·Review·

Device interchangeability on anterior chamber depth and white –to –white measurements: a thorough literature review

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Abstract

• We have reviewed a set of recently published studies that compared the anterior chamber depth (ACD) and/or white –to –white (WTW) distance obtained by means of different measuring devices. Since some of those studies reached contradictory conclusions regarding device interchangeability, this review was carried out in attempting to clarify which clinical devices can or cannot be considered as interchangeable in clinical practice to measure ACD and/or WTW distance, among these devices: A –scan, ultrasound biomicroscopy, Orbscan and Orbscan II (Bausch&Lomb Surgical Inc., San Dimas, California, USA), Pentacam and Pentacam HR (Oculus, Wetzlar, Germany), Galilei (Ziemer, Switzerland), Visante optical coherence tomography (Visante OCT, Carl Zeiss Meditec Inc., Dublin, California, USA), IOLMaster (Carl Zeiss Meditec, Jena, Germany), and Lenstar LS 900/ Biograph (Haag –Streit AG, Koeniz, Switzerland/Alcon Laboratories Inc., Ft Worth, Texas, USA).

• KEYWORDS: anterior camber depth measurement; white to white measurement; device interchangeability; anterior chamber eye

INTRODUCTION

N owadays, the measurement of anterior chamber depth (ACD) and white-to-white (WTW) distance has become increasingly important in ophthalmic practice, for instance, when it comes to planning cataract[1-3] and refractive[1-6] surgery, calculating phakic or pseudophakic intraocular lens (IOL) [3,7-10] power and diameter, screening glaucoma risk factors [2,9,11], and so on. Many papers have been published focusing on device interchangeability to measure ACD or WTW distance. However, some of these studies show discrepancies in their findings.

The inclusion criterion was that the study had to evaluate device interchangeability across two or more devices for the measurement of ACD or WTW distance. The devices included in this review were: A-scan, ultrasound biomicroscopy (UBM), Orbscan and Orbscan II (Bausch&Lomb Surgical Inc., San Dimas, California, USA), Pentacam and Pentacam HR (Oculus, Wetzlar, Germany), Galilei (Ziemer, Switzerland), Visante optical coherence tomography (Visante OCT, Carl Zeiss Meditec Inc., Dublin, California, USA), IOLMaster (Carl Zeiss Meditec, Jena, Germany) and Lenstar LS 900/Biograph (Haag-Streit AG, Koeniz, Switzerland/ Alcon Laboratories Inc., Ft Worth, Texas, USA). In this context, the purpose of this work was to clarify which devices are interchangeable to measure ACD or WTW distance values. A brief description of the measuring principle use of each device was also included. Finally, readers should consider that a brief description of each study methodology was included only the first time we mentioned the study.

METHODS

Method of Literature Search Articles studying device interchangeability or these ones that compare ACD or WTW distances among the devices included in this study were identified through a multistage systematic approach. First, we conducted a computerized search in MEDLINE database using PubMed (www.pubmed.com). A comprehensive search was made using the terms: ACD device interchangeability, WTW device interchangeability, ACD measurement, WTW measurement, and all of those terms followed by "AND" and the following: A-scan interchangeability, UBM interchangeability, Orbscan interchangeability, Pentacam interchangeability, Galilei interchangeability, Visante OCT interchangeability, IOLMaster interchangeability, and Lenstar interchangeability interchangeability.

Second, all entries were critically reviewed and those considered to be of significative were used, including those written in English, Spanish, and Germany, and also those from the non-English literature if an English abstract was available. Next, we reviewed the reference section of each article, to detect other studies not captured by the MEDLINE search. Once these articles were critically reviewed, they were included if there were considered to add additional data or to refute previous information.

Measuring Principle

A–scan This ultrasound contact device is used to measure eye biometric dimensions, *i.e.* axial length, ACD, posterior chamber depth and corneal and lens thickness. It calculates ACD on the basis of the difference in the time taken for ultrasound waves to reflect back to its receiver from the posterior corneal surface and anterior lens surface.

Ultrasound biomicroscopy This ultrasound contact device is used to image ocular tissue depths up to 4 to 5 mm with lateral and axial physical resolution of approximately 50- and 25-μm. ACD is measured with a rule over the echography.

Orbscan The Orbscan is a noncontact topography system that is used for anterior segment evaluation. It uses the horizontally moving scanning camera to acquire slit images. After image reconstruction, a mathematical three-dimensional model of the cornea and the anterior segment is calculated. To calculate the ACD, the software detects automatically the corneal endothelium surface and anterior surface of the crystalline lens on the acquired images.

Orbscan II The Orbscan II is a non-invasive topography system that scans the anterior segment, combining a three-dimensional scanning slit beam system with an added Placido attachment for evaluating corneal surfaces. This device calculates ACD as Orbscan.

Pentacam The Pentacam is a non-contact device using a rotating Scheimpflug camera. It uses a monochromatic slit light source to measure the anterior segment topography. It takes 50 images in 2s with a maximum of 25 000 measured points The internal software creates a three-dimensional reconstruction of the anterior segment by using the elevation data of these images, which gives information about anterior and posterior surface of the cornea, and ACD from endothelium to crystalline lens.

Pentacam HR Pentacam HR is one of the latest developments in three-dimensional topographers and is based on the Scheimpflug principle. The rotating camera rotates around the optical axes of the eye to calculate a three-dimensional model of the anterior segment. This device takes 50 images in 2s with a maximum of 138 000 measured points. The internal software creates a three-dimensional reconstruction of the anterior segment by using the elevation data of these images, giving information about anterior and posterior surface of the cornea, and ACD from endothelium to crystalline lens.

