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Comparative Study between Corneal Biomechanical Parameters in Diabetic Patients and Normal Individuals Using Ocular Response Analyzer (ORA)

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ABSTRACT

Background: the cornea exhibits viscoelastic properties, which give it the quality of hysteresis. Corneal hysteresis is an important indicator of the biomechanical properties of the cornea. **Objective**: this study aimed to compare corneal biomechanics in diabetics to that in healthy non diabetic individuals using ocular response analyzer (ORA).

Subjects and Methods: our study was performed on 120 eyes of 60 individuals as we categorized them into three groups. (**Group A)** involved 40 eyes from 20 controlled diabetic patients, (**group B)** involved 40 eyes from 20 non-controlled diabetic patients and 40 eyes from 20 healthy non diabetic individuals (**Group C**). **Results:** the corneal biomechanics in the diabetic groups were significantly higher compared to those of the control group, as the mean CH was 9.23 ± 0.98 mmHg in the controlled diabetic group (**Group A**), 10.11 ± 0.44 mmHg in the non-controlled diabetic group (**Group B**) and 8.03 ± 0.94 mmHg in the healthy non-diabetic individuals **(Group C).** Meanwhile, the mean CRF was 9.26 ± 1.35 mmHg in the controlled diabetic group (**Group A),** 10.03 ± 0.99 mmHg in the non-controlled diabetic group (**Group B)** and 8.37 ± 0.56 mmHg in the healthy non-diabetic individuals (**Group C).** As a result, the differences in CH and CRF between the three groups were statistically highly significant (P=0.00**).**

Conclusion: our study reported that diabetes mellitus led to an increase in corneal biomechanics as CH and CRF were elevated in patients with diabetes mellitus.

Keywords: cornea, ocular response analyzer, corneal hysteresis, corneal resistance factor, diabetes mellitus.

INTRODUCTION

Diabetes mellitus (DM) is a common systemic disease, its prevalence ranges between 8.3% and 11.6% of the general population in different ethnic groups [(1)]**.** DM is characterized by chronic hyperglycemia and an altered cellular homeostasis which may lead to multi-organ dysfunction. 70% of DM patients suffer a number of debilitating complications affecting the physiology, morphology and clinical appearance of the cornea. These complications caused diabetic keratopathy in the form of structural and functional abnormalities resulting in impaired epithelial and endothelial function, punctate keratitis, decreased corneal sensitivity, recurrent corneal erosions and delayed wound healing [(2)]**.** The hyperglycemia caused by DM induced formation and accumulation of advanced glycosylation end products (AGEs), which in turn was strongly associated with a number of pathological complications of DM [(3)]**.**

Studies had shown an increased levels of AGEs in the cornea of DM patients that lead to an increase in collagen cross-linking bonds [(4,5)]**.** As biomechanical behavior is dependent on the regulation and organization of structural components of the cornea, the formation of bonds, which is expected to be accelerated in diabetes, leads possibly to a gradual stiffening of corneal tissue [(6)] and that is consistent with the observation that diabetic corneas are less susceptible to the development and progression of keratoconus [(7)]**.**

The effect of diabetes mellitus on the human cornea may have a clinical significance. Corneal changes induced by chronic abnormal glucose metabolism had been reported in the epithelial, stromal and endothelial layers. Stromal changes included structural alterations produced by collagen cross-linking. *In vitro* studies showed that collagen cross-linking causes increased stiffness of the cornea, which in turn may affect the measurement of intraocular pressure (IOP) and causing overestimation of the true IOP [(8)]**.**

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The Ocular Response Analyzer (ORA) is a further development of a non-contact applanation tonometer, that measures the corneal hysteresis (CH) and the corneal resistance factor (CRF). CH is believed to reflect the damping properties of the cornea comparable with a shock absorber. The CRF provides the total resistance to deformation of the cornea. It also contains portions of the viscous damping [9].

AIM OF THE WORK

This study aimed to compare corneal biomechanics in diabetic to that in healthy non diabetic individuals using ocular response analyzer (ORA).

SUBJECTS AND METHODS

A total of 120 eyes of 60 subjects were enrolled in our study. They were selected from Ophthalmology Outpatient Clinic in AL-Azhar University Hospitals and Kobry El-Kobba Military Hospital; this study was carried out from January 2018 to august 2018. According to the principle of the declaration of Helsinki, the study was explained to the subjects and they were asked to sign a written informed consent.

