Int Ophthalmol (2019) 39:2741–2748
https://doi.org/10.1007/s10792-019-01118-4

ORIGINAL PAPER

Corneal biomechanical changes after trabeculectomy with mitomycin C in primary open-angle glaucoma and pseudoexfoliation glaucoma

Rana Sorkhabi · Farhad Najafzadeh · Ali Sadeghi · Mohamadhosein Ahoor · Ali Mahdavifard

Received: 4 January 2019 / Accepted: 22 May 2019 / Published online: 27 May 2019

Abstract

Purpose This study aimed to examine the effect of trabeculectomy with mitomycin C on corneal biomechanical characteristics in PEXG and POAG patients.

Methods In this prospective comparative case series study, 32 glaucoma patients of whom 17 patients were suffering from PEXG and 15 patients from POAG were enrolled. All patients underwent complete ocular examination, CCT using ultrasound pachymetry and corneal biomechanical study using ORA. The patients were hospitalized, and trabeculectomy surgery with mitomycin was done. Three months after surgery, patients were examined and ORA was obtained again.

Results The mean CH in patients with PEXG was lower compared to patients with POAG (5.66 ± 1.13, 7.49 ± 0.88, respectively) before surgery, which had a statistically significant difference ($P < 0.001$). CRF in patients with PEXG was significantly lower compared to patients with POAG (8.19 ± 1.48 vs. 9.35 ± 1.60, respectively) before surgery, with $P = 0.049$. CH remarkably increased and reached 6.69 ± 0.78 ($P < 0.001$) in the PEXG group after TBX + MMC surgery. CH increased in the POAG group after TBX + MIC surgery and reached 8.23 ± 1.09, which was statistically significant ($P = 0.001$). There was a significant relationship between CH and IOP_g changes in both PEXG and POAG groups ($P < 0.001$ and $P = 0.01$, respectively). Although TBX + MMC surgery changed the amount of CH in PEXG and POAG groups, no significant difference was shown in the parameters between the two groups comparing the CH changes ($P = 0.33$).

Conclusion According to the results of this study, the biomechanical characteristics of cornea, particularly CH, shows certain changes following surgery and is increased, reflecting the dynamic nature of these parameters. Our knowledge of the biomechanical changes after glaucoma surgery can help us better understand the pathophysiology of glaucoma diseases and make the right decisions for follow-up of the patients.

Keywords Ocular response analyzer · Corneal biomechanics · Glaucoma surgery

R. Sorkhabi · F. Najafzadeh (✉) · M. Ahoor · A. Mahdavifard
Nikookari Hospital (Eye Center), Tabriz University of Medical Sciences, Tabriz, Iran
e-mail: najafzadeh.farhad@gmail.com

A. Sadeghi
Eye Research Center, Rassoul Akram Hospital, Iran University of Medical Sciences, Tehran, Iran

Introduction

Glaucoma is one of the major causes of blindness and is defined as progressive optic neuropathy

accompanying an irreversible distinct pattern of visual field loss [1].

Although intraocular pressure (IOP) is not among the diagnostic criteria of glaucoma, it is a primary and very important risk factor, and is a parameter of which reduction and control can reduce the glaucoma progression [2, 3].

Goldmann applanation tonometer (GAT) is the standard measurement tool for intraocular pressure (IOP). It has been recognized that corneal biomechanical properties, including elasticity and viscosity, can be effective on corneal resistance against flattening; thus, these properties affect the measured IOP by Goldmann tonometer [4].

An ocular response analyzer (ORA) is being used to measure the corneal biomechanical properties. The device measures 3-mm central corneal curvature using a change tracking after collision to air pulses. Air pulses cause the cornea to move inward past a first applanation (flattening) into a concave shape, and then decrease corneal flattening by decreasing the air pressure and returning it to its normal convexity. The inward and outward movement in the ORA graph creates two waves called P1 and P2.

Corneal hysteresis (CH) is obtained by subtracting P1 and P2 waves and shows the viscosity properties of the cornea. Other parameters measured by the ORA include corneal resistance factor (CRF), which expresses the general strength of the cornea; IOP_g (Goldman); and IOP_{cc} (corneal compensate). IOP_{cc} is the measured intraocular pressure, which is less affected by corneal thickness, and IOP_g shows the estimated measured intraocular pressure by Goldman [5, 6].

