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ORIGINAL PAPER

Anterior chamber indices in a population-based study using the Pentacam

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Abstract
Purpose To determine the distribution of anterior chamber depth (ACD), anterior chamber volume (ACV), and anterior chamber angle (ACA) values in a rural population over 5 years of age using the Pentacam.
Methods In this cross-sectional study, samples were selected from over 1-year-old inhabitants of two villages in Iran using a multistage cluster sampling approach. All participants underwent the measurement of uncorrected and corrected visual acuity and auto-refraction, retinoscopy, subjective refraction, and slit lamp examination. Finally, corneal imaging was done for all subjects over 5 years of age using the Pentacam.
Results Of 3851 selected individuals, 3314 participated in the study, of whom 2681 met the inclusion criteria. The mean age of the sample was 36.03 ± 18.5 years (range 6–90 years). The mean ACD, ACA, and ACV values were 3.37 mm (95% CI: 3.37–3.39), 34.82° (95% CI: 34.45–35.2), and 159.17 µL (95% CI: 156–161.36), respectively. The results of multiple linear regression models showed that ACD, ACA, and ACV values reduced with age, and ACD and ACV values were significantly higher in males. ACA and ACV values correlated inversely with central corneal thickness, while the ACA value correlated directly with keratometry and inversely with the ACV value.
Conclusion This study is one of the few studies in the world showing changes in ACD values in different age groups using the Pentacam. According to the results, aging was associated with a decline in the mean ACD, ACA, and ACV values. These parameters were the largest in patients with emmetropia and smallest in hyperopic subjects.

Keywords Anterior chamber depth · Anterior chamber volume · Anterior chamber angle · Cross-sectional study · Distribution

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Introduction

Glaucoma is one of the major sight-threatening disorders throughout the world, and about half of the patients become blind [1]. It is expected that by 2020, there will be 80 million cases of glaucoma globally, of which 26% will be of the angle-closure type. It is predicted that by 2040, the number will rise to 111.8 million, with the majority of the patients being in Asia and Africa [2, 3]. Nonetheless, the use of comprehensive and accurate anterior segment imaging systems in recent years has greatly increased the odds of early diagnosis and timely treatment of glaucoma [4].

Anterior chamber angle (ACA) and anterior chamber depth (ACD) are important diagnostic indices in angle-closure glaucoma [5]. Several studies have assessed the relationship between ACD and angle-closure glaucoma and suggested that eyes with a shallow anterior chamber are at greater risk of glaucoma [6]. In addition, knowledge of anterior segment parameters is essential for implantation of intraocular lenses, especially anterior chamber intraocular lens (AC-IOL).

One of the available imaging techniques for the evaluation of the anterior chamber is Scheimpflug imaging employed in various devices. In this category, the Pentacam is commonly used in clinical settings. The Pentacam is a digital imaging device that is highly accurate for the evaluation of the anterior segment with more than 50% sensitivity and 100% specificity. It measures anterior segment parameters with a high reproducibility [7–9]. Since the Pentacam provides the opportunity for fast non-contact evaluation of the anterior segment, it is widely used in screening tests. [7–9]

Given the importance of anterior chamber indices in the assessment of ocular disorders and for therapeutic purposes, and since few studies have examined their distribution in the general population, we used the Pentacam to explore the distribution of anterior chamber parameters, including anterior chamber depth, angle, and volume in a population above 5 years of age.

Methods

The present cross-sectional study was conducted in 2015, and the target population was a rural Iranian population over 1 year of age.

Sampling method

The samples were selected using the national data and a multistage cluster sampling approach. First, two districts were randomly chosen from the north (Kajour, a district of Noshahr County, Mazandaran Province) and southwest (Shahyoun, a district of Dezful County, Khuzestan Province) of the country. Then, a number of villages were randomly selected from each district.

In each district, sampling was done proportional to the total population and the total sample size was calculated. Therefore, since southern villages were smaller and less populated, 15 villages were sampled in Shahyoun and 5 in Kajour to maintain the balance. All rural dwellers over 1 year old in each selected village were considered for inclusion.

