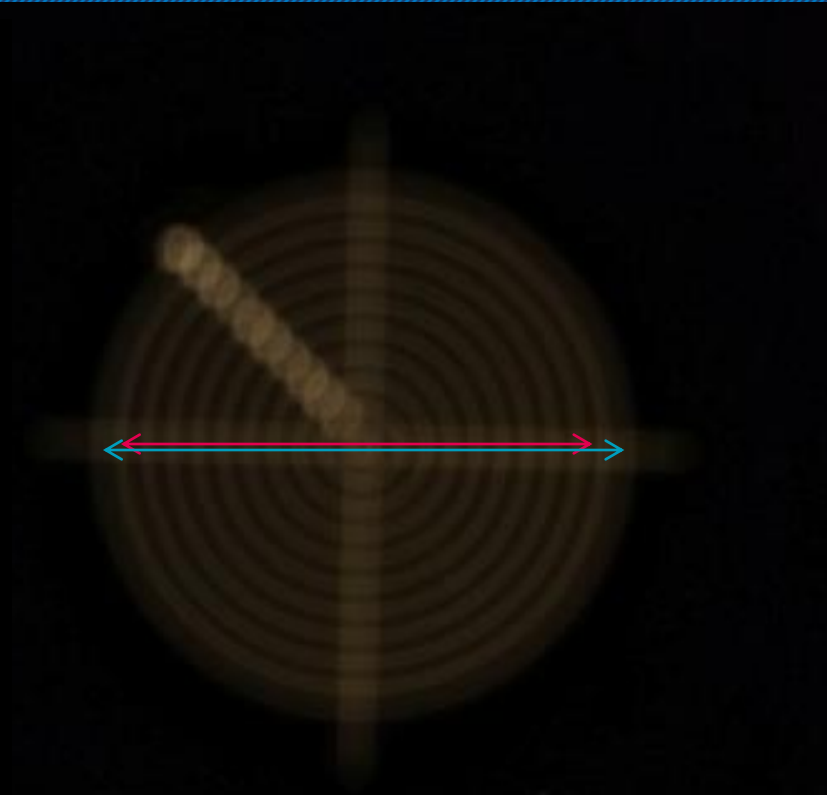
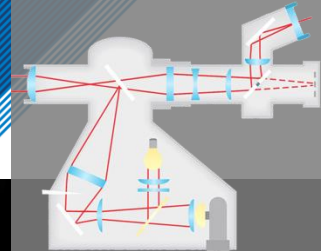


Camera

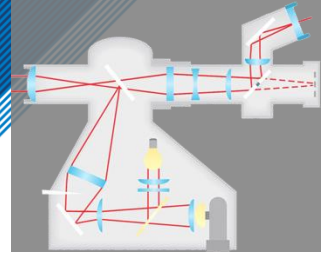
- Many different configurations possible
- Image has to be in focus
 - > camera optics might depend on subject's refraction