Pseudoexfoliation glaucoma (PEXG) is the most common type of open-angle glaucoma with a specified cause [7]. PEXG is often accompanied with higher IOP and more daily changes, and is clinically more progressive, more resistant to treatment and more likely to need glaucoma surgery compared with primary open-angle glaucoma (POAG) [8, 9].

Currently, several studies have shown that glaucoma patients have less CH and CRF than normal people, and the reduction of CH and CRP is associated with the severity of damage caused by glaucoma [10, 11]. Among patients with open-angle glaucoma, PEXG had lower CH compared to POAG. The low CH could explain the worse prognosis in PEXG [1, 12, 13].

Surgeries can alter the biomechanics of the cornea, and the effects of different surgeries, such as penetrating keratoplasty, cataract and refractive surgeries, have been studied [6, 14, 15].

Currently, studies on the effect of glaucoma surgery are limited. One of them is Pakravan et al.'s study on the effects of different surgeries of glaucoma [16].

This study examined the surgical effect of TBX + MMC on corneal biomechanical characteristics based on two common types of glaucoma, POAG and PEXG, for the first time.

Methods

This prospective comparative case series study was conducted in the Glaucoma Ophthalmic Clinic of Nikookari Hospital, Tabriz, Iran, from November 2014 to February 2016. In total, 32 glaucoma patients with surgical indication of TBX + MMC were enrolled in the study; 17 patients were suffering from PEXG and 15 patients from POAG.

The study was in accordance with the Declaration of Helsinki and was approved by the ethics committee. Written informed consent was obtained from all patients after giving a full description.

POAG was defined as including an open angle for the gonioscopy, characteristic optic neuropathy, visual field defect and absence of secondary causes for glaucoma. PEXG was defined as a typical pseudoexfoliative material on the surface of the lens capsule or pupillary margin after the maximum mydriasis.

Patient with history of contact lens and any ocular surgery, connective tissue disease and diabetes, corneal disorders like corneal ectasia and dystrophies and scars, central corneal thickness of less than 500 and more than 580 microns, an IOP after surgery of less than 5 or more than 21 and any surgical complications were excluded from the study.

All patients underwent a complete ocular examination including best corrected visual acuity, slit lamp bio microscopy, fundus examination, measurement of IOP by Goldmann applanation tonometer (GAT, Haag-Streit, Koeniz, Switzerland), gonioscopy with three mirror lens and pachymetry using NIDEK UP-1000 ultrasonic pachymetry (Nidek Technologies, Gamagori, Japan).

All patients were treated with anti-glaucoma drugs, and patients who had glaucoma progression despite

full dose medication underwent surgery in both study groups. Beta blockers, carbonic anhydrase inhibitor drops and prostaglandins were used for glaucoma control prior to surgery.

Corneal biomechanical examination was done using ORA (Reichert Inc., Depew, New York, USA) before any contact and dilation procedure to eliminate their effects. Highest quality data were selected based on waveform scores, and unreliable signals (waveform score < 4.0) were excluded. All examinations were performed from 9 to 12 o'clock to reduce the effect of diurnal changes as well.

The hospitalized patients underwent trabeculectomy surgery with mitomycin C by the same surgeon and technique. Fornix-based surgery was done in the superotemporal area by creating a semi-thick rectangular sclera flap for all patients, and then, mitomycin C (0.2 mg/ml) was used for 1.5 min. Then, a sclerostomy was created using a punch of 1.5×1 mm. Peripheral iridectomy was done using Vannas scissors, and then, the scleral flap was closed with two Nylon 10.0 sutures. Finally, conjunctiva was sutured by Nylon 10.0.

The patients were under care and regular visits after the surgery. The post-operation treatment regimen for patients included topical drops, chloramphenicol 0.5% four times a day for a week, homatropine 2% three times a day for 2 weeks and betamethasone 0.1% six times a day, which was usually tapered within 3–4 weeks based on the patients' conditions.

The patients were examined completely 3 months after the operation. If there were no complications and the IOP was in the range of 5–21, ORA was re-conducted and data were collected.

Statistical analysis was conducted using SPSS software version 19 (SPSS, Inc., Chicago, IL). Data were presented as mean and standard deviation, and P value of less than 0.05 was considered statistically significant.

