

# A Review on Different Tonometers for Intraocular Pressure Measurement After Photorefractive Keratectomy or Small Incision Lenticule Extraction

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**Abstract:** This paper aims to review different tonometers for intraocular pressure measurement in eyes after photorefractive keratectomy or small incision lenticule extraction. An Entrez Pubmed search was performed on July 19th, 2020. There were 32 eligible articles investigated in the use of tonometers or biomechanical properties of cornea in post photorefractive keratectomy eyes and 11 articles investigated in post small incision lenticule extraction eyes. Corvis ST and dynamic contour tonometry were found to be accurate for intraocular pressure measurement in post photorefractive keratectomy eyes. For post small incision lenticule extraction eyes, Corvis ST was found to be more accurate than other tonometers. Other tonometers such as Goldmann applanation tonometer, noncontact tonometry, Tonopen, ocular response analyzer can also be used in post photorefractive keratectomy or small incision lenticule extraction eyes in clinical practice; however, it is important for ophthalmologists to take note of the chances of discrepancies.

**Keywords:** tonometry, tonometer, glaucoma, photorefractive keratectomy, small incision lenticule extraction

## Introduction

Uncorrected refractive error is one of the major causes of visual impairment.<sup>1</sup> It is the second leading cause of worldwide blindness, caused by a mismatch between the axial length and optical power.<sup>2</sup> Spectacles, contact lens are most commonly used for the correction of refractive errors. Surgical treatment such as photorefractive keratectomy (PRK), laser assisted in situ keratomileusis (LASIK) and small incision lenticule extraction (SMILE) can be used for correction.<sup>3,4</sup>

Intraocular pressure (IOP) is one of the major risk factors for the development of glaucoma.<sup>5</sup> Therefore, it is important to measure the accurate intraocular pressure for screening or treatment of glaucoma. Studies have shown that in eyes after LASIK, PRK or SMILE may be difficult to obtain an accurate intraocular pressure.<sup>6-8</sup> With regard to the importance of measurement of accurate intraocular pressure, this review will mainly focus on the use of different tonometers in post PRK eyes or post SMILE eyes.

## Methodology

An Entrez Pubmed search was performed on July 19th, 2020, using the keywords “photorefractive keratectomy”, “PRK”, “SMILE”, “Small Incision lenticule Extraction”, “tonometry”, “tonometer”. The search was limited to human studies.

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A total of 93 articles were found using this search strategy. These articles were then manually curated by S. C. Chow to include those concerning the use of tonometers or biomechanical properties of cornea in post PRK or post SMILE eyes. Articles on animal research, in non-English language with no English abstract, review articles were excluded. Furthermore, studies concerning the use of tonometers in eyes performed with other surgery, not performed with PRK or SMILE, were excluded. The references of the curated articles were also checked to yield further relevant articles.

## Results

A total of 42 relevant articles were reviewed after manual curation. A total of 29 prospective studies and 13 retrospective studies were curated (Table 1). There were 32 articles investigated in the use of tonometers or biomechanical properties of cornea in post PRK eyes<sup>8–39</sup> and 11 articles investigated in the use of tonometers or biomechanical properties of cornea in post SMILE eyes.<sup>38,40–49</sup>

## Photorefractive Keratectomy

### Corneal Biomechanical Properties After PRK

After PRK, the central corneal thickness (CCT) will decrease significantly when compared with pre-surgery.<sup>11,12,31,36,37,39</sup> Study by Hamed Azzam has demonstrated a significant reduction of mean CCT by 75.5µm in post PRK eyes, when compared with the mean CCT before operation.<sup>12</sup> Munger showed that the measured change in CCT is found to be dependent on the amount of spherical correction during PRK in hyperopic eyes, but not on the cylindrical correction.<sup>31</sup> Six months after PRK, every diopter of applied spherical correction will result in  $5.0 \pm 0.9\mu\text{m}$  of corneal thinning. After 12 months of PRK,  $4.1 \pm 1\mu\text{m}$  per diopter of spherical correction was reported. After 18 months,  $2.5 \pm 1.2\mu\text{m}$  of CCT change per diopter was reported.<sup>31</sup> A significant reduction in keratometry of 5.56 D was also reported ( $P < 0.05$ ).<sup>12</sup> Another study by Zare demonstrated a significant reduction in corneal resistance factor and corneal hysteresis in post PRK eyes when compared with their preoperative baseline.<sup>37</sup> The study also compared the effect of PRK with or without adjunctive mitomycin C on postoperative IOP readings and corneal biomechanical properties, which were measured by Goldmann applanation tonometry and ocular response analyzer. The result showed that the use of mitomycin C intraoperatively in PRK did not significantly affect the postoperative IOP readings and corneal biomechanics.

