Corneal Biomechanical Response Alteration After Scleral Buckling Surgery for Rhegmatogenous Retinal Detachment

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• PURPOSE: To compare the corneal biomechanics of eyes that underwent scleral buckle (SB) for rhegmatogenous retinal detachment (RRD) with those of fellow eyes (fellow eyes) and to further investigate the effects of SB on intraocular pressure (IOP) values.

• DESIGN: Retrospective, fellow-eye matched cohort study.

• METHODS: A total of 18 consecutive patients (11 males and 7 females) treated with SB for RRD in 1 eye were enrolled. Goldmann applanation tonometry was used to measure IOP. Biomechanical properties of the cornea were investigated by using the Ocular Response Analyzer (ORA) (Reichert Instruments) for the calculation of corneal resistant factor (CRF), corneal hysteresis, Goldmann-correlated IOP, and corneal-compensated IOP. Customized software was used for analysis of the ORA infrared and pressure signals, and a significance threshold was set to a *P* value of .05.

• RESULTS: Operated eyes (OEs) showed significantly lower values of corneal hysteresis and CRF than fellow eyes (9.0 ± 1.8 vs 10.1 ± 1.8 mm Hg, respectively; *P* < .001; 10.0 ± 2.2 vs 10.9 ± 2.2 mm Hg; *P* < .001). GAT was significantly lower than corneal-compensated IOP in OEs (18.1 ± 4.9 vs 19.8 ± 4.8 mm Hg, respectively; *P* = .022) but not in fellow eyes. The second applanation event (A2) took place earlier in time, and the cornea was moving faster during A2 in the OEs than in the fellow eyes.

• CONCLUSIONS: SB for the treatment of RRD affects corneal biomechanical response, likely due to a less compliant sclera that limits corneal motion and reduces energy dissipation, reflected in a lower corneal hysteresis. This has potentially meaningful clinical implications as the accuracy of the measurement of IOP values may be affected in these eyes. **(Am J Ophthalmol 2020;217: 49–54.**

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RHEGMATOGENOUS RETINAL DETACHMENT (RRD) IS a sight-threatening disease characterized by the separation of the inner neurosensory retina from the outer retinal pigment epithelium, secondary to 1 or more retinal breaks.[1] Although there is an increasingly widespread use of pars plana vitrectomy, scleral buckling (SB) still represents an effective procedure for the treatment of RRD, particularly in young phakic patients.[2] SB is an episcleral procedure that consists of the placement of an encircling element around the circumference of the eye in order to cause the reduction of transvitreal traction and the closure of the retinal break(s), thus allowing retinal reattachment.[3] The mechanical force exerted by the scleral buckle causes well-known alterations of several ocular parameters such as an increased axial length (AL), a decreased anterior chamber depth (ACD), and induced corneal astigmatism. All these changes typically result in postoperative refractive shift.[4–11] It is reasonable to hypothesize that SB could impact not only geometric adaptation but also a biomechanical response of the cornea and globe. Currently, corneal biomechanics can be assessed using either the Ocular Response Analyzer (ORA) (Reichert Instruments, Depew, New York) or the CorVis ST (Radan, Sanaa, Yemen). The former is a noncontact tonometer that provides the measurement of 2 parameters of corneal biomechanics: the corneal resistant factor (CRF), which reflects the maximum correlation with central corneal thickness, and the corneal hysteresis, which measures the viscoelastic response of the cornea.[12] The CorVis ST instrument is a device that uses an ultra-high-speed Scheimpflug camera to record dynamic deformation of the cornea, providing response indices.

In clinical practice, corneal biomechanical modifications could alter routine intraocular pressure (IOP) measurements, affecting glaucoma and ocular hypertension diagnosis and management.[13] The purpose of the present study was to compare corneal biomechanical responses of eyes that had undergone SB for RRD with those of fellow eyes and to further investigate the effect of SB on the accuracy of IOP measurements.

