Predicting refractive aniseikonia after cataract surgery in anisometropia

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PURPOSE: To propose a comprehensive classification of anisometropia, a method to calculate the theoretical related aniseikonia (objective aniseikonia) and a purpose-designed eikonometer to measure aniseikonia psychophysically (subjective aniseikonia).

SETTING: University Hospital Antwerp, Department of Ophthalmology, Edegem, Belgium.

METHODS: The occurrence of anisometropia was evaluated in 263 patients scheduled for cataract surgery. Subjective aniseikonia was evaluated in 77 healthy patients. The theoretical model was validated to calculate objective aniseikonia by implementing data from the literature. Ultimately, an aniseikogram was developed and its practical use illustrated by 4 clinical cases of anisometropia.

RESULTS: In a population of 263 patients, the total incidence of anisometropia was 7.6%, with a dominance of axial anisometropia. Subjective aniseikonia between 2% and 4% was found in 3.0% to 7.5% of the cases, depending on the refractive error. The correlation coefficient between objective and subjective aniseikonia was good ($R^2 = 0.82$). Analysis of 4 clinical cases illustrated the calculated preoperative and postoperative aniseikonia in 4 types of anisometropia planned for lens removal.

CONCLUSIONS: Anisometropia is not a rare condition and should be assessed before cataract surgery. A comprehensive method to calculate the objective aniseikonia and to measure the subjective aniseikonia in anisometropia was proposed. If cataract surgery is considered in anisometropic patients, a postoperative aniseikonia of 4% or more may be induced in the case of emmetropization. A method to calculate the intraocular lens power resulting in an acceptable postoperative aniseikonia, especially in axial anisometropic patients, is also proposed.

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Aniseikonia occurs when "the images presented to the cortex from the 2 eyes are abnormally unequal in size, shape or luminance."[1] The brain is able to compensate for a certain degree of image inequality, including oblique aniseikonia.[2] However, in the case of severe image inequality, impairment of stereoacuity will occur.[3]

Although aniseikonia is not necessarily the cause of amblyopia, it is often associated with congenital anisometropia.[4] In the past few decades, aniseikonia related to high anisometropia, such as unilateral aphakia, has been well described.[5] Aniseikonia up to 35% has been reported.[6,7] With the advent of contact lenses and the development of a large number of intraocular lenses (IOLs), aniseikonia could be avoided in most cases.

Due to the growing popularity of refractive surgery, aniseikonia has again caught the attention of ophthalmologists. Troutman[8] warned corneal and cataract surgeons about the risk for inducing aniseikonia in the case of anisometropia. Häring et al.[9] reported near-vision aniseikonia in up to 12% (mean 2.4%) of patients implanted with the very first generation of multifocal IOLs. In patients with unilateral pseudophakia, Kramer et al.[10] found up to 10% aniseikonia (mean 4.1%). In a population of pseudophakic patients, he reported subjective complaints attributable to aniseikonia in 40.2%. Huber and Binkhorst[11] expressed concern about aniseikonia after implantation

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of anterior chamber IOLs for severe anisometropia. These numbers show that aniseikonia is not a marginal problem and thus should be considered in any case of anisometropia, particularly in anisometropic patients seeking lenticular refractive correction.[12,13]

According to Knapp's law,[14] axial anisometropia can be corrected with spectacles without inducing aniseikonia. However, this law does not seem to be clinically confirmed.[14–18] The explanation was formulated by Awaya and von Noorden,[17] who stated that pure axial anisometropia is a rare condition because it is often combined with refractive anisometropia (corneal or lenticular).

In this paper, we propose a comprehensive approach to aniseikonia to (1) define the refractive balance of the eye, (2) define the type of anisometropia, (3) measure aniseikonia in the normal population, (4) calculate the theoretical aniseikonia, (5) predict postoperative aniseikonia in the case of preoperative anisometropia, and (6) validate the proposed method.

PATIENTS AND METHODS

Defining a Patient's Refractive Balance

To obtain a patient's refractive balance, the 4 pure types of anisometropia should be defined.