### Goldmann Applanation Tonometer in Post PRK Eyes

Goldmann applanation tonometry is a device for measuring IOP. It is based on the Imbert Fick principle. The principle states that the pressure within a flexible elastic, thin and dry sphere equals to the force required to flatten its surface divided by the flattened area. The thickening of cornea will result in falsely high reading while its thinning will result in falsely low readings.<sup>9,13</sup> Eyes after performing PRK may affect the corneal thickness and hence, this will result in inaccurate results for IOP measurement using Goldmann applanation tonometer.

### Changes in Measured IOP After Operation

A total of 15 studies have demonstrated a significant reduction in the measured IOP by Goldmann applanation tonometer in post PRK eyes when compared with the baseline before operation.<sup>9,12,13,15,16,20,24,29–32,35,38,39,50</sup> Aristeidou demonstrated a fall in measured IOP value by Goldmann applanation tonometer before and after PRK. The preoperative measurement of IOP was  $12.9 \pm 2.8\text{ mmHg}$ , which was then reduced to  $11.4 \pm 2.9\text{ mmHg}$  after one month,  $11.1 \pm 2.3\text{ mmHg}$  after three months,  $11.1 \pm 2.5\text{ mmHg}$  after 6 months and  $11.0 \pm 2.8$  after 12 months.<sup>16</sup> A similar result was also demonstrated by Rosa, showing a significant underestimation in post PRK eyes by Goldmann applanation 1 month, 6 months and 12 months when compared to the baseline of preoperative eyes.<sup>32</sup>

### Relationship Between Changes of Measured IOP, CCT and Corneal Curvature

The significant reduction of IOP by Goldmann applanation tonometer in post PRK eyes was shown to be related to the CCT and corneal curvature.<sup>9,13,15,29,37,50</sup> Garzosi found a significant correlation between the percentage change in IOP by Goldmann applanation tonometer and the percentage change in keratometry and CCT.<sup>9</sup> In post PRK eyes, 4% reduction in CCT will not result in a change in IOP measured by Goldmann applanation tonometer. However, for eyes showing more than 4% drop in CCT, there will be a 1:1 reduction in Goldmann applanation tonometer measured IOP.<sup>9</sup> Another study by Sadigh illustrated that in every  $1\mu\text{m}$  of reduction in CCT, the measured IOP by Goldmann applanation tonometer will decrease by 0.03 mmHg by the univariate linear regression.<sup>13</sup> In the study by Munger, there was a significant correlation between the change in CCT and change in measured IOP by Goldmann applanation tonometer (decrease of 2.1mmHg per 100 microns of corneal thinning)( $P < 0.05$ ).<sup>29</sup>

