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BASIC SCIENCE

Measurement of angle Kappa with Orbscan II and Galilei G4: effect of accommodation

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Abstract
Purpose To measure angle kappa distance with Orbscan II and Galilei G4, and to evaluate possible variations in this value for different accommodation degrees.
Methods Angle kappa was measured using the Orbscan II and the Galilei G4 in the right eye of 80 patients aged from 20 to 40 years. This value was measured three times per eye and per device, and the average was retained. Angle kappa was measured for far vision using the Orbscan II and the Galilei G4 in a random order for each subject. The Galilei G4 was used to measure angle kappa as a function of accommodation, where the first measure started at +1 D and the vergence was changed until reaching −4 D, in 1 D steps. In both measures, the kappa distance was expressed in millimetres.
Results At distance, the values of angle kappa were 0.43± 0.13 mm and 0.27±0.15 mm measured with the Orbscan II and Galilei G4 systems respectively. Statistical significant differences were found ($P<0.01$). With regard to the angle kappa values obtained as a function of accommodation, the values were 0.25±0.15 mm, 0.26±0.15 mm, 0.30±0.20 mm, 0.27±0.15 and 0.26±0.15 mm, for +1 D, −1 D, −2 D, -3 D and −4 D respectively. No statistical significant differences were found among 0 D and the other vergences evaluated ($P>$ 0.01).
Conclusions For far vision, Orbscan II measured significantly higher angle kappa values than Galilei G4, the mean difference being 0.16±0.08 mm. For different accommodation levels, the kappa distance did not change significantly.

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Introduction

The angle kappa is defined [1] as the angle between the visual and pupillary axes. The former axis connects the fixation point with the nodal points and the fovea; the latter axis contains the centre of the pupil and is normal to the cornea.

Previous literature focused on evaluating the distribution of angle kappa in normal population, as a function of the refractive error [2–6] or the strabismus direction [7]; studying the angle kappa measurement with an automatic device (the OrbscanII) [2–4, 8]; comparing [2] angle kappa measurement with synoptophore and OrbscanII in a normal population; evaluating [5, 9, 10] the effect of angle kappa to compensate ocular aberrations; and studying [10] the angle kappa as a function of the age. Moreover, several manuscripts also evaluated the angle kappa as a possible sign of pathology; for example, Merrill et al. [11, 12] studied the positive angle kappa as a sign of aniridia or albinism. Finally, recent studies published are focused on studying the role of angle kappa on visual function after myopic [13] or hyperopic [14–17] laser refractive surgery, and after intraocular lens surgery [8, 18]. On the other hand, there is another technique for measuring angle kappa. It is called Purkinje meters, which are based on light reflections of Purkinje images at ocular surfaces. These instruments can be used to measure angle Kappa between the pupil centre and the first Purkinje image. However, they can also be used to study intraocular lens decentration and tilt after refractive surgery [19, 20].

As has been proposed by some authors, angle kappa distance should be considered before any refractive surgery procedure [8, 13–18]. Nowadays, the corneal topographers, such as Orbscan II or Galilei G4, measure this value automatically. The knowledge of the angle kappa measured with automatic devices should enable the practitioner to make more accurate interpretations of these readings. On the other hand, the angle kappa could change depending of the accommodation level. If this happens, the patient binocular vision will change depending of the accommodation state. Unfortunately, no previous literature comparing the angle kappa measurement between two automatic devices, and studies evaluating its possible variation with the accommodation, are available. Therefore, in this study we compared the angle kappa measurement between the OrbscanII (Bausch&Lomb Surgical Inc., San Dimas, California, USA) and Galilei G4 (Ziemer, Switzerland), and we studied the possible variations of the angle kappa as a function of the accommodation level.

Method

Patients

Eighty right eyes of 80 volunteers from the University of Valencia were included in this transversal study. All of them were healthy volunteers from the university staff, without any systemic and ocular pathology. There were 39 males and 41 females, whose ages ranged from 20 to 40 years (mean: 30.36 ±7.32 years). The spherical equivalent (SE) ranged from −0.50 to +0.50 diopters (D) (mean: 0.07±0.41D). All patients were informed about the details of this study, and a written informed consent was obtained from each one of them in accordance with the Helsinki Declaration.