Corneal Anisometropia Corneal anisometropia is the difference between the corneal powers in the left eye and the right eye. This can be directly derived from both keratometric values obtained by topographical devices.

The difference between the axial powers in both eyes is called axial anisometropia. Axial power can be accurately estimated by measuring the axial length (AL) (obtained by biometry measurement) using the following formula[19]:

$$P_{\text{axial}} = \frac{n}{L - IPP}$$

where L is the ocular AL (mm); $n = 1336$, the refractive index of the vitreous; and $IPP = 1.6$ mm,[19] the estimated position of the image principal plane in the Gullstrand eye model.

Lenticular Anisometropia Lenticular anisometropia is the difference between the crystalline lens power in both eyes. The lenticular power P_{lens} can be estimated from the AL and the keratometry using an IOL power calculation formula (eg, SRK II,[20] SRK/T,[21] Holladay[22]) or ray-tracing calculation.[23] When an IOL power formula is used, the spherical equivalent (SE) of the best spectacle refraction should be used for the targeted refraction R.

Spectacle Anisometropia Spectacle anisometropia is the difference between the SEs of both spectacles. It can also be defined as the difference between the axial anisometropia and the sum of corneal and lenticular anisometropia.

Mixed Anisometropia Mixed anisometropia is the combination of 2 or more pure types of anisometropia. It can thus be corneal and axial; corneal and lenticular; axial and lenticular; or corneal, axial, and lenticular.

To measure the optical balance of the eye, the following parameters are needed[5,19,23,24]: best spectacle-corrected refraction, corneal power, ocular AL, and anterior chamber depth (ACD) (endothelium to anterior lens capsule) in both eyes. Table 1 shows all required parameters to calculate the theoretical anisometropia. For the vertex distance, an estimated distance of 12.0 mm is generally accepted.

Defining the Type of Anisometropia

Using this anisometropic assessment, the type and rate of anisometropia in a population of 263 patients planned for cataract surgery were analyzed. The parameters studied were best subjective spectacle correction in both eyes with estimated vertex distance at 12.0 mm, AL, keratometry, and ACD. The last 3 parameters were determined using the IOLMaster (Zeiss).

Table 1. Anisometropia assessment form (ocular parameters from which the theoretical aniseikonia will be derived).

Parameter	Source of Parameter	Eye: Right	Eye: Left
Spectacle spherical equivalent R	Subjective refraction	..... D	..... D
Mean corneal power K	Keratometry	..... D	..... D
Axial length L	Biometry	..... mm	..... mm
Anterior chamber depth*	Biometry	..... mm	..... mm
Axial power	$P_{\text{axial}} = \frac{1336}{L-1.6}$	..... D	..... D
Axial anisometropia	$\alpha_A = P_{\text{axial}_{OD}} - P_{\text{axial}_{OS}}$	..... D	
Effective corneal power	$K_{\text{eff}} = \frac{K}{1-0.0016\times K}$	..... D	.....D
Corneal anisometropia	$\alpha_C = K_{\text{eff}_{OD}} - K_{\text{eff}_{OS}}$	..... D	
Lens power	$P_{\text{lens}} = 119 - 2.5 \times L - 0.9 \times K - R_{\text{eff}}$	..... D	..... D
Effective lenticular power	$P_{\text{eff lens}} = \frac{P_{\text{lens}}}{1-0.001(\text{ACD}-1.6)\times P_{\text{lens}}}$	..... D	..... D
Lenticular anisometropia	$\alpha_L = P_{\text{eff lens}_{OD}} - P_{\text{eff lens}_{OS}}$	..... D	
Effective spectacle spherical equivalent power	$R_{eff} = \frac{R}{1-0.0136\times R}$	..... D	..... D
Spectacle anisometropia	$\alpha_S = R_{\text{eff}_{OD}} - R_{\text{eff}_{OS}}$	..... D	

*Distance between endothelium and anterior lens capsule

Measuring Aniseikonia in the Normal Population

Few eikonometers are commercially available. In collaboration with Metrovision, the authors developed a direct-comparison eikonometer consisting of liquid crystal spectacles, a computer screen, and software technology. The patient was asked to wear liquid crystal spectacles on top of his/her corrective spectacles and to look at a computer screen.