Table 1 Summary of Selected Relevant Studies

Post PRK Eyes	Studies	Tonometry Used	Type of Study	Number of Eyes	Study Arms	Preoperative Eyes	Related Significant Findings
	Schallhorn et al 2015 <sup>8</sup>	Noncontact tonometer	Retrospective study	174,666	i. Post LASIK eyes (myopia) ii. Post LASIK eyes (hyperopia) iii. Post PRK eyes (myopia) iv. Post PRK eyes (hyperopia)	Manifest spherical equivalent: Myopic LASIK: $-3.22 \pm 1.88$ D Hyperopic LASIK: $+1.92 \pm 0.84$ D Myopic PRK: $-3.21 \pm 2.00$ D Hyperopic PRK: $+1.79 \pm 0.81$ D	In eyes performed with LASIK or PRK, the measured IOP by noncontact tonometer was found to be lower when compared to pre-operation. Myopic eyes has a greater decrease than eyes with hyperopia
	Garzoli et al 2001 <sup>9</sup>	i. Goldmann applanation tonometer ii. Noncontact tonometer iii. Tonopen	Prospective study	149	Post PRK eyes	Mean spherical equivalent error: $-6.07 \pm 3.58$ D	A significant reduction of measured IOP by noncontact tonometer was found when compared with pre-operation
	Schipper et al 2000 <sup>10</sup>	i. Goldmann applanation tonometry ii. Tonopen	Prospective study	35	Post PRK eyes	Mean spherical equivalent:- $6.2 \pm 2.6$ D	The postoperative measured IOP measured by Tonopen C was lower than Tonopen P
	Levy et al 1999 <sup>11</sup>	i. Goldmann applanation tonometry ii. Tonopen	Prospective study	36	i. Post PRK eyes ii. Nonoperated healthy eyes	Mean manifest spherical equivalent in PRK eyes: $-5.51 \pm 2.05$ D Mean manifest spherical equivalent in control eyes: $-5.07 \pm 1.96$ D	The measured IOP by Goldmann applanation is significantly lower than Tonopen C in eyes performed with PRK

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Table 1 (Continued).

Post PRK Eyes	Studies	Tonometry Used	Type of Study	Number of Eyes	Study Arms	Preoperative Eyes	Related Significant Findings
	Hamed-Azzam et al 2013 <sup>12</sup>	i. Goldmann applanation tonometer ii. Noncontact tonometry iii. Tonopen	Prospective study	200	i. Post LASIK eyes ii. Post PRK eyes	Mean refraction in pre LASIK eyes: $-4.52 \pm 0.24$ D Mean refraction in pre PRK eyes: $-5.11 \pm 0.31$ D	No significant difference is found between the measured IOP by Noncontact tonometer and Goldmann applanation tonometer in post PRK eyes. No significant difference is found between Tonopen C and Tonopen P in terms of the change of delta IOP after PRK
	Sadigh et al 2013 <sup>13</sup>	i. Goldmann applanation tonometer ii. Dynamic contour tonometry	Prospective study	184	Post PRK eyes	Preoperative sphere: $-3.81 \pm 1.64$ D Preoperative cylinder: $-0.83 \pm 0.9$ D	No significant correlation between CCT changes and IOP measured by dynamic contour tonometry was found
	Lanza et al 2016 <sup>14</sup>	i. Goldmann applanation tonometer ii. Dynamic contour tonometry iii. Ocular response analyzer iv. Corvis ST v. Pentacam	Prospective study	109	i. Post PRK eyes ii. Keratoconus iii. Nonoperated healthy eyes	Mean spherical equivalent in PRK eyes: $-5.48 \pm 2.27$ D	The measured IOP by Goldmann applanation tonometer is significantly lower than Corvis ST in post PRK eyes
	Roszkowska et al 2009 <sup>15</sup>	i. Goldmann applanation tonometer ii. Dynamic contour tonometry	Prospective study	70	i. Post PRK eyes ii. Nonoperated healthy eyes	PrePRK eyes spherical equivalent: within $-1$ to $-8$ D Nonoperated healthy eyes spherical equivalent: within $-3$ to $+2$ D	No significant correlation was found between change in CCT and IOP by dynamic contour tonometry

Aristeidou et al 2010 <sup>16</sup>	i. Goldmann applanation tonometer ii. Pascal dynamic contour	Prospective study	309	i. Post PRK eyes (myopia) ii. Post LASIK eyes (myopia) iii. Post LASIK eyes (hyperopia)	Post PRK eyes (Myopia) Mean spherical equivalent:- 4.5±2.3 Post LASIK eyes (myopia) Mean spherical equivalent -5.1±2.0 Post LASIK eyes (hyperopia) Mean spherical equivalent: 3.5±1.7	IOP measured by Goldmann applanation tonometer was lower than dynamic contour tonometry in post PRK eyes
Landoulsi et al 2013 <sup>17</sup>	i. Ocular response analyzer ii. Goldmann applanation tonometer	Prospective study	200	i. Post PRK eyes ii. Post LASIK eyes iii. normal nonoperative eyes (<30 years old) iv. Normal Nonoperative eyes (30–50 years old) v. Normal Nonoperative eyes (>50 years old)	NA	Lower limit of substantial agreement is researched in post PRK eyes using IO ocular response analyzer measurements
Tamburrelli et al 2005 <sup>18</sup>	Non contact tonometer	Prospective study	30	Post PRK eyes	Refractive error: -6.57 ±2.39D	The IOP measured by noncontact tonometer and corrected IOP by Orssengo and pye formula were significantly lower in post PRK eyes when compared with preoperative baseline

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Table 1 (Continued).