Inclusion and exclusion criteria

The inclusion criterion was eyes whose best-corrected visual acuity (BCVA) was 20/25 or better. With regard to their binocular vision, all of them were orthophoric for distance and near vision (checked with the Cover Test, Maddox test, Von Graefe test and four prism diopters base-out). Subjects with strabismus, microtropia, esophoria, or exophoria, ocular or systemic disease, ocular surgery history, or presence of retinal or optic-disk pathology were excluded from this study.

Devices used

OrbscanII

The Orbscan II (Fig. 1) is a non-invasive topography system that relies on two different techniques: a Placido-disk system, which assesses anterior corneal topography and creates an elevation map, and a horizontally moving scanning camera, which acquires slit-lamp images. The angle kappa is measured automatically with special software by measuring the distance between the centre of the pupil and the centre of the Placido ring reflection on the cornea. This measuring procedure has a resolution of 0.01 mm.

Galilei G4

Galilei G4 (Fig. 2) is the last version of the Galilei topographer, which was also used to measure angle kappa for far vision and for different accommodation levels. This device combines a Placido disc ring to evaluate the anterior corneal surface, with a rotational scan of Dual-Scheimpflug slit

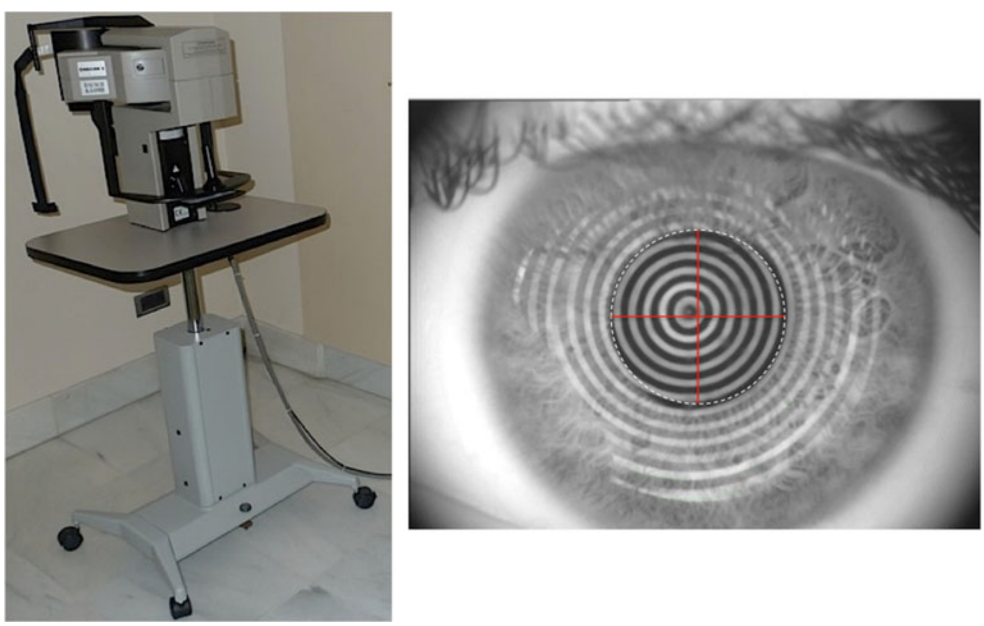

Fig. 1 Photograph of the Orbscan II used in this study (*left*), with a scheme (*right*) marking pupil centre and Placido Disc centres used to calculate angle Kappa