In each rural region, examinations were performed at a designated site. First, for each individual, visual acuity was measured using a Snellen chart; then, autorefraction was measured using the NIDEK ARK-510A Ref/Keratometer, and the results were refined with retinoscopy (Heine Beta 200 retinoscope, HEINE Optotechnik, Germany). After recording the manifest refraction, subjective refraction was done, and finally, corrected visual acuity was measured. After visual acuity testing, slit lamp biomicroscopy was done by an ophthalmologist. At the final step, Pentacam imaging was done for all subjects over 5 years of age. If any error messages were generated, Pentacam imaging was repeated 10 min after artificial tears instillation. All images were acquired between 9 AM and 2 PM. Moreover, to minimize the effect of diurnal variation, examinations were done at least 3 h after wake-up.

Any participant with a history of ocular surgery, current use of contact lenses, corneal opacities, pterygium, strabismus, keratoconus, corneal dystrophy, or ptosis, as well as those with erroneous data in their Pentacam images, was excluded from the study.

The mean ACD, ACV, and ACA values are presented with their 95% confidence intervals. Simple and multiple linear regression models and ANOVA were used to evaluate the correlation between variables.

Ethical statement

The Ethics Committee of Shahid Beheshti University of Medical Sciences approved the study protocol. The study was conducted in accord with the tenets of the Helsinki Declaration. All participants signed a written informed consent. Informed consent was obtained from the parents or legal guardians of subject below 18 years.

Results

Of 3851 selected individuals, 3314 participated in the study, and 2681 subjects above 5 years were eligible for inclusion after applying the exclusion criteria. The mean age of the participants was 36.03 ± 18.51 years, and 58.1% (n = 1558) of them were female. Moreover, 1281 (47.81%) were from the southwest and 1400 (52.2%) were from the north of Iran.

ACD

Table 1 summarizes the mean and 95% confidence interval of ACD, ACA, and ACV values. The mean ACD value was 3.37 mm (95% CI: 3.37–3.39) in all subjects. The mean ACD value was higher in men. As presented in Table 1, the mean ACD value decreased from 3.57 mm in the age group 6–10 years to 2.95 mm in the age group 61–70 years and increased again in the age group above 70 years. The mean ACD value in rural dwellers of the southwest (3.41 mm, 95% CI: 3.38–3.44) was greater than the mean ACD value in northern residents (3.34 mm, 95% CI: 3.31–3.37).

We used a multiple linear regression model to assess the correlation of ACD with age, region of residence, gender, and ACA. The results of this model are summarized in Table 2. Age (coef = − 0.007, $p < 0.001$) was inversely correlated, while male sex (coef = 0.079, $p < 0.001$), region of residence (coef = 0.034, $p < 0.001$), and ACA (coef = 0.026, $p < 0.001$) had a direct correlation with ACD.

The findings of this study showed that the mean ACD value was the highest in emmetropic individuals and lowest in cases with hyperopia. The mean ACD value was 3.44 mm (95% CI: 3.41–3.46), 3.40 mm (95% CI: 3.36–3.44), and 3.11 mm (95% CI: 3.06–3.15) in emmetropic, myopic, and hyperopic subjects, respectively. ANOVA was applied to examine the correlation of different types of refractive errors with ACD, ACA, and ACV. The results showed a significant relationship between ACD and refractive errors ($p < 0.001$, F = 138.749). Two-by-two comparisons using the Scheffe's method showed that the mean ACD value differed significantly between emmetropic and hyperopic, as well as myopic and hyperopic subjects.

Table 1 Mean and 95% confidence intervals of the anterior chamber depth (ACD), anterior chamber angle (ACA), and anterior chamber volume (ACV) in an Iranian population