These liquid crystal glasses were configured in such a way that both sides change between transparent and opaque at a high frequency in opposite phase with each other. Meanwhile, the computer screen was synchronized with these liquid crystal glasses so that 1 image was presented when 1 side was transparent and a different image was presented when the other side was transparent. This occurred at a frequency of 120 Hz, a frequency undetectable by the human eye, giving the patient the illusion of looking at 1 image with both eyes. In the setup, 2 horizontally oriented half circles were chosen; one half remained unchanged, while the other varied in size.

The test starts with the half circle being 20% larger than the other. This size is reduced stepwise until the patient perceives both half circles as equal. The eventual size difference, expressed in percentage, corresponds to the patient's aniseikonia.

To get an idea of the prevalence of aniseikonia in a normal population, aniseikonia was measured in a randomized population of 77 individuals presenting with no ocular comorbidity other than myopia, emmetropia, or hyperopia. A patient was considered emmetropic if no spectacles were used and the SE measured by objective refractometer was lower than $\pm$1.0 diopter (D).

Calculating the Theoretical Aniseikonia

Aniseikonia is the ratio of the anterior focal distance of each eye. A theoretical formula to estimate the anterior focal distance and the resulting aniseikonia is developed in Appendix A.

Oblique aniseikonia can be calculated by using the focal point in each direction. The relative aniseikonia of each eye was estimated with respect to the Gullstrand eye model. Based on the vectorial combination of the relative aniseikonia in both eyes, a diagram called an aniseikogram can be calculated.

This aniseikogram shows the distortion of the ideal circle as would be observed by the Gullstrand eye compared with the patient's optical eye.

Predicting Postoperative Aniseikonia in Cases of Preoperative Anisometropia

Based on the calculation developed in Appendix A, it is possible to calculate the theoretical aniseikonia in patients presenting with anisometropia and seeking lenticular correction. In the case of planned cataract surgery (correction in the lenticular plane), a corneal anisometropia of 8.0 D or an axial anisometropia of more than 1.0 mm should warn the surgeon of possible postoperative aniseikonia if emmetropia were the goal. Because corneal anisometropia of 8.0 D does not occur very frequently (mainly after penetrating keratoplasty [PKP]), axial anisometropia would be the main cause of postoperative aniseikonia of 4% or more. The usefulness of the theoretical aniseikonia calculation will be illustrated by 4 clinical cases. In Appendix B, the derivations to calculate aniseikonia in patients presenting pure axial anisometropia are developed. In these cases, the calculation of aniseikonia can be significantly reduced to the ratio of both ALs.

Validating the Proposed Method

To validate this theoretical approach, data available from the literature were implemented. The reference paper is by Winn et al.[16] In this article, the authors published the full refractive assessment of 18 patients, which they correlated with the subjective aniseikonia assessed with an eikonometer of their design. After the parameters of these 18 patients were applied to the calculation method presented here, objective aniseikonia was obtained and the results were compared with the subjective aniseikonia found by Winn et al.

RESULTS

Defining a Patient's Refraction Balance and Type of Anisometropia

The mean age of the 263 patients planned for cataract surgery was 65.2 years $\pm$ 18.4 (SD). Table 2 summarizes the results: anisometropia was found in 7.56% of patients. Lenticular anisometropia was obviously most frequently found (2.70%). The total of pure anisometropia was found in 3.80%, which is in the same range as mixed anisometropia (3.76%). Axial anisometropia type was found in 4.10%.