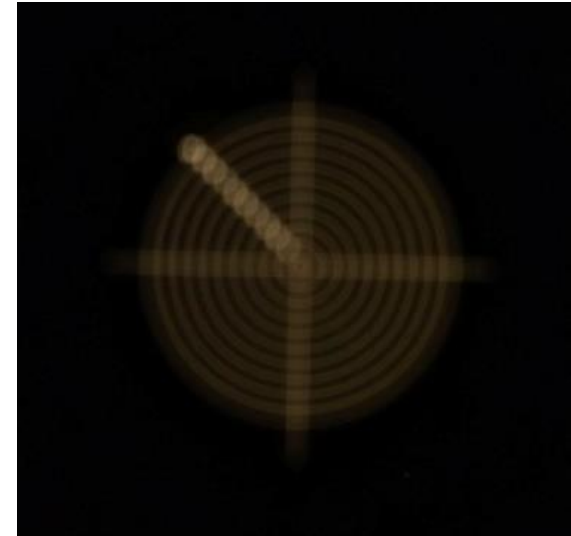
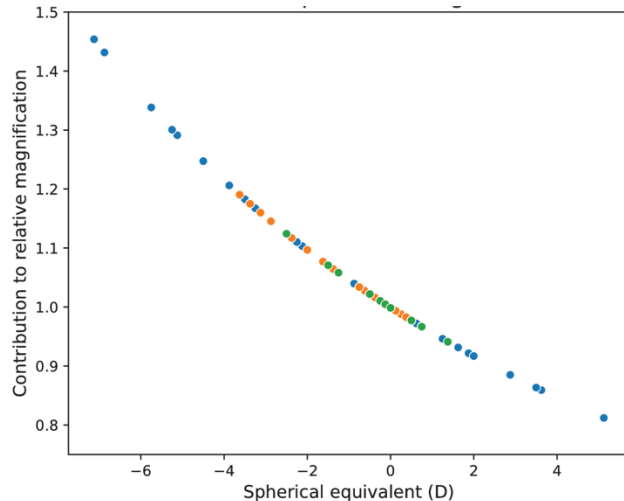
Camera



Camera



- Many different configurations possible
- Image has to be in focus
 - > camera optics **depends** on subject's refraction
- Optics of the two systems are “coupled”



Bennet-Littmann method

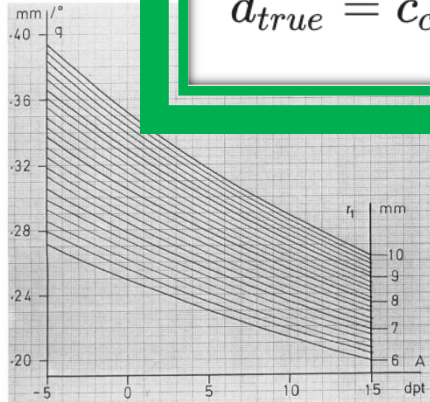
286 *Klin. Mbl. Augenheilk.* 180 (1982)

Experimentelle und theoretische Studien

Klin. Mbl. Augenheilk. 180 (1982) 286-289
© 1982 F. Enke Verlag Stuttgart

Zur Bestimmung der
wahren Größe eines
Objektes auf dem
Hintergrund des
Auges

H. Littmann



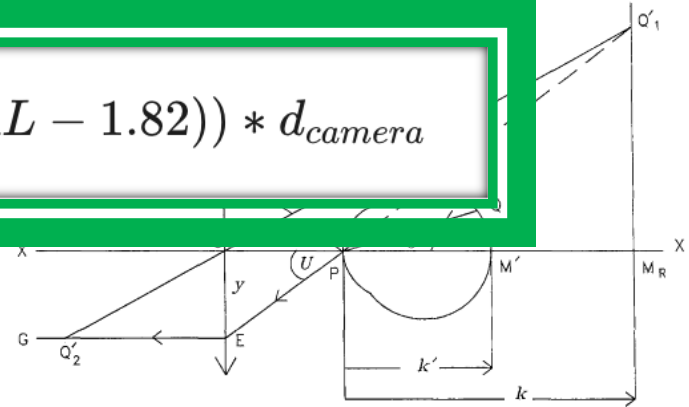
Graefe's Arch Clin Exp Ophthalmol (1994)
232:361-367 © Springer-Verlag 1994

LABORATORY INVESTIGATIONS

Arthur G. Bennett
Alicja R. Rudnicka
David F. Edgar

Improvements on Littmann's method
of determining the size of retinal features
by fundus photography