	n	ACD (mL) Mean(95% CI)	ACA(ml) Mean(95% CI)	ACV(ml) Mean(95% CI)
Age				
6–10	210	3.57(3.53–3.61)	37.99(37.17–38.80)	183.17(179.65–186.70)
11–20	454	3.65(3.62–3.68)	38.22(37.64–38.80)	189.34(186.53–192.15)
21–30	439	3.56(3.52–3.6)	37.66(36.75–38.58)	181.38(176.99–185.78)
31–41	447	3.41(3.37–3.45)	34.71(33.89–35.52)	160.55(156.19–164.90)
41–50	424	3.2(3.15–3.24)	33.14(32.35–33.94)	140.02(135.8–144.24)
51–60	399	3.08(3.03–3.13)	31.37(30.55–32.18)	127.85(123.45–132.25)
61–70	157	2.95(2.87–3.03)	28.81(27.66–29.95)	116.19(109.73–122.66)
> 70	97	3.13(3–3.25)	29.06(26.67–31.45)	128.81(116.79–140.83)
Gender				
Female	1558	3.33(3.3–3.36)	34.33(33.84–34.82)	154.37(151.56–157.19)
Male	1123	3.43(3.4–3.47)	35.51(34.93–36.09)	165.9(162.51–169.29)
Total	2627	3.37(3.35–3.39)	34.82(34.45–35.2)	159.17(156.98–161.36)

Table 2 Results of the multiple linear regression model assessing the relationship between the anterior chamber angle (ACA) and anterior chamber volume (ACV) and related factors

	ACA(ml)			ACV(ml)		
	Coefficients		*P* value	Coefficients		*p* value
	Unstandardized	Standardized		Unstandardized	Standardized	
Age (year)	− 0.056	− 0.151	< 0.001	− 0.899	− 0.412	< 0.001
Region	− 0.576	− 0.042	0.008	9.475	0.117	< 0.001
ACD	9.289	.542	< 0.001			
CCT	− 0.009	− 0.051	0.001	− .090	− 0.081	< 0.001
Mean-k	0.137	0.030	0.059	− 3.713	− 0.135	< 0.001
Angle				2.715	0.457	< 0.001
Sex				6.938	0.085	< 0.001

ACD anterior chamber depth; *CCT* central corneal thickness; *mean-k* mean of keratometry

ACA

The mean ACA value was 34.82° (95% CI: 34.45–35.20) in all subjects. As shown in Table 1, the mean ACA value was higher in men compared to women. The mean ACA value declined from 37.99° in the age group 6–10 years to 28.81° in the age group 61–70 years and then increased again in the age group over 70 years. The findings of this study showed that the mean ACA value was the highest in emmetropic and lowest in hyperopic subjects.

The mean ACA value was 35.78° (95% CI: 35.5–36.26), 34.78° (95% CI: 34.05–35.69), and 31.56° (95% CI: 30.74–32.28) in emmetropic, myopic, and hyperopic groups, respectively. The mean ACA value was higher in southwestern residents (35.78°, 95% CI: 35.18–36.3) than subjects living in the north of Iran (34.01°, 95% CI: 33.51–34.51).

We used a multiple linear regression model to study the correlation of ACA with age, region of residence, central corneal thickness (CCT), and mean keratometry (mean-k). The results are shown in Table 2. Age, region of residence, and CCT had had an inverse correlation with ACA, while ACD and mean-k showed a direct correlation with ACA. ANOVA showed a significant relationship between ACA and refractive errors ($p < 0.001$, $F = 69.862$). Pairwise comparisons using the Scheffe's method showed that the mean ACA significantly differed between emmetropic and hyperopic, emmetropic and myopic, and myopic and hyperopic subjects.

ACV

The mean ACV value was 159.17 µL (95% CI: 156–161.36) in all subjects. As presented in Table 1, the mean ACV value was higher in men. The mean ACV value decreased from 183.17 µL in the age group 6–20 years to 116.19 µL in the age group 61–70 years and then increased again in the age group above 70 years. The findings of this study showed that mean ACV value was the highest in emmetropic subjects and lowest in hyperopic individuals. The mean ACV value was higher in subjects living in the southwest (161.03 µL, 95% CI: 157.82–164.25) compared to those residing in the north of Iran (157.52 µL, 95% CI: 154.54–160.51).

A multiple linear regression model was applied to assess the correlation of ACV with age, region of residence, CCT, and mean-k. The results are presented in Table 2. Age, CCT, and mean-k correlated inversely with ACV, while the place of residence, male sex, and ACA had a direct correlation with ACV.

The mean ACV value was 166.84 µL (95% CI: 164.22–169.46), 162.44 µL (95% CI: 157.45–167.43), and 130.23 µL (95% CI: 125.81–134.66) in emmetropic, myopic, and hyperopic subjects, respectively. ANOVA showed a significant association between ACV and refractive errors ($p < 0.001$, $F = 178.134$). Pairwise comparisons using the Scheffe's method showed that the mean ACV value significantly differed between emmetropic and hyperopic, emmetropic and hyperopic, and myopic and hyperopic subjects.

