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# From monocular photograph to angle lambda

## New clinical approach for quantitative assessment

### Clinical quantification of angle lambda

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#### Keywords:

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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 propose 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<sup>1,2</sup>. 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  $\lambda$ <sup>1,3</sup>. 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<sup>4,5</sup>. 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<sup>6</sup> (Fig. 1).

Previously, angle  $\lambda$  –often improperly designated as angle  $\kappa$ – has often been estimated by using the major amblyoscope or the synoptophore<sup>7,8</sup>. Currently, some corneal topographs assert to provide a value of angle  $\kappa$ , which actually also corresponds to angle  $\lambda$ <sup>8-10</sup>. 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  $\lambda$ <sup>11</sup>. 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<sup>12-14</sup>.

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<sup>9,15</sup>. 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<sup>16-18</sup>.

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<sup>19-22</sup>. 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<sup>23</sup>. 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”<sup>24</sup>. 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.

## 99 Method

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

### 103 1- Digital picture and ratio analysis.

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

109 The analysis of these pictures is then processed through the free image editor software GIMP (v2.10.14).

110 The ruler tool is used so as to measure the distance between the nasal edge of the iris (NP) and the corneal  
111 vertex (V) and the pupil diameter ( $[NP\ TP]$ ) (Fig. 3). Then, the ratio of both distances  $R$  is calculated:

112  $R = \frac{[NP\ V']}{[NP\ TP]}$ , where  $[NP\ V']$  and  $[NP\ TP]$  are expressed in pixels.

### 113 2- From ratio to angle $\lambda$ .

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

119 
$$Angle\ Lambda = deg \left( \tan^{-1} \frac{[V\ P']}{[P'\ P]} \right)$$

121 The distance  $[P'P]$  corresponds to the depth of the anterior chamber (DAC).

122 According to the orthogonal projection of V on the segment  $([NP-TP])$ , it follows that:

$$[VP'] = [V'P]$$

123  $[V'P] = [NP P] - [NP V'] = \left(\frac{[NP TP]}{2}\right) - (R \times [NP TP])$  (with R= Ratio calculated for angle  $\lambda$ )

124

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

129

$$[NP TP] (in mm) = \frac{[NL TL] (in mm) \times [NP TP] (in pixels) \times 0.86}{[NL TL] (in pixels)}$$

130

131 From this, it follows that:

$$Angle\ Lambda = deg \left( \tan^{-1} \frac{\frac{[NP TP]}{2} - (R \times [NP TP])}{[P'P]} \right)$$

132

133 The values of the corneal diameter  $([NL TL]$  in the formula) and of the DAC  $([P-P']$  in the formula) can  
134 be measured by performing a corneal topography and an ocular biometry, respectively. They can  
135 otherwise be approximated by using theoretical values: 11.71mm for the corneal diameter and 3.4mm for  
136 the DAC<sup>26,27</sup>.

137

138 **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, SD= 1.99, 4 males – 6 females, spherical equivalent (SE): [-6.00D, +1.50D], median= -1.56D). 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 ( $[P-P']$ ) 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  $[NL-TL]$  and DAC ( $[P-P']$ ) measured by corneal topography and ocular biometry. The second one was performed using theoretical values for  $[NL-TL]$ : 11.71mm and  $[P-P']$ : 3.4mm. Then, following the method provided by Sung *et al.*, approximation of angle  $\lambda$  was performed using Pentacam measurement and second law of cosines<sup>15</sup>. Student t-test (t) following 19 degrees of freedom (df) was used to compare the mean of corneal diameters to the theoretical value (11.71mm) 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:  $[NL-TL] = 11.90 \pm 0.57\text{mm}$ ; the mean pupil diameter was:  $[NP-TP] = 3.85 \pm 0.49\text{mm}$ ; the mean DAC was:  $[P-P'] = 3.54 \pm 0.19\text{mm}$  and the mean axial length was:  $24.67 \pm 1.10\text{mm}$ . The SE range was:  $[-6.00\text{D}; +1.50\text{D}]$  (med= -1.94; 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 ( $[NL - TL]$ ) 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:  $p= 0.3017$ ; series of repeated pictures:  $p= 0.2910$ ). There was no significant difference between the measured corneal diameter and the theoretical value (11.71mm), while there was a significant difference between the DAC and the theoretical value (3.4mm) (respectively  $p= 0.147$  and  $p= 0.0021$ ). 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 ( $p= 0.671$ ). Then, the linear equation between  $\lambda_{\text{pentacam}}$  and  $\lambda_{\text{photograph}}$  was:  $y = 1.0455x - 0.0329$  with a determination coefficient of:  $R^2= 0.9229$ .