The study was approved by the Ethics Board of Al-Azhar University.

The type of our study was a cross-sectional descriptive comparative one. Subjects were categorized into three equal groups**: Group A*:*** 20 controlled diabetic patients with HbA1c < 7%. **Group B*:*** 20 non-controlled diabetic patients with HbA1c ≥ 7%. **Group C*:*** 20 healthy non diabetic individuals.

Inclusion criteria: healthy non diabetic individuals, controlled diabetic patients group with HbA1c < 7%, non-controlled diabetic patients group with HbA1c ≥ 7%. **Exclusion criteria:** active corneal infection, corneal scarring, sever dry eye, neo-vascular glaucoma, patients with previous refractive corneal surgery and corneal degenerative diseases (keratoconus and pellucid marginal degeneration).

Methods: subjects were evaluated including (history, examination and investigations).

History: personal data: name, age, gender, residency, telephone number and occupation, data related to inclusion and exclusion criteria, past history of ocular diseases, trauma and ocular surgery, duration of diabetes mellitus.

Examination: visual acuity assessment by Landolt`s C type chart: unaided and best corrected with spectacles. Anterior segment using: slit-lamp examination. Fundus examination using: slit-lamp bio-microscopy and indirect ophthalmoscopy.

Investigations: Ocular response analyzer (Reichert Ophthalmic Instruments, Inc., Buffalo, NY, USA): was a device which became commercially available for in vivo measurements of the corneal biomechanical parameters, which include corneal hysteresis (CH) and corneal resistance factor (CRF), and for the non-contact assessment of IOP, described as Goldmann-correlated IOP (IOPg) and corneal-compensated IOP (IOPcc).

Glycated hemoglobin (HbA1c):

HbA1c was obtained by venous blood sampling. HbA1c was the product of a stable linkage of glucose to the N-terminal valine of the beta-chain of hemoglobin. It defined the average blood glucose level of the previous (2–3) months. It reflected the success of diabetes therapy. Thus, it was possible to assess the glucose metabolism of the body more objectively and in long-term than with a blood glucose sample, which reflected only the current sugar level. Usually 4–6.4% of hemoglobin was glycosylated. Higher values are a sign of insufficient blood glucose control. It also has advanced our understanding of the association between glycemic control and long-term complications of diabetes.

Statistical Analysis

Data were collected, revised, coded and entered to the Statistical Package for Social Science (IBM SPSS) version 23. The quantitative data were presented as mean, standard deviations and ranges when their distribution found parametric. Also, qualitative variables were presented as number and percentages. The comparison between groups regarding qualitative data was done by using **Chi-square test.** The comparison between two independent groups with quantitative data and parametric distribution were done by using **Independent t-test** while, quantitative data with non parametric distribution were done by using **Mann-Whitney test.** The comparison between more than two independent groups with quantitative data and parametric distribution were done by using **One Way ANOVA** followed by post hoc analysis using LSD test while quantitative data with non parametric distribution were done by using ***Kruskall-Wallis test*** followed by post hoc analysis using **Mann-Whitney test. Spearman correlation coefficients** were used to assess the correlation between two quantitative parameters in the same group.

The confidence interval was set to 95% and the margin of error accepted was set to 5%. So, the p-value was considered significant as the following: P-value > 0.05: Non significant (NS). P-value < 0.05: Significant (S). P-value < 0.01: Highly significant (HS).

RESULTS

Table 1: the age of the study groups in years

		Group A	Group B	Group C	Test value••	P-value	Sig.
		No. = 20	No. = 20	No. = 20			
Age	Mean ± SD	67.45 ± 7.07	63.10 ± 8.21	67.65 ± 6.31	2.524	0.089	NS
	Range	45 – 77	46 – 75	57 – 78			

P-value > 0.05: non significant; P-value < 0.05: Significant; P-value < 0.01: highly significant
••: One Way ANOVA test

Table 2: the gender distribution of the study groups in %

		Group A	Group B	Group C	Test value*	P-value	Sig.
		No. (%)	No. (%)	No. (%)			
Gender	Males	11 (55.0%)	10 (50.0%)	12 (60.0%)	0.404	0.817	NS
	Females	9 (45.0%)	10 (50.0%)	8 (40.0%)			