Measuring Aniseikonia in the Normal Population

Of the 77 normal individuals, 32 were myopic, 32 were emmetropic, and 13 were hyperopic. Aniseikonia of 2% was found in 31% in the myopic group, 19% in the emmetropic group, and 23% in the hyperopic group (Table 3). Because aniseikonia of 2% is clinically insignificant, only values higher than 2% were then considered. The prevalence of clinically significant aniseikonia in these groups ranged between 3% and 7%, with a mean of 3.9% in the total group. There were no statistically significant differences between

Table 2. Rate and type of anisometropia in a population of 263 cataractous patients.

Type	Rate (%)
Pure anisometropia	
Corneal	0.00
Lenticular	2.70
Axial	1.10
Mixed anisometropia	
Corneal and axial	0.00
Corneal and lenticular	0.76
Axial and lenticular	1.90
Corneal, axial, and lenticular	1.10
Total anisometropia	7.56

the 3 ametropia groups. The highest aniseikonia value was 4%.

Calculating the Theoretical Aniseikonia

The dioptric data of 4 patients presenting complex cases of anisometropia were implemented in the assessment form.

Using Excel software (Microsoft Corp.), the theoretical aniseikonia can be calculated over 360 degrees. The maximum and minimum aniseikonia can be defined as well as their axes (Figure 1). These 2 axes are not necessarily perpendicularly oriented.

This method was applied to 4 cases of manifest anisometropia. LBM, a 25-year-old man, had bilateral developmental cataract. Both eyes required cataract surgery. VHF, a 75-year-old woman, had cataract with pseudoexfoliation in the right eye. The left eye was already pseudophakic. HV, a 4-year-old boy, had unilateral congenital cataract. VBA, an 80-year-old woman, was pseudophakic in the right eye before having PKP. The right eye presented with significant post-PKP astigmatism that was poorly accepted. Contact lens adaptation gave satisfactory subjective results but was not well tolerated. LBM presented with axial anisometropia; VHF, with mixed corneal and lenticular anisometropia; HV, with mixed axial, corneal, and lenticular anisometropia; and VBA, with corneal aniseikonia (Figure 1).

Predicting Postoperative Aniseikonia in Cases of Preoperative Anisometropia

The theoretical aniseikonia is calculated over 360 degrees, allowing creation of the aniseikogram. The highest degree of positive and negative aniseikonia can be deduced (= objective aniseikonia).

In Figure 2, the aniseikogram is simulated in a case in which emmetropia was the postoperative goal in both eyes. When looking at the results, it is obvious that only VHF would benefit from emmetropia after cataract surgery. LBM and HV would have an aggravation of their theoretical aniseikonia, and VBA's aniseikonia would remain unchanged postoperatively. Vice versa, this aniseikogram can be used to calculate the aimed postoperative refraction to achieve a clinically acceptable postoperative aniseikonia.

Considering the clinical examples (Figure 3), the refractive outcome in LBM's left eye should be targeted at −7.0 D (−2 to 161 degrees) to limit postoperative aniseikonia to a maximum 4%, which was approximately the preoperative aniseikonia (Figure 1). Emmetropizing the left eye would induce aniseikonia up to 17% (Figure 2). VHF would be fine with emmetropization of both eyes. The postoperative aniseikonia (Figure 4) would remain unchanged from the preoperative one (Figure 1).

HV presented with approximately 4.0% of aniseikonia preoperatively (Figure 1), which was well tolerated. Emmetropization of the right eye would induce 8% of aniseikonia (Figure 2). To reduce the aniseikonia from 8.0% to 4.0%, the targeted postoperative SE refraction of the right eye should be +4.75 D to limit postoperative aniseikonia to 3.5% (Figure 3).

The situation of VBA is complex. She is already pseudophakic in the right eye and presents with a significant corneal astigmatism after PKP. Emmetropization of the right eye would result in 18% aniseikonia (Figure 2), which is similar to the actual aniseikonia (Figure 1). Intraocular lens exchange would not help much because no toric IOL of that power is available. To limit the postoperative aniseikonia to approximately 6%, the proposal would be to implant a toric anterior chamber Artisan IOL (Ophtec) of +12.0 D (−7 to 160 degrees) and to correct the remaining corneal astigmatism with laser surgery or spectacles.