Post PRK Eyes	Studies	Tonometry Used	Type of Study	Number of Eyes	Study Arms	Preoperative Eyes	Related Significant Findings
	Cennamo et al 1997 <sup>19</sup>	Non-contact tonometry	Prospective study	47	i. Post PRK eyes (between 1 and 5 D) ii. Post PRK eyes (between 6 and 10 D) iii. Post PRK eyes (between 11 and 15 D)	Group 1: between 1 and 5 D Group 2: between 6 and 10 D Group 3: between 11 and 15 D	A correcting factor is needed for IOP measurement in post PRK eyes by noncontact tonometry
	Montes-Mico et al 2001 <sup>20</sup>	i. Goldmann applanation ii. Noncontact tonometry	Prospective study	194	i. Post PRK eyes ii. Post LASIK eyes iii. Normal unoperated eyes	Selected patients refractive error to have one of four specific initial values (-2.5, -5.0, -7.5, -10.0 D)	Correction of 0.5mmHg/D of myopic correction is needed in post PRK eyes
	Zhang et al 1998 <sup>21</sup>	Noncontact tonometer	Prospective study	150	Post PRK eyes	NA	A significant correlation between reduction of IOP and corneal thickness changes is found in eyes before and after PRK
	Cernak et al 2003 <sup>22</sup>	Noncontact tonometer	Prospective study	149	i. Post PRK eyes ii. Post LASIK eyes	PRK eyes refractive error: $-5.27 \pm 2.32$ LASIK eyes: $-10.18 \pm 4.36$	Corneal thickness, corneal curvature were found to be factors influencing IOP measurement in post PRK eyes
	Chatterjee et al 1997 <sup>23</sup>	i. Goldmann applanation ii. Noncontact tonometry	Retrospective study	2640	Post PRK eyes	Mean preoperative sphere: $-3.74 \pm 1.73D$ Mean preoperative cylinder: $-0.9D \pm 0.91$	An equation: IOP drop (mmHg) = $1.6(0.4 \times \text{treatment MSE diopters})$ is needed in post PRK eyes when measuring intraocular pressure
	Abbasoglu et al 1998 <sup>24</sup>	i. Goldmann applanation tonometer ii. Pneumotonometer	Prospective study	40	Post PRK eyes	Mean preoperative spherical refractive error: $-4.29 \pm 1.47D$ Mean astigmatic error: $1.04 \pm 0.94D$	No significant difference between central or peripheral measured IOP was found by Goldmann tonometry and pneumotonometry