P-value > 0.05: Non significant; P-value < 0.05: Significant; P-value < 0.01: Highly significant
*: Chi-square test

Table 3: the duration of DM for the diabetic groups (**Group A& B)** in years

		Group A	Group B	Test value	P-value	Sig.
		No. = 20	No. = 20			
Duration	Mean ± SD	8.15 ± 4.70	15.20 ± 4.99	-4.597•	0.000	HS
	Range	2 – 20	5 – 21			

P-value > 0.05: non significant; P-value < 0.05: significant; P-value < 0.01: highly significant
*: Chi-square test; •: independent t-test

Table 4: the mode of treatment of diabetes in diabetic groups (**Group A& B)**

		Group A	Group B	Test value	P-value	Sig.
		No. = 20	No. = 20			
Treatment	OHD	19 (95.0%)	9 (45.0%)	11.905*	0.001	HS
	Insulin	1 (5.0%)	11 (55.0%)			

P-value > 0.05: non significant; P-value < 0.05: significant; P-value < 0.01: highly significant
*: Chi-square test; •: independent t-test

Table 5: the HbA1c of the study groups in %

		Group A	Group B	Group C	Test value••	P-value	Sig.
		No. = 20	No. = 20	No. = 20			
HbA1c	Mean ± SD	6.31 ± 0.63	8.51 ± 1.03	5.50 ± 0.45	87.529	0.001	HS
	Range	4.9 – 6.9	7.1 – 10.3	4.5 – 6.3			
Post hoc analysis by LSD							
	Group A vs Group C		Group B vs Group C		Group A vs Group B		
HbA1c	0.001		0.000		0.001		

P-value > 0.05: non significant; P-value < 0.05: significant; P-value < 0.01: highly significant

••: One Way ANOVA test

Table 6: the UCVA of the study groups in decimals

UCVA	Group A	Group B	Group C	F	P-value	Sig.
Average	0.24 ± 0.12	0.22 ± 0.06	0.31 ± 0.14	3.396	0.040	S

Table 7: the BCVA of the study groups in decimals

BCVA	Group A	Group B	Group C	F	P-value	Sig.
Average	0.40 ± 0.22	0.38 ± 0.16	0.52 ± 0.24	2.550	0.087	NS

Table 8: the refraction of the study groups in diopters

	Group A	Group B	Group C	F	P-value	Sig.
Refraction						
Sphere						
Average	-1.11 ± 2.65	-1.86 ± 2.69	-1.14 ± 3.27	0.364	0.697	NS
Cylinder						
Average of the cylinder power	-0.63 ± 0.85	-0.59 ± 0.78	-0.48 ± 0.85	0.125	0.883	NS
Average of the cylinder axis	92.14 ± 11.39	89.64 ± 2.57	85.54 ± 21.91	0.758	0.475	NS

Table 9: the spherical equivalent of the study groups in diopters

Spherical equivalent	Group A	Group B	Group C	F	P-value	Sig.
Average	-1.28 ± 2.93	-2.03 ± 3.06	-1.32 ± 3.57	0.289	0.751	NS

Table 10: fundus examination of the study groups

	Group A	Group B	Group C	F	P-value	Sig.
Fundus Examination				16.500	0.011	S
Normal	15 (75.0%)	12 (60.0%)	17 (85.0%)			
ARMD	0 (0.0%)	0 (0.0%)	3 (15.0%)			
NPDR	5 (25.0%)	6 (30.0%)	0 (0.0%)			
PDR	0 (0.0%)	2 (10.0%)	0 (0.0%)			

ARMD: Age Related Macular Degeneration, NPDR: Non Proliferative Diabetic Retinopathy, PDR: Proliferative Diabetic Retinopathy

Table 11: the corneal hysteresis of the study groups in mmHg

	Group A No. = 20	Group B No. = 20	Group C No. = 20	Test value••	P-value	Sig.
Average						
CH	9.23 ± 0.98	10.11 ± 0.44	8.03 ± 0.94	32.356	0.001	HS
Post hoc analysis by LSD						
	Group A vs Group C	**Group B vs Group C**	**Group A vs Group B**			
Average CH	0.001	0.001	0.001			

P-value > 0.05: non significant; P-value < 0.05: significant; P-value < 0.01: highly significant
••: One Way ANOVA test