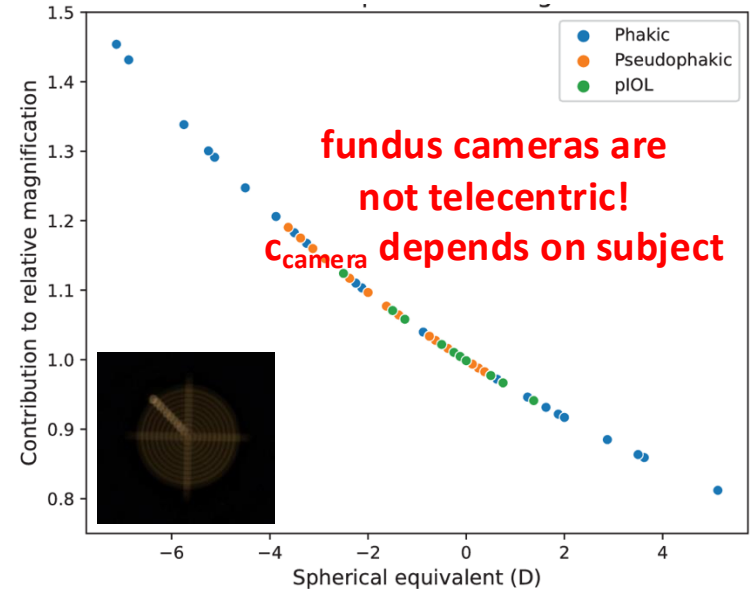
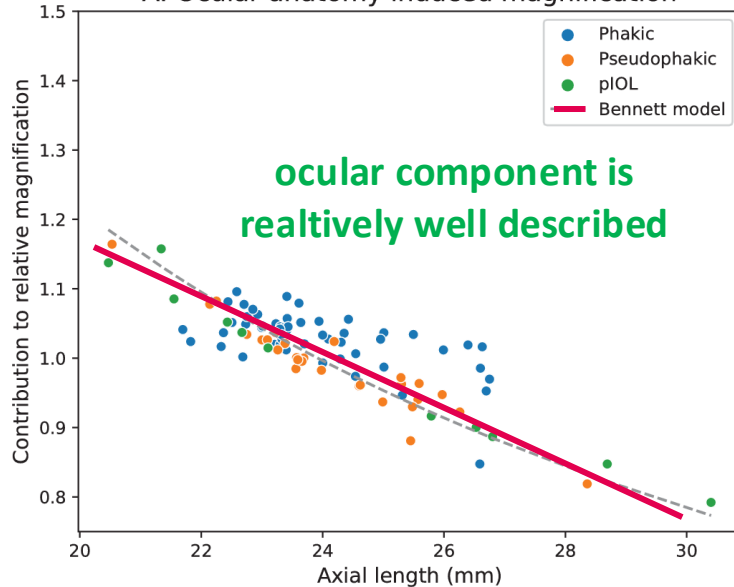
$$d_{true} = c_{camera} * (0.01306 * (AL - 1.82)) * d_{camera}$$



Bennet-Littmann method

$$d_{true} = c_{camera} * (0.01306 * (AL - 1.82)) * d_{camera}$$

A. Ocular anatomy induced magnification



PAROS

Correction Method for Optical Scaling of Fundoscopy Images: Development, Validation, and First Implementation

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Gregorius P. M. Luyten ², Gwyneth A. van Rijn ^{4,5}, T. H. Khanh Vu ²,
Coen R. N. Rasch ¹, Nanda Horeweg ^{1,2} and Jan-Willem M. Beenakker ¹⁻³

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Citation: Pors LJ, Haasjes C, van Vught L, et al. Correction method for optical scaling of fundoscopy images: Development, validation, and first implementation. *Invest Ophthalmol Vis Sci.* 2024;65(1):43. <https://doi.org/10.1167/iov.65.1.43>

PURPOSE. Although fundus photography is extensively used in ophthalmology, refraction prevents accurate distance measurement on fundus images, as the resulting scaling differs between subjects due to varying ocular anatomy. We propose a PARaxial Optical fundus Scaling (PAROS) method to correct for this variation using commonly available clinical data.