Galilei The Galilei is a non-invasive diagnostic system designed for the analysis of the anterior eye segment. The system is based on a rotating dual-Scheimpflug camera integrated with a Placido topographer. This device captures slit images from opposite sides of the illuminated slit and averages the elevation data obtained from corresponding opposite slit images. This dual Scheimpflug imaging technique improves the detection of the posterior corneal surface and provides outstanding accuracy in pachymetry across the entire cornea, even when the camera is decentered because of eye movements.

Visante optical coherence tomography Visante OCT is a time domain non-invasive system that employs high-resolution images. The light source is a superluminiscent light-emitting diode with a short wavelength that has a limited penetration depth into the eye. By moving the scanning spot laterally across the eye, this device acquires multiple A-scans and aligns them to construct two-dimensional images analogous to an ultrasound B-scan. The scanning speed is 4000 axial scans/s, and each image frame has 500 axial scans/image. It can be used to measured central corneal thickness and ACD.

IOLMaster The IOLMaster is designed to measure the parameters used in IOL calculation, including: axial length, corneal curvature, ACD and WTW distance. The IOLMaster emits 780-nm infrared light and uses partial coherence interferometry to measure axial length. ACD is determined automatically using a lateral slit illumination of the corneal and crystalline lens and a white-light-emitting diode of 590 nm as the light source. The lateral slit illumination is 0.7 mm wide and employed at an angle of 30 degrees during ACD measurements.

Lenstar The Lenstar optical biometer is based on low coherence reflectometry, with an 820-mm superluminiscent diode. The Lenstar detects the anterior and posterior corneal, and anterior crystalline lens peaks in the optical low coherence reflectometry waveform to measure the ACD and corneal thickness. In addition to ACD and corneal thickness, the Lenstar also measures axial length.

EyeSys The EyeSys topographer uses a Placido disc-based data acquisition system designed for rapid and quantitative photokeratoscopy, to capture the anterior segment's topographic features. The computer calculates the corneal diameter automatically.

Anterior Chamber Depth Device Interchangeability

Table 1 includes mean difference and 95% limit of agreement obtained after each device comparison for phakic eyes. Studies included in this section compared at least two of the following devices: A-scan, UBM, Orbscan, Orbscan II, Pentacam, Pentacam HR, Galilei, Visante OCT, IOLMaster, and Lenstar.

Table 1 Mean difference between each pair device comparison for healthy eyes   mm

Anterior segment system	A-scan	UBM	Orbscan	Orbscan II	Pentacam	Pentacam HR	Galilei	Visante OCT	IOLMaster	Lenstar
A-scan		-	-	0.03±0.01[2]	0.02[5]; 0.10[12]	0.19[13]	-	-	0.10±0.14[2]; 0.01[12]	0.27±0.32[14]
UBM	-		-	0.08±0.09[15]	-	-	-	0.07±0.09[16]	-	-
Orbscan	-	-		-	0.04±0.06[7]; 0.14[17]	-	-	0.10[17]	-	-
Orbscan II	0.03±0.01[2]	0.08±0.09[15]	-		0.08±0.04[4]; 0.05±0.02[11]; 0.17[18]; 0.05[19]	0.30±0.04[20]	0.32±0.05[20]	0.15±0.05[4]; 0.06±0.03[11]	0.01[1]; 0.12±0.07[2]; 0.04±0.12[9]; 0.16±0.09[11]; 0.06[19]	-
Pentacam	0.02[5]; 0.10[12]	-	0.04±0.06[7]; 0.14[17]	0.08±0.04[4]; 0.05±0.02[11]; 0.17[18]; 0.05[19]		-	-	0.07±0.04[4]; 0.02±0.02[11]; 0.04[17]; 0.07[21]	0.02[6]; 0.05[8]; 0.03[10]; 0.12±0.09[11]; 0.09[12]; 0.11[19]	0.03[21]; 0.02±0.07[22]
Pentacam HR	-	-	-	0.30±0.04[20]	-		0.02±0.01[20]; 0.07±0.11[23]	-	0.05[24]	-
Galilei	-	-	-	0.32±0.05[20]	-	0.02±0.01[20]; 0.07±0.11[23]		-	-	-
Visante OCT	-	0.07±0.09[16]	0.10[17]	0.15±0.05[4]; 0.06±0.03[11]	0.07±0.04[4]; 0.02±0.02[11]; 0.04[17]; 0.07[21]	-	-		0.10±0.08[11]; 0.06±0.01[25]	0.10[21]
IOLMaster	0.10±0.14[2]; 0.01[12]	-	-	0.01[1]; 0.12±0.07[2]; 0.04±0.12[9]; 0.16±0.09[11]; 0.06[19]	0.02[6]; 0.05[8]; 0.03[10]; 0.12±0.09[11]; 0.09[12]; 0.11[19]	0.05[24]	-	0.10±0.08[11]; 0.06±0.01[25]		-
Lenstar	0.27±0.32[14]	-	-	-	0.03[21]; 0.02±0.07[22]	-	-	0.10 (0.27)[21]	-	

A-scan vs Orbscan II There is one study (Hashemi et al[2]) that compared A-scan with Orbscan II for the measurement of ACD in healthy eyes (Table 1). They obtained comparable results between these devices, the mean difference and the 95% limits of agreement width being 0.03±0.01 mm and 0.45 mm, respectively. These authors concluded that differences between these devices might be clinically negligible depending on the parameter measured.