Results

Among 32 patients who underwent TBX + MMC, 17 patients were suffering from PEXG and 15 from POAG. Demographic characteristics, clinical findings and preoperative ORA in both patient groups are shown in Table 1.

There was no significant difference between two groups in terms of sex, age, central corneal thickness (CCT), vertical cup to disk ratio (VCDR), measured IOP by Goldman (IOP GAT), IOP_{cc}, IOP_g, number of drugs used and type of medication at the beginning of study (Table 1).

The mean CH in patients with PEXG was lower compared to patients with POAG (5.66 ± 1.13, 7.49 ± 0.88, respectively) before surgery, which had a statistically significant difference ($P < 0.001$).

CRF in patients with PEXG was significantly lower compared to patients with POAG (8.19 ± 1.48 vs. 9.35 ± 1.60, respectively) before surgery, with $P = 0.049$ (Table 1).

ORA and IOP GAT parameter difference after TBX + MMC surgery in the two groups of PEXG and POAG are shown in Tables 2 and 3, respectively.

CH remarkably increased and reached 6.69 ± 0.78 ($P < 0.001$) in the PEXG group after TBX + MMC surgery. CRF decreased significantly after surgery ($P = 0.001$). In addition, a significant decrease in IOP_{cc}, IOP_g and IOP GAT was observed after surgery in this group.

CH increased in the POAG group after TBX + MIC surgery and reached 8.23 ± 1.09, which was statistically significant ($P = 0.001$). However, a significant decrease was seen in the CRF along with IOP_g, IOP_{cc} and IOP GAT in this group after surgery.

Although TBX + MMC surgery changed the amount of CH, CRF, IOP GAT, IOP_g and IOP_{cc} in PEXG and POAG groups, no significant difference was shown in the parameters between the two groups comparing the changes (Table 4).

There was a significant negative correlation between IOP_g changes and CH changes in the PEXG group following the surgery ($r = -0.65$; $P < 0.001$) (Fig. 1). There was also a significant negative correlation between IOP_g changes and CH changes in POAG group following the surgery ($r = -0.45$; $P < 0.01$) (Fig. 2).

CRF changes along with IOP_g changes were also examined. A significant direct relation was observed between CRF and IOP_g changes in the PEXG group ($r = +0.24$ and $P = 0.04$). However, there was no significant direct relation between CRF and IOP_g changes in the POAG group ($P = 0.07$).

Table 1 Baseline patient characteristics

	PEXG (n = 17)	POAG (n = 15)	P value
Gender	Female 4 (23.5%)	Female 5 (33.3%)	0.70*
	Male 13 (76.5%)	Male 10 (67.7%)	
Eye	OD 11 (64.7%)	OD 8 (53.3%)	0.51**
	OS 6 (35.3%)	OS 7 (46.7%)	
Age	66.24 ± 6.81	63.67 ± 5.74	0.37***
CCT	530.53 ± 20.87	542.60 ± 19.24	0.08***
VCDR	0.81 ± 0.12	0.83 ± 0.09	0. 79***
IOP GAT	5.66 ± 1.13	7.49 ± 0.88	< 0.001***
CRF	8.19 ± 1.48	9.35 ± 1.60	0.049***
IOP_g	21.41 ± 3.61	20.65 ± 4.65	0. 71***
IOP_{cc}	24.22 ± 4.47	23.35 ± 4.17	0.50***
Number of medications	3.76 ± 0.59	4.00 ± 0.0	0.41***

*Fisher's exact test; **Chi-Square tests; ***Mann–Whitney U

OD, right eye; OS, left eye; CCT, central corneal thickness; VCDR, vertical cup to disk ratio; IOP GAT, intraocular pressure with Goldmann applanation tonometer; CH, corneal hysteresis; CRF, corneal resistance factor; IOP_g, Goldmann-correlated intraocular pressure; IOP_{cc}, corneal-compensated intraocular pressure

Table 2 The changes of the IOP GAT and ORA data before and 3 months after trabeculectomy surgery with mitomycin C (TBX + MMC) in patients with pseudoexfoliation glaucoma (PEXG)

	Pre	Post	p value*
IOP GAT	22.29 ± 2.28	14.71 ± 2.11	< 0.001
CH	5.66 ± 1.13	6.69 ± 0.78	0.001
CRF	8.19 ± 1.48	7.11 ± 1.15	0.001
IOP_g	21.41 ± 3.61	13.99 ± 2.95	< 0.001
IOP_{cc}	24.22 ± 4.47	17.76 ± 2.53	0.001

