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## - To cite this version:

Maxence Rateaux, Dominique Bremond-Gignac, Matthieu Robert. From monocular photograph to angle lambda: A new clinical approach for quantitative assessment. Journal of Binocular Vision and Ocular Motility , 2022, 10.1080/2576117X.2022.2083541 . hal-03947978

HAL Id: hal-03947978

## https://hal.science/hal-03947978

Submitted on 2 Feb 2023

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# From monocular photograph to angle lambda 

# New clinical approach for quantitative assessment 

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#### Abstract

: Angle lambda assessment is essential in pediatric and strabismus practice. A highly angle lambda will modify the visual appearance of a strabismus or mimic one. Currently, angle lambda can be assessed by corneal topographs. Unfortunately, the use of these devices remains limited in the context of a strabismus clinic. Herein we purpose an easy, low cost and reproducible method for angle lambda quantification, based on monocular photographs.

Monocular pictures were performed by using a camera with a ring flash, centered by a fixation point. A digital evaluation analyzed the position of the corneal reflex on the pupil diameter. Using a trigonometric formula, the resulting ratio was converted into the value of angle lambda. This method was tested on 20 healthy eyes, on two successive couple of pictures, to evaluate its repeatability. Assessment using Pentacam was performed for comparison.

The mean value of angle lambda was: $+2.61^{\circ} \pm 2.92^{\circ}$ and $2.63^{\circ} \pm 2.85^{\circ}$ in the both pictures series respectively -Lin's repeatability coefficient: 0.99 - with a systematic deviation of $-0.071^{\circ}$ compared to Pentacam assessment. Angle lambda distribution was in range with values from the literature.

This new method allows for angle lambda assessment without requiring a specific device, and can be used in strabismus and pediatric clinics.


## Introduction

Ophthalmologic and physiological optics relies on several specific axes ${ }^{1,2}$. Relations between these axes allow to define various angles: alpha ( $\alpha$ ), kappa ( $\kappa$ ) and lambda ( $\lambda$ ). Their definitions, however, are not consensual and vary according to authors, which has led to much confusion between angles $\kappa$ and $\lambda^{1,3}$. Angle $\alpha$ designates the angle between the visual axis (broken line between the fovea and the fixation point and passing through one nodal point) and the optical axis (line passing through the nodal point and the corneal apex). Angle $\kappa$ can be defined as the angle formed by the visual axis and the pupillary axis (line passing through the center of the pupil and orthogonal to the cornea). As the human eye is not a centered optical system and as nodal points are mathematical constructions without anatomical location, both these angles cannot actually be used clinically; optical and visual axes are purely theoretical ${ }^{4,5}$. On the other hand, the angle between the pupillary axis and the line of sight (line connecting the fixation point and the center of the entrance pupil; crossing the cornea at a point named corneal sighting center), most often called angle $\lambda$, can be easily located. It can be considered as a close equivalent, clinically relevant, of angle $\kappa$. In addition, for a coaxial light source, we can define the keratometric axis, which connects the fixation target and the center of the corneal curvature. Its perpendicular intersection with the cornea defines the corneal vertex, which corresponds to the position of the first Purkinje image on the cornea ${ }^{6}$ (Fig. 1).

Previously, angle $\lambda$-often improperly designated as angle $\kappa$ - has often been estimated by using the major amblyoscope or the synoptophore ${ }^{7,8}$. Currently, some corneal topographs assert to provide a value of angle $\kappa$, which actually also corresponds to angle $\lambda^{8-10}$. Indeed, the assessment of angle $\kappa$ by these devices is provided by the distance between the pupil center and the corneal reflex point, corresponding to the definition of angle $\lambda^{11}$. From now, to avoid any confusion, we will refer to all such values of so-called angle $\kappa$ as $\lambda$.

For one given patient, there is only one angle $\alpha$, but several angles $\lambda$ : while angle $\alpha$ relies on the corneal diameter, angle $\lambda$ rely on the pupil diameter, which changes over time, due to intrinsic (age, emotions,
etc.) and extrinsic (luminance) factors. These fluctuations can induce a small displacement of the location of the entrance pupil, therefore of the pupillary axis, and can consequently marginally alter the value of angles $\lambda$, according to the pupil diameter values ${ }^{12-14}$.