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TABLE. Biomechanical and Signal Analysis Parameters in Eyes Treated with SB for Rhegmatogenous Retinal Detachment and Fellow Eyes

Parameter	Operated Eyes	Fellow Eyes	P[a]
Mean ± SD CH, mm Hg	9.0 ± 1.8	10.1 ± 1.8	**<.001**
CRF, mm Hg	10.0 ± 2.2	10.9 ± 2.2	**<.001**
IOPcc, mm Hg	19.8 ± 4.8	18.4 ± 3.4	**.021**
P1, mm Hg	242.9 ± 39.2	242.4 ± 30.8	.910
P2, mm Hg	171.8 ± 36.30	166.3 ± 26.4	.185
fwhm1, s	12.8 ± 2.8	12.5 ± 3.7	.815
fwhm2, s	7.7 ± 3.0	9.9 ± 3.2	**.021**
Time 1, s	8.2 ± 0.6	8.2 ± 0.5	.773
Time 2, s	18.7 ± 0.2	18.8 ± 0.2	**.005**
Peak 1, mm Hg	785.2 ± 151.1	823.0 ± 89.2	.3
Peak 2, mm Hg	655.6 ± 160.6	667.1 ± 146.8	.795
Pmax, mm Hg	453.6 ± 50.6	457.3 ± 42.6	.490
tPmax, s	12.8 ± 0.5	12.8 ± 0.4	.637

CRF = corneal resistance factor; fwhm = full-width-half maximum; IOPcc = corneal-compensated intraocular pressure; P = applanation pressures; SB = scleral buckling; VCH = corneal hysteresis.

Values in bold represent significant P values (<.05).

[a]Student t-test.

SUBJECTS AND METHODS

• **STUDY DESIGN AND PATIENTS:** This study included patients treated for RRD at a single tertiary referral center (S. Orsola-Malpighi University Hospital, Bologna, Italy) between January 2016 and May 2019. The study was performed in accordance with the principles of the Declaration of Helsinki and was approved by the local Institutional Review Board. Written informed consent was obtained from all subjects. Consecutive patients older than 50 years treated with SB for RRD in 1 eye were screened for enrollment. SB was performed by the same surgeon (P.G.T.) in phakic patients with RRD due to single retinal break or small confluent multiple breaks without significant lens opacification. Eyes that had SB were included as the study eye, and the fellow eyes served as controls. Exclusion criteria were any previous ocular surgery in both eyes, keratoconus, corneal dystrophy, diabetes, wearing contact lenses, tear film instability, use of glaucoma medications, keratometry <40 diopters (D) and > 46 D, spherical equivalent ≥7 D, anisometropia ≥1.5 D, and any ocular infection within 3 months prior to enrollment.

Biometric and keratometric data were measured using the Lenstar optical biometer (Haag-Streit, Köniz, Switzerland), which is an optical low-coherence reflectometry biometer that uses dual-zone keratometry with 32 marker points to provide measurement of the astigmatism and axis, equivalent to gold standard manual keratometry. White-to-white lens thickness, AL, and ACD were analyzed in all eyes. Goldmann applanation tonometry was used to measure IOP.

• **EPISCLERAL SURGERY TECHNIQUE:** A 360-degree limbal conjunctival peritomy incision was made, and traction sutures were placed beneath the insertions of the exposed rectus muscles to facilitate positioning the globe. A 2.5-mm wide silicone band was passed around the circumference of the globe and beneath the rectus muscles at a distance of 14 mm from the limbus. The band was anchored with single, interrupted suture with bites parallel to the limbus placed in the center of each quadrant. The ends of the band were then joined in the opposite quadrant of the retinal break(s) with a silicone sleeve. In all cases, a drainage procedure was performed by using a sclerotomy just below the retinal break(s) and then sutured by a single scleral stitch. Ab externo cryotherapy was done in the retinal break(s) location. In order to increase the buckling effect, an adjunctive biconvex silicone 9-mm-wide element was placed beneath the band above the retinal break(s). The ends of the encircling silicone band were then pulled until the desired buckle effect was reached. A paracentesis was done, and an sulfur hexafluoride injection was performed 4-mm posterior to the limbus.