*Wilcoxon

IOP GAT, intraocular pressure with Goldmann applanation tonometer; CH, corneal hysteresis; CRF, corneal resistance factor; IOP_g, Goldmann-correlated intraocular pressure; IOP_{cc}, corneal-compensated intraocular pressure

Table 3 The changes of the IOP GAT and ORA data before and 3 months after trabeculectomy surgery with mitomycin C (TBX + MMC) in primary open-angle glaucoma (POAG) patients

	Pre	Post	P value*
IOP	21.87 ± 3.14	14.13 ± 2.21	< 0.001
CH	7.49 ± 0.88	8.23 ± 1.09	0.01
CRF	9.35 ± 1.60	8.31 ± 1.42	0.001
IOP_g	20.65 ± 4.65	13.07 ± 2.60	0.001
IOP_{cc}	23.35 ± 4.17	16.31 ± 0.77	0.001

*Wilcoxon

IOP GAT, intraocular pressure with Goldmann applanation tonometer; CH, corneal hysteresis; CRF, corneal resistance factor; IOP_g, Goldmann-correlated intraocular pressure; IOP_{cc}, corneal-compensated intraocular pressure

Discussion

Human cornea includes physical and structural characteristics such as thickness, as well as biomechanical features [14]. Corneal biomechanical characteristics are very important in many fields of ophthalmology, and their evaluation increases our knowledge of pathological changes in the cornea.

An ocular response analyzer (ORA) is a device that measures the corneal biomechanical properties. ORA data include CH, CRF, IOP_g and IOP_{cc}. CH is the most important data of ORA and shows the measurement of the corneal viscosity. Indeed, CH shows the ability of corneal tissue to absorb and distribute energy, and its normal range is 9.6–12.2 [16]. This parameter appears to be independent of the IOP in normal eyes, but it has an inverse relationship with IOP in glaucoma patients [17].

Several studies have shown that corneal biomechanical changes are consistent with changes and

Table 4 The comparison of data changes in ocular response analyses (ORA) before and after trabeculectomy surgery with mitomycin C (TBX + MMC) in two PEXG and POAG groups

	(n = 17) PEXG	(n = 15) POAG	P value*
ΔCH	− 1.03 ± 0.22	− 0.75 ± 0.26	0.33
ΔCRF	1.08 ± 0.30	1.04 ± 0.27	0.74
ΔIOP_g	7.41 ± 4.67	7.58 ± 3.65	0. 82
ΔIOP_{cc}	6.46 ± 5.03	7.04 ± 3.68	0.79

*Mann–Whitney U

ΔCH, CH change; ΔCRF, CRF change; ΔIOP_g, IOP_g change; ΔIOP_{cc}, IOPcc change

damages caused by glaucoma. In a study by Prata et al., they found that low CH together with higher C/D ratio is independent of the IOP and disk size. CH also matches with the findings of the GDX [18].

Corneal biomechanical findings, and CH in particular, can play an important role in determining prognosis. In a retrospective cohort study, De Moraes et al. [19] demonstrated that low CH was associated with faster progression of glaucoma.

Biomechanical characteristics of the cornea, particularly CH, were studied in different types of glaucoma such as congenital glaucoma, normal tension glaucoma, POAG, PEXG and primary angle closer glaucoma, and CH was lower compared to normal people in all of these studies [20–24].

In a study by Ozkok et al., the viscoelastic properties of the cornea in PEXG patients were compared with POAG patients. This study was conducted on 38 POAG patients and 35 PEXG patients and showed that CH was significantly lower in PEXG patients compared to POAG patients (8.8 ± 1.4 vs. 9.9 ± 1.2 with P = 0.0007). Besides, CRF was lower in PEXG patients than POAG patients, $P < 0.0001$. In this study, there was no significant difference in CCT between the two groups.

In our study, CH was lower than average in both PEXG and POAG groups (5.66 ± 1.13 and 7.49 ± 0.88, respectively). Comparing the two groups, CH was significantly lower in the PEXG group than the POAG group ($P <$ O.OOO1). CRF was lower in PEXG patients than POAG patients, P = 0.0001. In our study, CCT showed no significant difference between the groups [1].

