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# Density of crystalline lens and cornea in different trimesters of pregnancy

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ABSTRACT

*Purpose:* To evaluate topographic measurements of the anterior segment and densitometric measurements of the cornea and lens by Pentacam HR in different trimesters of pregnancy.
*Methods:* This prospective study included 150 healthy pregnant women in their first, second, or third trimester (Groups 1, 2 and 3, respectively) and 54 non-pregnant healthy women (Group 0). Topographic measurements, including central corneal thickness (CCT), corneal volume (CV), anterior chamber depth (ACD), corneal densitometry (CD) and lens densitometry (LD), were done with the Pentacam HR (Oculus, Wetzlar, Germany). The measurement results of the healthy pregnant women and non-pregnant healthy women were compared.
*Results:* CD values were found in Group 1 to be 13.19, in Group 2 to be 13.16, in Group 3 to be 13.17 and in Group 0 to be 13.22 ($p = 0.811$). The mean Group 1, Group 2, Group 3 and Group 0 LD-horizontal was $5.40 \pm 0.5$, $5.47 \pm 0.38$, $5.53 \pm 0.44$, $5.36 \pm 0.43$, respectively. The mean Group 1, Group 2, Group 3 and Group 0 LD-vertical was $5.6 \pm 0.43$, $5.66 \pm 0.32$, $5.71 \pm 0.40$ and $5.5 \pm 0.44$, respectively. Area LD values were higher in the advanced trimester period, and the only statistically significant difference was between Group 3 and Group 0 ($p = 0.025$). The difference between three-dimensional (3D) and peak LD values was not statistically significant between the groups ($p = 0.89$ and $p = 0.91$, respectively).
*Discussion:* The Pentacam HR seems to be an important option for the evaluation of LD, CD and topographic measurements of the anterior segment in pregnancy. In the present study, CD and LD, including LD-horizontal, LD-vertical, peak and 3D values, were not significantly different between pregnant women and non-pregnant women.

## 1. Introduction

Pregnancy is a time when many changes occur in a woman's body. Metabolic, haematological, vascular, hormonal and immunological changes lead to the necessary anatomical and functional adaptive changes. Arterial underfilling in pregnancy leads to the stimulation of arterial baroreceptors, activating the renin-angiotensin-aldosterone system (RAAS) and the sympathetic nervous system. This results in a non-osmotic release of arginine vasopressin (AVP) from the hypothalamus. These changes lead to sodium and water retention in the kidneys and create the hypervolaemic, hypoosmolar state characteristic of pregnancy. Extracellular volume increases by 30–50% and plasma volume by 30–40% [1,2].

The Pentacam HR (Oculus Inc, Wetzlar, Germany) is a high resolution rotating Scheimpflug camera system that is used to analyse topographic measurements of the anterior segment and densitometric measurements of the cornea and lens [3,4]. Its rotating Scheimpflug camera quickly generates a series of images to create a three-dimensional (3D) model of the anterior chamber. This system makes it possible to acquire reproducible images of the anterior chamber in different planes. The Pentacam HR allows for determination of lens transparency through evaluation of lens density. The Pentacam lens density software can provide objective and repeatable results with automatic calculation of lens density measurements in different dimensions [4]. It also provides objective measurements of corneal clarity [5,6].

Hypoosmolar states and hormonal changes in pregnancy might influence the cornea. Corneal thickness and corneal curvature have been

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shown to be influenced by pregnancy and sex hormones [7–9]. In addition, the lens mainly consists of 66% water 33% protein. Therefore, the lens can be affected by plasma volume changes. During pregnancy, increased thickness and refractive changes of the lens have been reported in the literature [10]. However, at present, there are no reports in the literature regarding the effects of pregnancy on corneal densitometry (CD) and lens densitometry (LD).

The aim of this study was to investigate the effect of pregnancy on topographic measurements of the anterior segment and densitometric measurements of the cornea and lens by comparison of healthy eyes of pregnant women with those of non-pregnant healthy women.