Hahn et al 2017 <sup>25</sup>	i. Tonopachymetry ii. US pachymetry iii. Goldmann applanation	Prospective study	216	i. Post PRK eyes ii. Normal unoperated eyes	Normal unoperated eyes mean spherical equivalent: -2.34±2.64D Post PRK eyes mean spherical equivalent: -0.07 ±10.36D	A higher repeatability is found in tonopachymetry when compared with pachymetry and Goldmann applanation in terms of CCT and IOP in post PRK eyes
Lee et al 2017 <sup>26</sup>	i. Dynamic Scheimpflug analyzer ii. Noncontact tonometer	Retrospective study	129	i. Post PRK eyes ii. Post LASIK eyes	PRK eyes mean spherical equivalent: -4.36±1.60D LASIK eyes mean spherical equivalent: -4.28±1.36D	A smaller change in measured IOP by Corvis ST is found between eyes before and after PRK when compared with noncontact tonometer
Chen et al 2014 <sup>27</sup>	Corvis ST	Prospective study	82	i. Post PRK eyes ii. Virgin eyes	Virgin eyes manifest refraction spherical equivalent: -2.15±2.28D PRK eyes: -3.52±1.93D	Good repeatability and reproducibility of IOP measurement by Corvis ST in post PRK eyes is found
Svedberg et al 2005 <sup>29</sup>	Goldmann applanation tonometry	Retrospective Study	40	i. Post PRK/LASEK eyes ii. Post LASIK eyes	PRK/LASEK eyes: -3.2D ±1.4D LASIK eyes: -3.6±1.1D	The measured IOP by Goldmann applanation tonometry in post PRK eyes was affected by CCT and corneal curvature
Munger et al 1998 <sup>29</sup>	Goldmann applanation tonometry	Retrospective (descriptive) study	481	Post PRK eyes	Mean preoperative refractive error: -6.5 D	Significant correlation between change in CCT and measure IOP by Goldmann applanation tonometer was found in post PRK eyes
Mardelli et al 1998 <sup>30</sup>	Goldmann applanation tonometry	Retrospective Study	222	i. Post PRK eyes ii. Normal unoperated eyes	Varied from myopia 1.0– 6.25 D, less than 1.0D astigmatism	IOP measured by Goldmann tonometer was found to be slightly lowered after PRK
Munger et al 2001 <sup>31</sup>	i. Goldmann applanation tonometer ii. Tonometer	Retrospective study	191	Post PRK eyes	Preoperative sphere: +3.03 ±1.52 Preoperative Astigmatism: 0.53±0.66	The relationship between CCT and measured IOP by Goldmann applanation tonometer will be affected at different time intervals after PRK
Rosa et al 1998 <sup>32,32</sup>	Goldmann applanation tonometer	Prospective study	87	Post PRK eyes	Preoperative refractive error: -7.6±4.1D	A significant underestimation of IOP by Goldmann applanation in post PRK eyes was found

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Table 1 (Continued).

Post PRK Eyes	Studies	Tonometry Used	Type of Study	Number of Eyes	Study Arms	Preoperative Eyes	Related Significant Findings
	Gimeno et al 2000 <sup>33</sup>	Goldmann applanation tonometer	Prospective study	103	i.Post PRK eyes ii.Post LASIK eyes	LASIK eyes mean spherical equivalent: $-5.58 \pm 2.52D$ PRK eyes mean spherical equivalent: $-5.05 \pm 2.58D$	A greater number of diopter before surgery may have a greater decrease in tonometry
	Zare et al 2012 <sup>37</sup>	i.Goldmann Applanation tonometer ii.Ocular response analyzer	Prospective study	33	Post PRK eyes	Mean spherical equivalent: $-3.25 \pm 1.34D$	A significant decrease in corneal hysteresis and corneal resistance factor was found in post PRK eyes when compared with preoperative eyes
	Hassan et al 2014 <sup>28</sup>	Corvis ST	Prospective study	78	i.Post LASIK eyes ii.Post PRK eyes	NA	No significant difference was found in IOP measured by Corvis ST before PRK and after PRK
	Tamburrelli et al 2004 <sup>36</sup>	Noncontact tonometer	Prospective study	48	Post PRK eyes	Mean spherical equivalent: $-6.38 \pm 2.26$	Due to reduction of CCT in post PRK for myopia, there may be underestimation of IOP reading and effect of hypotensive drugs
	Wu et al 2002 <sup>50</sup>	Goldmann applanation tonometer	Retrospective study	364	Post PRK eyes	NA	In preoperative PRK eyes with myopia, the IOP measurement will be influenced by corneal thickness and curvature and use of steroid after PRK
	Faucher et al 1997 <sup>35</sup>	Goldmann applanation tonometer	Retrospective study	1239	i.Post radial keratotomy ii.Post PRK	NA	The accuracy of IOP by Goldmann tonometer was found to be affected by refractive surgery
	Hosny et al 2017 <sup>40</sup>	i.Ocular response analyzer ii.Goldmann applanation	Prospective study	30	Post femto SMILE eyes	Refractive error: $-4.05 \pm 1.76D$	A significant reduction in measured IOP by Goldmann applanation or ocular response analyzer was found in post SMILE eyes
Post SMILE Eyes	Li et al 2016 <sup>41</sup>	i.Ocular response analyzer ii.Noncontact tonometer	Retrospective study	193	i.Post SMILE eyes ii.Post FS LASIK eyes	SMILE eyes mean refraction spherical equivalent: $-5.6 \pm 1.43D$ FS LASIK eyes mean refraction spherical equivalent: $-5.95 \pm 1.78D$	An insignificant reduction in IOP after SMILE was reported in Dresden, Orsengo and Kohlhaas formula by non contact tonometer



