Corneal biomechanics and intraocular pressure changes after uneventful phacoemulsification surgery
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Background
Biomechanics of the cornea is represented by corneal hysteresis (CH), which is defined as the viscous damping owing to viscoelastic resistance of the cornea to deformation.

Aim
Assessing intraocular pressure (IOP) and corneal biomechanics alterations after phacoemulsification.

Patients and methods
Thirty eyes were uneventfully operated on using phacoemulsification. CH, corneal resistant factor (CRF), corneal compensated intraocular pressure (IOPcc), and Goldmann correlated intraocular pressure (IOPg) values were recorded by ocular response analyzer (ORA). Central corneal thickness (CCT) was evaluated using pentacam preoperatively and postoperatively after 1 day, 1 week, and 1 month.

Results
Patients comprised 22 males and 8 females, with a mean age of 63.8±6.8 years. Preoperative mean CCT was 532.4±39.2 μm, mean CH was 9.4±1.7 mmHg, mean CRF was 9.5±2.0 mmHg, mean IOPg was 15.4±3.9 mmHg, and mean IOPcc was 17.1±3.6 mmHg. CCT significantly increased after 1 day and significantly decreased after 1 week, and decreased again after 1 month but remained significantly higher. CH decreased significantly after 1 day and increased to the preoperative values after 1 week and 1 month. CRF significantly increased after 1 day and then decreased significantly after 1 week and remained significantly lower. Both IOPcc and IOPg insignificantly elevated after 1 day, then significantly declined after 1 week, and insignificantly increased after 1 month but was still lower than the preoperative value. CH, CRF, and CCT correlated significantly except for 1 day after surgery.

Conclusion
Cataract surgery causes corneal structural alterations, changing biomechanical properties and IOP initially. CCT contributes in these parameters, as there is a correlation with CH and CRF.

Keywords:
biomechanics, cataract, intraocular pressure, ocular response analyzer, phacoemulsification

Introduction
The ability to recover vision affection owing to cataract has been improved by the enhancement of latest phacoemulsification techniques. Cataract surgery is one of the most commonly performed ophthalmic surgical procedure of any kind, and there is an accelerating pace in using phacoemulsification surgery worldwide [1].

It is possible that the postoperative biomechanical properties might be compromised with time, which may play roles in the refractive outcomes and in evaluation of intraocular pressure (IOP), after surgery [2].

Cataract surgery causes corneal structural alterations, changing biomechanical properties and IOP initially. CCT contributes in these parameters, as there is a correlation with CH and CRF.

Keywords:
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measurements: corneal hysteresis (CH), corneal resistant factor (CRF), Goldmann correlated intraocular pressure (IOPg), and corneal compensated intraocular pressure (IOPcc). CH is the difference between two pressure values, representing corneal viscoelastic damping, whereas CRF is an indicator of the whole corneal resistance. IOPg is the mean of first ‘P1’ and second ‘P2’ applanation pressures, and IOPcc is a pressure value which eliminates the effects of corneal properties [5].

Our aim was to assess corneal biomechanics and IOP changes after phacoemulsification and implantation of intraocular lens.

Patients and methods
This study was a prospective and randomized clinical study, including 30 eyes of 30 nondiabetic patients presented with senile cataract. All patients were recruited and evaluated at Research Institute of Ophthalmology. This study was performed from June 2019 to August 2019.

This study was approved by the Ethics Committee of Faculty of Medicine Al-Azhar University for Girls. An official approval for implementation of the study was obtained from Research Institute of Ophthalmology, and an informed verbal approval was obtained from all the patients after explaining to them the aim of the study and before involvement in the study.

Exclusion criteria included patients refusing to participate in this study, patients with previous ocular surgery, patients with ocular pathology, patients with ocular trauma, patients with corneal scarring, patients with elevated IOP, patients with any systemic disease that may affect corneal parameters, and any patient experiencing intraoperative or postoperative complications.

A history was taken from all patients including personal data (name, age, and sex), past medical history and medications used, and detailed ophthalmological history. Ocular examination was done by eight-point eye examination, including visual acuity, extraocular motility and alignment, IOP measurement, confrontation visual field, external examination, slit lamp examination, and fundoscopic examination.