Table 12: relation between the average duration of DM and the average CH in the diabetic groups **(Group A&B)**

	Average CH in All diabetic patients	
	R- value	**P-value**
Duration of DM	0.266	0.096

Table 13: relation between HbA1c & the average CH in the diabetic groups **(Group A&B)**

	HbA1c					
	All DM cases		**Controlled DM**		**Non-controlled DM**	
	R- value	**P- value**	**R- value**	**P-value**	**R- value**	**P- value**
Average						
CH	0.588**	0.001	0.413	0.071	0.210	0.374

P-value > 0.05: non significant; P-value < 0.05: significant; P-value < 0.01: highly significant
Spearman correlation coefficient

Table 14: the corneal resistance factor of the study groups in mmHg

	Group A No. = 20	Group B No. = 20	Group C No. = 20	Test value••	P-value	Sig.
Average						
CRF	9.26 ± 1.35	10.03 ± 0.99	8.37 ± 0.56	13.270	0.001	HS
Post hoc analysis by LSD						
	Group A vs Group C	**Group B vs Group C**	**Group A vs Group B**			
Average CRF	0.008	0.001	0.021			

P-value > 0.05: non significant; P-value < 0.05: significant; P-value < 0.01: highly significant
••: One Way ANOVA test

Table 15: relation between the average duration of DM and the average CRF in the diabetic groups (**Group A&B)**

	Average CRF in All diabetic patients	
	R- value	**P-value**
Duration of DM	0.220	0.172

Table 16: relation between HbA1c & the average CRF in the diabetic groups (**Group A&B)**

	HbA1c					
	All DM cases		**Controlled DM**		**Non-controlled DM**	
	R- value	**P-value**	**R- value**	**P-value**	**R- value**	**P-value**
Average						
CRF	0.507**	0.001	0.575**	0.008	0.381	0.098

P-value > 0.05: non significant; P-value < 0.05: significant; P-value < 0.01: highly significant

Spearman correlation coefficient

DISCUSSION

The human cornea is a viscoelastic tissue that can be described by two principal properties: a) A static resistance component (characterized by the CRF), for which deformation is proportional to applied force and

b) A dynamic resistance component (characterized by CH), for which the relationship between deformation and applied force depends on time, both CH and the CRF were measured by using a dynamic bidirectional applanation process using the ORA [(10)]**.** Diabetes significantly impacts the morphological, metabolic, physiological, and clinical properties of the cornea. Chronic hyperglycemia resulting from poorly controlled diabetes leads to tissue modifications and changes in the corneal structure. Glucose can act as a collagen cross-linking agent with the help of advanced glycation end products (AGEs) [(11)]**.** The presence of AGEs in tissues leads to an increase in collagen cross-linking that result in an impairment of tissue function. It is thought that increased collagen cross-linking in the corneas of diabetic patients results in gradual corneal stiffening, increased corneal thickening, and biomechanical changes. Therefore, the aim of our clinical study was to investigate whether the biomechanical parameters (CH and CRF) of the cornea were altered in diabetes according to the HbA1c level and to compare the metabolic status of diabetic and non -diabetic individuals, HbA1c was obtained.

Our population study was categorized into three equal groups: **group A** included 40 eyes of 20 controlled diabetic patients with HbA1c less than 7%, **group B** included 40 eyes of 20 non-controlled diabetic patients with HbA1c equal to or greater than 7% and **group C** included 40 eyes of 20 healthy non-diabetic individuals provided a reference to establish the typical values and ranges of corneal biomechanical parameters.

In our study, the mean CH in the controlled diabetic group (**Group A)** was 9.23 ± 0.98 mmHg in comparison with the mean CH in the non-controlled diabetic group (**Group B)** which was 10.11 ± 0.44 mmHg and the mean CH in healthy non-diabetic individuals (**Group C**), which was 8.03 ± 0.94 mmHg. It was statistically significantly higher in the diabetic patients when compared with the control group and was statistically significantly higher in **group B** diabetic patients (P-value = 0.00).