From the mean difference and limits of agreement obtained in this study, there is a 95% chance that Orbscan II will measure 0.25 mm shallower and 0.20 mm deeper ACD than EchoScan. These differences were clinically significant to estimate IOL vault, but were not to calculate IOL power, as IOL power varies by 0.25 D for each 0.6 mm of ACD[26]. Then, from Hashemi et al[2] results it can be concluded that depending on anterior eye measurement, these devices they can or cannot be used interchangeable.

However, these authors included both eyes from their healthy volunteers, and a possible bias could be included in this study. As was explained by McAlinden et al[27], paired data simply doubles the number of data points that were included in the study and the statistical power test was reduced. Then, further studies should avoid this bias to confirm if these devices can be used interchangeable.

A-scan vs Pentacam Nemeth et al[5] and Elbaz et al[12] compared ACD measurements using A-scan and Pentacam in phakic and healthy eyes. The latter study obtained that Pentacam measured significant higher ACD than A-scan, which limits of agreement width was 0.59 mm. According to Elbaz et al[12] results, they concluded that device difference was broad enough to be clinical significant. Then, they concluded that for some clinical applications these devices couldn't be used interchangeable. Considering Food and Drug Administration (FDA) tolerance values[28], these devices are interchangeable to assess IOL power but they are not to assess IOL vault.

On the other hand, Nemeth et al[5] obtained comparable measurements, which mean difference was 0.02 mm. They concluded that these devices should be used interchangeable in clinical practice. Despite of this conclusion, the method used to study device agreement was not correct. In this sense, they performed a linear regression analysis, and as was reported by Bland and Altman[29], this method measures the strength of a relation between two variables, not the agreement between them. Then, after these studies, it seems that these devices can be used interchangeable to measure ACD distance.

A-scan vs Pentacam HR Szalai et al[13] compared the ACD measures that A-scan and Pentacam HR provide in healthy eyes. They observed that A-scan yielded significantly higher ACD values than Pentacam HR, the limit of agreement being 0.56 mm. Thus concluding that these two devices cannot be assumed to be interchangeable in clinical practice. However, according to Nuvita Nomogram, the required IOL power varies by 0.10 D for each 0.20 mm of ACD. So from Szalai et al[13] results, device difference is not clinical significant to calculate IOL power, but, to estimate IOL vault device difference is significant[28].

A-scan vs IOLMaster A total of two studies[2,12] compared ACD measurements between A-scan and IOLMaster. Hashemi et al[2] and Elbaz et al[12] obtained contradictory results: while the former one obtained that the IOLMaster measuring significant higher ACD than A-scan (the 95% limits of agreement width being 0.54 mm), the latter one did the opposite trend (the 95% limits of agreement being 0.65 mm). Despite these differences between both studies, they concluded that differences between A-scan might be clinically negligible depending on the use of the

measurement. In this sense, to calculate IOL power these differences are negligible and to assess IOL vault they are not.

A-scan vs Lenstar Gursoy et al [14] has compared A-scan with Lenstar for the measurement of ACD in children eyes under cyclopegia. They included 530 eyes with A-scan and 557 eyes with the Lenstar, the former device measuring significant shallower ACD than the last one (the 95% limit of agreement being 1.24 mm). Despite these findings, they concluded that mean difference was clinically insignificant for IOL power calculation. However, this conclusion is based on mean bias alone, and as has been recommended [27], conclusions about device interchangeability should be based on mean bias and limits of agreement, instead of consider the mean bias alone. Consequently, according to their results, these devices can be used interchangeable to calculate IOL power, but they are not to assess IOL vault.

Ultrasound biomicroscopy vs Orbscan II Only one study so far, carried out by Lee et al [15], have compared UBM with Orbscan II for the measurement of ACD in healthy eyes, and the UBM measured significant shallower ACD than Orbscan II, the mean difference being 0.08±0.09 mm, thus concluding that these differences were not clinically meaningful. However, this conclusion should not be considered because the analysis used to assess device agreement was incorrect. As was proposed by Bland and Altman [29], the limits of agreement between both devices should be used to assess device agreement, instead of using only the mean bias. Then, there is not sufficient information to conclude if these devices can be used as interchangeable. Consequently, further studies should clarify it.

Ultrasound biomicroscopy vs Visante optical coherence tomography Only one study so far (Zhang et al [16]) has included an ACD comparison between UBM and Visante OCT in phakic eyes. The mean difference was 0.07±0.09 mm and the limit of agreement width was 0.36 mm. Finally, these authors concluded that UBM and Visante OCT measurements were interchangeable in phakic eyes.

As was proposed by McAlinden et al [27] clinical interpretation is an essential attribute to determine device interchangeability. Then, if the required IOL power is considered to vary by 0.10 D for each 0.20 mm of ACD, difference for phakic eyes were not clinically significant, but they were significant to IOL safety[28].

Orbscan vs Pentacam Lackner et al [7] and Yazici et al [17] studied the agreement between Orbscan with Pentacam in healthy eyes. The former one obtained that the Scheimpflug device resulted with shallower values than the Orbscan; meanwhile the latter study obtained the opposite. In one study, the mean difference was 0.04±0.06 mm [7] and in the other was 0.14 mm[17]. Moreover, both authors concluded that differences between both devices were small to create any noticeable difference in refractive outcome, the limit of

agreement width being 0.25 mm in Lackner et al [7] study and 0.45 mm in Yazici et al [17] one. However, it should be considered that differences were clinical significant to assess IOL vault [28]. On the other hand, these authors included both eyes of each volunteer, and include both eyes from healthy volunteers only increases sample size and could reduce statistic power because of eye symmetry. Then, further studies should clarify device interchangeability.