## 2. Methods

### 2.1. Study design and participants

In this prospective cross-sectional comparative case series, 150 women who were pregnant and 54 healthy non-pregnant women, were recruited. The study protocol was approved before initiation. Written consent was obtained after detailed information about the purpose of the procedure was provided. The study was conducted in accordance with the ethical standards of the Declaration of Helsinki and was approved by the Institutional Ethical Committee. There were four groups in this study (Groups 1, 2, 3 and 0). The patients were age-matched between the groups. Because cataract formation in the right and left eyes is frequently not identical, both eyes of the subjects were examined. Subjects who were 12 weeks pregnant or less were Group 1, 13–24 weeks pregnant were Group 2, 25–39 weeks pregnant were Group 3 and non-pregnant healthy women were Group 0. Participants whose ages ranged between 18 and 40 years were included. This is because aging may affect lens density. It was wanted to separate age-related cataractogenesis from pregnancy-induced cataractogenesis. The exclusion criteria were any history of ocular surgery, any systemic disorders (including diabetes), any ocular diseases and smoking. None of the patients had subcapsular, traumatic, uveitic or congenital cataracts. The refractive status of patients ranged from +1.0 D to -1.0 D spherical equivalent. Higher ametropies were excluded. Patients who wore contact lenses were also excluded. All the eyes had 1.0 (0.0 logMAR) best corrected visual acuity values according to the Snellen chart (20 feet). The Snellen visual acuity values were converted to logMAR equivalents. Before their participation in the study, all subjects underwent an ophthalmic examination, including visual acuity assessment (Snellen chart), biomicroscopy, air-puff tonometry, static retinoscopy and Scheimpflug anterior segment analysis (Pentacam HR). Central corneal thickness (CCT), corneal volume (CV), anterior chamber depth (ACD), CD and LD measurements were done using the Pentacam HR. The CCT value was accepted as the central corneal thickness (apex). The right eye of each participant was used in the study. All Pentacam HR measurements were obtained by the same masked clinician.

### 2.2. Cornea and lens densitometry measurement techniques

The data of the patients were collected during a single visit. One experienced observer scanned both eyes three times and one good quality image was selected for LD measurements. Pupillary dilation was not done. Each subject's head and chin were positioned properly, and the subjects were asked to keep both eyes open and look directly at the fixation target localised in the slit light during the scanning process for each measurement. The Pentacam HR was adjusted to automatic release mode to rule out operator-related variabilities. Images of 90-270° were assessed to standardisation because LD measurements in the horizontal, vertical and oblique plane may change. LD measurement techniques were as follows: peak, vertical linear, horizontal linear, areal and 3D. Fig. 1 shows the vertical linear LD measurement screen of the Pentacam HR. Fig. 2 shows the 3D LD measurement screen. The peak LD values were recorded directly from the axis line appearing on the right side of the Scheimpflug image screen. For linear LD measurements, a 1 mm vertical line and a 2 mm horizontal line at the centre of the lens were drawn. For areal and 3D LD measurements, a 1 mm (vertical) x 2 mm (horizontal) rectangle was drawn. The values of 1 mm vertical and 2 mm horizontal lines were chosen in order to maintain standardisation, although some adjustments were performed due to individual nucleus dimension variabilities. The Pentacam HR calculated the linear, areal and 3D LD values automatically. CD measurements were performed on the apex of the cornea manually.

### 2.3. Statistical analysis

For statistical analysis, SPSS 22.0 software for Windows (SPSS Inc., Chicago, IL) was used to analyse outcomes. "p" values lower than 0.05 were considered to be statistically significant. The measurement results of the research and control groups were compared using the independent samples t-test. The ANOVA test was used for parametric comparisons between groups of more than two, and the significance between groups was determined using the Bonferroni test.

## 3. Results

The basic demographic and clinical characteristics, as well as anterior segment parameters of the groups, are shown in Table 1. There was no statistically significant difference in age, CCT and ACD between groups ($p = 0.94$, 0.115 and 0.89, respectively). The gestational age, height, weight, systolic blood pressure (SBP), diastolic blood pressure (DBP) and CV revealed statistically significant differences between the groups ($p < 0.001$, $< 0.001$, $< 0.025$, $< 0.001$, $< 0.001$ and $< 0.001$, respectively).