Chen et al 2020 <sup>38</sup>	i. Dynamic Contour tonometer ii. Goldmann applanation tonometer iii. Corvis ST iv. Ocular response analyzer	Prospective study	144	i. Post FS-LASIK eyes ii. Post SMILE eyes iii. Post tPRK eyes	SMILE eyes mean spherical equivalent: $-5.62 \pm 1.72$ FS-LASIK eyes mean spherical equivalent: $-5.94 \pm 1.78$ tPRK eyes: $-5.78 \pm 2.1$	The measured IOP in post PRK eyes by Goldmann applanation tonometer was lower than dynamic contour tonometry. No significant difference is found in bIOP by Corvis ST in post PRK eyes when compared with preoperative eyes
Shen et al 2016 <sup>42</sup>	i. Noncontact tonometer ii. Ocular response analyzer iii. Corvis ST	Prospective study	22	Post SMILE eyes	Mean refraction spherical equivalent $-6.76 \pm 1.39$ D	A significant decrease in measure IOP by noncontact tonometer and Corvis ST after SMILE was found.
Chen et al 2018 <sup>43</sup>	i. Corvis ST ii. Goldmann applanation tonometer	Retrospective study	69	i. Post LASIK eyes ii. Post SMILE eyes	LASIK eyes mean spherical equivalent: $-3.65 \pm 1.12$ D SMILE eyes mean spherical equivalent: $-3.81 \pm 0.95$ D	No significant reduction of bIOP in post SMILE eyes by Corvis ST was found when compared with preoperative baseline
Sefat et al 2016 <sup>44</sup>	i. Goldmann tonometry ii. Noncontact tonometry iii. Corvis ST	Prospective study	128	i. Post FS-LASIK eyes ii. Post SMILE eyes	FS LASIK eyes: $-3.23 \pm 1.64$ D SMILE eyes: $-4.83 \pm 1.53$ D	Significant changes in corneal biomechanical parameters by Corvis ST was found in post SMILE eyes when compared with preoperative eyes
Pedersen et al 2014 <sup>45</sup>	i. Corvis ST ii. Ocular response analyzer	Prospective study	126	i. Post LASIK eyes ii. Post ReLex flex eyes iii. Post ReLex smile eyes	LASIK eyes: $-7.40 \pm 0.2$ D ReLex flex eyes: $-7.43 \pm 0.2$ D ReLex smile eyes: $-7.1 \pm 0.29$	CH and CRF in post SMILE eyes were significantly lower when compared with normal eyes

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Table 1 (Continued).

Post PRK Eyes	Studies	Tonometry Used	Type of Study	Number of Eyes	Study Arms	Preoperative Eyes	Related Significant Findings
	Fernandez et al 2016 <sup>46</sup>	Corvis ST	Retrospective study	68	Post SMILE eyes (preoperative spherical equivalent):-1.00 to -3.00D Post SMILE eyes (Preoperative spherical equivalent):-3.25 to -5.00D Post SMILE eyes (preoperative spherical equivalent):-5.25 to -7.25D	SMILE eyes: spherical equivalent:-1.00 to -7.25 D and refractive astigmatism less than 3.00D	A significant change in Corvis ST parameters and deformation on amplitude was found
	Mastropasqua et al 2014 <sup>47</sup>	Corvis ST	Prospective study	20	Post SMILE eyes	Spherical equivalent refraction: -3.00 to -7.00 D, refractive astigmatism: 0.5 to 1.50D	A significant change in first and second applanation time and deformation amplitude was reported in post SMILE eyes
	Yu et al 2016 <sup>48</sup>	NA	Retrospective study	84	Post SMILE eyes	NA	Post SMILE eyes surrounding cornea would move slightly forward and the central posterior cornea would move slightly backward and return to normal gradually
	Fu et al 2020 <sup>49</sup>	i. Corvis ST ii. Ocular response analyzer	Prospective study	13	Post SMILE eyes	Spherical diopter: 4.17 ± 1.55D Cylinder:-0.9±0.75D	Goldmann correlated IOP and cornea compensated IOP by ocular response analyzer was found to have a significant decrease and was greater than bIOP by Corvis ST

**Abbreviations:** PRK, photorefractive keratectomy; LASIK, laser-assisted in situ keratomileusis; SMILE, small incision lenticule extraction; CCT, central corneal thickness; IOP, intraocular pressure; bIOP, biomechanically corrected intraocular pressure; IOPg, Goldmann correlated intraocular pressure; IOPcc, corneal compensated intraocular pressure.