METHODS. The complete optics of the eye and fundus camera were modeled using ray transfer matrix formalism to obtain fundus image magnification. The subject's ocular geometry was personalized using biometry, spherical equivalent of refraction (RSE), keratometry, and/or corneal topography data. The PAROS method was validated using 41 different eye phantoms and subsequently evaluated in 44 healthy phakic subjects (of whom 11 had phakic intraocular lenses [pIOLs]), 29 pseudophakic subjects, and 21 patients with uveal melanoma.

RESULTS. Validation of the PAROS method showed small differences between model and actual image magnification (maximum 3.3%). Relative to the average eye, large differ-

Paraxial ray-transfer formalism

Input:

- Biometry data
- Corneal curvature
- Objective refraction
- (p)IOL data

“Simple” linear model of camera

$$\begin{aligned}
 \mathbf{M}_{\text{cor}} &= \mathbf{M}_{\text{corF}} \mathbf{M}_{\text{dcor}} \mathbf{M}_{\text{corB}} & (A.3) \\
 &= \mathbf{M}_{\text{sphere}}(r_{\text{corF}}, n_{\text{cor}}, n_{\text{air}}) \mathbf{M}_{\text{unif}}(d_{\text{cor}}) \mathbf{M}_{\text{sphere}}(r_{\text{corB}}, n_{\text{aq}}, n_{\text{cor}}) \\
 &= \begin{bmatrix} \frac{d_{\text{cor}}(-n_{\text{cor}}+n_{\text{aq}})}{r_{\text{corB}}n_{\text{cor}}} + 1 & \frac{d_{\text{cor}}n_{\text{aq}}}{n_{\text{cor}}} \\ \frac{-n_{\text{air}}+n_{\text{cor}}}{r_{\text{corF}}n_{\text{air}}} + \frac{(-n_{\text{cor}}+n_{\text{aq}})\left(\frac{d_{\text{cor}}(-n_{\text{air}}+n_{\text{cor}})}{r_{\text{corF}}n_{\text{air}}} + \frac{n_{\text{cor}}}{n_{\text{air}}}\right)}{r_{\text{corB}}n_{\text{cor}}} & n_{\text{aq}}\left(\frac{d_{\text{cor}}(-n_{\text{air}}+n_{\text{cor}})}{r_{\text{corF}}n_{\text{air}}} + \frac{n_{\text{cor}}}{n_{\text{air}}}\right) \end{bmatrix}
 \end{aligned}$$

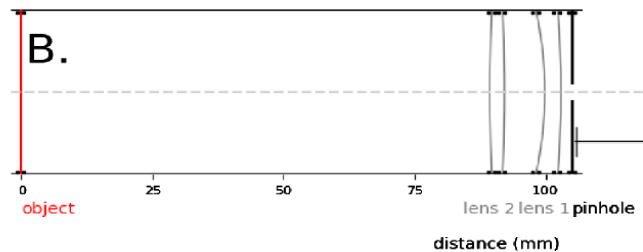
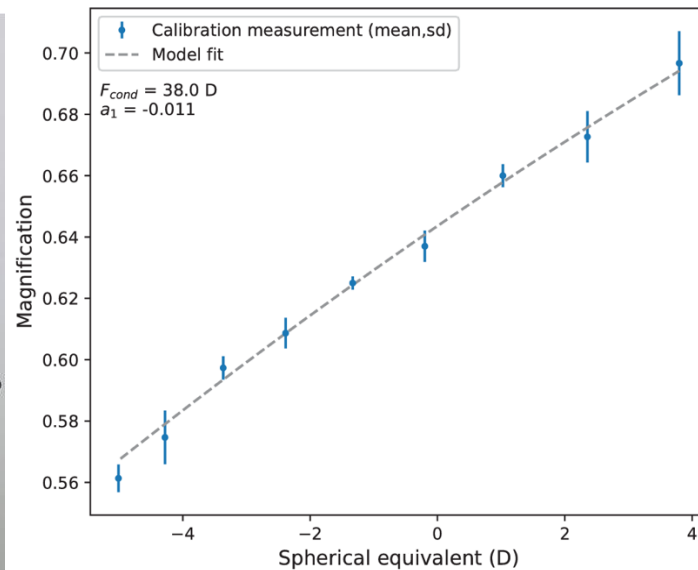
$$\mathbf{M}_{\text{ACD}} = \mathbf{M}_{\text{unif}}(d_{\text{ACD}}) = \begin{bmatrix} 1 & d_{\text{ACD}} \\ 0 & 1 \end{bmatrix} \quad (A.4)$$