Discussion

In this study, we investigated the distribution of anterior chamber indices in rural areas of Iran.

This study is one of the few studies of the distribution of anterior chamber parameters in a wide age group, and given its large sample size, the results add to our current knowledge of the anterior chamber parameters. One of the highlights of this study was showing changes in anterior chamber indices in a population with different age groups, which has been addressed by few studies to date.

As presented in the results, the mean ACD value was 3.37 mm in this study. For comparison purposes, the results of previous studies on the distribution of anterior chamber parameters are summarized in Table 3.

As demonstrated, ACD changes vary from 2.8 to 3.54 mm; differences in age groups and measuring devices are some points that should be taken into consideration when comparing the results [8, 10]. For example, the difference between our study and a study by Asli Dinc, despite using the Pentacam in both studies, appears to be due to the younger age of the samples in our study [8]. Nonetheless, genetic and ethnic differences among different populations may be other reasons for different results.

In this study, age had an inverse correlation with ACD. Most previous studies have also reported that ACD decreases with age [11–14]. The reason for this correlation is not clear; however, it should be noted that older age groups have a smaller axial length, and eyes with a shorter axial length tend to have a shallower anterior chamber [14]. The role of a decreased axial length is a hypothesis proposed by some researchers. Another reason can be an age-related increase in the thickness of the crystalline lens. As the lens thickens with no change in the corneal sagittal depth, ACD is expected to decrease [15, 16].

According to the findings of this study, ACD was higher in males compared to females. In agreement with our results, a number of previous studies also reported that the anterior chamber is shallower in women compared to men [11, 17, 18]. This inter-gender difference may be related to the shorter axial length in women, and eyes with a shorter axial length can be expected to have a shallower anterior chamber as well [19, 20].

The results of this study showed a significant relationship between ACD and refractive errors; for example, hyperopic cases had the smallest ACD. A significant relationship was also observed between ACD and refractive error in a study by He et al. [11] who reported that ACD was significantly lower in hyperopic subjects compared to the other two groups (emmetropic and myopic individuals). Conversely, Meang et al. [21] reported a significant relationship between hyperopia and ACD. Since people with a shorter axial length are more likely to be hyperopic, one reason for this correlation may be a short axial length in these cases [21]. Hence, the results of the present study seem more logical.

The mean ACA value was 34.82° in our study. In agreement with the results of our study, the mean ACA value was 34.8° using Pentacam in a study by Tanja et al. [12] which is quite close to our results. Muller et al. [22] used OCT and reported a mean ACA of 35.9° measured by the first operator and 36.2° by the second operator. These results were not markedly different, and the small differences observed between different studies can be related to differences in measurement methods or the age range of the participants [22]. Based on the results of the present study, younger age, ACD, and mean-k had a significant direct relationship with ACA, while the region of residence and CCT had an inverse correlation with ACA. In the present study, aging showed an inverse correlation with ACA. Similar to our results, a number of previous studies have shown that ACA decreased with age. [13, 14, 23] We believe that this relationship is also affected by ACD changes. We observed a direct correlation between ACA and ACD, and ACA can be expected to decrease as the anterior chamber becomes smaller with age.

The direct relationship observed between keratometry readings and ACA indicates that the steeper the cornea is, the wider the angle is. A report by Cheon et al. [13] also showed a direct relationship between keratometry readings and ACA. These findings seem logical, because the sagittal depth is usually greater in steep corneas, which can explain the wider angle [24]. In a study by Emre et al. [25], keratoconus progression was associated with significant changes in anterior chamber parameters. Their findings can corroborate

Table 3 Comparison of the mean anterior chamber depth (ACD), anterior chamber angle (ACA), and anterior chamber volume (ACV) in different studies using different measurement methods