Orbscan vs Visante optical coherence tomography Yazici et al [17], also compared ACD values yielded by Orbscan and by Visante OCT. Comparable results were obtained between these devices, the width of the limits of agreement being 0.54 mm. These authors concluded that these differences were small and did not influence decisions for refractive surgery. However, it should be specified that for IOL power calculation these differences were not significant, but to evaluate IOL safety [28] these differences were significative.

Orbscan II vs Pentacam Four studies [4,11,18-19] assessed the interchangeability between Orbscan II and Pentacam in healthy eyes. Contradictory results were obtained among these studies because Dinc et al [11] obtained comparable results between these devices, and the other studies obtained that Orbscan II measured significant shallower ACD distances than Pentacam. Moreover, contradictory conclusions were also obtained: while Doors et al [4] and Dinc et al[11] concluded that these devices should not be use interchangeable, the other two authors [18-19] did the opposite. Differences in sample characteristics could explain these contradictions. In this sense, Dinc et al [11] included emmetropic volunteers and Hashemi and Mehravaran [18] and Utine et al [19] included myopic ones. Unfortunately, Doors et al [4] did not specified volunteers' characteristics. Independently of these contradictions, it was observed that Pentacam tends to measure deeper ACD than Orbscan II in all studies.

Finally, according to these studies it seems that Orbscan II measures shallower ACD values than Pentacam. This could be due to the relatively low-depth resolution of slit scanning compared to Pentacam [30]. However, contradictions about device interchangeability between healthy eyes should be clarified. On the other hand, a possible bias was observed in these studies because of all of them, except Utine et al[19], included both eyes of each volunteer. As was explained before, include both eyes from a healthy volunteer adds little information because of eye symmetry. Consequently, the sample size was increased and the statistical test power could be decreased.

Orbscan II vs Pentacam HR Salouti et al [20] compared ACD values yielded by Orbscan II and Pentacam HR as a function of volunteer's ACD. They divided the sample size in: ACD less than 3.00 mm, ACD between 3.00 and 3.50 mm and

ACD deeper than 3.50 mm. For the middle group, the Orbscan II measured significant deeper ACD than Pentacam HR, the mean difference and limits of agreement being 0.27± 0.06 mm and from -0.26 to 0.80 mm, respectively. This behavior was also observed for the deepest ACD group, the mean difference and 95% limits of agreement width being 0.46 ±0.02 mm and from 0.38 to 0.54 mm, respectively. However comparable results were obtained for the lowest one. Finally, these authors concluded that differences between these devices were not within clinically acceptable levels and they are not interchangeable in every clinical situation. However, according to their limits of agreement, differences between these devices were not clinical significant to calculate IOL power, but they were to assess IOL vault[28], which maximum width was 1.14 mm.

Finally, according to this study, it seems that Orbscan II measures higher ACD values than Pentacam HR. However, a possible bias was observed in this study because both eyes of each volunteer were included. Consequently, the sample size was duplicated and the power of the statistical test could be virtually decreased. So further studies should clarify device agreement.

Orbscan II *vs* **Galilei** Salouti *et al* [20] also studied the interchangeability between Orbscan II and Galilei as a function of volunteer's ACD, and comparable results were only obtained for the shallowest ACD group. Moreover, differences between Orbscan II and Galilei were not within clinically acceptable levels, whose maximum and minimum limit of agreement width was 1.14 mm (for the shallowest group) and 0.12 mm (for the deepest ACD group), respectively. After these results, they concluded that differences between these devices were not within clinically acceptable levels, and Orbscan II and Galilei should not be used interchangeably in every clinical situation. However, if 0.47 mm is subtracted for subjects whose ACD is deeper than 3.50 mm, the Orbscan II measurement will be equivalent to this obtained with the Galilei. Nevertheless, it should be considered that both eyes were included and the power of the statistical test could be virtually decreased.

Orbscan II *vs* **Visante optical coherence tomography** Doors *et al* [4] and Dinc *et al* [11], compared Orbscan II with Visante OCT for the measurement of ACD in healthy eyes. Both studies obtained that Visante OCT produced significantly deeper ACD values than Orbscan II. Although the mean difference between these devices was small (0.15± 0.05 mm [4] and 0.06±0.03 mm [11]), both authors concluded that these devices cannot be use interchangeable because the 95% limits of agreement were large and clinically relevant (0.18 mm [4] and 0.10 mm [11]). However, if the required IOL power is considered to vary by 0.10 D for each 0.20 mm of ACD, about 0.30 mm difference, which corresponds to the highest difference obtained with these authors, is not

clinically significant. Then, it can be concluded that these devices can be used interchangeable to calculate IOL power, but not to assess IOL vault.

Orbscan II *vs* **IOLMaster** Five studies [1-2,9,11,19] have compared Orbscan II with IOLMaster with dissenting findings, after measuring ACD in healthy volunteers. While Frisch *et al* [1], Hashemi *et al* [2] and Dinc *et al* [11], obtained that Orbscan II measured shallower ACD than IOLMaster, Rosa *et al* [9] and Utine *et al* [19] obtained the opposite trend. Despite these contradictions, four of these studies [1-2,9,19] concluded that these devices can be used interchangeable and only one[11] concluded the opposite.

Although these studies concluded that these devices should be used interchangeable to measure ACD in healthy eyes, some of them did not specify when employ both devices interchangeable. Then, according to previous studies, Orbscan II and IOLMaster can be used interchangeable to calculate IOL power, but not to assess IOL safety. Finally, after these results, it seems that Orbscan II measures shallower ACD distances than IOLMaster. This could be because of IOLMaster measures ACD away from the centre as the slit source comes from the temporal side, which may also result in a higher ACD measurement[11].