In the healthy population, Gharaee et al. reported an angle $\lambda$ equal to $+4.96^{\circ} \pm 1.38^{\circ}$, provided by Orbscan II (Baush\&Lomb, Rochester, NY, USA), while Sung et al. provided an estimation of angle $\lambda$ equal to $+4.41^{\circ} \pm 2.23^{\circ}$, based on measurements provided by Pentacam (Oculus Instruments, Wetzlar, Germany) combined to second law of cosines ${ }^{9,15}$. The value of angle $\lambda$ can be altered by high ametropia and by several congenital disorders -highly positive angle $\lambda$ in high hypermetropia, in oculocutaneous albinism, aniridia, and retinal folds ${ }^{16-18}$.

The evaluation of angle $\lambda$ is important in refractive surgery for the optical zone centration, and has also been used in cataract surgery for determining intraocular lens position ${ }^{19-22}$. It is also crucial in the assessment of strabismus. A patient with a highly positive angle $\lambda$ seems to exhibit a divergent strabismus, while he is orthophoric; a highly positive angle $\lambda$ can minimize the visual aspect of an esotropia, and even offset it, according to the respective angle values ${ }^{23}$. In contrast, a highly negative angle $\lambda$ can simulate an esotropia. In all situations where the strabismus angles provided by cover-test measurements do not fit the observed or reported strabismus, and in all situations of fundus malformations, a precise quantification of angle $\lambda$ can be useful. In this context, at least one smartphone application has been developed to measure ocular misalignment, which reportedly also provides an evaluation of "angle kappa" ${ }^{24}$. However, so far, no simple method to quantify angle $\lambda$ in daily strabismus practice is readily available. The use of corneal topography remains limited by its cost and restricted diffusion; besides, it is often time consuming and complex to manipulate, especially in young patients. Herein we purpose a new digital approach for the evaluation of horizontal angle $\lambda$, based on simple photographs of subjects' eyes.

## Method

The study was carried out in accordance with Declaration of Helsinki and it received approval from the Ethical Committee from Île-de-France (IRCB : 2020-A03370-39).

## 1- Digital picture and ratio analysis.

The subject, placed one meter from a camera, is asked to keep his gaze straight on a fixation point centered in the middle of the camera lens or in the case of a young child, to look at a fixation target sticked at the center of the camera lens; a ring flash being placed around it, so as to get coaxially sighted corneal light reflex as suggested by Uozato and Guyton ${ }^{25}$ (Fig. 2). Two pictures are successively performed: one of the right eye and one of the left eye.

The analysis of these pictures is then processed through the free image editor software GIMP (v2.10.14). The ruler tool is used so as to measure the distance between the nasal edge of the iris (NP) and the corneal vertex (V) and the pupil diameter ([NPTP]) (Fig. 3). Then, the ratio of both distances $R$ is calculated: $R=\frac{\left[N P V^{\prime}\right]}{[N P T P]}$, where $\left[N P V^{\prime}\right]$ and $[N P T P]$ are expressed in pixels.

## 2- From ratio to angle $\lambda$.

Figure 1 represents the geometrical optics of the anterior chamber. In this analysis, we assume that the distance between V and C is negligible, and therefore that value of angle $\lambda$, which corresponds to the angle $\widehat{C P P^{\prime}}$, can be approximated by the value of the angle $\widehat{V P P^{\prime}} . V^{\prime}$ is the orthogonal projection of $V$ on [NP TP] segment and $P^{\prime}$ is the orthogonal projection of $P$ on the cornea. As $V P^{\prime} P$ is drawing a right triangle, the value of angle $\lambda$ is obtained by the following formula:

$$
\text { Angle Lambda }=\operatorname{deg}\left(\tan ^{-1} \frac{\left[V P^{\prime}\right]}{\left[P^{\prime} P\right]}\right)
$$

The distance $\left[P^{\prime} P\right]$ corresponds to the depth of the anterior chamber (DAC).
According to the orthogonal projection of V on the segment ([NP-TP]), it follows that:

$$
\left[\begin{array}{ll}
V & P^{\prime}
\end{array}\right]=\left[\begin{array}{ll}
V^{\prime} & P
\end{array}\right]
$$

$$
\left[V^{\prime} P\right]=[N P P]-\left[N P V^{\prime}\right]=\left(\frac{[N P T P]}{2}\right)-(R \times[N P T P])(\text { with R}=\text { Ratio calculated for angle } \lambda)
$$