Another study by Munger has demonstrated that the relationship between CCT and measured IOP by Goldmann applanation tonometer will increase at different time intervals after PRK.<sup>31</sup> A significant relationship was found between the measured CCT and IOP measured by Goldmann applanation tonometer. The relationship increased from preoperation 1.7mmHg/100  $\mu$ m to 2.11 mmHg/100  $\mu$ m 6 months postoperation. This shows that CCT is a significant predictor of IOP measured by Goldmann applanation tonometer.<sup>31</sup> However, an insignificant correlation between the changes in IOP and changes in CCT in postoperative eyes is not found at any time point. The change in measured IOP in different eyes on a given change in CCT varied greatly at any time point.<sup>31</sup>

#### Measurement at the Central Cornea versus Peripheral Cornea

Schipper demonstrated that the mean IOP measured at the temporal cornea by Goldmann applanation tonometer was significantly higher than the central after one and three months PRK ( $P < 0.0001$ ).<sup>10</sup> No significant difference was found between the measured IOP by Goldmann tonometer over the central cornea and temporal cornea before operation, showing that PRK may affect the CCT and hence affect the accuracy of measured IOP by Goldmann applanation tonometer.

#### Relationship Between Preoperative Refractive Error and Postoperative Measured IOP

Gimeno suggested that by observation, a greater number of diopter before surgery may have a greater decrease in tonometry.<sup>33</sup> In the cases of eyes less than  $-5D$  before surgery, 63.5% of eyes have a decrease in tonometry by Goldmann applanation tonometer after PRK. Meanwhile, as for eyes more than  $-5D$ , 78.4% of eyes have a decrease in tonometry after PRK. However, no significant difference was found when comparing the two groups ( $P = 0.173$ ).<sup>33</sup>

#### Noncontact Tonometer in Post PRK Eyes

Noncontact tonometer is based on the principle of applanation. The deformation of corneal apex is caused by a jet of air. It measures the time required to flatten the cornea for the measurement of IOP.<sup>9</sup> Because of its convenience, sterility and safety, it is common in clinical practice, especially for screening.<sup>19</sup> It is yet important to note that it is accurate only when the IOP is in low to middle range.<sup>9</sup> A total of ten studies have investigated the use of

noncontact tonometer in eyes that had undergone PRK.<sup>8,9,12,18-24</sup>

#### Changes in Measured IOP After Operation

Four studies have demonstrated a significant reduction in the measured IOP by noncontact tonometer in postoperative PRK eyes when compared with preoperative measured baseline IOP.<sup>18-20,23</sup> Garzozzi has demonstrated a significant reduction of measured IOP by noncontact tonometer when comparing preoperative and 12 months postoperative eyes (13.51 mmHg vs 12.074 mmHg).<sup>9</sup> Chatterjee demonstrated the change in IOP before and after operation in eyes performed with PRK and eyes were not performed with PRK, measured by non-contact tonometry. As concluded in this study, eyes performed with PRK had a greater reduction in IOP ( $3.5 \pm 2.7$  mmHg vs  $0.3 \pm 2.4$  mmHg).<sup>23</sup> Another study performed by Tamburrelli compared measured IOP by noncontact tonometer and corrected IOP by Orssengo and Pye formula (IOPC), which takes corneal curvature and CCT into account, in post 6-month PRK eyes during a water drink test.<sup>18</sup> The measured IOP and IOPC were significantly lower than in postoperative eyes when compared with their preoperative baseline by multivariate analysis of variance.