Pentacam *vs* **Visante optical coherence tomography** Doors *et al*[4], Dinc *et al* [11], Yazici *et al* [17] and O'Donnell *et al* [21] assessed device agreement between Pentacam and Visante OCT. No statistically significant differences were found neither by Dinc *et al* [11] nor by Yazici *et al* [17] and nor O'Donnell *et al* [21]. Contrariwise, Door *et al* [4] obtained that Visante OCT measured significantly deeper ACD values than Pentacam, the mean difference and limits of agreement width being 0.07 ±0.04 mm and 0.16 mm, respectively. Despite these results, three studies [4,11,21] concluded that these devices should not be used interchangeable, and only one [17] concluded the opposite. Independently of these contradictions, from limits of agreement obtained in each study, it can be concluded that differences between device measurements were not clinical significant to calculate IOL power but they were to estimate IOL vault.

Pentacam *vs* **IOLMaster** Six studies [6,8,10-12,19] have so far compared Pentacam with IOLMaster for the measurement of ACD with distending results: two studies [6,11] obtained that Pentacam measured shallower ACD than IOLMaster and the others [8,10,12,19] obtained the opposite trend. Contradictory conclusions were also obtained: while Dinc *et al* [11] and Elbaz *et al* [12] concluded that differences were clinical significant, Savant *et al* [6], Reuland *et al* [8], Woodmass and Rocha [10] and Utine *et al*[19] concluded the opposite. Despite these contradictions, according to limits of agreement and that IOL power varies by 0.25 D for each 0.60 mm of ACD[26] it can be concluded that differences obtained with these devices was within clinical tolerance level to use them in the

clinical practice as interchangeable to calculate IOL power. However, to estimate IOL vault, these devices should not be used interchangeable.

Pentacam *vs* Lenstar Only two studies so far [21-22] have compared Pentacam with Lenstar as far as ACD measurement is concerned. Similar results obtained between these studies: the 95% limit of agreement width obtained in both studies was smaller than 0.30 mm and the mean difference was less than 0.05 mm in both studies. However, contradictory conclusions were achieved in each study: while O'Donnell *et al*[21] concluded that these devices should not be used interchangeable, Huang *et al*[22] concluded the opposite. Contradictions between these studies could be related to differences in sample size. While O'Donnell *et al*[21] included 27 subjects, Huang *et al* [22] included 108 ones. However, according to these results, differences between these devices seems to be clinical significant to assess IOL vault but to assess IOL power they do not.

Pentacam HR *vs* Galilei Salouti *et al* [20], who studied device interchangeability as a function of volunteer ACD, obtained that the 95% limit of agreement width within all groups was lower than 0.25 mm. These authors concluded that differences were within clinical acceptable levels, so they can be used interchangeable. However, it should be specified that they are interchangeable to calculate IOL power, but to assess IOL safety they cannot[28]. It should be in mind that these authors included both eyes, so the sample size was increased and the statistical test power could be decreased. On the other hand, another study [23] also assessed the agreement between these devices and only one eye per patient was included. According to that study, the 95% limit of agreement width was 0.43 mm, and the authors concluded that these devices should not be used as interchangeable to estimate the IOL vault, but they could be to estimate the IOL's power to implant.

Pentacam HR *vs* IOLMaster Németh *et al* [24], assessed agreement between Pentacam HR and IOLMaster. Comparable results were obtained between these devices, the mean difference (0.05 mm) and limits of agreement (from -0. 40 mm to 0.30 mm) being within clinical tolerance levels to assess IOL power. But, differences between both devices were not within clinical tolerance level to assess IOL vault[28]. However, a bias could be included in this study because they both healthy eyes were measured. Thus, this only increases sample size and does not include new information. Then, further studies should confirm Németh *et al*'s[24] conclusions.

Visante optical coherence tomography *vs* IOLMaster Two studies[11,25] have compared Visante OCT and IOLMaster for the measurement of ACD in healthy eyes. Contradictory results and conclusions were obtained: while Dinc *et al*[11] found that the IOLMaster measured significantly deeper ACD, Lavanya *et al* [25] obtained the opposite trend.

Regarding to these studies, Dinc *et al* [11] concluded that these devices should not be used interchangeably to measure ACD, and Lavanya *et al* [25] concluded the opposite. Contradictions between these studies could be related to sample bias observed in Dinc *et al* [11] study, who measured both eyes of each volunteer (they increased sample size and could decrease the statistical power test). So, from Lavanya *et al* [25] it can be we concluded that Visante OCT and IOLMaster can be used interchangeable to assess IOL power in clinical practice.

Visante optical coherence tomography *vs* Lenstar O'Donnell *et al*[21] also compared ACD values measured with Visante OCT and Lenstar. These authors obtained significantly deeper ACD values with Visante OCT, the mean difference and limit of agreement with being 0.10 mm and 0.27 mm, respectively. After these results, they concluded that these two devices should not be used interchangeably in the clinical practice. Nonetheless, the limit of agreement range between Visante OCT and Lenstar lied within clinical acceptable tolerance level to calculate IOL power, which suggests that these devices could be considered interchangeable in clinical practice. However, to assess IOL vault, they cannot be interchangeable.

White −to −white Distance Device Interchangeability Table 2 lists the eight comparative studies in which the WTW distance was measured using two or more of the following devices: UBM, Orbscan, Orbscan II, Pentacam, Galilei, Visante OCT, IOLMaster, Lenstar and EyeSys. The table also summarises the results of each study (mean WTW distance±standard deviation).