Our results could be attributed to increased glucose in diabetes that acts as a collagen cross-linking agent with the help of AGEs. AGEs accumulate in collagen proteins, resulting in the formation of covalent cross-linking bonds and gradual corneal stiffening. Results of **Elmazara** ***et***

al. [12] agreed with our results as they mentioned in their results that the mean CH in the control group (Group A) was 7.1186 ± 0.84660 mmHg in comparison with the mean CH in the controlled diabetic group (Group B), which was 8.2958 ± 1.09100 mmHg, and the mean CH in non-controlled diabetic group (Group C), which was 11.2992 ± 1.17842 mmHg. It was statistically significantly higher in diabetic patients when compared to the control group and was statistically significantly higher in group C diabetic patients (P = 0.00). **Kotecha *et al.*** [13] mentioned in their results that CH was slightly higher in the diabetic eyes with P value = 0.21. On the contrary, **Sahin *et al*.** [11] reported that mean CH in the control group was 10.41 ±1.66 mmHg in comparison with mean CH in the diabetic group which was 9.51 ± 1.82 mmHg. They also reported that mean CH was significantly lower in the diabetic patients when compared to the control group, (P value = 0.0001). They explained the decrease in CH by an alteration in the collagenous components due to collagen cross-linking suggesting that the dampening effects of the cornea decrease due to diabetes and were induced to increase during the cross-linking of collagen fibrils. Meanwhile, results of **Goldich *et al.*** [8]**; Cankaya *et al.*** [14] disagreed with our results as they noted that there was no statistically significant difference between the control and diabetic groups regarding CH values. They didn't note any explanations. According to **Cankaya *et al.*** [14] mean CH in control group was 9.41 ± 0.5 mmHg and mean CH in diabetic group was 9.44 ± 0.62 mmHg, (P-value = 0.738).**Scheler *et al.*** [9] also disagree with our results as they showed that there were no differences between healthy controls and patients with well-controlled diabetes as regards to CH. They reported that the diabetic changes caused by increased glucose levels with a consecutive formation of AGEs, seemed not to be surprising in a group of patients with diabetes who had a normal HbA1c. Hypothesis **of Scheler *et al.*** [9] was confirmed by **Odetti *et al.*** [15] and **Traverso *et al.*** [16] as they reported that insulin may reduce or exaggerate the effect of diabetes, which they showed in insulin-dependent patients with diabetes. Meanwhile as we found in our study **Scheler *et al.*** [9] also noted that CH was higher in poorly controlled diabetics than the control group. In our study, the mean CRF value of the controlled diabetic group (**Group A**) was 9.26 ± 1.35 mmHg in comparison with 10.03 ± 0.99 mmHg in the non-controlled diabetic group **(Group B)** and 8.37 ± 0.56 mmHg in the healthy non-diabetic individuals (**Group C**). It was statistically significantly higher in diabetic patients when compared to the control group and was statistically significantly higher in **group B** diabetic patients (P-value = 0.00).Results of **Elmazara *et al.*** [12] agreed with our results as they mentioned in their results that the mean CRF value of the control group (group A) was 7.1731 ±0.97952 mmHg in comparison with 8.6902 ±1.25195 mmHg in the controlled diabetic group (Group B) and 11.8928 ±1.54254 mmHg in the non-controlled diabetic group (Group C). The difference between the three groups was significantly higher in diabetic patients and more significantly higher in group C (the non-controlled diabetic group) (P = 0.001). Also, there were other previous studies that showed similar results to ours as **Goldich *et al*.** [8] **and Kotecha *et al.*** [13]. **Cankaya *et al.*** [14] also showed similar results to ours as they reported that, the mean CRF in the control group was 10.56 ± 0.5 mmHg in comparison with 11.58 ± 0.6 mmHg in the diabetic group. They also reported that the difference between the control and diabetic groups was statistically significantly higher in diabetics compared to the control group (P- value <0.01), but they didn't explain their finding.

In contrast, results of **Sahin *et al.*** [11] disagreed with our results. They denoted that there were no statistical significant differences between the control and diabetic groups, (P- value =0.8) and mean CRF in the control group was 10.36 ± 1.97 mmHg and mean CRF in the diabetic group was

10.32 ± 1.76 mmHg. They could not find an exact explanation for their finding, but they matched the findings of **Scheler *et al.*** *[9]*.

Results of ***S*cheler *et al.*** [9] also disagreed with our results as they mentioned that there were no detectable differences between healthy controls and patients with well-controlled diabetes as regards to CRF.

Meanwhile, as we found in our study **Scheler *et al.*** *[9]* also noted that CRF was higher in poorly controlled diabetics than the control group.