$$\begin{aligned}
 \mathbf{M}_{\text{lens}} &= \mathbf{M}_{\text{lensF}} \mathbf{M}_{\text{dlens}} \mathbf{M}_{\text{lensB}} \\
 &= \mathbf{M}_{\text{sphere}}(r_{\text{lensF}}, n_{\text{lens}}, n_{\text{aq}}) \mathbf{M}_{\text{unif}}(d_{\text{lens}}) \mathbf{M}_{\text{sphere}}(r_{\text{lensB}}, n_{\text{vitr}}, n_{\text{lens}}) \\
 &= \begin{bmatrix} \frac{d_{\text{lens}}(-n_{\text{lens}}+n_{\text{vitr}})}{r_{\text{lensB}}n_{\text{lens}}} + 1 & \frac{d_{\text{lens}}n_{\text{vitr}}}{n_{\text{lens}}} \\ \frac{-n_{\text{aq}}+n_{\text{lens}}}{r_{\text{lensF}}n_{\text{aq}}} + \frac{(-n_{\text{lens}}+n_{\text{vitr}})\left(\frac{d_{\text{lens}}(-n_{\text{aq}}+n_{\text{lens}})}{r_{\text{lensF}}n_{\text{aq}}} + \frac{n_{\text{lens}}}{n_{\text{aq}}}\right)}{r_{\text{lensB}}n_{\text{lens}}} & n_{\text{vitr}}\left(\frac{d_{\text{lens}}(-n_{\text{aq}}+n_{\text{lens}})}{r_{\text{lensF}}n_{\text{aq}}} + \frac{n_{\text{lens}}}{n_{\text{aq}}}\right) \end{bmatrix}
 \end{aligned}$$

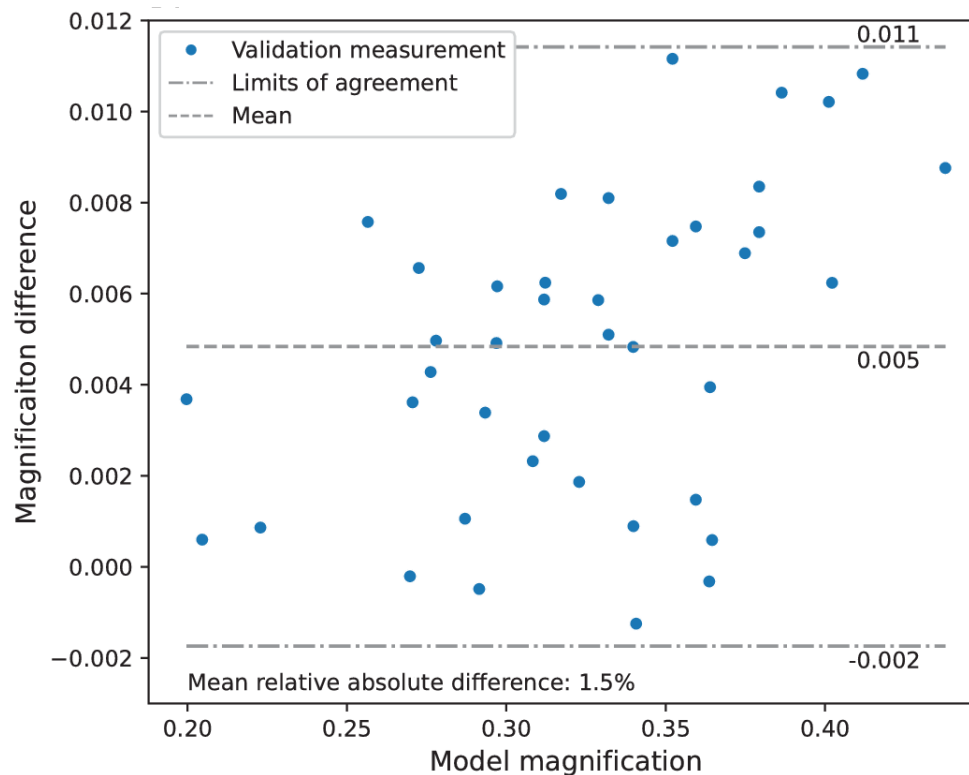
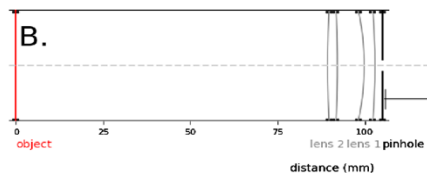
$$\mathbf{M}_{\text{vitr}} = \mathbf{M}_{\text{unif}}(d_{\text{vitr}}) = \begin{bmatrix} 1 & d_{\text{vitr}} \\ 0 & 1 \end{bmatrix} \quad (A.5)$$