Validating the Proposed Method

Figure 4 shows the calculated aniseikonia with respect to the measured; the correlation factor is 0.82. It can be deduced that the theoretical model fits well with the results obtained by Winn et al.[16]

Table 3. Measurement of aniseikonia in an ad random population.

		Mean ± SD		
Group	n	Age (Y)	Absolute Aniseikonia (%)	Prevalence of Aniseikonia >2% (%)
Myopia	32	26 ± 6	0.7 ± 1.1	3.1
Emmetropia	32	31 ± 16	0.4 ± 0.9	3.1
Hyperopia	13	46 ± 25	0.6 ± 1.2	7.7
All patients	77	31 ± 16	0.51 ± 1.0	3.9

DISCUSSION

In a large study including 5023 students between 6 and 18 years old,[25] 6% of anisometropia was reported. This number is close to the 7.6% found in our series. Looking at myopic children, 17% presented with anisometropia.[26] These results suggest that the importance of anisometropia and the possible associated aniseikonia are not so uncommon. In clinical practice, ophthalmologists will have to manage 6% to 7.6% of anisometropic patients at risk for developing some degree of induced aniseikonia after cataract or refractive surgery.

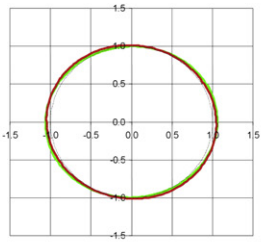
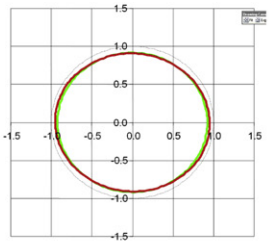
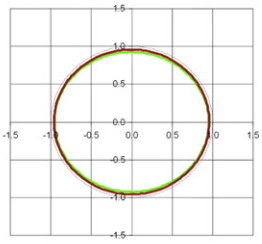
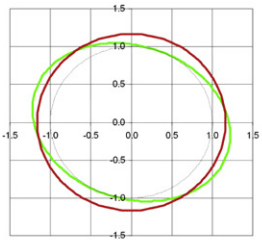
Patient	LBM (M, 25 years old)		VHF (F, 75 years old)		HV (M, 4 years old)		VBA (F, 80 years old)	
Eye	RE	LE	RE	LE	RE	LE	RE	LE
L	25.1 mm	28.2 mm	21.6 mm	21.4 mm	20.0 mm	22.4 mm	26.5 mm	28.0 mm
K_1	41.8@7°	42.2@165°	45.6@173°	48.3@171°	45.2@176°	41.7@13°	33.2@157°	42.1@88°
ΔK	4.7@97°	3.1@75°	1.4@83°	4.0@81°	2.4@86°	1.0@103°	16.6@67°	1.2@178°
R	−3.5 −5@10°	−14 −4@170°	0 −0.5@150°	4 −3.75@175°	7 −2.25@75°	0 0@0°	10 −16@157°	0 0@0°
P_{lens}	17.9	26.3	22.6(*)	15.0	18.2	24.6	10(*)	10
Objective aniseikonia	-3%@120° 2.5%@26°		-3%@80° 1%@170°		-3.5%@ 84° -0.5%@174°		-16%@68° 9%@158°	
Preoperative aniseikogram Color legend RE LE Gullstrand								

Figure 1. Aniseikogram of 4 types of anisometropia. *Green*: Right eye. *Red*: Left eye. *Dashed line*: 0% aniseikonia (ΔK = difference between keratometries between eyes [astigmatism]; ACD = anterior chamber depth; F = female; K_1 = flattest meridian keratometry; L = axial length; LE = left eye; M = male; P_{lens} = power lens; R = subjective best corrected spherical equivalent; RE = right eye).

Improvement of stereopsis in anisometropia has been found in only 10% to 33% of children who had refractive surgery to correct anisometropia.[27–29] However, none of these studies clearly distinguishes which type of anisometropia they were evaluating. It would have been more interesting to assess which type of anisometropia had the best success rate.