All patient had Pentacam (Allegro Oculyzer; Allegro, Germany) done to obtain CCT and ORA (Reichert Ophthalmic Instruments Inc., Buffalo, New York, USA) to evaluate corneal biomechanics parameters (Figs 1 and 2).

All surgeries were performed by a single surgeon from Research Institute of Ophthalmology. The same routine phaco chop technique was used in all patients, with a 2.4 mm clear corneal incision and implantation of foldable sensor PCIOL. Same phaco machine (Infinity Vision System; Alcon Laboratories, Germany) was used in all patients, with conventional linear ultrasound pulse mode (60 pulse/se), maximum power of 70%, vacuum limit of 350 mmHg, and aspiration flow rate of 35 ml/min.

Ocular examinations by the eight-point eye examination, Pentacam, and ORA were repeated post-operatively (first day-first week-first month).
Statistical analysis
Statistical analysis was done using the SPSS statistical software package (version 21; SPSS Inc., Armonk, New York, USA) of Windows. Continuous variables were stated in form of mean and SD and as percentage if the variables were categorical. The normality of all data samples was first confirmed using Kolmogorov–Smirnov test. Repeated measures analysis of variance and Bonferroni test were used to measure the differences between preoperative and postoperative values of CCT and corneal biomechanics parameters in order to evaluate the time sequence of their changes after cataract surgery. The Pearson correlation coefficient was calculated to judge the correlations between CCT, CH, CRF, IOPg, and IOPcc. All tests were two sided, and statistically significant difference was set at \( P \) value 0.05 or less.

Results
A total of 30 eyes of 30 patients with senile cataract who had uneventful cataract surgery were included in this prospective clinical study. A total of eight (27%) patients were female and 22 (73%) patients were male, with a mean age of 63.8±6.8 years (range: 50–78 years), including 19 (63%) right eyes and 11 (37%) left eyes (Table 1, Figs 3 and 4).

The pre-operative mean IOP measured with Goldmann applanation tonometer was 17.1±2.5 mmHg, mean CCT was 532.4±39.2\( \mu \)m, mean of CH was 9.4±1.7 mmHg, mean CRF was 9.5±2.0 mmHg, mean IOPg was 15.4±3.9 mmHg, and mean IOPcc was 17.1±3.6 mmHg (Table 2).

Statistically significant changes occurred after cataract surgery (first day–first week–first month) postoperatively in mean values of CCT, CH, CRF, IOPg, and IOPcc (Table 3).

Preoperatively, there was a positive correlation between CCT and CH and CRF. CH positively correlated with CRF, whereas CH and IOPcc correlated negatively, with no correlation with IOPg. CRF positive correlated with IOPg but not with IOPcc (Table 4, Fig. 5).

After 1 day postoperatively, CH negatively strongly correlated with IOPg and IOPcc, whereas CRF positively strongly correlated with both of them (Table 5 and Fig. 6).

After 1 week, the correlations of the corneal biomechanics parameters were back to the preoperative state, as CCT correlated positively with CH and CRF, CH and IOPcc correlated negatively, whereas CRF and IOPg correlated positively (Table 6, Fig. 7).

| Table 1 Distribution of samples (eyes) according to participant characteristics |
|------------------------------|--------|
| Sex | n (%) |
| Female | 8 (27) |
| Male | 22 (73) |
| Age | |
| Mean±SD | 63.8±6.8 |
| Range | 50–78 |
| Affected eye | |
| OD | 19 (63) |
| OS | 11 (37) |

OD, right eye; OS, left eye.
Discussion
Cataract is a disease occurring commonly in elderly populations. However, age-related cataracts can develop in the fourth and fifth decades of life. Cataracts that occur during middle age are small and do not impair vision, whereas most cataracts that impair vision occur after the age of 60 years [4].

Ultrasound phacoemulsification is today a method of choice to treat visual loss owing to cataract. Advantages of phacoemulsification are shorter healing times, and even better postoperative outcomes are associated with a shorter duration of surgery, less damage, and safety of the surgery [7].

Phacoemulsification surgery does not only recover affected visual acuity owing to cataract, but it could also lower IOP transiently in normal subjects and patients with glaucoma [3].