$$\mathbf{M}_{\text{eye}} = \mathbf{M}_{\text{cor}} \mathbf{M}_{\text{ACD}} \mathbf{M}_{\text{lens}} \mathbf{M}_{\text{vitr}}, \quad (A.6)$$

Camera calibration

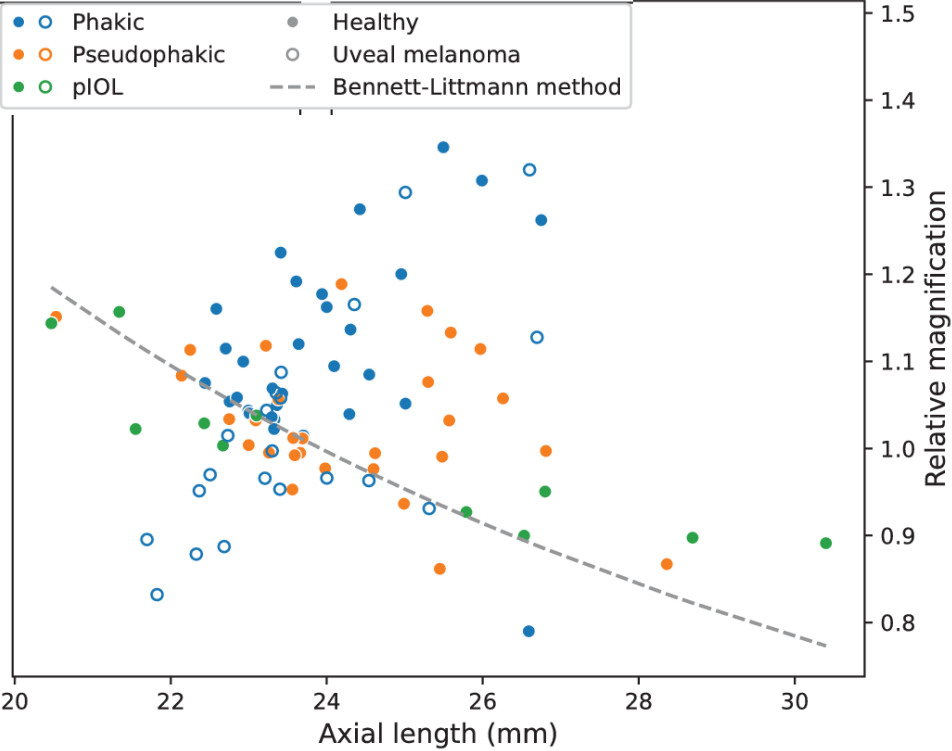


Model validation (41 phantom eyes)