The value of the pupil diameter ([NP-TP]) in mm is provided from the value of the corneal diameter, by measuring the ratio of the pupil diameter on the corneal diameter on the picture. As the entrance pupil is estimated to be $14 \%$ larger than the real pupil, because of a magnification effect through the cornea, a reduction coefficient was applied to the pupil diameter ${ }^{25}$.

$$
[N P T P](\text { in } \mathrm{mm})=\frac{[N L T L](\text { in } m m) \times[N P T P](\text { in pixels }) \times 0.86}{[N L T L](\text { in pixels })}
$$

From this, it follows that:

$$
\text { Angle Lambda }=\operatorname{deg}\left(\tan ^{-1} \frac{\frac{[N P T P]}{2}-(R \times[N P T P])}{\left[P^{\prime} P\right]}\right)
$$

The values of the corneal diameter ([NLTL] in the formula) and of the DAC ([P-P'] in the formula) can be measured by performing a corneal topography and an ocular biometry, respectively. They can otherwise be approximated by using theoretical values: 11.71 mm for the corneal diameter and 3.4 mm for the $\mathrm{DAC}^{26,27}$.

## 3- Patients

The method was applied to 20 eyes from 10 healthy volunteers (subjects with no current or past ophthalmological disorder including strabismus) (age [22.5-28.5], median $=26.3, \mathrm{SD}=1.99,4$ males -6 females, spherical equivalent (SE): [-6.00D,$+1.50 \mathrm{D}]$, median $=-1.56 \mathrm{D}$ ). Previous consent was obtained. Pictures of the right eye and of the left eye were taken twice successively, in order to evaluate the repeatability of the method. The DAC ( $\left[P-P^{\prime}\right]$ ) was measured by ocular biometry (IOL Master 500, Carl Zeiss Meditec, Germany), and the corneal diameter ([NL-TL]) was measured by corneal topography (Pentacam, Oculus Instrument, Wetzlar, Germany).

Ratio $R$ was obtained by image analysis and value of the angle was calculated using the previously expressed formulas.

For each picture, two calculations were performed. The first one was performed using the value of the corneal diameter $[N L-T L]$ and DAC $\left(\left[P-P^{\prime}\right]\right)$ measured by corneal topography and ocular biometry. The second one was performed using theoretical values for $[N L-T L]: 11.71 \mathrm{~mm}$ and $\left[P-P^{\prime}\right]: 3.4 \mathrm{~mm}$.

Then, following the method provided by Sung et al., approximation of angle $\lambda$ was performed using Pentacam measurement and second law of cosines ${ }^{15}$.

Student t-test (t) following 19 degrees of freedom (df) was used to compare the mean of corneal diameters to the theoretical value $(11.71 \mathrm{~mm})$ and to compare the mean of DAC to the theoretical value. Pearson test was used to test to the correlation between angle $\lambda$ and the DAC, and between angle $\lambda$ and Axial Length (AL). Values provided by practical and theoretical value were also compared using paired t-tests. Repeatability was assessed by using Lin's concordance correlation coefficient. Comparison with Pentacam approach was performed by Bland \& Altman test and bilateral paired t-Student test. The significance threshold $\alpha$ was set at $5 \%$.

## Results

The mean corneal diameter was: $[N L-T L]=11.90 \pm 0.57 \mathrm{~mm}$; the mean pupil diameter was: $[N P-T P]=$ $3.85 \pm 0.49 \mathrm{~mm}$; the mean DAC was: $\left[P-P^{\prime}\right]=3.54 \pm 0.19 \mathrm{~mm}$ and the mean axial length was: $24.67 \pm$ 1.10 mm . The SE range was: $[-6.00 \mathrm{D} ;+1.50 \mathrm{D}]$ ( $\mathrm{med}=-1.94 ; \mathrm{sd}=2.22$ ).

The mean value $\pm$ standard deviation of angle $\lambda$ using measured biometric values was: $+2.61^{\circ} \pm 2.92^{\circ}$ for the series using the pictures taken first, and $+2.63^{\circ} \pm 2.85^{\circ}$ for the repeated pictures.