Author	Country	Measurement method	*n*	Population characteristics	Number of female	Age average	ACD (mm)	ACA	ACV
Nemeth [10]	Hungary	Pentacam	84	50% phakic, 50% pseudophakic	Not reported	65.12 ± 14.27	2.87		
		Ultrasound A-Scan				29.6 ± 5.3	2.98		
Dinc [8]	Turkey	Pentacam	40	Normal phakic	18	6/29 ± 3/5	2.93		
		OCT, SL-OCT					2.85		
		IOL Master					3.33		
		OCT					2.98		
		Orbscan IIz					2.80		
Salouti [30]	Iran	Galilei	37	Normal phakic	28	27.4 ± 7.2	3.22		
		Pentacam					3.25		
		Orbscan II					3.54		
Rabsilber [12]	Germany	Pentacam	76	Normal phakic	Not reported	46.6 ± 16.7	2.93	34.8	
Maya Muller [22]	Germany	AS-OCT	9	Normal phakic	5	32.1		35.9	
Labiris [28]	Greece	Pentacam	20	Normal phakic	9	54.4 ± 19.2			17.1
		OCT							171
Dinc [29]	Turkey	Pentacam	40	Normal phakic	18	29.6 ± 5.3			163.7
		SL-OCT							164.1
		SL-OCT							164.1
Hashemi [7]	Iran	Pentacam	4395	Normal phakic	2551	40–64		34.3	139
Auffarth [31]	Germany	Orbscan	37	Normal phakic	Not reported	70.4 ± 13.2	3.23		
		Ultrasound					3.27		
Lackner [32]	Not reported	Pentacam	30	Normal phakic	16	31.5	3.18		
		Orbscan					3.23		
Hashemi [33]	Iran	Biograph	4849	Normal phakic	2825	40–64	2.62		

our reasoning, because keratometry readings, sagittal depth, and elevation increase in keratoconus, and the cornea becomes steeper [24]. Therefore, the angle is expected to be wider in these eyes.

We observed an inverse relationship between CCT and ACA, while in the Beijing Study, the mean ACA value showed no significant relationship with CCT [17]. Previous studies have shown thicker central corneas in angle-closure glaucoma compared to open-angle glaucoma, which can explain the relationship between a narrower angle and a thicker cornea. In fact, it may be argued that as the angle becomes wider, the cornea becomes steeper, the pulling tension increases, and the corneal thickness decreases [17].

As mentioned earlier, a significant relationship was observed between ACA and refractive errors in this study. This finding is in agreement with the results of a study by OH et al. [26] who reported a significant relationship between ACA and RE. The Beijing Study also showed an association between a narrow ACA and hyperopia [17]. More recent studies have revealed a relationship between RE and the position of the iris insertion as well as a relationship between ethnicity and iris insertion. Therefore, there may be a direct relationship between the anatomic shape of the iris and

ACA, which may be one of the reasons for the relationship between ACA and refractive errors [17]. Nonetheless, refractive errors can result from complex interactions between refractive components and their relative status in the eye [27].

In the present study, the mean ACV value was 159.2 µL. In a study by Labiris et al., the mean ACA value was 171.1 µL by the Pentacam and 171.0 µL by the OCT [28]. Dinc et al. [29] reported a mean ACV value of 163.74 µL by the Pentacam and 163.74 by the SL-OCT. Since there are differences in the measurement technique, age group, ethnicity, and geographical characteristics of the study population between different studies, it is difficult to make a precise comparison of the results. In fact, the differences between studies can be explained by the above reasons [28, 29]. We found a significant relationship between ACV and ACA. Therefore, we believe that factors related to ACV are similar to those related to ACA.

In general, it can be concluded that ACV and ACA values are lower in older people. Regarding refractive errors, the anterior chamber angle, depth, and volume are smaller in hyperopic subjects compared to emmetropic and myopic individuals. Another important factor that is associated with both is the corneal thickness. CCT has an inverse relationship with ACA and ACV. In fact, the wider the angle of the anterior chamber and the larger its volume is, the thinner the central cornea is.

This study is one of the few studies exploring ACD changes in different age groups using the Pentacam. The results showed aging is associated with a decline in the mean ACD, ACA, and ACV values. These parameters had the largest values in patients with emmetropia and smallest values in those with hyperopia. CCT and mean-k significantly correlated with ACA and ACV. Few studies have evaluated these relationships; therefore, our study adds valuable information to our current knowledge of anterior chamber parameters.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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