Table 2 shows the CD and LD measurements in the groups. The distributions of CD and LD parameters of research and control groups are shown in Fig. 3. Horizontal and vertical LD values were higher in the advanced trimester period, but there was no statistically significant difference between the groups ($p = 0.122$, $p = 0.12$, respectively). Area LD values were higher in the advanced trimester period, and there was a statistically significant difference between Group 3 and Group 0 only ($p = 0.03$). 3D and peak LD values were slightly higher in the advanced trimester, but this difference was not statistically significant ($p = 0.89$, $p = 0.91$, respectively).

## 4. Discussion

Measuring of CCT, CV and ACD is useful when assessing corneal and anterior chamber health. Alterations may indicate different pathologies, so in clinical practice, it is important to obtain reliable CCT, CV and ACD values for a patient. A review of the literature reveals that CCT, CV and ACD are controversial issues in pregnancy. Atas et al. found an increase in CCT, CV and ACD in the third trimester of pregnancy [11]. However, Sen et al. and Goldich et al. did not find any significant differences in CCT, CV and ACD in healthy pregnant women [12,13]. Efe et al. noted a significant increase in CCT in pregnant women during their second and third trimesters, which returned to first trimester levels after delivery[14]. In this study, it was investigated CCT, CV and ACD measurements as measured with the Pentacam HR. The average CCT in pregnant women was 544.10 ± 27.39 µm. Although there was an increase in CCT in the second and third trimesters, the difference was not statistically significant. The CV was higher in the second and third trimester groups than in the healthy group. This difference was statistically significant compared to the healthy group. In addition, ACD values of pregnant women were not significantly different than those of healthy non-pregnant women.

Pregnant healthy women have demonstrated corneal structural differences, such as corneal curvature and thickness increase, corneal biomechanical parameter changes and increased refractive index of the


**Fig. 1.** Vertical Linear Lens Densitometric Measurement Screen of Pentacam HR.

cornea [15–17]. In addition, oestrogen receptors have been found in corneal tissues, and Lambert et al. reported that progestins and oestrogens increase the water content of the cornea during pregnancy [18]. CD measurements provide information about corneal clarity and transparency. Higher CD indicates increased haze and decreased corneal transparency [19]. As far as is known, this study is the first cross-sectional clinical study evaluating CD in healthy pregnant women. The significant differences were not observed in CD between pregnant women and non-pregnant women.

Although the physiological hormonal changes, systemic hypervolaemic conditions, increased corneal water content and other structural changes in the cornea during pregnancy were shown, this results did not show any changes in CD. There are many studies in the literature revealing keratoconus progression during pregnancy [20,1–23]. Also, keratoconus has been shown to affect CD. Lopes et al. reported that patients with keratoconus had higher LD than healthy controls and also found that CD was correlated with the severity of keratoconus [24]. Therefore, especially in keratoconus with pregnant women, corneal density can give a helpful idea about the onset and progression of the keratoconus.

The optical properties of the lens are a product of its transparency and refractive properties. To focus light, the lens has to be transparent, and this is achieved by the unique cellular architecture of the lens, the absence of blood vessels, the removal of cellular organelles, the minimisation of the extracellular space and the matching of the refractive index between the membranes and the cytoplasm. Together, these features eliminate potential sources of light scattering and, therefore, establish the transparent properties of the lens. The optical properties of the lens are a direct result of its specialised tissue architecture that is initially established during embryonic development. This architecture is continually modified as the lens grows throughout life without the loss of those original primary fibre cells [25]. The details of how this