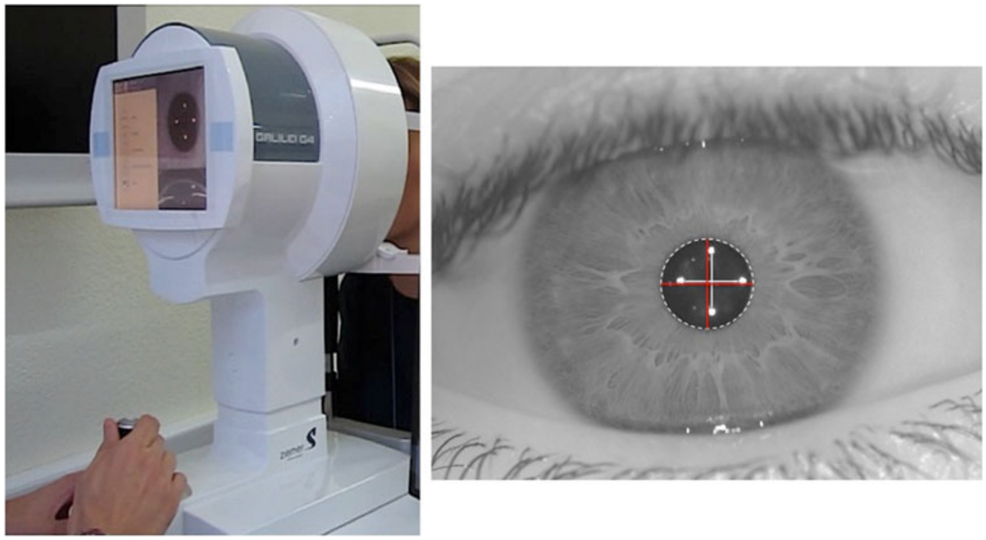

Fig. 2 Photograph of the Galilei G4 used in this study (*left*), with a scheme (*right*) marking pupil centre and Purkinje centre dots used to calculate angle Kappa

images that compensates decentrations due to eye motion. The Galilei G4 has a red LED that serves as a fixation target and can be moved in 0.25 D steps from -20D to +20D. To measure angle kappa, Galilei G4 measures automatically the distance between the pupil centre and the centre of the reflection of the four Purkinje dots, which corresponds to the first Purkinje reflex in the cornea of four light dots included in the Galilei G4, with a measure resolution of 0.01 mm.

Experimental procedure

Angle kappa distance was measured 3 times per eye and per device, and the average value was retained for all distances evaluated. The same specialist, who was not aware of the study`s goal with extensive experience using the Orbscan II and Galilei G4 systems, carried out all measurements. While Orbscan II was only used to measure angle Kappa for far vision, the Galilei G4 was used to measure angle kappa for far vision and for different vergences. Only the right eye was used in this experiment. First, angle kappa was measured for far vision using the Orbscan II and the Galilei G4 in a random order for each subject. After that, the Galilei G4 was used to measure angle kappa as a function of accommodation, where the first measure started at +1D and the vergence was changed until reaching −4D, in 1D steps. Before starting the measurement, the volunteer had to fixate the target during 2 s to allow an appropriate accommodation response. During the measure, the patient was request to no blink because it could affect the measurement. This procedure was performed during a single session. In both measurements, the kappa distance was expressed in millimetres.

Statistical analysis

Statistical analysis was performed by means of the SPSS statistical software package SPSS/Pc+10.1 for Windows (SPSS, Chicago, IL, USA). A Student t-test for paired data was used to compare the angle kappa value instead of the devices. To study differences in angle kappa with accommodation, a one-way ANOVA for repeated measurements was used to study differences among all vergences studied. Differences were considered to be statistically significant for $P <$ 0.010. To assess the agreement and interchangeability between these devices to measure anterior eye distances [21], the method suggested by Bland and Altman for repeated measurements was used. The 95 % limits of agreement were computed as the mean difference of ±1.96SD. On the other hand, the repeatability for repeated measurements of each instrument was also studied using the procedure described in the Bland–Altman manuscript [21].

Results

The mean kappa distance measured by Orbscan II and Galilei G4 was 0.43±0.13 mm and 0.27±0.15 mm. Subsequent analysis of the whole data set revealed that Orbscan II yields significantly higher Kappa values than Galilei G4 (P= 0.001), the mean difference amounting to −0.16±0.08 mm. Figure 3 includes a Bland–Altman plot of difference against mean for different eye angle studied in this study, and Table 1 resumes Bland–Altman results. Moreover, the spread shows great variability, whose 95 % limit of agreement was within 0.34 mm. On the other hand, the confidence interval between these devices was within 0.31 mm. With regard to device repeatability (Fig. 4), it can be observed that 95 % of limit