In children presenting with congenital cataracts, poorer results in visual performance were found in those with axial anisometropia.[30] These poor results can be explained by the postoperative differences in image size. We could not make the calculation because the dioptric data were missing.

By implementing the refractive data of 18 patients, as published in Winn et al.'s paper,[16] into our formula, the correlation was 0.82. This correlation factor is very good when considering that subjective aniseikonia reflects not only the optical properties of the eye but also the retinal and/or cerebral properties.[31]

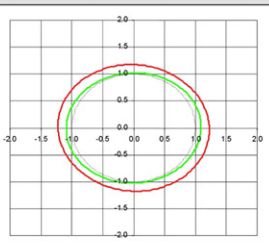
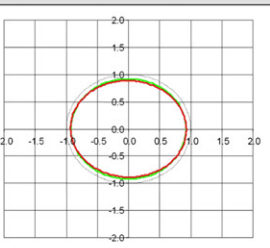
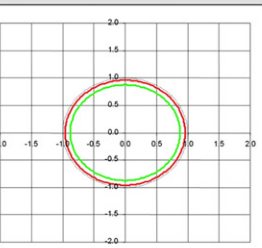
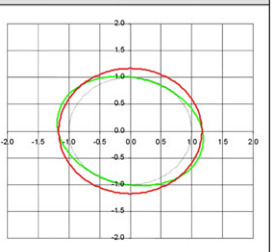
Patient	LBM (M, 25 years)		VHF (F, 75 years)		HV (M, 4 years)		VBA (F, 80 years)	
Eye	RE	LE	RE	LE	RE	LE	RE	LE
R	2.5 −5@10° = 0	2 −4@170° = 0	0	2 −4@175° = 0	1 −−2@75° = 0	0	8 −16@67° = 0	0
Estimated aniseikonia in case of emmetropia	−17%@128° −11%@34°		−0.5%@170° 3.5%@80°		−8%@ 84° −8%@174°		−18%@68° 6%@158°	
Aniseikogram in case of emmetropia Color legends RE LE Gullstrand								

Figure 2. Estimated postoperative aniseikonia in 4 types of anisometropia with an IOL aiming at emmetropia. *Green*: Right eye. *Red*: Left eye. *Dashed line*: 0% aniseikonia (F = female; LE = left eye; M = male; R = target spherical equivalent to achieve emmetropia; RE = right eye).

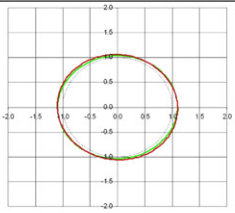
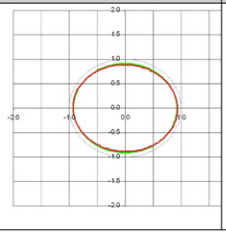
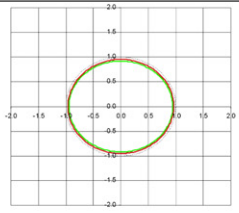
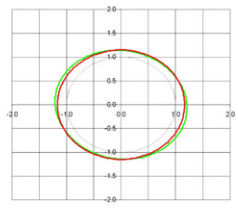
Patient	LBM (M, 25 years)		VHF (F, 75 years)		HV (M, 4 years)		VBA (F, 80 years)	
Eye	RE	LE	RE	LE	RE	LE	RE	LE
P_{IOL} (D)	16	18	20	-----	21.5	------	+12 -7.5@160° anterior chamber IOL	----
Targeted refraction	2 -4@97	-7 -2@161	0	3 -3.75@175°	6 -2.5@86°	0 0@0	0 -6@120°	0 0@0
Minimally aniseikonia	-4%@125° 1%@30°		-0.5%@170° 3.5%@80°		-3.5%@80° -1.7%@170°		-2.5%@60° 6%@155°	
Corresponding aniseikogram								

Figure 3. Targeted refraction to achieve a minimally acceptable postoperative aniseikonia. *Green*: Right eye. *Red*: Left eye. *Dashed line*: 0% aniseikonia (F = female; LE = left eye; M = male; P_{IOL} = power of the IOL; R = target spherical equivalent to achieve emmetropia, RE = right eye).