**Fig. 2.** 3D Lens Densitometric Measurement Screen of Pentacam HR.

**Table 1**
Demographic, Clinical Characteristics and Anterior Segment Parameters of Groups.

| | Group 1 ($n$ = 49) | Group 2 ($n$ = 48) | Group 3 ($n$ = 53) | Group 0 ($n$ = 54) | $p$ Value |
|---|---|---|---|---|---|
| **Number of eyes/patients** | 49/49 | 48/48 | 53/53 | 54/54 | |
| **Age (years)** | | | | | |
| **Mean ± SD** | 28.01 ± 5.3 | 28.46 ± 4.4 | 27.45 ± 5.82 | 27.7 ± 4.46 | 0.94[a] |
| **Range** | 19-40 | 19-38 | 18-40 | 19-37 | |
| **Gestational age, week** | | | | | |
| **Mean ± SD** | 10.45 ± 1.93 | 20.22 ± 3.46 | 32.62 ± 4.04 | – | **< 0.001**[a] |
| **Range** | 6-12 | 13-24 | 25-39 | | |
| **Weight, kg** | | | | | |
| **Mean ± SD** | 68.33 ± 10. 23 | 73.56 ± 12. 11 | 72.38 ± 11. 6 | 60.24 ± 9.6 | **< 0.00**[a] |
| **Range** | 50-98 | 54-110 | 54-102 | 36-83 | |
| **Heigh, cm** | | | | | |
| **Mean ± SD** | 162.1 ± 6.6 | 161 ± 6,4 | 161.2 ± 5.2 | 163.2 ± 5.8 | **0.025**[a] |
| **Range** | 150-175 | 150-173 | 147-172 | 154-176 | |
| **SBP, mmHg** | | | | | |
| **Mean ± SD** | 112 ± 8.03 | 113.1 ± 8.1 | 113.9 ± 8.7 | 118.3 ± 7.1 | **0.00**[a] |
| **Range** | 90-130 | 100-130 | 90-130 | 110-135 | |
| **DBP, mmHg** | | | | | **< 0.00**[a] |
| **Mean ± SD** | 66.1 ± 6.7 | 68.5 ± 8.1 | 67.6 ± 8.9 | 73.5 ± 5.2 | |
| **Range** | 50-80 | 40-80 | 50-90 | 60-85 | |
| **CCT, µm** | | | | | 0.115[a] |
| **Mean ± SD** | 536.9 ± 24.3 | 545 ± 31.3 | 547.01 ± 25.6 | 539.22 ± 17.48 | |
| **Range** | 498-590 | 498-614 | 501-606 | 503-572 | |
| **CV, mm** [3] | | | | | |
| **Mean ± SD** | 59.13 ± 2.14 | 61.1 ± 2.52 | 61.22 ± 2.49 | 59.73 ± 1.54 | **< 0.00**[a] |
| **Range** | 54.6-64.3 | 56.3-66.1 | 56.4-66.4 | 56.3-63.2 | |
| **ACD, mm** | | | | | |
| **Mean ± SD** | 2.96 ± 0.25 | 2.93 ± 0.24 | 2.94 ± 0.24 | 2.95 ± 0.16 | 0.89[a] |
| **Range** | 2.39-3.52 | 2.59-3.82 | 2.41-3.4 | 2.63-3.34 | |

SD: standard deviation, SBP: systolic blood pressure, DBP: diastolic blood pressure, CCT: central corneal thickness, CV: corneal volume, ACD: anterior chamber depth.
[a] Bonferroni test, Boldface: significant values, $p < 0.05$.

microcirculation system maintains lens transparency and refraction are not fully understood [26]. Microcirculation involves the creation of a water flux that circulates throughout the lens. It has been proposed that the differential expression of members of the aquaporin (AQP) family of water channels in these different lens regions plays an important role in the generation of the microcirculation [27]. Some studies have reported that the water content of the lens increases in pregnancy due to progestins, oestrogens and the hypervolaemic state. Therefore, it is conceivable that lens transparency may change in pregnancy. LD using Scheimpflug imaging was highly repeatable and provided information about lens clarity and transparency [4]. Upon review of the literature, there is no study evaluating LD in pregnancy. This is the first study to evaluate LD in healthy pregnant women. It was found that there was no statistically significant difference between pregnant women and non-pregnant women in terms of LD-horizontal, LD-vertical, 3D and peak LD. Areal LD values were slightly higher in Group 3, and there was a statistically significant difference between Group 3 and Group 0 only. In spite of the increase in water content of the lens and the hypervolaemic state, the change in lens transparency can be due to the balance provided by the AQP family of water channels.

There are several limitations to the current study. First, topographic measurements of the anterior segment and densitometric measurements