Ultrasound biomicroscopy *vs* Pentacam Kim *et al*[31] studied device agreement to measure internal WTW, and they obtained that UBM measured significant lower WTW than Pentacam. Moreover, the limit of agreement width between these devices was 0.84 mm. Considering FDA tolerance limits and that IOLs are sized to the nearest 0.50 mm, it can be concluded that these devices cannot be used interchangeable. However, these authors included both eyes of each volunteers. So, the sample size was increased and the statistical test power could be reduced. Then, further studies should avoid this bias to clarify whether or not UBM and Pentacam can be used interchangeable.

Ultrasound biomicroscopy *vs* Visante optical coherence tomography Kim *et al* [31] also studied agreement between UBM and Visante OCT to measure WTW distance. They obtained that UBM measured significant lower WTW values than Visante OCT, the width of limit of agreement being 0.51 mm. Despite these findings, these authors concluded that these devices should be used interchangeably. However, the mean difference and limits of agreement were large enough to be within clinical acceptable levels when it comes to calculate anterior-chamber IOL diameter. Then, it can be

Table 2 Mean difference between each pair device comparison for healthy eyes for WTW distance (mm)

Anterior segment system	UBM	Orbscan II	Pentacam	Pentacam HR	Galilei	Visante OCT	IOLMaster	Lenstar	EyeSys
UBM		-	0.86±0.43[31]	-	-	0.71±0.26[31]	-	-	-
Orbscan II	-		-	-	0.38±0.56[3]	0.68±0.26[32]	0.32±0.11[32]	-	0.42±0.78[3]
Pentacam	0.86±0.43[31]	-		-	-	0.15±0.50[31]	-	-	-
Pentacam HR	-	-	-		0.05±0.39[23]	-	-	-	-
Galilei	-	0.38±0.56[3]	-	0.05±0.39[23]		-	-	-	0.05±0.75[3]
Visante OCT	0.71±0.26[31]	0.68±0.26[32]	0.15±0.50[31]	-	-		0.36±0.18[32]	-	-
IOLMaster	-	0.32±0.11[32]	-	-	-	0.36±0.18[32]		0.06[33]	-
Lenstar	-	-	-	-	-	-	0.06[33]		-
EyeSys	-	0.42±0.78[3]	-	-	0.05±0.75[3]	-	-	-	

concluded that these devices cannot be used interchangeable to measure WTW distance. However, these authors included both eyes of each volunteers. So, the sample size was increased and the statistical test power could be reduced. Then, further studies should avoid this bias to clarify whether or not UBM and Pentacam can be used interchangeable.

Orbscan II vs Galilei Salouti et al [3] studied the interchangeability of Orbscan II and Galilei, obtaining that Galilei provides significantly higher WTW values than Orbscan II (the limits of agreement width being 2.20 mm). After this study it can be concluded that these devices cannot not be considered as interchangeable to measure WTW distances in the clinical practice. A possible bias was observed in this study because of Salouti et al [3] included both eyes and it increases the sample size and could reduce the statistical power test. Consequently, further studies should be done to confirm the device agreement.

Orbscan II vs Visante optical coherence tomography Kohnen et al [32] assessed the interchangeability of Orbscan II and Galilei. The mean difference between these devices was about 0.68 mm and the limits of agreement width was about 0.90 mm. However, the mean difference and limits of agreement were large enough to be within clinical acceptable levels when it comes to calculate anterior-chamber IOL diameter. Then, it can be concluded that these devices should not be used interchangeable to measure WTW distance.

Orbscan II vs IOLMaster Kohnen et al [32] studied the interchangeability of Orbscan II and IOLMaster. Comparable results between these devices, the limits of agreement width being about 0.45 mm [32]. According to results obtained in these studies, the mean difference and limits of agreement between Orbscan II's and IOLMaster's values exceeded the tolerance limit for the calculation of anterior-chamber IOLs. However, this study included both eyes of each volunteers,

and as was said, the sample size was increased and the statistical test power could be reduced. Then, further studies should be carried out to assess device interchangeability.

Orbscan II vs EyeSys One study (Salouti et al [3]) has so far compared Orbscan II and EyeSys for the measurement of WTW distance, obtaining significantly lower values with Orbscan II the limits of agreement width being 3.06 mm. Therefore, as IOLs are size to the nearest 0.50 mm, it can be concluded that these devices cannot be used interchangeable to measure this distance. A possible bias was observed in this study because of Salouti et al [3] included both eyes and it only increases sample size and could decrease the statistical test power. Consequently, further studies should be done to confirm the device agreement.

Pentacam vs Visante optical coherence tomography Kim et al [31] studies internal horizontal anterior chamber diameter measured with Pentacam and Visante OCT. They obtained comparable results, but the 95% limits of agreement were big enough (1.97 mm) to be clinical significant. Then, it can be concluded that these devices cannot be used interchangeable in clinical practice. These authors included a possible bias in the study because they included both eyes of each volunteer. Consequently, further studies should confirm this device agreement.

Pentacam HR vs Galilei One study [23] assessed the agreement between the Pentacam HR and Galilei to measure WTW distances. According to that study, the Pentacam HR measured in average 0.05 mm wider WTW distances than the Galilei. Nevertheless, the 95% limits of agreement was big enough to be clinical significant, and consequently these authors suggested no to use these instruments as interchangeable in clinical practice.

Galilei vs EyeSys One study (Salouti et al [3]) has to date compared Galilei and EyeSys for the measurement of WTW

distance. Comparable results were obtained between these devices, the 95% limits of agreement being without clinical tolerance levels. Then, it can be concluded that Dual Scheimpflug device and EyeSys cannot be use interchangeable in clinical practice. A possible bias was observed in this study because of Salouti *et al* [3] included both eyes and it only increases sample size and could decrease the statistical test power. Consequently, further studies should be done to confirm this device agreement.