• **ORA MEASUREMENTS:** The ORA measures 2 applanation pressure points during a dynamic bidirectional applanation process generated by a precisely metered air pulse. The first applanation pressure event (A1) occurs as the air puff pushes the cornea inward by applanation to a concave shape during the loading phase. The second applanation pressure event (A2) occurs as the cornea returns from the concave state during the unloading or recovery phase by outward applanation to its baseline convex state. The differences between these 2 applanation pressures (P1

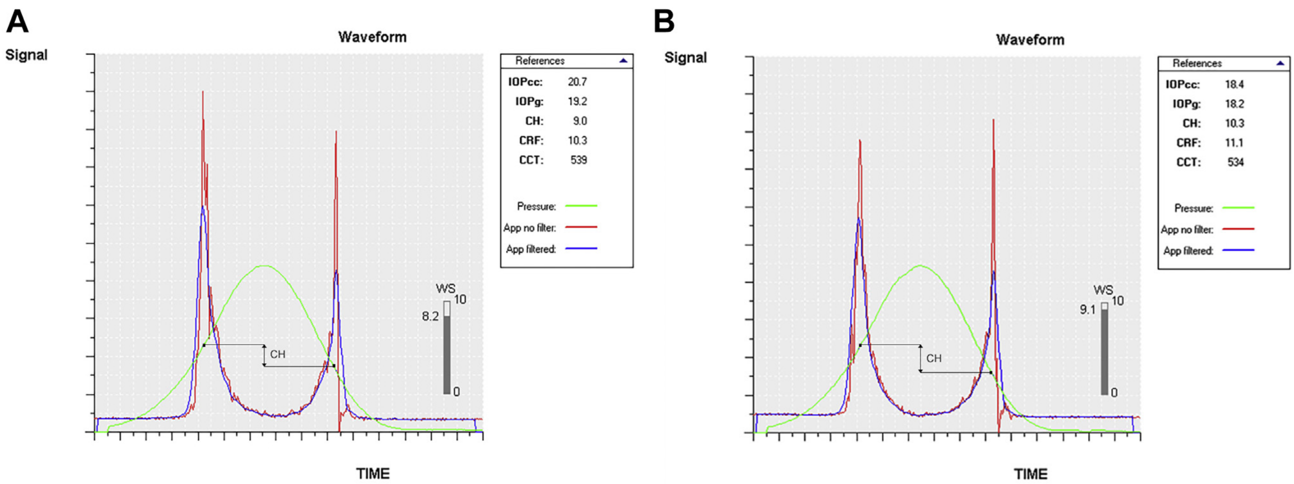

FIGURE 1. Ocular response analyzer signals in a patient who underwent scleral buckling surgery. The operated eye (A) showed lower values of corneal hysteresis and corneal resistant factor and higher values of corneal-compensated IOP than the contralateral healthy eye (B). IOP = intraocular pressure.

and P2, respectively) are defined as the corneal hysteresis, whereas the CRF is calculated as a linear function of the 2 values. The average of both pressures provides Goldmann-correlated IOP, whereas the corneal-compensated IOP is the empirically determined IOP value that compensates for corneal biomechanical effects.[12,14]

All ORA examinations were performed at least 4 months after the surgery by 2 operators (M.R. and F.B.), both masked to the subject's characteristics. Before each examination, central corneal thickness values obtained with an ultrasonic pachymeter (Dicon P55, Paradigm Medical Industries, Salt Lake City, Utah) were inserted in the software. Because of the potential confounding effect of diurnal IOP variations, all measurements were obtained between 10 AM and 12 PM. All ORA measurements had a waveform score >7.0.[15] The average values of 4 measurements with desirable curves were recorded for statistical analysis.