Studies on the CCT difference in patients with PEXG and POAG had varying results. Bechmann et al. [25] reported thinner CCT in PEXG patients. Ventura et al. [26] showed no difference in CCT in both groups, which was consistent with the study by Ozkok et al.

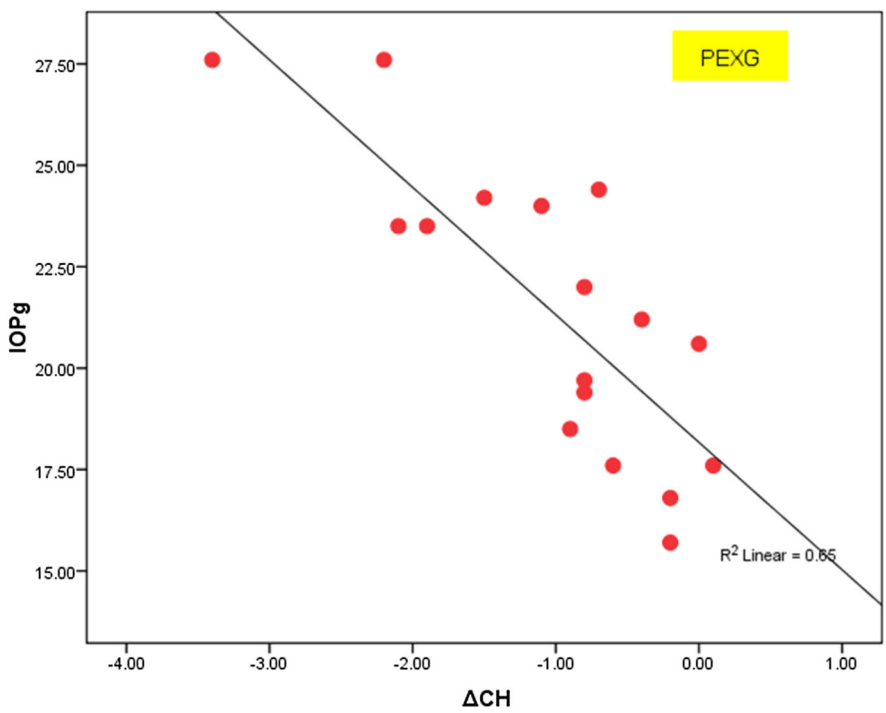

Fig. 1 The scatter plot shows the inverse relationship between changes in corneal hysteresis (CH) by reducing IOP_g after trabeculectomy surgery with mitomycin C (TBX + MMC) in patients with pseudoexfoliation glaucoma (PEXG). ΔCH, CH change; ΔIOP_g, IOP_g change