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.*<sup>28</sup>–, 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<sup>8</sup>. 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<sup>10</sup>.

Angle  $\lambda$  values ( $+2.61^\circ \pm 2.92^\circ$ ) found in this study are in range with the values presented by Yeo *et al.* using ultrasound biomicroscopy ( $+3.19^\circ \pm 1.15^\circ$ )<sup>10</sup>. 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  $+4.96^\circ \pm 1.36^\circ$ <sup>9</sup>. 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<sup>10,29</sup>. 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  $+4.41^\circ \pm 2.23^\circ$ <sup>15</sup>. This value is higher than the average angle  $\lambda$  measured here with the same method ( $+2.70^\circ \pm 3.38^\circ$ ). 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 & Kim<sup>30</sup>. 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<sup>8</sup>. 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 increase with angle  $\lambda$  values. This error, although not relevant for the daily strabology practice, could however be corrected by using the regression coefficient ( $y = 1.0455x - 0.0329$ ).

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 11.71mm can reasonably be used, apart from cases of obvious pathological conditions –microphthalmia or buphthalmia. The DAC, however, fluctuates with age, ethnicity, and refractive error<sup>31,32</sup>. 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 stucked 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<sup>33</sup> –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.

## References

1. Le Grand Y, El Hage SG, Le Grand Y. Chap.5: The retinal image. In: Physiological optics. Berlin Heidelberg: Springer; 1980. (Springer series in optical sciences).
2. Lancaster WB. Terminology in Ocular Motility and Allied Subjects. American Journal of Ophthalmology. 1943 Feb;26(2):122–32.
3. Chang DH, Waring GO. The subject-fixated coaxially sighted corneal light reflex: a clinical marker for centration of refractive treatments and devices. Am J Ophthalmol. 2014 Nov;158(5):863–74.
4. Khan AO. Nodal point of the eye. Ophthalmology. 2007 Sep;114(9):1791.
5. Harris WF. Nodes and nodal points and lines in eyes and other optical systems: Nodes and nodal points and lines. Ophthalmic and Physiological Optics. 2009 Dec 11;30(1):24–42.
6. Mandell RB, Chiang CS, Klein SA. Location of the major corneal reference points. Optom Vis Sci. 1995 Nov;72(11):776–84.
7. Von Noorden GK, Campos EC. Chap.2: Examination of the patient. In: Binocular vision and ocular motility: theory and management of strabismus. 6th ed. St. Louis, Mo: Mosby; 2002. p. 169–73.

8. Basmak H, Sahin A, Yildirim N, Papakostas TD, Kanellopoulos AJ. Measurement of angle kappa with synoptophore and Orbscan II in a normal population. *J Refract Surg.* 2007 May;23(5):456–60.
9. Gharaee H, Shafiee M, Hoseini R, Abrishami M, Abrishami Y, Abrishami M. Angle Kappa Measurements: Normal Values in Healthy Iranian Population Obtained With the Orbscan II. *Iran Red Crescent Med J.* 2015 Jan;17(1):e17873.
10. Yeo JH, Moon NJ, Lee JK. Measurement of Angle Kappa Using Ultrasound Biomicroscopy and Corneal Topography. *Korean J Ophthalmol.* 2017 Jun;31(3):257–62.
11. Rodríguez-Vallejo M, Piñero DP, Fernández J. Avoiding misinterpretations of Kappa angle for clinical research studies with Pentacam. *Journal of Optometry.* 2019 Apr;12(2):71–3.
12. Bouffard MA. The Pupil. *Continuum (Minneap Minn).* 2019 Oct;25(5):1194–214.
13. Wilson MA, Campbell MC, Simonet P. The Julius F. Neumueller Award in Optics, 1989: change of pupil centration with change of illumination and pupil size. *Optom Vis Sci.* 1992 Feb;69(2):129–36.
14. Mathur A, Gehrmann J, Atchison DA. Influences of luminance and accommodation stimuli on pupil size and pupil center location. *Invest Ophthalmol Vis Sci.* 2014 Apr 7;55(4):2166–72.
15. Sung YJ, Nam SM, Lew H. Measurement of Angle Lambda Using Pentacam in Normal and Exotropic Children. *J Korean Ophthalmol Soc.* 2015;56(8):1263.
16. Merrill KS, Lavoie JD, King RA, Summers CG. Positive angle kappa in albinism. *J AAPOS.* 2004 Jun;8(3):237–9.
17. Merrill KS, Summers CG. Positive angle kappa: a possible sign of aniridia. *Am Orthopt J.* 2012;62:70–6.
18. Brodsky MC, Fray KJ. Positive angle kappa: a sign of albinism in patients with congenital nystagmus. *Am J Ophthalmol.* 2004 Apr;137(4):625–9.
19. Arba Mosquera S, Verma S, McAlinden C. Centration axis in refractive surgery. *Eye Vis (Lond).* 2015;2:4.