The amount of IOP decline after phacoemulsification varies from 1 to 6.5 mmHg up to 12 months after surgery. Higher preoperative IOPs have been related to greater IOP decreases, and eyes with narrow angles experience greater fall in IOP compared with those with open angles [8].

Many studies were done to learn the contributing biophysical factors to rigidity and elasticity of the corneal shape in normal patients, after cataract surgery, limbal relaxing incision after simultaneous phacoemulsification, LASIK, keratoconus, glaucoma, and FCD [9].

This study was done at Research Institute of Ophthalmology. The study sample included 30 eyes of 30 nondiabetic patients with no previous ocular or medical history that could cause alteration to their corneal biomechanics.

Several studies reported a varied range of normal values of corneal biomechanics parameters in different populations and have settled that there are ethnic, geographic and genetic variances in ORA measurements [10].

In this study, the preoperative mean value of CCT was 532.4±39.2 μm, mean value of CH was 9.4 ±1.7 mmHg, mean value of CRF was 9.5±2.0, IOPg was 15.4±3.9 mmHg, and that of IOPcc was 17.1±3.6 mmHg.

### Table 2 Preoperative parameters

| Parameter | Mean±SD | Range |
|-----------|---------|-------|
| IOP       | 17.1±2.5 | 12.0–21.0 |
| CCT (μm)  | 532.4±39.2 | 472.0–613.0 |
| CH (mmHg) | 9.4±1.7 | 6.1–12.3 |
| CRF (mmHg) | 9.5±2.0 | 6.2–14.0 |
| IOPg (mmHg) | 15.4±3.9 | 6.4–22.8 |
| IOPcc (mmHg) | 17.1±3.6 | 9.3–22.1 |

CCT, central corneal thickness; CH, corneal hysteresis; CRF, corneal resistant factor; IOP, intraocular pressure; IOPcc, corneal compensated intraocular pressure; IOPg, Goldmann correlated intraocular pressure.

### Table 3 Changes in biomechanical parameters of the cornea after cataract surgery

| Parameter | Preoperative | 1 Day | 1 Week | 1 Month | F     | P value |
|-----------|--------------|-------|--------|---------|-------|---------|
| CCT (μm)  | 532.4±39.2   | 586.0±62.1 | 571.3±68.0 | 557.0±54.0 | 13.58 | <0.001 |
| CH (mmHg) | 9.4±1.7      | 8.5±2.6   | 9.2±1.8  | 8.9±1.4  | 3.26  | 0.047   |
| CRF (mmHg) | 9.5±2.0    | 9.7±2.7   | 8.5±1.7  | 8.6±1.8  | 6.05  | 0.006   |
| IOPg (mmHg) | 15.4±3.9  | 18.8±12.3 | 12.6±3.1  | 13.5±3.8  | 5.89  | 0.016   |
| IOPcc (mmHg) | 17.1±3.6 | 20.9±12.6 | 14.7±3.3  | 15.9±3.3  | 5.496 | 0.020   |

CCT, central corneal thickness; CH, corneal hysteresis; CRF, corneal resistant factor; IOPcc, corneal compensated intraocular pressure; IOPg, Goldmann correlated intraocular pressure.

### Table 4 Correlations between corneal biomechanics parameters before cataract surgery

| Parameters | CCT | CH | CRF | IOPcc |
|------------|-----|----|-----|-------|
| r (P)      | r (P) | r (P) | r (P) |
| CCT       |   |   |     |       |
| CH        | 0.509 (0.004)                       |     |       |
| CRF       | 0.564 (0.001)                       | 0.814 (<0.001) |     |
| IOPg      | 0.319 (0.085)                       | 0.124 (0.513) | 0.677 (<0.001) |
| IOPcc     | 0.032 (0.868)                       | −0.397 (0.029) | 0.209 (0.267) | 0.861 (<0.001) |

CCT, central corneal thickness; CH, corneal hysteresis; CRF, corneal resistant factor; IOPcc, corneal compensated intraocular pressure; IOPg, Goldmann correlated intraocular pressure.
In Egypt, data were collected from 195 Egyptian participants with ages ranging from 19 to 71 years. The mean CH value was 10.25±0.12 mmHg, and the mean CRF was 10.25±0.15 mmHg. The CH and CRF values were lower in the oldest age group (40–71 years) [11].