Using the theoretical value of the corneal diameter $([N L-T L])$ and the DAC, the mean value of angle $\lambda$ was: $+2.64^{\circ} \pm 2.96^{\circ}$ for the first pictures and $+2.66^{\circ} \pm 2.89^{\circ}$ for the second ones. Distribution of angle $\lambda$ values quantified with the present method for both series and with the Pentacam method is displayed in figure 4.

Lin's concordance correlation coefficient was equal to 0.99 (confidence interval= [0.96;0.99]). No significant difference was found between the values of angle $\lambda$ calculated with measured values and those calculated with theoretical values (series of first pictures: $\mathrm{p}=0.3017$; series of repeated pictures: $\mathrm{p}=$ 0.2910 ). There was no significant difference between the measured corneal diameter and the theoretical value ( 11.71 mm ), while there was a significant difference between the DAC and the theoretical value (3.4mm) (respectively $\mathrm{p}=0.147$ and $\mathrm{p}=0.0021$ ). The mean angle $\lambda$ approximated by Pentacam and law of cosines was: $+2.70^{\circ} \pm 3.18^{\circ}$. The Bland-Altman plot for the 20 eyes is showed on figure 5. Both methods provided comparable results, with a systematic deviation of $-0.071^{\circ}$, a $95 \%$ confidence interval of -1.86 to +1.79 and no significant difference between the average of both measurements $(\mathrm{p}=0.671)$. Then, the linear equation between $\lambda_{\text {pentacam }}$ and $\lambda_{\text {photograph }}$ was: $y=1.0455 x-0.0329$ with a determination coefficient of: $\mathrm{R}^{2}=0.9229$.

A negative correlation between the axial length and angle $\lambda$ was demonstrated $(\rho=-0.5471, p=0.013)$ while no significant correlation between DAC and angle $\lambda$ was found ( $\rho=-0.3507, p=0.123$ ).

## Discussion

In the present study, we propose a novel method for angle $\lambda$ assessment, based on easy-to-take pictures of the eyes and a provided formula, and apply it to a series of healthy subjects.

Lin's concordance correlation coefficient was 0.99 , which demonstrated a high repeatability of the method used by a same practitioner -'excellent' coefficient value according to the classification of Partick et al. ${ }^{28}-$, while the comparison with Sung's method showed a systematic deviation of $-0.071^{\circ}$ with no significant difference between both methods.

Other methods proposing to assess angle $\lambda$-mistakenly designated as angle $\kappa$ - are based on the use of the synoptophore or major amblyoscope, and a few corneal topographs. While the first methods, relying on the displacement the reflection point on a graduate arc, require specific tools and technical knowledge, the second require a costly material of restricted availability ${ }^{8}$. The method proposed in this study is derived from the ultrasound biomicroscopy (UBM) method provided by Yeo et al.. Besides its cost and availability, the realization of an UBM is not appropriate for the pediatric practice and requires acute cooperation of the patient ${ }^{10}$.

Angle $\lambda$ values $\left(+2.61^{\circ} \pm 2.92^{\circ}\right)$ found in this study are in range with the values presented by Yeo et al. using ultrasound biomicroscopy $\left(+3.19^{\circ} \pm 1.15^{\circ}\right)^{10}$. The higher standard deviation found in our series can be explained by the high range of refractive errors and the small sample size. Using Orbscan II, Gharaee et al. found an average angle $\lambda$ of $+4.96^{\circ} \pm 1.36^{\circ}$. The higher values reported by Gharaee et al. might be partly explained by the fact that the Orbscan II tends to underestimate DAC values, compared with UBM or IolMaster ${ }^{10,29}$. A lower DAC increases the value of angle $\lambda$, as demonstrated by Yeo et al. (UBM assessment $=+3.19^{\circ} \pm 1.15^{\circ}$; Orbscan II assessment $=+3.98^{\circ} \pm 1.12^{\circ}$ ). Using Pentacam and second law of cosines method, Sung et al. reported an average angle $\lambda$ of $+4.41^{\circ} \pm 2.23^{\circ 15}$. This value is higher than the average angle $\lambda$ measured here with the same method $\left(+2.70^{\circ} \pm 3.38^{\circ}\right)$. This difference could be explained by the younger age of patients in Sung et al. study ( $7.87 \pm 3.66$ years) compared with our population ( $26.05 \pm 1.99$ years). Indeed, angle $\lambda$ is influenced by age: Gharaee et al. demonstrated that angle $\lambda$ significantly decreases with age, which is in agreement with the negative correlation between
axial length and angle $\lambda$ demonstrated by Choi \& $\operatorname{Kim}^{30}$. The negative value of angle $\lambda$ found in four of the twenty eyes can be explained by the myopic distribution of the refractive errors in our series, which is in agreement with the conclusion of Basmak et al., who reported a smaller angle $\lambda$ in their myopic group ${ }^{8}$. In the present method, we assumed that C and V were superimposed, while V and the keratometric axis are often slightly displaced nasally compared to C and the line of sight. For this reason, the present formula could theoretically slightly overestimate angle $\lambda$ value. Although this overestimation is negligible for small, usual values of angle $\lambda$, it could increases with angle $\lambda$ values. This error, although not relevant for the daily strabology practice, could however be corrected by using the regression coefficient ( $y=$ $1.0455 x-0.0329$ ).