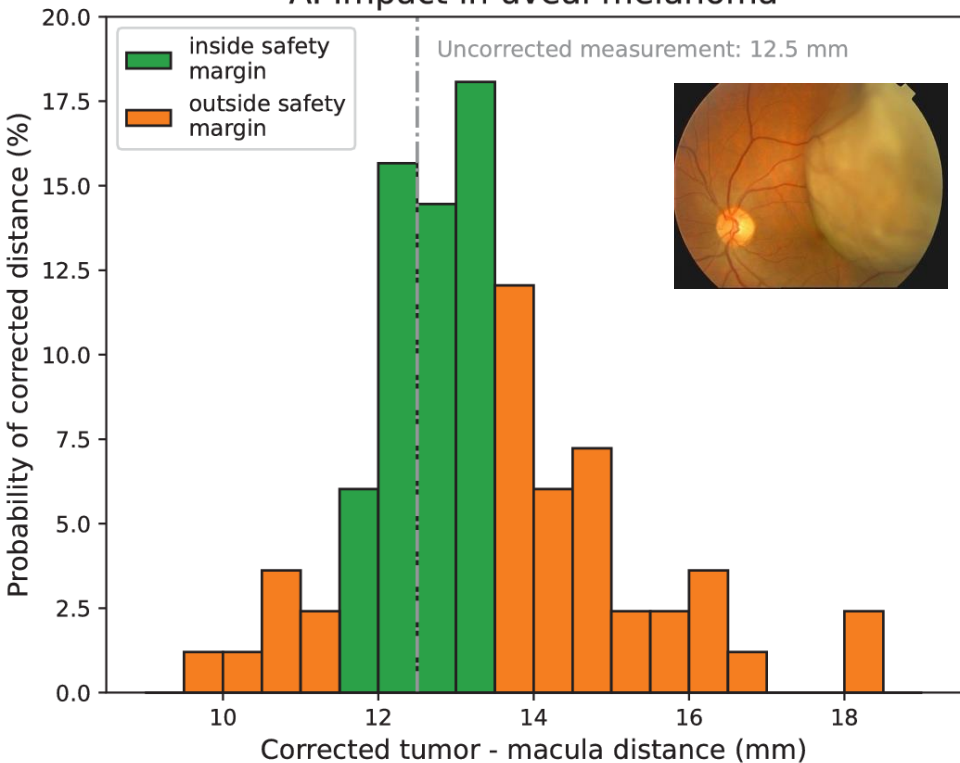
Comparison with Bennett-Littmann

B.