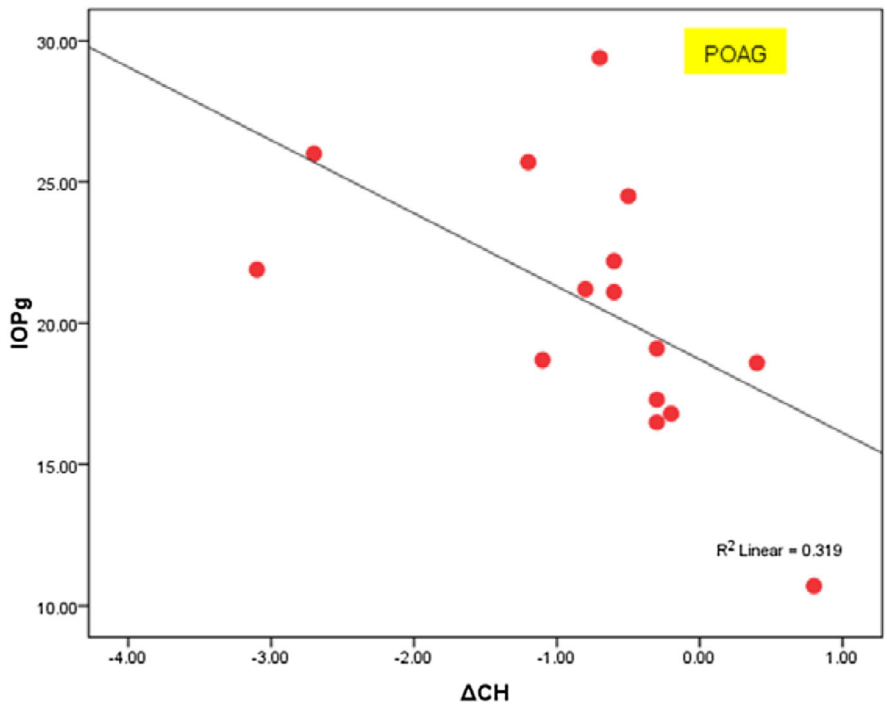

Fig. 2 The scatter plot shows the inverse relationship between changes in corneal hysteresis (CH) by reducing IOP_g after trabeculectomy surgery with mitomycin C (TBX + MMC) in patients with primary open-angle glaucoma (POAG). ΔCH, CH change; ΔIOP_g, IOP_g change

[1], as well as our study. This lack of difference in CCT between POAG and PEXG groups can indicate that biomechanical characteristics play a role in glaucoma pathogenesis independent of CCT. On the other hand, a decrease in CH in PEXG patients compared to POAG patients may justify the worse prognosis in these patients. PEX syndrome is a systemic disease which can affect all structures of the eye including the cornea. CH reduction, which is a factor for the absorption and distribution of energy, can be associated with similar changes and with a reduction of support in the lamina and peripapillary sclera of the optic nerve in these patients [27, 28]. Therefore, this justifies tougher and faster progression of PEXG disease compared to POAG, even when IOP is similar between these two.

Studies on the impact of glaucoma surgical methods are limited. The only available study is that of Pakravan et al. In this study, corneal biomechanical changes were examined after different glaucoma surgeries including trabeculectomy, phacotrabeculectomy and Ahmed glaucoma valve, and a group of patients who only had phacoemulsification surgery were selected as the control group. This study was prospective, and the patient ORA was measured before and 3 months after the surgery; thus, the changes before and after surgery were evaluated. In this study, 23 patients with open-angle glaucoma underwent trabeculectomy surgery using mitomycin. CH was significantly lower in glaucoma patients before surgery compared to non-glaucoma patients (5.4 vs. 8.1, $P < 0.001$). CH increased in trabeculectomy, phacotrabeculectomy and Ahmed valve surgeries 3 months after surgery (2.16, 2.29, 2.30, respectively), $P < 0.001$. CRF also increased in all groups ($P < 0.001$), whereas there were no significant changes in CH and CRF in patients undergoing phacoemulsification [16].

In our study, TBX + MMC surgery increased CH significantly in both POAG and PEXG groups ($P = 0.01$ and $P = 0.001$, respectively). It also caused a significant decrease in IOP GAT, IOP_g and IOP_{cc} in both groups. Unlike Pakravan et al.'s study, in our study, there was a significant reduction in CRF changes following surgery in both groups. The study by Beyazyildiz et al., which investigated the ORA parameters in POAG and PEXG patients, can be used as an evidence to justify this difference. In that study, there was a significant reduction in CH and CRP in PEXG patients compared to POAG patients and normal people. That study measured the relationship of different parameters and concluded that there was

direct relationship between CRF and IOP_g in all groups [12]. Therefore, the reduction in CRF in all patients following TBX + MMC surgery can be due to the reducing effect of surgery on IOP.

Corneal biomechanical changes following glaucoma surgery can have multiple causes including surgical procedure and manipulation of the eye, the use of intraoperative drugs such as MMC and topical medications that are often cut off after surgery. Considering all these factors, it seems that the main reason for the change is due to control and reduction of IOP after surgery resulting in less stress applied to the cornea.

However, in our study, an inverse significant relationship was seen between IOP_g CH changes following surgery in both PEXG and POAG groups ($P < 0.001$ and $P = 0.01$, respectively).

Considering the inverse relationship of CH and IOP_g, the eye strain reduction after surgery can lead to CH increase, which is fully justified.

There are contradictory results on CRF changes. In our study, there was CRF reduction after surgery and the relationship between IOP_g and CRF changes was different; a positive significant relationship was found only in the PEXG group. Considering different results on CRF in various studies, it appears that this data can be affected by several factors and has less reliability than CH.

Topical drugs used to treat glaucoma can cause corneal biomechanical changes. In general, these drugs increase CH mainly due to the reducing effect on IOP [16, 17]. In the case of prostaglandins, studies have shown that this effect is independent of IOP [29]. In our study, the two PEXG and POAG groups had no significant difference in terms of the number and type of drugs, especially Latanoprost.