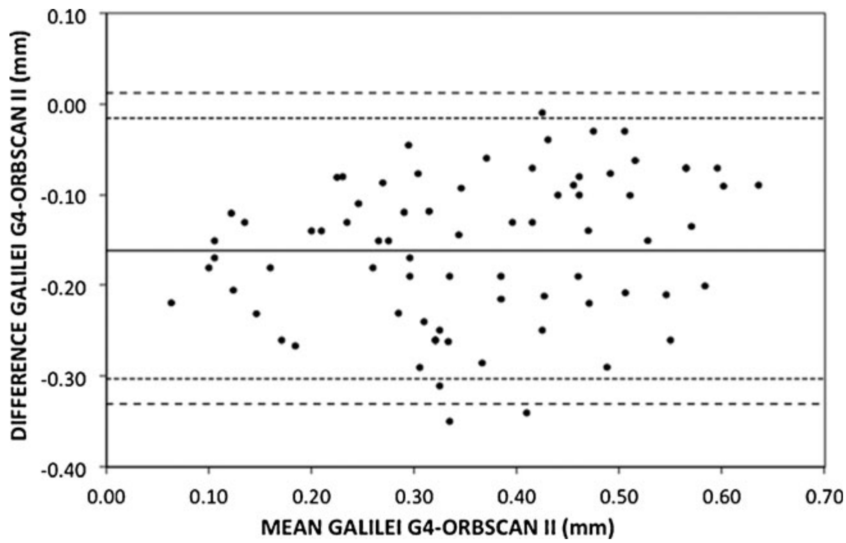

Fig. 3 Bland–Altman plot comparing OrbscanII and GalileiG4 measures for kappa distance. *Dotted lines* represent Confident interval, while *dashed lines* represent the limit of agreement

of agreement for Orbscan II and Galilei G4 was within 0.079 mm and 0.055 mm respectively.

With regard to the angle kappa values obtained as a function of accommodation, the values were 0.25± 0.15 mm, 0.26±0.15 mm, 0.30±0.20 mm, 0.27±0.15 mm and 0.26±0.15 mm, for +1D, −1D, −2D, −3D, and −4D respectively. However, the ANOVA analysis revealed no statistical significant differences among 0D and the other vergences evaluated, where the P values were 0.128, 0.057, 0.142, 0.434, and 0.254 respectively.

Discussion

The aim of the present study was to evaluate the angle kappa measurement between the Orbscan II and the Galilei G4, and to study the possible angle kappa variations as a function of the accommodation level. Consequently, it could be elucidated whether Orbscan II and Galilei G4 measure comparable angle kappa for far vision, and if this angle changes with accommodation.

Our angle kappa distance measured with the Orbscan II was 0.43±0.13 mm. This value was similar to those [2, 3] obtained in the previous literature that include an emmetropic group and used the Orbscan II. The first of the studues, which was carried out by Basmak et al. [2], used a cohort of 300 healthy individuals, and the mean value was 5.55±0.13 °, which corresponds to about 0.47 mm. The latter study was done by Hashemi et al. [3], using a cohort of 442 participants, and the mean value for this group was 0.43±0.18 mm. With regard to the value obtained with the Galilei G4, the mean value obtained was 0.26±0.14 mm. Unfortunately, there are no previous studies published in the literature using this technology to compare our results.

Table 1 Bland–Altman results obtained for Galilei G4 and Orbscan II. SD: Standard deviation

	Mean difference ± SD	95 % limit of agreement	Confidence interval
Galilei G4–Orbscan II	−0.16±0.08	−0.330 to 0.011	−0.015 to −0.303

The mean difference in angle kappa measured with the Orbscan II and the Galilei G4 was −0.16±0.08 mm, which corresponds about −3.60 ° (where the minus sign means that the former device measured a significantly higher angle kappa distance than the latter one). Moreover, the repeatability range of each device was about 2 ° and 1.23 ° for the Orbscan II and Galilei G4 respectively. After these results, it can be concluded that these devices were repeteable. However, there was a low agreement between the angle kappa measured by the two devices. In this sense, the 95 % of limits of agreement was 0.34 mm and the confidence interval was 0.31 mm. Therefore, it can be concluded that these devices cannot be used interchangeably to measure kappa angle. Only one study, carried out by Basmak et al. [2], has compared the angle kappa distance between Orbscan II and another system, a Synoptophore, in a normal population. These authors determined that the Orbscan II measures significantly higher angle kappa values than the Synoptophore, the mean difference for emmetropic eyes being about 2.77 °.