IOLMaster *vs* Lenstar A study[33] measured WTW distance with these devices, and comparable results were obtained. In this sense, Montés-Micó *et al*[33] obtained comparable WTW distances. However, according to device agreement obtained in this study can be concluded that IOLMaster and Lenstar cannot be used interchangeable.

CONCLUSION

Anterior Chamber Depth There present review reveals that the device pairs included cannot be used to assess IOL safety. However, the device pair that can be used interchangeable to calculate IOL power, are A-scan-Pentacam, A-scan-Pentacam HR, A-scan-IOLMaster, A-scan-Lenstar; UBM-Pentacam and UBM-VisanteOCT; Orbscan-VisanteOCT; OrbscanII-Pentacam, OrbscanII-VisanteOCT and OrbscanII-IOLMaster; Pentacam-VisanteOCT, Pentacam-IOLMaster and Pentacam-Lenstar; VisanteOCT-IOLMaster and VisanteOCT-Lenstar; IOLMaster-Lenstar.

Regarding to discrepancies across the studies that have been analysed, they may be due to differences in the measurement method upon which each device is based. For instance, A-scan and BMU rely on ultrasound; Orbscan and Orbscan II rely on scanning-slit topography; Pentacam, Pentacam HR and Galilei use Scheimpflug photography; Visante OCT uses low coherence interferometry; IOLMaster uses a lateral slit illumination and is based on partial coherence interferometry; whereas Lenstar measures ACD with optical biometry. Other sources of discrepancies can be the age group included in each study and the ability of the researcher to control the accommodation state during the measurement in those studies that included young subjects.

As was said by Bland and Altman [29], methods which agree well enough for one purpose may not agree well enough for another. This explains why some devices have good agreement to measure IOL power and to estimate IOL vault they did not agree. On the other hand, further studies, should use a Bland-Altman procedure to assess device agreement and include only one eye to avoid a possible bias. Moreover, all of them should specify the clinical application that the device pair should be used.

White-to-white After these results it can be concluded that any device comparison showed good agreement between device compared. Differences between each device could be related with differences in digital image processing carried out by each WTW measurement. Computers compare grey-scale steps to detect the limbus point-which lies between the white sclera and the darker iris image-and then calculate the corneal diameter. As a result, this measurement is affected by anything that induces some darkness during the measurement; for instance, eyelash shadow, nose shadow or device shadow. Consequently, any corneal disease affecting corneal transparency will have an impact upon the resulting WTW value. Therefore, to measure WTW distances a method that remains unaffected by shadows or ocular artefacts should be used. If this was not possible, the angle-to-angle or sulcus-to-sulcus distance should be measured instead for the calculation of anterior-chamber IOLs or posterior-chamber IOLs, respectively. Moreover, it should be born in mind that these two last measures are more useful when it comes to calculating anterior-chamber width or IOL size.

As for ACD and WTW, further studies should be undertaken, aiming to study the interchangeability of ACD measures across different age groups, ocular conditions and the interchangeability across other devices. Moreover, other studies should clarify the devices pair which interchangeability is yet unclear. Moreover, it should be interesting to attain a relationship between the gold standard for ACD and WTW and the rest of the devices that are able to measure these distances. For surgeons it would be useful because they could know the ACD or WTW that a gold standard would yield without the need to have the device it in the ophthalmology clinic. Consequently, it would avoid some postsurgical problems, as pupil ovalization or problems related to IOL power.

REFERENCES

1 Frisch I, Rabsilber T, Becker K, Reuland A, Auffarth G. Comparison of anterior chamber depth measurements using Orbscan II and IOLMaster. *Eur J Ophthalmol* 2007;17(3):327-331.

2 Hashemi H, Yazdani K, Mehravaran S, Fotouhi A. Anterior chamber depth measurement with a-scan ultrasonography, Orbscan II, and IOLMaster. *Optom Vis Sci* 2005;82(10):900-904.

3 Salouti R, Nowroozzadeh M, Zamani M, Ghoreyshi M, Salouti R. Comparison of horizontal corneal diameter measurements using Galilei, EyeSys and Orbscan II systems. *Clin Exp Optom* 2009;92(5):429-433.

4 Doors M, Cruysberg L, Berendschot T, de Brabander J, Verbakel F, Webers C, Nuijts R. Comparison of central corneal thickness and anterior chamber depth measurements using three imaging technologies in normal eyes and after phakic intraocular lens implantation. *Graefes Arch Clin Exp Ophthalmol* 2009;247(8):1139-1146.

5 Nemeth G, Vajas A, Kolozsvari B, Berta A, Modis LJ. Anterior chamber depth measurements in phakic and pseudophakic eyes: Pentacam versus ultrasound device. *J Cataract Refract Surg* 2006;32(8):1331-1335.

6 Savant V, Chavan R, Pushpoth S, Ilango B. Comparability and intra-/interobserver reliability of anterior chamber depth measurements with the Pentacam and IOLMaster. *J Refract Surg* 2008;24(6):615−618.

7 Lackner B, Schmidinger G, Skorpik C. Validity and repeatability of anterior chamber depth measurements with Pentacam and Orbscan. *Optom Vis Sci* 2005;82(9):858−861.

8 Reuland M, Reuland A, Nishi Y, Auffarth G. Corneal radii and anterior chamber depth measurements using the IOLmaster versus the Pentacam. *J Refract Surg* 2007;23(4):368−373.

9 Rosa N, Lanza M, Capasso L, Lucci M, Polito B, Romano A. Anterior chamber depth measurement before and after photorefractive keratectomy: comparison between IOL master and Orbscan II. *Ophthalmology* 2006;113 (6):962−969.