**Table 2**
Optic Densitometric Values for the Lens and Cornea of Groups.

| | Group 1 ($n$ = 49) | Group 2 ($n$ = 48) | Group 3 ($n$ = 53) | Group 0 ($n$ = 54) | $p$ Value |
|---|---|---|---|---|---|
| **CD** | | | | | |
| **Mean ± SD** | 13.19 ± 0.42 | 13.16 ± 0.58 | 13.17 ± 0.54 | 13.22 ± 0.49 | 0.811[a] |
| **Range** | 12.4-14.3 | 12.10 14.21 | 12.1-14.2 | 12.50 14.72 | |
| **LD-horizontal** | | | | | |
| **Mean ± SD** | 5.4 ± 0.5 | 5.47 ± 0.38 | 5.53 ± 0.44 | 5.36 ± 0.43 | 0.122[a] |
| **Range** | 4.1-6.7 | 4.7-6.4 | 4.7-6.5 | 4.4-6.2 | |
| **LD-vertical** | | | | | |
| **Mean ± SD** | 5.6 ± 0.43 | 5.66 ± 0.32 | 5.69 ± 0.4 | 5.52 ± 0.44 | 0.12[a] |
| **Range** | 4.6-6.6 | 5.1-6.5 | 4.9-6.7 | 4.5- 6.5 | |
| **LD-areal** | | | | | |
| **Mean ± SD** | 5.19 ± 0.53 | 5.20 ± 0.3 | 5.39 ± 0.4 | 5.13 ± 0.35 | **0.03**[a] |
| **Range** | 3.7-6.4 | 4.4-5.9 | 4.5-6.2 | 4.4-6.2 | |
| **3D** | | | | | |
| **Mean ± SD** | 7.29 ± 0.23 | 7.3 ± 0.24 | 7.31 ± 0.24 | 7.28 ± 0.3 | 0.89[a] |
| **Range** | 7.1- 8.2 | 6,.7-8.2 | 7.1-8.3 | 7.1-8.3 | |
| **Peak** | | | | | |
| **Mean ± SD** | 7.63 ± 0.43 | 7.65 ± 0.4 | 7.65 ± 0.43 | 7.63 ± 0.47 | 0.91[a] |
| **Range** | 7.1-8.7 | 7.1-8.8 | 7.0-8.6 | 7.1-8.9 | |

SD: standard deviation, CD: corneal density, LD: lens densitometry, 3D: three dimension.
[a] Bonferroni test, Boldface: significant values, $p < 0.05$.