We found no significant difference between angle $\lambda$ calculated with measured biometrical values and with average theoretical values. In the daily practice, the assessment of corneal diameter by ocular biometry is therefore not required and the value of 11.71 mm can reasonably be used, apart from cases of obvious pathological conditions -microphthalmia or buphthalmia. The DAC, however, fluctuates with age, ethnicity, and refractive error ${ }^{31,32}$. According to these parameters, performing a slit-lamp measurement or a biometry can increase the precision of the quantification of angle $\lambda$. Although ocular biometry reports indicate a pupil diameter [NP-TP], we suggest that this provided value should not be used in the formula, as this diameter can differ from the one at the time of the photograph. Instead, the pupil diameter [NP-TP] and the center of the pupil should be measured at given time on a single photograph. Here we used the cross product from the white-to-white giving the snapshot pupil diameter.

In order to avoid displacements of the reflection point location resulting from the distance separating the center of the flash from the center of the lens, we now use routinely in our practice a ring flash unit combined with a fixation target sticked at the center of the camera lens, so as to get a coaxially sighted corneal light reflex. Although such a flash was used in the present study, a usual flash, positioned as suggested by Hunter and Guyton ${ }^{33}$-below the camera lens, with the fixation target located one fifth of the
distance from the center of the flash to the center of the camera lens- can also be used for angle $\lambda$ assessment, where vertical artifacts would virtually have no clinical consequence.

## Conclusion

The presence of a highly positive angle $\lambda$ can modify the visual appearance of a strabismus. Although the evaluation of these angles is important during strabismus examination, there was so far no available method allowing for their easy assessment. While a subjective evaluation of the angle lambda can be provided by monocular photographs, the present method, allows for a precise and reproducible quantification of this angle.

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## Figure Captions

Figure 1A: Schematic representation of axes and angles of the eye. Solid line (PP'): pupillary axis; dashed line (PC): line of sight; solid line (VO): keratometric axis; dashed line (OF): visual axis; $\lambda$ : angle $\lambda$; к: angle к. 1B: Schematic representation of the anterior chamber with marks used for the calculation. NL: nasal limb; TL: temporal limb; V: corneal vertex; $\mathrm{V}^{\prime}$ : orthogonal projection of V ; C : corneal sighting center; NP: nasal edge of the iris; TP: temporal edge of the iris; P: pupil center; $\mathrm{P}^{\prime}$ : orthogonal projection of P on the cornea; F : fovea; O : fixation target.

Figure 2: Central fixation target at the center of the camera lens and ring flash.

Figure 3: Position of the different marks used for the ratio calculation.
TL: Temporal Limbus; TP: Temporal edge of the iris; V: corneal vertex; NP: Nasal edge of the iris; NL: Nasal Limbus.

Figure 4: Scatter-plot of angle $\lambda$ distribution with Pentacam data on $X$ axis and data from the current method on Y axis; yellow and grey dots: angle $\lambda$ using biometrical values (yellow: for the series of
pictures taken first, grey: for the repeated series of pictures); orange and blue dots: angle $\lambda$ using theoretical values (orange: for the series of pictures taken first, blue: for the repeated series of pictures).

Figure 5: Bland-Altman plot comparison between angle $\lambda$ measured with the present method and Pentacam.