In the study by Ostadimoghaddam et al. [12] on 30 normal Iranian subjects with an age range of 20–30 years, it was found that the CH mean value was 10.07±1.5 mmHg, CRF mean value was 9.67±1.5 mmHg, and IOPg mean value was 13.99±3.38 mmHg.

However, in Saudi individuals, a study on 215 normal subjects with mean age of (33.6±11.75) years, the mean value of CH was 11.16±2.11, whereas that of CRF was 11.07±2.31 [13].
Preoperative CCT mean value was 532.4±39.2 μm, which significantly increased after 1 day postoperatively to 586.0±62.1 μm and significantly decreased again after 1 week postoperatively to 571.3±68 μm, and the reduction continued to the end of the first month postoperatively to 557.0±54.0 μm, but was still significantly higher than the baseline mean value.

Hager et al. [14] agreed with these results, as CCT increased significantly after 1 day postoperatively.

Kandarakis et al. [15] also agreed with this study, as on the first postoperative day, they found a significant increase in CCT, which remained 1 week after surgery.

Table 6 Correlations between corneal biomechanics parameters 1 week after cataract surgery

| Parameters, 1 week (postoperative) | CCT | CH | CRF | IOPg |
|-----------------------------------|-----|----|-----|------|
|                                   | r (P) | r (P) | r (P) | r (P) |
| CCT                              | 0.433 (0.017)* | 0.365 (0.047)* | 0.841 (<0.001)** | 0.021 (0.912) |
| CH                               | -0.021 (0.912) | -0.037 (0.847) | 0.508 (0.004)** | -0.266 (0.155) |
| CRF                              | -0.597 (<0.001)** | -0.070 (0.713) | 0.823 (<0.001)** |
| IOPg                             | -0.037 (0.847) | 0.508 (0.004)** | 0.823 (<0.001)** |

CCT, central corneal thickness; CH, corneal hysteresis; CRF, corneal resistant factor; IOPcc, corneal compensated intraocular pressure; IOPg, Goldmann correlated intraocular pressure.
Kamiya et al. [2] disagreed, as CCT mean value increased briefly 1 day after surgery but soon recovered to the preoperative levels and became stable thereafter.

Kucumen et al. [16] also disagreed with this study, stating that the mean CCT did not change significantly from preoperatively to the end of the first postoperative month.

Preoperative CH mean value decreased significantly after 1 day postoperatively from 9.4±1.7 mmHg to 8.5±2.6 mmHg, increasing again to the preoperative level after 1 week to 9.2±1.8 mmHg and 1 month to 8.9±1.4 mmHg.

Hager et al. [14] agreed in their study that CH decreased significantly after 1 day postoperatively.

Similarly, in the study by Kamiya et al. [2], CH mean value decreased briefly 1 day after surgery but soon recovered to the preoperative levels and became stable thereafter.

The study by Kandarakis et al. [15] also came in agreement with this result, as CH demonstrated a significant decrease on the 1st post-operative day, with an ascending course.

Cankaya et al. [17] agreed as well with the present study, stating that CH values were significantly lower on the first day, but in contrary to this study, the reduction in comparison with the preoperative measurements remained significant after the first week and month.

Meanwhile, Kucumen et al. [16] agreed also that the mean CH decreased from before surgery with a gradual increase to preoperative values after 1 and 3 months.

Preoperative CRF mean value was 9.5±2.0 mmHg, which increased slightly after 1 day follow-up to 9.7
±2.7 mmHg, with no significance, and then decreased significantly to 8.5±1.7 mmHg after 1 week postoperatively and increased again to 8.6±1.8 mmHg after 1 month postoperatively, but remained significantly lower than the preoperative mean value.

Cankaya et al. [17] agreed with this study, as CRF values were significantly lower 1 day, 1 week, and 1 month after the surgery.

Kucumen et al. [16] also agreed that the mean CRF decreased at 1 week, except in their study the mean CRF increased to preoperative values after 1 and 3 months.

On the contrary, Kamiya et al. [2] disagreed stating that the mean CRF decreased briefly at 1 day after surgery and soon recovered to the preoperative levels and became stable thereafter.