In our study, we wanted to investigate whether the biomechanical parameters (CH and CRF) of the cornea were altered in diabetes; we correlated CH and CRF to duration of diabetes and HbA1c. Regarding CH and duration of diabetes in diabetic groups (**Groups A&B),** the correlation was a weak positive linear correlation, (r-value = 0.266) and (p-value =0.096). Also, regarding CH and HbA1c in diabetic groups (**Groups A& B)** there was a strong positive linear correlation, (r-value = 0.588) and (p-value =0.00). This elevation in HbA1c led to a slightly increased CH indicating an increase in the viscosity of the ground substance. The increased viscosity was associated with higher corneal shearing strength and increased damping. This increased damping effect, which was reflected in a higher CH, was most likely due to the glycosylation of proteoglycans and glycosaminoglycans with a consecutive formation of AGEs. Diabetes reduces the washout of proteoglycans and glycosaminoglycans, as they are connected stronger among each other compared to non-diabetic patients. This 'fixation' of the glycosaminoglycans can change the biomechanical properties of the cornea by increasing the damping capacity.

However, results of **Sahin *et al*.** [11] disagreed with our results as they reported that neither HbA1c nor disease duration had any statistically significant effect on CH, (p-value> 0.05).

Kotecha *et al.* [13] disagree with our results as they confirmed **Sahin *et al.*** [11] findings. As **Sahin *et al.*** [11] proposed that there was no association between CH and HbA1c,

(r-value= 0.1) and (p-value = 0.44).

But, results of **Kotecha *et al.*** [13] agreed with our results in having a positive association between duration of diabetes and CH,

(r-value = 0.16) and (p-value=0.23). They reported that a longer duration of diabetes was associated with a greater CH, although this trend did not achieve significance. Results of **Del Buey *et al.*** [17] disagreed with our results as they proposed that CH was significantly influenced by the viscosity of the ground substance and a decrease in viscosity led to a decrease in CH.

Regarding CRF and duration of diabetes in diabetic groups **(Groups A&B),** the correlation done revealed a weak positive linear correlation,

(r-value= 0.220) and (p-value = 0.172). Regarding CRF and HbA1c in diabetic groups (**Groups A&**

B) there was a strong positive linear correlation,

(r-value = 0.507) and (p-value = 0.001).

Results of **Sahin *et al.*** [11] disagreed with our results as they reported that neither HbA1c nor disease duration had any statistically significant effect on CRF, (p-value> 0.05). Also, results of **Kotecha *et al.*** [13] disagreed with our results as they found no correlation between CFR and HbA1c, (r-value=0.07) and (p-value =0.60) and no correlation was found between CRF and duration of diabetes, (r-value =0.11) and (p-value =0.39).

Kotecha [18] proposed that CRF was strongly associated with corneal stiffness. In our study, mean HbA1c in the controlled diabetic group (**Group A**) was 6.31 ± 0.63%, 8.51 ± 1.03% in the non-controlled diabetic group (Group B), and in the control group **(Group C**) was 5.50 ± 0.45%. **Kotecha *et al.*** [13] reported that, the mean HbA1c for the diabetic group was 7.2 ± 1.4%, (p-value= 0.69). **Sahin *et al*.** [11] also proposed that, the mean

HbA1c in the diabetic group was 7.31± 1.53%.**Scheler *et al*.** [9] proposed that, the mean HbA1c was 5.44 ± 0.46% in the control group, 6.00 ± 0.78% in the diabetic group 1 and 8.58 ± 2.44% in the diabetic group 2, where, group1 with HbA1c <7% and group 2 with HbA1c ≥7%, noted that HbA1c was a statistically significantly different between the control group and all patients with diabetes (Groups 1, 2), (p-value= 0.0001).

In our study the duration of diabetes was 8.15 ± 4.70 years in the controlled diabetic group (**Group A)** and 15.20 ± 4.99 years in the non-controlled diabetic group (**Group B**), while **Sahin *et al.*** [11] proposed that the mean of diabetes duration in their study group was 13.5 ± 6.3 years.

CONCLUSION

Our study reported that diabetes mellitus led to an increase in corneal biomechanics as CH and CRF were elevated in patients with diabetes mellitus. Also, we found that both HbA1c and disease duration have an impact on corneal biomechanics as the higher the HbA1c and the longer the duration of diabetes the higher the corneal biomechanics.

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