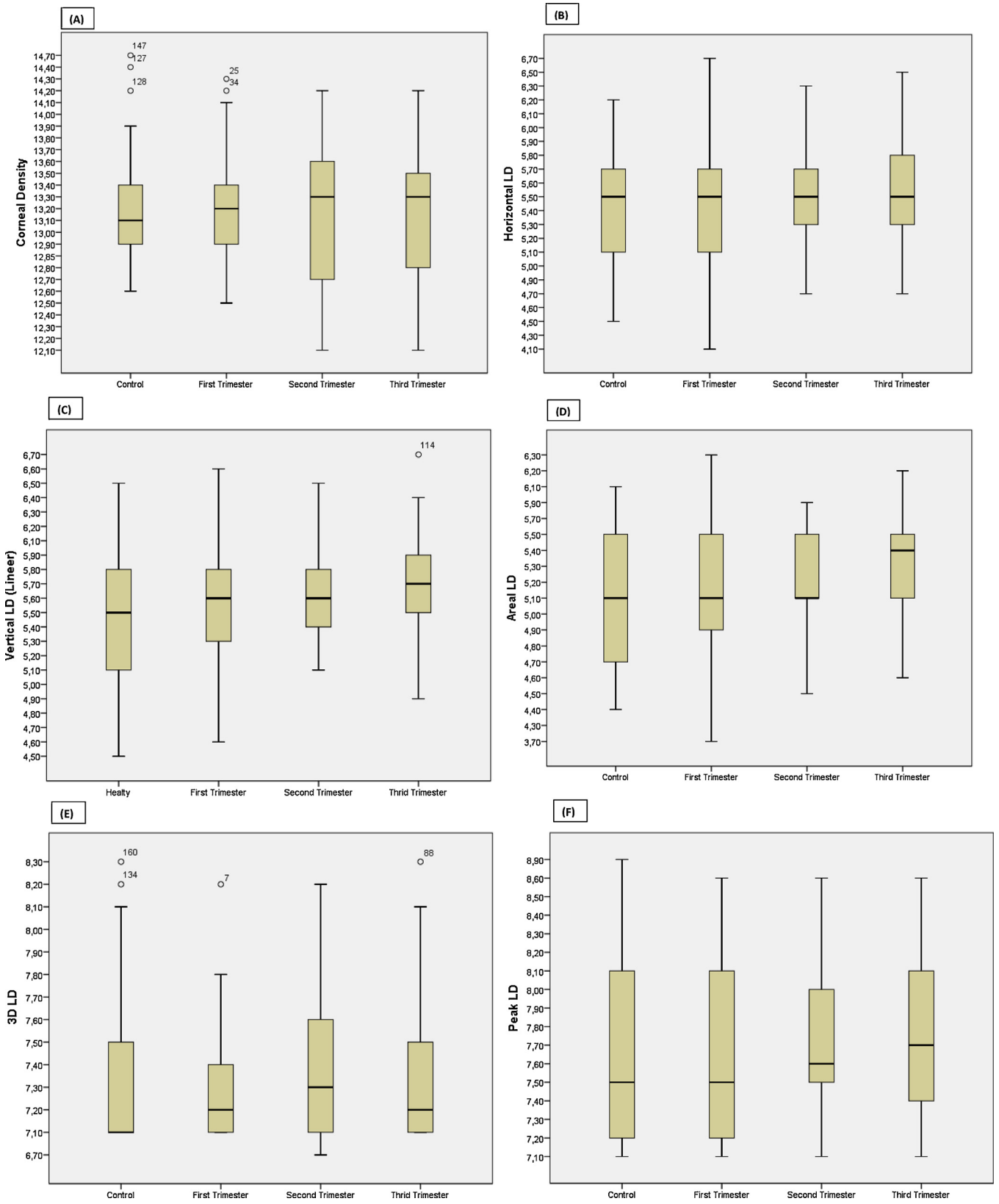


**Fig. 3.** Box plots of Pentacam measurements in groups: (A) corneal density, (B) horizontal lens densitometry, (C) vertical lens densitometry, (D) areal lens densitometry, (E) three dimensional (3D) lens densitometry, and (F) peak lens densitometry.

of the cornea and lens could be done during the prepregnancy, pregnancy and postpregnancy follow-up period in the same patients. Instead of this, to compare the groups, an age-matched control group of healthy non-pregnant women were used as control group. Second, pupillary dilatation was not performed because it was used phenylephrine, cyclopentolate and tropicamide to dilate pupils in clinical practice. These drugs are in the C category in pregnancy and may be teratogenic.

In conclusion, CV was significantly higher in healthy pregnant women. CD and LD, including LD-horizontal, LD-vertical, peak and 3D values were not significantly different between pregnant women and non-pregnant women. New studies are needed to evaluate the effects of corneal and lens pathologies in pregnancy on CD and LD.

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No author has a financial or proprietary interest in any material or method mentioned