Preoperative IOPg mean value was 15.4±3.9 mmHg. It firstly insignificantly elevated after 1 day postoperatively to 18.8±12.3 mmHg, followed by a statistically significant decline after 1 week postoperatively to 12.6±3.1 mmHg, and then a slight increase after 1 month postoperatively to 13.5±3.8 mmHg; however, it was still reduced compared with preoperative value.

IOPcc mean value changed in the same manner as IOPg; preoperatively, it was 17.1±3.6 mmHg, and it initially insignificantly elevated after 1 day postoperatively to 20.9±12.6 mmHg, then declined after 1 week postoperatively to 14.7±3.3 mmHg and this reduction was statistically significant mmHg, followed by insignificant increase after 1 month post-operatively to 15.9±3.3 mmHg, but it was still lower than the preoperative value.

Although the rise of IOP in our study 1 day postoperatively was statistically insignificant, Hager et al. [14] disagreed that the IOP values as measured by the ORA increased significantly 1 day after the surgery.

Cankaya et al. [17] also disagreed with our results, as IOPg and IOPcc values were significantly higher on the first day after the surgery and significantly lower in the first month after the surgery when compared with the preoperative measurements; however, this alteration tends to increase toward preoperative values.

Kamiya et al. [2] disagreed with this study as no significant IOP rise occurred at any time during the postoperative period of their study (1 week, 1 month, and 3 months).

Kucumen et al. [16] disagreed also as the change in the mean IOPcc in their study from preoperatively was not statistically significant after 1 week or 1 month. However, the mean IOPcc was significantly lower after 3 months than preoperatively, and the change in the mean IOPg was insignificant any time point postoperatively compared with the preoperative value.

Preoperatively, there was a positive correlation between CCT and CH and CRF, and CH negatively correlated with IOPcc. These correlations were disturbed after 1 day postoperatively but were restored after the first week. After 1 day postoperatively, CH negatively strongly correlated with IOPg and IOPcc, whereas CRF positively strongly correlated with both of them. After 1-week follow-up, the correlations between corneal biomechanics parameters were back to the preoperative levels.

Preoperatively, there was a positive correlation between CCT and CH and CRF, and CH negatively correlated with IOPcc. These correlations were disturbed after 1 day postoperatively but were restored after the first week. After 1 day postoperatively, CH negatively strongly correlated with IOPg and IOPcc, whereas CRF positively strongly correlated with both of them. After 1-week follow-up, the correlations between corneal biomechanics parameters were back to the preoperative levels.

These results could be explained by the transient corneal edema induced by the surgical stress to the corneal endothelium, reducing corneal damping capacity, which is reversible and normalizes afterward [2].

Several causes could be attributed to the increase of IOP in the initial period after phacoemulsification surgery like lens cortex residues, residual viscoelastic substances, inflammation, and reduced CH [17].

IOP restores the cornea to its original position acting like a sling shot, so CRF increases and CH decreases with rising IOP, showing that resistance against corneal deformation is elevated in eyes with increased IOP values [18].

Several explanations have been proposed to interpret the reduction in IOP after cataract surgery, including a reduction in aqueous production followed by ciliary body stimulation and an increase in outflow of aqueous owing to widening of the angle of anterior chamber [19].

Biologic mechanisms for postoperative IOP reduction have also been proposed, that endogenous
prostaglandin F2 released from the low-grade inflammation after phacoemulsification increased aqueous outflow [20].

Conclusion

In conclusion, corneal structural alterations after phacoemulsification lead to changes of corneal biomechanical parameters and in IOP in the early period after standard cataract surgery; however, this change tends to increase toward pre-operative values.

Significant correlations were also found between CH, CRF, and CCT except for one day after surgery, suggestive of that CCT contributes in these parameters even in postcataract eyes after resolving of any temporary edema.

Evaluation of IOP in the days and weeks following cataract surgery should consider these alterations of corneal biomechanics and CCT.

This study limitations were that we used the pentacam to obtain the CCT, owing to the lack of CCT set with the ORA. The CCT values might be slight dissimilar from other studies. Moreover, the differences in surgical procedures, race, and age across studies may explain contradiction in results. In addition, measuring these parameters at 1 day postoperatively was not very dependable owing to the existence of superficial punctate keratitis, inflammatory reactions, or inability to open the eyes.

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Conflicts of interest

There are no conflicts of interest.

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