We observed that there were clear and definite changes in ORA parameters such as CH, CRF, IOP_g and IOP_{cc} before and after surgery in both PEXG and POAG groups. But the rate of changes in any of the parameters showed no significant difference between the two groups. This study showed that the effect of TBX + MMC surgery on corneal biomechanical characteristics based on the type of glaucoma (PEXG or POAG) is not different, which can be due to the similar reducing effects on IOP after TBX + MMC surgery independent of the type of primary glaucoma.

According to the results of our study, the biomechanical characteristics of cornea, particularly CH, show certain changes following surgery and is increased, reflecting the dynamic nature of these parameters. With regard to the effects of corneal biomechanical characteristics on routine IOP measurements, and also considering the importance of these characteristics in diagnosis, determining prognosis and determining the probability of response to treatment, our knowledge on biomechanical changes after glaucoma surgery can help us better understand the pathophysiology of glaucoma diseases and make the right decisions for follow-up of patients.

Further studies on different types of glaucoma, at different stages of the disease, with a larger sample size, and an extended follow-up can help us better understand the mutual relationship between surgical methods of glaucoma and biomechanical changes.

Acknowledgement We would like to thank the education deputy that sponsored us to fulfill the project in the form of thesis research. Our next thanks go to all the patients who cooperated in this study.

Compliance with ethical standards

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

Ethical approval All procedures performed in this study were in accordance with the ethical standards of the Tabriz University of medical science ethical committee and with the 1964 Declaration of Helsinki and its later amendments.

Informed consent Written informed consent was obtained from all patients after giving a full description.

References

1. Ozkok A, Tamcelik N, Ozdamar A, Sarici AM, Cicik E (2013) Corneal viscoelastic differences between pseudoexfoliative glaucoma and primary open-angle glaucoma. J Glaucoma 22(9):740–745
2. Congdon NG, Broman AT, Bandeen-Roche K, Grover D, Quigley HA (2006) Central corneal thickness and corneal hysteresis associated with glaucoma damage. Am J Ophthalmol 141(5):868–875
3. Leske MC, Heijl A, Hussein M, Bengtsson B, Hyman L, Komaroff E et al (2003) Factors for glaucoma progression and the effect of treatment: the early manifest glaucoma trial. Arch Ophthalmol 121(1):48–56
4. Mansouri K, Leite MT, Weinreb RN, Tafreshi A, Zangwill LM, Medeiros FA (2012) Association between corneal biomechanical properties and glaucoma severity. Am J Ophthalmol 153(3):419–427 **e1**