In relation to the angle kappa changes with the accommodation, which was only studied with the Galilei G4, no statistical significant differences were found between far vision and each vergence evaluated. However, from the results of Wilson et al. [22], these outcomes were not expected, because after accommodation the pupil size decreases, so the pupil centre

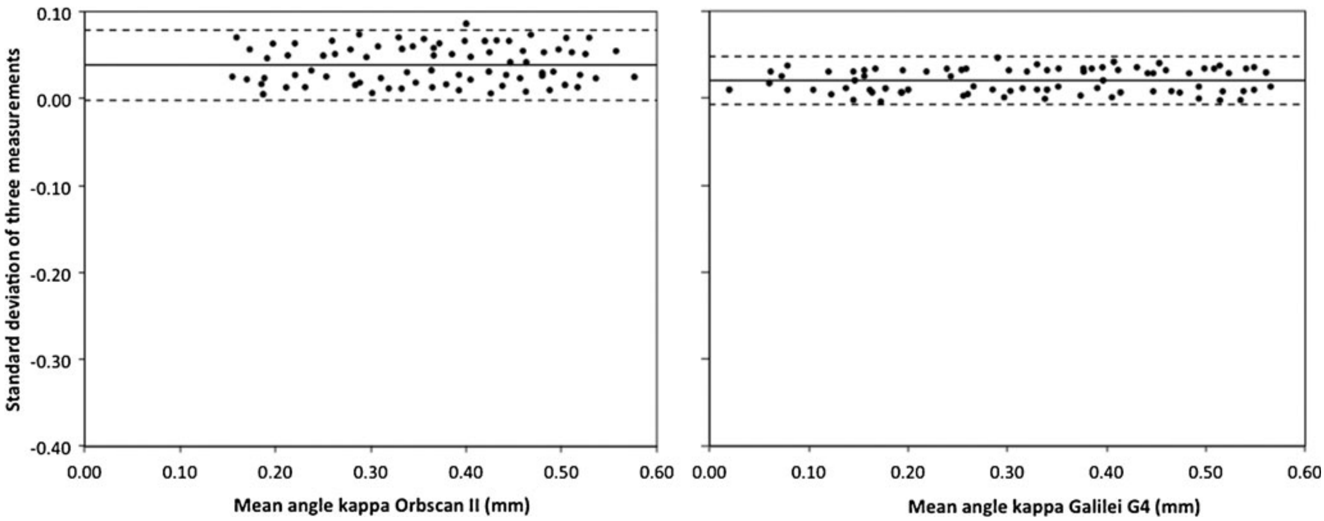

Fig. 4 Bland–Altman showing repeatability measurements. *Left plot* includes repeatability values of Orbscan II and *right plot* includes repeatability values of Galilei G4

should vary and consequently, the angle kappa should be different. This discrepancy can be related to the pupil centre calculation used with these devices, because they use the geometrical pupil centre, which remains constant after decreasing pupil diameter. Unfortunately, there are no previous studies published in the literature evaluating the relationship between the angle kappa and accommodation to compare our results.

Berrio et al. [10] studied the mechanism of aberration compensation as the eye ages. To carry out their study, they measured ocular and corneal aberrations and the angle kappa as a function of age in volunteers with low refractive error and ages ranging between 20 and 70 years. They determined that both ocular and corneal root mean square (RMS) were positively correlated with age, with a faster rate of growth for the ocular RMS (0.0032 μm/year) than for the corneal RMS (0.0015 μm/year). Moreover, they determined that optical alignment was constant with age (angle kappa did not vary with age). Consequently, the increase in eye aberrations was associated to variations in crystalline lens radii curvature, because this modifies its shape factor, reducing the compensation of ocular aberrations.