Calculating the theoretical aniseikonia is time consuming. It is easier for the surgeon to obtain the objective aniseikonia in each anisometropic patient for whom cataract surgery is planned. In complicated cases, the results obtained can be simulated using contact lenses before surgery.[24] The subjective aniseikonia can then be measured using an eikonometer. In this way, the surgeon and the patient will be more confident about the decision to perform or not perform surgery.

Combining the theoretical aniseikonia with the subjective one is clinically useful. The difference between the objective and subjective aniseikonia could be considered to correspond to a certain degree to the retina/brain causes for aniseikonia.[30]

An orthoptic examination should be performed routinely in anisometropic patients[32] to evaluate the degree of suppression of the recessive eye. Managing aniseikonia is a key issue in preserving the ocular balance. Lenticular anisometropia will be corrected after IOL implantation aiming at emmetropia, but axial anisometropia (from 1.0 mm on) cannot be corrected after IOL implantation without inducing aniseikonia. In patients presenting with preoperative suppression, the aniseikonia can be well tolerated, but that is not the case in patients with good binocular vision.

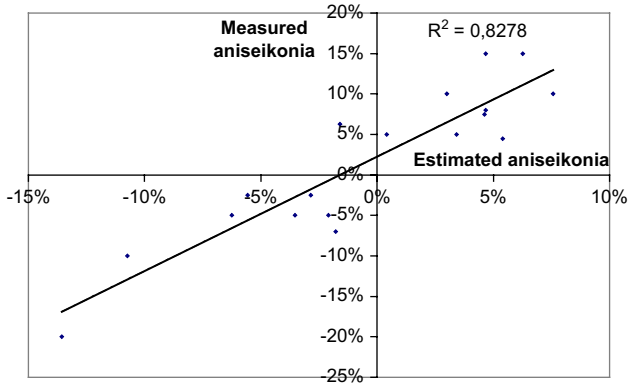


Figure 4. Subjective aniseikonia measured by Winn et al.'s eikonometer with respect to the calculated aniseikonia using the formula in Appendix A after the data provided by Winn et al.[16] were implemented.

Based on our theoretical model of anisometropic correlated aniseikonia, the following rules regarding correction of the various types of anisometropia should be considered:

1. Pure axial anisometropia should preferentially be corrected with spectacles. If cataract surgery is necessary in patients with axial anisometropia, the aim should be to emmetropize the dominant eye. The power of the IOL in the recessive eye should be the difference between the emmetropizing power in the recessive eye minus the difference between both axial powers (cf, patient HV, Figure 1, and therapeutic proposal in Figure 3).
2. Corneal anisometropia can be corrected with contact lenses, refractive surgery, or cataract surgery.
3. Lenticular anisometropia would best be corrected with cataract surgery in older patients. In younger patients, it can be corrected with refractive surgery.
4. Combined anisometropia must be broken down into its components (axial, corneal, and lenticular), and the balance of the induced aniseikonia should be calculated by function of the planned surgical procedure.

APPENDIX A

Predicting Postoperative Aniseikonia in Cases of Refractive Anisometropia (Lenticular or Corneal)

Aniseikonia induced by correcting refractive anisometropia at another plane than the one causing anisometropia (eg, aniseikonia induced by the spectacle correction of a corneal anisometropia) can be calculated with matrix optics:

$$\text{Aniseikonia} = \frac{f_{OD}}{f_{OD}}$$

with

$$\frac{1}{f_{OS}} = P_{OS} + P_{L^{OS}} + K_{OS} - (c+v)P_{OS}P_{L^{OS}} - vP_{L^{OS}}K_{OS} - cP_{OS}K_{OS} + vcP_{L^{OS}}P_{OS}K_{OS}$$

$$\frac{1}{f_{OD}} = P_{OD} + P_{L^{OD}} + K_{OD} - (c+v)P_{OD}P_{L^{OD}} - vP_{L^{OD}}K_{OD} - cP_{OD}K_{OD} + vcP_{L^{OD}}P_{OD}K_{OD}$$

where

$$c = \frac{\text{ACD}}{n}$$

ACD is the anterior chamber depth, n is the aqueous humor refractive index, and v is the vertex distance of the spectacles from the anterior cornea estimated at 12.0 mm.