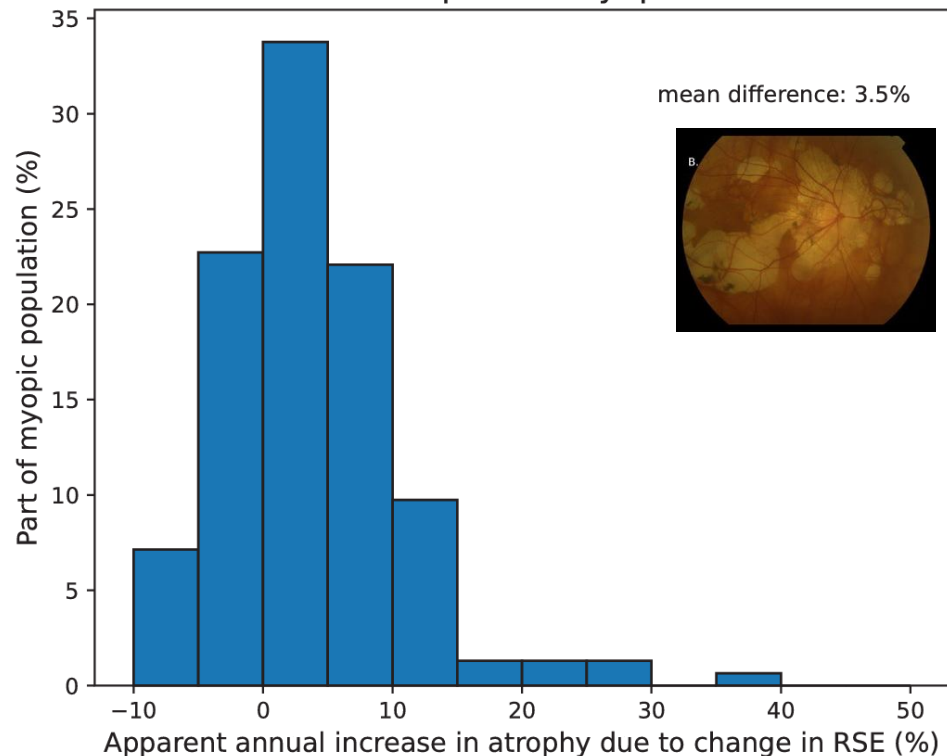


OK, nice, but why bother?

A. Impact in uveal melanoma

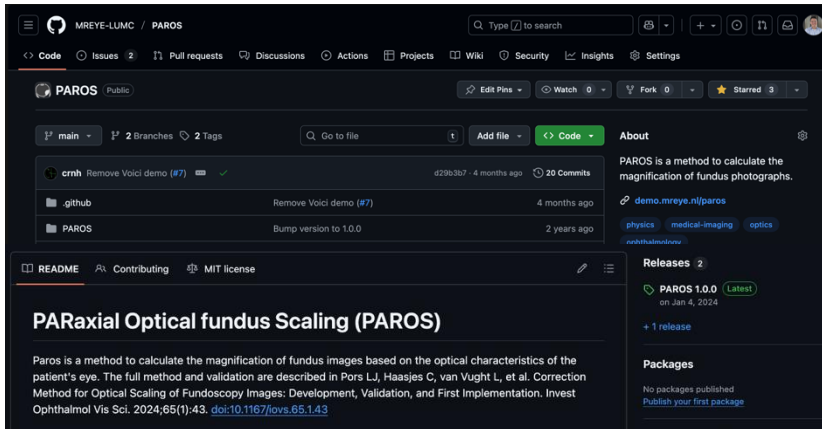


B. Impact in myopia



How to start correcting

- Read the PAROS paper (Pors et al, IOV 2024)
- Full method is available on github.com/MREYE-LUMC/PAROS
- Calibrate your camera
- and/or: explore the impact for our camera



demo.mreye.nl/paros/

Eye model parameters

Model type

Phakic

Anterior corneal curvature (mm)

7.72

Posterior corneal curvature (mm)

6.5

Anterior lens curvature (mm)

10.2

Posterior lens curvature (mm)

6.0

Corneal thickness (mm)

0.55

Anterior chamber depth (mm)

3.05

Crystalline lens thickness (mm)

4

Vitreous chamber depth (mm)

16.3203

Spherical eq. of refraction (D)

0

Estimate posterior corneal curvature

Fit posterior lens curvature

Camera parameters

See our publication for an explanation of the camera-specific parameters. Parameters used in this demo:

Condenser lens power 38 D

First order correction term -0.01

Result

Parameter	Value
Magnification eye model	1.60
Necessary correction at camera phakic	0.00



Conclusions and limitations

- The magnification of fundus images differs between subject
- Validation of methods is important (but often "future work")

Limitations:

- Only valid for central retina (but, see last presentation of session)
- Not (yet) validated for scanning laser ophthalmoscopes, OCT,....



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L. Pors

C. Haasjes

L. van Vught



www.mreye.nl