10 Woodmass J, Rocha G. A comparison of Scheimpflug imaging simulated and Holladay equivalent keratometry values with partial coherence interferometry keratometry measurements in phakic eyes. *Can J Ophthalmol* 2009;44(6):700−704.

11 Dinc U, Gorgun E, Oncel B, Yenerel M, 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):341−346.

12 Elbaz U, Barkana Y, Gerber Y, Avni I, Zadok D. Comparison of different techniques of anterior chamber depth and keratometric measurements. *Am J Ophthalmol* 2007;143(1):48−53.

13 Szalai E, Berta A, Németh G, Hassan Z, Módis LJ. Anterior chamber depth measurements obtained with Pentacam HR® imaging system and conventional A−scan ultrasound. *Ophthalmic Surg Lasers Imaging* 2011; 42(3):248−253.

14 Gursoy H, Sahin A, Basmak H, Ozer A, Yildirim N, Colak E. Lenstar versus ultrasound for ocular biometry in a pediatric population. *Optom Vis Sci* 2011;88(8):912−919.

15 Lee J, Kim J, Kim H, Song J. Comparison of anterior chamber depth measurement between Orbscan IIz and ultrasound biomicroscopy. *J Refract Surg* 2007;23(5):487−491.

16 Zhang Q, Jin W, Wang Q. Repeatability, reproducibility, and agreement of central anterior chamber depth measurements in pseudophakic and phakic eyes: optical coherence tomography versus ultrasound biomicroscopy. *J Cataract Refract Surg* 2010;36(6):941−946.

17 Yazici A, Bozkurt E, Alagoz C, Alagoz N, Pekel G, Kaya V, Yilmaz O. Central corneal thickness, anterior chamber depth, and pupil diameter measurements using Visante OCT, Orbscan, and Pentacam. *J Refract Surg* 2010;26(2):127−133.

18 Hashemi H, Mehravaran S. Corneal changes after laser refractive surgery for myopia: comparison of Orbscan II and Pentacam findings. *J Cataract Refract Surg* 2007;33(5):841−847.

19 Utine C, Altin F, Cakir H, Perente I. Comparison of anterior chamber depth measurements taken with the Pentacam, Orbscan IIz and IOLMaster in myopic and emmetropic eyes. *Acta Ophthalmol* 2009;87(4):386−391.

20 Salouti R, Nowroozzadeh M, Zamani M, Ghoreyshi M, Salouti R. Comparison of anterior chamber depth measurements using Galilei, HR Pentacam, and Orbscan II. *Optometry* 2010;81(1):35−39.

21 O'Donnell C, Hartwig A, Radhakrishnan H. Comparison of central corneal thickness and anterior chamber depth measured using LenStar LS900, Pentacam, and Visante AS−OCT. *Cornea* 2012;31(9):983−988.

22 Huang J, Pesudovs K, Wen D, Chen S, Wright T, Wang X, Li Y, Wang Q. Comparison of anterior segment measurements with rotating Scheimpflug photography and partial coherence reflectometry. *J Cataract Refract Surg* 2011;37(2):341−348.

23 Domínguez−Vicent A, Monsálvez−Romín D, AJ A−C, García−Lázaro S, Montés−Micó R. Measurements of anterior chamber depth, white−to−white distance, anterior chamber angle, and pupil diameter using two Scheimpflug imaging devices. *Arq Bras Oftalmol* 2014;77(4):233−237.

24 Németh G, Hassan Z, Módis LJ, Szalai E, Katona K, Berta A. Comparison of anterior chamber depth measurements conducted with Pentacam HR® and IOLMaster®. *Ophthalmic Surg Lasers Imaging* 2011;42(2):144−147.

25 Lavanya R, Teo L, Friedman D, Aung H, Baskaran M, Gao H, Alfred T, Seah S, Kashiwagi K, Foster P, Aung T. Comparison of anterior chamber depth measurements using the IOLMaster, scanning peripheral anterior chamber depth analyser, and anterior segment optical coherence tomography. *Br J Ophthalmol* 2007;91(8):1023−1026.

26 Rozema J, Wouters K, Mathysen D, Tassignon M. Overview of the repeatability, reproducibility, and agreement of the biometry values provided by various ophthalmic devices. *Am J Ophthalmol* 2014;158 (6): 1111−1120.

27 McAlinden C, Khadka J, Pesudovs K. Statistical methods for conducting agreement (comparison of clinical tests) and precision (repeatability or reproducibility) studies in optometry and ophthalmology. *Ophthal Physiol Opt* 2011;31(4):330−338.

28 Food and Drug Administration, Division of Ophthalmic Devices. Intraocular lens guide document. In, http://www.fda.gov/ohrms/dockets/ 98fr/994052gd.pdf

29 Bland J, Altman D. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986;8(1):307−310.

30 Cairns G, McGhee C. Orbscan computerized topography: attributes, applications, and limitations. *J Cataract Refract Surg* 2005;31(1):205−220.

31 Kim S, Kim H, Song J. Comparison of internal anterior chamber diameter imaging modalities: 35−MHz ultrasound biomicroscopy, Visante optical coherence tomography, and Pentacam. *J Refract Surg* 2010;26 (2): 120−126.

32 Kohnen T, Thomala M, Cichocki M, Strenger A. Internal anterior chamber diameter using optical coherence tomography compared with white−to−white distances using automated measurements. *J Cataract Refract Surg* 2006;32(1):1809−1813.

33 Montés−Micó R, Carones F, Buttacchio A, Ferrer−Blasco T, Madrid−Costa D. Comparison of immersion ultrasound, partial coherence interferometry, and low coherence reflectometry for ocular biometry in cataract patients. *J Refract Surg* 2011;27(9):665−671.