This complicated formula is easy to implement in a worksheet to compare the aphakic preoperative situation corrected by spectacles with the pseudophakic situation corrected by IOL (Figure A1).

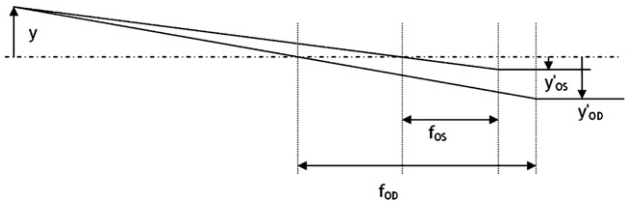


Figure A1. Ray tracing of the left and right eye using only the focal and principal plane positions and the object size y

Aniseikonia is also the equation between the magnification M as perceived by both eyes. The magnification M can be calculated as follows[28]:

$$M = \frac{y'}{y} = \frac{f}{s-f} \tag{A1}$$

where y is the object size, y' is the image size, f is the focal distance, and s the object distance from the object principal plane PP. When this is applied to both eyes, the result is

$$\begin{cases} M_{OD} = \dfrac{y'_{OD}}{y} = \dfrac{f_{OD}}{s_{OD} - f_{OD}} \\ M_{OS} = \dfrac{y'_{OS}}{y} = \dfrac{f_{OS}}{s_{OS} - f_{OS}} \end{cases} \tag{A2}$$

It can be considered that $s_{OD} \approx s_{OS} \approx s$ (distance of the object from each eye is to be considered equal) and $s >> f_{OD}$ and $s >> f_{OS}$:

$$\text{Aniseikonia} = \frac{y'_{OD}}{y'_{OS}} = \frac{y'_{OD}}{y} \times \frac{y}{y'_{OS}} = \frac{M_{OD}}{M_{OS}} \tag{A3}$$

Calculating aniseikonia as a function of image magnification M of both eyes yields

$$\text{Aniseikonia} = \frac{M_{OD}}{M_{OS}} = \frac{f_{OD}}{f_{OS}} \times \frac{s - f_{OS}}{s - f_{OD}} \approx \frac{f_{OD}}{f_{OS}} \quad \text{(A4)}$$

APPENDIX B

Predicting Postoperative Aniseikonia in Cases of Axial Anisometropia

In the case of cataract surgery planned in pure axial anisometropia, aiming at emmetropizing both eyes, postoperative aniseikonia can easily be estimated by making the ratio of the axial lengths (ALs) only. The focal length is expressed in function of the axial length:

$$\frac{f_{OD}}{f_{OS}} = \frac{L_{OD} - PP_{OD}}{L_{OS} - PP_{OS}} \approx \frac{L_{OD}}{L_{OS}} \quad \text{(A5)}$$

with *PP* being the second principal plane of the eye (approximately 1.6 mm for the Gullstrand eye). As *PP* is only 8% to 10% of the ocular AL and can be considered as equal in both eyes, the ratio of both eyes' ALs can be used as a quick approximation of the ratio of the focal lengths.

Combining equations A4 and (A5, the postoperative aniseikonia after emmetropization can be estimated using a preoperative axial anisometropia as follows:

$$\text{Aniseikonia} \approx \frac{L_{OD}}{L_{OS}} \quad \text{(A6)}$$

Example: $L_{OD} = 23.1$ mm and $L_{OS} = 25.9$ mm → the theoretical aniseikonia in case emmetropization of both eyes is the aim, will be 12%.

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