Customized software was used to extract parameters from both the infrared and air pressure signals exported by the ORA. P1 and P2 represent the first and second applanation pressures, respectively. Full-width-half maximum 1 and 2 (fwhm1 and fwhm2) represent how long it takes the cornea to move through applanation in seconds. A smaller value means the cornea has a greater velocity. Time 1 and Time 2 represent the timing of A1 and A2. Pmax is the maximum magnitude of the air pressure pulse, and tPmax is the timing of this value. Note that the ORA produces an air puff magnitude that is a function of the timing of A1, such that an earlier A1 produces a lower Pmax. A subject with a lower IOP will thus receive a lower-magnitude air puff. Peak 1 and Peak 2 represent the maximum values of the infrared signal during A1 and A2 and represent the stiffness of the corneal response, such that a high peak represents a stiffer cornea.[12]

• **STATISTICAL ANALYSIS:** SPSS software (SPSS Inc., Chicago, Illinois) was used for data analysis, and SAS software (Cary, North Carolina) was used to analyze the parameters produced by the customized software. Values are expressed as mean ± SD. Continuous variables between operated eyes and fellow eyes were compared using Student *t*-test. A *P* value <.05 was considered statistically significant.

RESULTS

THIRTY PATIENTS TREATED WITH SB FOR RRD WERE initially identified. Of these, 12 patients did not satisfy the inclusion and exclusion criteria and were excluded from the final analysis. In particular, 2 patients presented with high myopia, 8 had previous eye surgery, 1 used topical antiglaucoma drugs, and 1 was lost to follow-up. Finally, 18 patients were enrolled in the study. Mean age was 61.6 ± 6.4 years; 11 patients (61.1%) were males, and 7 (39.9%) were females.

Operated eyes were significantly longer than fellow eyes (25.79 ± 1.49 mm vs 25.31 ± 1.63 mm, respectively; *P* = .004), whereas no significant differences were found for K1 and K2 values between the eyes (42.3 ± 1.1 D vs 42.5 ± 1.3 D, respectively; *P* = .072; and 43.2 ± 1.2 vs 43.4 ± 1.2, respectively; *P* = .072). In addition, central corneal thickness, Goldmann applanation tonometry, ACD, lens thickness, and white-to-white did not significantly differ among eyes (551.1 ± 24.6 vs 518.3 ± 134.7 μm, respectively; *P* = .292; 18.1 ± 4.9 vs 17.9 ± 3.9 mm Hg, respectively; *P* = .868; and 3.09 ± 0.45 vs 3.15 ± 0.46 mm, respectively; *P* = .089; and 4.23 ± 0.21 vs 4.19 ± 0.26 mm, respectively;

$P = 0.257$; and 12.38 ± 0.54 vs 12.44 ± 0.54 mm, respectively; $P = .144$).

Corneal biomechanics and signal analysis parameters in operated eyes and fellow eyes are reported in the Table. In all patients, the waveform score was ≥7, with a mean value of 8.3 ± 0.9 in operated eyes and 8.1 ± 0.8 in fellow eyes ($P = .461$). Operated eyes showed significantly lower values of corneal hysteresis (all $P < .001$), whereas corneal-compensated IOP was significantly higher in operated eyes than in fellow eyes (Figure 1). In operated eyes, Goldmann applanation tonometry was significantly lower than corneal-compensated IOP (18.1 ± 4.9 vs 19.8 ± 4.8 mm Hg, respectively; $P = .022$) (Figure 2). Conversely, in fellow eyes, no significant differences between Goldmann applanation tonometry and corneal-compensated IOP were found (17.9 ± 3.9 vs 18.4 ± 3.4 mm Hg, respectively; $P = .389$).

Signal analysis showed significantly lower Time 2 ($P = .005$) and fwhm 2 ($P = .021$) in operated eyes than in fellow eyes. No other parameter was different between eyes.