20. Kermani O, Oberheide U, Schmiedt K, Gerten G, Bains HS. Outcomes of hyperopic LASIK with the NIDEK NAVEX platform centered on the visual axis or line of sight. *J Refract Surg.* 2009 Jan;25(1 Suppl):S98-103.
21. Park CY, Oh SY, Chuck RS. Measurement of angle kappa and centration in refractive surgery. *Curr Opin Ophthalmol.* 2012 Jul;23(4):269–75.
22. Fu Y, Kou J, Chen D, Wang D, Zhao Y, Hu M, et al. Influence of angle kappa and angle alpha on visual quality after implantation of multifocal intraocular lenses. *J Cataract Refract Surg.* 2019;45(9):1258–64.
23. Rateaux M, Espinasse-Berrod M-A, Couret C, Bremond-Gignac D, Robert MP. Pseudo-Gaze Deviation Resulting From Positive Angle Kappa and Esotropia. *J Neuroophthalmol.* 2021 Jun 1;41(2):e234–6.
24. Luo G, Pundlik S, Tomasi M, Houston K. Using an Automated Hirschberg Test App to Evaluate Ocular Alignment. *J Vis Exp.* 2020 Mar 24;(157)
25. Uozato H, Guyton DL. Centering corneal surgical procedures. *Am J Ophthalmol.* 1987 Mar 15;103(3 Pt 1):264–75.
26. Rüfer F, Schröder A, Erb C. White-to-white corneal diameter: normal values in healthy humans obtained with the Orbscan II topography system. *Cornea.* 2005 Apr;24(3):259–61.
27. Dawson DG, Ubels JL, Edelhauser HF. Chap. 4: Cornea and sclera. In: Kaufman PL, Alm A, Adler FH, editors. *Adler's physiology of the eye: clinical application.* 10th ed. St. Louis: Mosby; 2003.
28. Partik BL, Stadler A, Schamp S, Koller A, Voracek M, Heinz G, et al. 3D versus 2D ultrasound: accuracy of volume measurement in human cadaver kidneys. *Invest Radiol.* 2002 Sep;37(9):489–95.
29. Dinc UA, Gorgun E, Oncel B, Yenerel MN, Alimgil L. Assessment of Anterior Chamber Depth Using Visante Optical Coherence Tomography, Slitlamp Optical Coherence Tomography, IOL Master, Pentacam and Orbscan IIz. *Ophthalmologica.* 2010;224(6):341–6.
30. Choi SR, Kim US. The Correlation between Angle Kappa and Ocular Biometry in Koreans. *Korean Journal of Ophthalmology.* 2013;27(6):421.

31. Feng MT, Belin MW, Ambrósio R, Grewal SPS, Yan W, Shaheen MS, et al. Anterior chamber depth in normal subjects by rotating scheimpflug imaging. Saudi Journal of Ophthalmology. 2011 Jul;25(3):255–9.
32. Shih Y-F, Chen T-C, Chiang T-H, Lin LL-K, Hung P-T. Changes of Anterior Segment During Childhood: A Biometric Study. Journal of Medical Ultrasound. 2011 Jun;19(2):33–40.
33. Hunter DG, Guyton DL. Vertical location of the corneal light reflex in strabismus photography. Arch Ophthalmol. 1998 Jun;116(6):767–71

## 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  $\lambda$ ;  $\kappa$ : angle  $\kappa$ . 1B: Schematic representation of the anterior chamber with marks used for the calculation. NL: nasal limb; TL: temporal limb; V: corneal vertex; V': orthogonal projection of V; C: corneal sighting center; NP: nasal edge of the iris; TP: temporal edge of the iris; P: pupil center; P’: 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

333 pictures taken first, grey: for the repeated series of pictures); orange and blue dots: angle  $\lambda$  using  
334 theoretical values (orange: for the series of pictures taken first, blue: for the repeated series of pictures).

335

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