Several manuscripts report angle kappa in a population as a function of the refractive error. Donders, cited in Von Norden et al. [6], found that the angle kappa range obtained in emmetropic and hyperopic eyes varied from 3.5 ° to 6.0 ° and from 6.0 ° to 9.0 ° respectively. However, in the myopic group the angle kappa was generally smaller, averaging approximately 2.0 °, and in some cases it could be negative. Basmak et al. [2] grouped their volunteers cohort according to their refractive status in myopic (SE less than −0.5D), emmetropic (SE between −0.50D and +0.50D) and hyperopic (SE higher than +0.50D). Their results revealed that myopic group values were less positive or more negative than hyperopic or emmetropic group. A study carried out by Hashemi et al. [3] also evaluated the angle kappa as a function of refractive error, grouping their sample into emmetropic, mild, moderate, and severe myopic, and mild, moderate, and severe hyperopic. They obtained a larger or more positive angle kappa in the hyperopic group compared to myopic one. In the study by Qazi et al. [4]this tendency was also obtained, where angles kappa were higher in hyperopic patients in comparison with myopic or emmetropic ones. Consequently, from these studies [2–4, 6] it can be concluded that hyperopic individuals had greater positive angle kappa than myopic ones. However, contradictory results were found between angle kappa in hyperopic and emmetropic eyes. While Basmak et al. [2] found that hyperopic eyes had a higher angle kappa than emmetropic ones, Hashemi et al. [3] found the opposite.

Recently, angle kappa has been measured before any refractive surgery procedure. In this sense, Pande et al. [14] proposed that the optimal zone to centrate the corneal ablation is in the line joining the fovea to the fixation point, i.e., the ablation zone should be decentered by a magnitude equal to the angle kappa. Nepomuceno et al. [16], performed hyperopic laser-assisted in-situ keratomileusis (LASIK) with the ablation centered on the coaxially sighted corneal light reflex, concluding that the traditional centering method based on the pupil entrance could lead to decentration in the presence of a large angle kappa, especially in hyperopic patients. Wachler et al. [15] achieved in a case report better visual acuity results when the ablation was centered on corneal light reflex than when it was centered over the entrance pupil center. In this sense, Chan et al. [17] reported better visual outcomes when hyperopic LASIK was centered on corneal light reflex instead of centering over the entrance pupil center. In the study carried out by Hashemi et al. [3], they proposed that quantifying the angle kappa is an important part in any refractive error correction, especially in refractive surgery. Moreover, these authors posit that in ammetropic patients with larger angle kappa, surgeons need to consider this value during the surgery preparation to ensure surgical success.

Contrary to these studies, several manuscripts report evidence concerning centering the ablation pattern with the pupil center during a refractive surgery procedure. In this sence, Uozato et al. [23] asserted that centering the corneal ablation on the pupil center is the proper method of centration, because the photoreceptors are aimed toward the center of a normal pupil. Espinosa et al. [24] reported in a theoretical eye model simulation that the best point spread function was achieved when light came into the eye obliquely with a tilt comparable with mean values of angle kappa, thus suggesting a mechanism of corneal passive compensation of corneal astigmatism. Several reports have studied, using a visual simulator, the effect of decentering a monofocal or multifocal IOL after its implantation. For example, Madrid et al. [25] and. Ruiz et al. [26] studied the implication of decentering and tilting an IOL in the patient's visual function. To carry out these studies, they compensate volunteer ocular aberrations and simulate the aberration patterns that a patient should have if the IOL was centered, decentered 0.2 mm or 0.4 mm, and tilted 2 ° and 4 °. They determined that centered IOL induced higher visual acuity and contrast sensitivity than IOL decentered 0.2 mm or 0.4 mm.

In conclusion, for far vision Orbscan II measured significantly higher angle kappa values than Galilei G4, being the mean difference 0.16±0.08 mm. Moreover, this value remains constant with accommodation in emmetropic subjects. However, some limitation of the present study should be considered: this study includes only one age group range (from 20 to 40 years), all subjects included were emmetropic, and only one pair of devices that measure the kappa distance was included. Further studies should aim to increase the sample age groups, study its changes in myopic and hyperopic eyes, and find a relationship between the gold standard to measure the angle kappa (the Synoptophore) and the current equipment that measure this value.

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