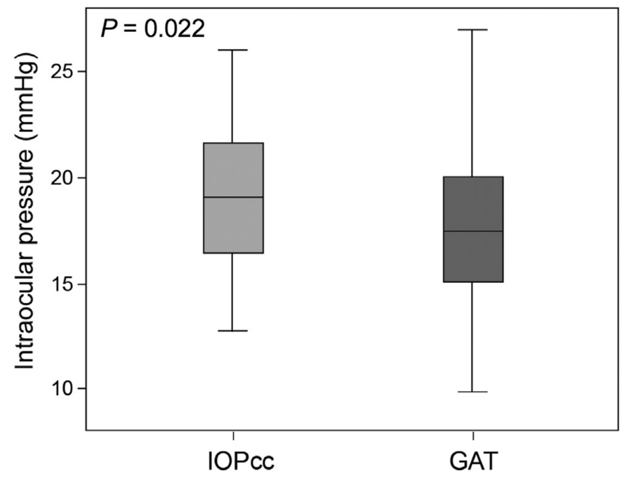

FIGURE 2. Box plot analysis of IOP measurements in operated eyes. Box plot analysis of Goldmann applanation tonometry and corneal-compensated IOP in eyes treated with scleral buckling for rhegmatogenous retinal detachment. Operated eyes showed significantly lower Goldmann applanation tonometry values than those in corneal-compensated IOP eyes. IOP = intraocular pressure.

DISCUSSION

IT IS WELL KNOWN THAT SB FOR RRD COULD MODIFY different anatomical structures of the eye globe, thus affecting refractive status.[3] Consistent with a previous study, the present results showed that encircling scleral buckle led to an increased AL in the absence of significant induced astigmatism.[2] Moreover, ACD reduction and lens thickness modifications could also occur after SB, contributing to the postoperative refractive change.[9,16–18] The presence of the encircling scleral buckle generates an annular tangential pressure that serves to stiffen the scleral response, thus limiting corneal deformation. The theory of a stiffened sclera limiting corneal deformation under an air puff has been demonstrated both theoretically and in human donor eyes.[19–21] Indeed, the ORA signal parameter analysis in the current study demonstrated that A2 is shifted to an earlier time point and the corneal is moving faster at A2 in the operated eyes, with smaller Time2 and fwhm2, respectively. Both these parameters occur in the unloading or recovery phase, likely the result of a less compliant sclera in the operated eyes. The lower corneal hysteresis means the eye is less able to dissipate energy with a less compliant sclera in the operated eyes. The lower corneal hysteresis means the eye is less able to dissipate energy with a less compliant sclera in the operated eyes. The type of scleral buckle (e.g., materials and shape) and the surgical technique are surgeon-related factors that may influence the whole biomechanical modification.[22]

The anatomical composition of the cornea is responsible for its viscoelastic nature and, thus, for its biomechanical deformation response. Elastic materials deform instantly and reversibly under external stress and do not dissipate energy under mechanical stress; the deformation is proportional to the force applied, and it is fully recovered upon unloading, following the same path as during the loading phase. On the other hand, losing energy through a loading cycle, viscous materials do not necessarily regain their original shape when the force is removed, and in viscoelastic materials, the unloading pathway is different than the loading pathway, demonstrating a lag in response. The difference in pathways is characterized by the corneal hysteresis, with P2 less than P1. However, biomechanical response of the cornea under an air puff load could be influenced from both alteration of its biological constituent elements (ectasia, dry eye), structural modification (refractive surgery, stiffness of the tissue),[23–25] or by a change in the compliance of the sclera, either stiffer or softer.[19–21]