## References

[1] P.E. Rasmussen, F.R. Nielsen, Hydronephrosis during pregnancy: a literature survey, Eur J Obstet Gynecol Reprod Biol 27 (3) (1988) 249–259.
[2] E.R. Lumbers, K.G. Pringle, Roles of the circulating renin-angiotensinaldosterone system in human pregnancy, Am J Physiol Regul Integr Comp Physiol 306 (2) (2014) 91–101.
[3] T.M. Rabsilber, R. Khoramnia, G.U. Auffarth, Anterior chamber measurement using Pentacam rotating Scheimpflug camera, J Cataract Refract Surg 32 (2006) 456–459.
[4] F.P. Magalhaes, E.F. Costa, A.J. Cariello, E.B. Rodrigues, A.L. Hofling Lima, Comparative analysis of the nuclear lens opalescence by the Lens Opacities Classification System III with nuclear density values provided by Oculus Pentacam: a cross-section study using Pentacam Nucleus Staging software, Arq Bras Oftalmol 74 (2011) 110–113.
[5] X. Weiner, M. Baumeister, T. Kohnen, J. Bühren, Repeatability of lens densitometry using Scheimpflug imaging, J Cataract Refract Surg 40 (2014) 756–763.
[6] H.M. Elflein, T. Hofherr, F. Berisha-Ramadani, V. Weyer, C. Lampe, M. Beck, et al., Measuring corneal clouding in patients suffering from mucopolysaccharidosis with the Pentacam densitometry programme, Br J Ophthalmol 97 (2013) 829–833.
[7] S.B. Park, K.J. Lindahl, G.O. Temnycky, J.V. Aquavella, The effect of pregnancy on corneal curvature, CLAO J 18 (1992) 256–259.
[8] P.M. Kiely, L.G. Carney, G. Smith, Menstrual cycle variations of corneal topography and thickness, Am J Optom Physiol Opt 60 (1983) 822–829.
[9] Y. Goldich, Y. Barkana, E. Pras, A. Fish, Y. Mandel, A. Hirsh, et al., Variations in corneal biomechanical parameters and central corneal thickness during the menstrual cycle, J Cataract Refract Surg 37 (2011) 1507–1511.
[10] F. Mackensen, W.E. Paulus, R. Max, T. Ness, Ocular changes during pregnancy, Dtsch Arztebl Int 111 (33-34) (2014) 567-75.
[11] M. Atas¸, N. Duru, D.M. Ulusoy, H. Altinkaynak, Z. Duru, et al., Evaluation of anterior segment parameters during and after pregnancy, Cont Lens Anterior Eye 37 (2014) 447–450.
[12] E. Sen, Y. Onaran, P. Nalcacioglu-Yuksekkaya, U. Elgin, F. Ozturk, Corneal biomechanical parameters during pregnancy, Eur J Ophthalmol 24 (2013) 314–319.
[13] Y. Goldich, M. Cooper, Y. Barkana, J. Tovbin, K. Lee Ovadia, et al., Ocular anterior segment changes in pregnancy, Cataract Refract Surg 40 (2014) 1868–1871.
[14] Y.K. Efe, S.C. Ugurbas, A. Alpay, S.H. Ugurbas, The course of corneal and intraocular pressure changes during pregnancy, Can J Ophthalmol 47 (2012) 150–154.
[15] D. Kuhl, S.G. Schwarts, B.P. Sheth, W.F. Mieler, Ocular manifestations of pregnancy, in: J.F. Are´valo (Ed.), Retinal and choroidal manifestations of selected systemic diseases, Springer, New York, 2013, pp. 465–477, , https://doi.org/10.1007/978-1-4614-3646-1_25.
[16] R.B. Dinn, A. Harris, P.S. Marcus, Ocular changes in pregnancy, Obstet Gynaecol Surv 58 (2) (2003) 137–144.
[17] A.D. Grant, M. Sophia, The eye in pregnancy: ophthalmologic and neuroophthalmologic changes, Clin Obstet Gynaecol 56 (2) (2013) 397–412.
[18] C.O. Imafidon, J.E. Imafidon, Contact lenses in pregnancy, Br J Obstet Gynecol 99 (1992) 865–868.
[19] S. Ni Dhubhghaill, J.J. Rozema, S. Jongenelen, I. Ruiz Hidalgo, N. Zakaria, et al., Normative values for corneal densitometry analysis by Scheimpflug optical assessment, Invest Ophthalmol Vis Sci 55 (2014) 162–168.
[20] Z. Gatzioufas, S. Thanos, Acute keratoconus induced by hypothyroxinemia during pregnancy, J Endocrinol Invest 31 (2008) 262–266.
[21] F. Hafezi, H.P. Iseli, Pregnancy-related exacerbation of iatrogenic keratectasia despite corneal collagen crosslinking, J Cataract Refract Surg 34 (2008) 1219–1221.
[22] K. Bilgihan, A. Hondur, S. Sul, S. Ozturk, Pregnancy-induced progression of keratoconus, Cornea 30 (2011) 991–994.
[23] N. Soeters, N.G. Tahzib, L. Bakker, A. Van der Lelij, Two cases of keratoconus diagnosed after pregnancy, Optom Vis Sci 89 (2012) 112–116.
[24] B. Lopes, I. Ramos, R. Ambro´sio Jr., Corneal densitometry in keratoconus, Cornea 33 (2014) 1282–1286.
[25] P.J. Donaldson, A.C. Grey, B. Maceo Heilman, J.C. Lim, et al., The physiological optics of the lens, Prog Retin Eye Res 56 (2017) e1–e24.
[26] D.C. Beebe, R.J. Truscott, Counterpoint The lens fluid circulation model a critical appraisal, Invest Ophthalmol Vis Sci 51 (May (5)) (2010) 2306–2310.
[27] R.T. Mathias, J. Kistler, P. Donaldson, The lens circulation, J Membr Biol 216 (2007) 1–16.