5. Luce DA (2005) Determining in vivo biomechanical properties of the cornea with an ocular response analyzer. J Cataract Refract Surg 31(1):156–162
6. Murugesan V, Bypareddy R, Kumar M, Tanuj D, Anita P (2014) Evaluation of corneal biomechanical properties following penetrating keratoplasty using ocular response analyzer. Indian J Ophthalmol 62(4):454–460
7. Ritch R (1994) Exfoliation syndrome-the most common identifiable cause of open-angle glaucoma. J Glaucoma 3(2):176–177
8. Brooks AM, Gillies WE (1988) The presentation and prognosis of glaucoma in pseudoexfoliation of the lens capsule. Ophthalmology 95(2):271–276
9. Konstas AG, Stewart WC, Stroman GA, Sine CS (1997) Clinical presentation and initial treatment patterns in patients with exfoliation glaucoma versus primary open-angle glaucoma. Ophthalmic Surg Lasers 28(2):111–117
10. Medeiros FA, Meira-Freitas D, Lisboa R, Kuang TM, Zangwill LM, Weinreb RN (2013) Corneal hysteresis as a risk factor for glaucoma progression: a prospective longitudinal study. Ophthalmology 120(8):1533–1540
11. Pensyl D, Sullivan-Mee M, Torres-Monte M, Halverson K, Qualls C (2012) Combining corneal hysteresis with central corneal thickness and intraocular pressure for glaucoma risk assessment. Eye 26(10):1349–1356
12. Beyazyildiz E, Beyazyildiz O, Arifoglu HB, Altintas AK, Koklu SG (2014) Comparison of ocular response analyzer parameters in primary open angle glaucoma and exfoliative glaucoma patients. Indian J Ophthalmol 62(7):782–787
13. Deol M, Taylor DA, Radcliffe NM (2015) Corneal hysteresis and its relevance to glaucoma. Curr Opin Ophthalmol 26(2):96–102
14. Hjortdal JO (1998) On the biomechanical properties of the cornea with particular reference to refractive surgery. Acta Ophthalmol Scand Suppl 225:1–23
15. Song X, Langenbucher A, Gatzioufas Z, Seitz B, El-Husseiny M (2014) Effect of biometric characteristics on the change of biomechanical properties of the human cornea due to cataract surgery. Biomed Res Int 2014:628019
16. Pakravan M, Afroozifar M, Yazdani S (2014) Corneal biomechanical changes following trabeculectomy, phacotrabeculectomy, ahmed glaucoma valve implantation and phacoemulsification. J Ophthalmic Vis Res 9(1):7–13
17. Sun L, Shen M, Wang J, Fang A, Xu A, Fang H, Lu F (2009) Recovery of corneal hysteresis after reduction of intraocular pressure in chronic primary angle-closure glaucoma. Am J Ophthalmol 147(6):1061–1066 **6 e1-2**
18. Prata TS, Lima VC, Guedes LM, Biteli LG, Teixeira SH, de Moraes CG, Ritch R, Paranhos AJ (2012) Association between corneal biomechanical properties and optic nerve head morphology in newly diagnosed glaucoma patients. Clin Exp Ophthalmol 40(7):682–688
19. De Moraes CV, Hill V, Tello C, Liebmann JM, Ritch R (2012) Lower corneal hysteresis is associated with more rapid glaucomatous visual field progression. Glaucoma 21:209–213
20. Anand A, De Moraes CG, Teng CC, Tello C, Liebmann JM, Ritch R (2010) Corneal hysteresis and visual field asymmetry in open angle glaucoma. Invest Ophthalmol Vis Sci 51(12):6514–6518
21. Kaushik S, Pandav SS, Banger A, Aggarwal K, Gupta A (2012) Relationship between corneal biomechanical properties, central corneal thickness, and intraocular pressure across the spectrum of glaucoma. Am J Ophthalmol 153(5):840–849 **e2**
22. Morita T, Shoji N, Kamiya K, Fujimura F, Shimizu K (2012) Corneal biomechanical properties in normal-tension glaucoma. Acta Ophthalmol 90(1):e48–e53
23. Narayanaswamy A, Su DH, Baskaran M, Tan AC, Nongpiur ME, Htoon HM, Wong TY, Aung T (2011) Comparison of ocular response analyzer parameters in Chinese subjects with primary angle-closure and primary open-angle glaucoma. Arch Ophthalmol 129(4):429–434
24. Sullivan-Mee M, Billingsley SC, Patel AD, Halverson KD, Alldredge BR, Qualls C (2008) Ocular response analyzer in subjects with and without glaucoma. Optom Vis Sci 85(6):463–470
25. Bechmann M, Thiel MJ, Roesen B, Ullrich S, Ulbig MW, Ludwig K (2000) Central corneal thickness determined with optical coherence tomography in various types of glaucoma. Br J Ophthalmol 84(11):1233–1237
26. Ventura AC, Bohnke M, Mojon DS (2001) Central corneal thickness measurements in patients with normal tension glaucoma, primary open angle glaucoma, pseudoexfoliation glaucoma, or ocular hypertension. Br J Ophthalmol 85(7):792–795
27. Medeiros FA, Sample PA, Zangwill LM, Bowd C, Aihara M, Weinreb RN (2003) Corneal thickness as a risk factor for visual field loss in patients with preperimetric glaucomatous optic neuropathy. Am J Ophthalmol 136(5):805–813
28. Wells AP, Garway-Heath DF, Poostchi A, Wong T, Chan KC, Sachdev N (2008) Corneal hysteresis but not corneal thickness correlates with optic nerve surface compliance in glaucoma patients. Invest Ophthalmol Vis Sci 49(8):3262–3268
29. Bolivar G, Sanchez-Barahona C, Teus M, Castejon MA, Paz Moreno-Arrones J, Gutierrez-Ortiz C, Mikropoulos DG (2017) Effect of topical prostaglandin analogues on corneal hysteresis: author's reply. Acta Ophthalmol 95(2):e152. https://doi.org/10.1111/aos.12791