Previous studies have identified central corneal thickness as an independent risk factor for development and progression of glaucoma, underlining the existing relationship between IOP measurements and cornea.[26–29] It has also been suggested that corneal biomechanics have a greater impact on IOP estimation than central corneal thickness.[13,24] Moreover, IOP and corneal biomechanics have mutual influence as both the cornea and the sclera exhibit stiffer behavior as IOP increases.[23] In clinical practice, routine IOP measurement is still performed by mechanical methods, but most nomograms do not take into account corneal biomechanical modification.[13,30,31] In the present study, Goldmann applanation tonometry values were significantly lower than corneal-compensated

IOP values in operated eyes. It is known that corneal-compensated IOP was empirically developed and has been shown to provide a more accurate estimation of IOP under conditions of a more compliant cornea, such as after refractive surgery.[32] However, it has not been evaluated under conditions of a less compliant cornea or sclera. The current study indicates that it is likely that corneal-compensated IOP is overestimating IOP under the condition of a less compliant sclera in operated eyes, which may limit corneal deformation. Goldmann applanation tonometry has minimal corneal displacement, only to applanation. However, an air puff induces a concave state of the cornea, which would be more influenced by a less compliant sclera. Hence, IOP values measured with conventional tools may affect the proper diagnosis and follow-up of glaucoma/ocular hypertension in these eyes. Furthermore, on one hand, it has been demonstrated that eyes affected by primary open angle glaucoma are at higher risk to develop RRD. On the other hand, the incidence of primary open angle glaucoma in eyes treated for a previous RRD is 4 to 12 times higher than in healthy eyes.[33,34] Therefore, given these epidemiological data, the present results suggest that IOP must be carefully evaluated in this kind of patients, taking into account the iatrogenic changes affecting not only the cornea but also the sclera in its influence on the deformation response.

A recent study validated a new algorithm to overcome IOP measurement systematic error in patients with altered corneal biomechanics related to soft cornea with the CorVis ST instrument.[35] However, it is not known how this algorithm will perform with an altered sclera. Therefore, it would be desirable to develop new tools able to adjust the IOP measurements in patients who also present with a modified scleral response, including those who have undergone SB.

To the best of the present authors' knowledge, this is the first clinical study that showed the potential influence of scleral properties on IOP measurements. The retrospective nature represents the main limitation of this study because it hampered the evaluation of corneal-compensated IOP and Goldmann applanation tonometry before and after SB in order to detect their postoperative changes and their association with corneal biomechanics. Another limitation is the small sample size that did not allow for stratification of patients according to anatomical and clinical characteristics (e.g., IOP and AL). However, because several factors could influence corneal biomechanical assessment, a significant number of SB patients did not satisfy the study criteria and were excluded from the final analysis.[36,37]

Future prospective clinical studies are mandatory to elucidate corneal and scleral biomechanical modification and the clinical implications in RRD patients treated with SB.

In conclusion, based on the present findings, SB for the treatment of RRD affects the corneal biomechanical deformation response by limiting corneal motion and reducing dissipation of energy through a stiffer sclera. In these patients, the conventional algorithm for glaucoma diagnosis and follow-up may not be appropriate. Future prospective clinical studies are mandatory to elucidate corneal and scleral biomechanical modification and the clinical implications in RRD patients treated with SB.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

LEONARDO TARONI: CONCEPTUALIZATION, METHODOLOGY, Writing - original draft, Validation. **Federico Bernabei:** Data curation, Methodology, Investigation, Writing - original draft. **Marco Pellegrini:** Data curation, Formal analysis. **Matilde Roda:** Data curation, Investigation. **Pier Giorgio Toschi:** Investigation. **Ashraf M. Mahmoud:** Software. **Costantino Schiavi:** Supervision, Project administration. **Giuseppe Giannaccare:** Writing - review & editing, Supervision. **Cynthia J. Roberts:** Writing - review & editing, Validation, Supervision.

ALL AUTHORS HAVE COMPLETED AND SUBMITTED THE ICMJE FORM FOR DISCLOSURE OF POTENTIAL CONFLICTS OF INTEREST and none were reported.

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