#### Relationship Between Changes of Measured IOP, CCT and Corneal Curvature

The reduction of measured IOP in eyes after PRK may be due to the reduction of corneal thickness and curvature and tissue softening after healing.<sup>20</sup> Cernak and Zhang have demonstrated a significant correlation between the reduction of IOP before and after operation and corneal thickness and curvature ( $P < 0.05$ ).<sup>21,22</sup>

#### Noncontact Tonometer versus Goldmann Applanation Tonometer

Three studies have demonstrated different results by comparing the reduction of measured IOP in Goldmann applanation tonometer and noncontact tonometer before and after PRK operation.<sup>9,12,24</sup> Garzozzi has shown that a greater reduction in measured IOP was found in Goldmann applanation tonometer when compared to non-contact tonometer (1.504 mmHg vs 1.436 mmHg).<sup>9</sup> However, Abbasoglu et al and Hamed-Azzam suggested that there is no significant difference between the measured IOP by the two tonometers in post PRK eyes.<sup>12,24</sup>

### Measurement at the Central Cornea versus Peripheral Cornea

Abbasoglu has measured IOP by Goldmann tonometry and pneumotonometry at the central and peripheral cornea in eyes in post PRK eyes at different time intervals, including 1 week, 1 months and 3 months after surgery.<sup>24</sup> No significant difference was found between central or peripheral measured IOP.

### Relationship Between Preoperative Refractive Error and Postoperative Measured IOP

Myopic eyes underwent PRK or LASIK were found to have a greater difference in preoperative and postoperative measurement of IOP when compared to hyperopic eyes by non-contact tonometer. Schallhorn performed a retrospective study, demonstrating that eyes performed with either LASIK or PRK had a lower IOP measured by noncontact tonometer, when compared to pre-operation.<sup>8</sup> Myopic eyes performed with LASIK has a greater decrease in mean IOP when comparing preoperative and one month after surgery (4.57mmHg vs 2.28 mmHg). Similar trend is also demonstrated in eyes after performing PRK (preoperative 0.83mmHg vs 1-month postoperative 2.28 mmHg). The study also showed that for every 1Diopter correction of myopic correction, the postoperative measured IOP will be decreased by 0.4mmHg in eyes performed with LASIK and PRK. In hyperopic eyes performed with LASIK, for every 1 Diopter correction, the IOP measured post-operation will be lowered by 0.063mmHg at one month.<sup>8</sup>

To determine the true IOP in eyes performed PRK by noncontact tonometer, correction will be needed to prevent underestimation of the IOP. Montes-Mico suggested that a correction of adding 0.5mmHg/D of myopic correction is needed, while another study by Chatterjee suggested an equation:  $\text{IOP drop (mmHg)} = 1.6 - (0.4 \times \text{treatment MSE diopters})$ , in which the measured IOP drop must be added to the measured IOP by tonometer in post PRK eyes.<sup>20,23</sup>

### Tonopen in Post PRK Eyes

Tonopen is a device based on the principle of Mackay-Marg tonometer. It is a handheld, portable and miniaturized electronic contact tonometer.<sup>9</sup> It works by the use of probe tip with a transducer in contact with the cornea. A total of four studies had investigated on the measurement of IOP in eyes performed with PRK by Tonopen, showing a decrease in the measured IOP after PRK when compared with preoperative measured IOP.<sup>9-12</sup>

### Changes in Measured IOP After Operation (Central Cornea versus Peripheral Cornea)

IOP can be measured by Tonopen at the central (Tonopen-C) or temporal peripheral (Tonopen-P) of the cornea.<sup>9</sup> Two studies demonstrated that Tonopen C tends to have a greater difference between the measured IOP before and after PRK than Tonopen P, while one study did not demonstrate significant difference.<sup>9-11</sup> Garzozzi has shown that the reduction of measured IOP by Tonopen C is higher than TonoPen P, when comparing pre PRK with 1 month post PRK (1.295mmHg vs 0.227mmHg).<sup>9</sup> A similar result was shown in the study by Schipper et al, showing that the postoperative mean IOP measured by Tonopen C was lower than Tonopen P ( $P < 0.0001$ ).<sup>10</sup> The preoperative mean IOP has no significant difference between the two groups. However, Hamed Azzam has demonstrated an insignificant difference between Tonopen C and Tonopen P in the change of delta IOP after the operation (0.99mmHg vs 0.92mmHg, respectively).<sup>12</sup>

### Relationship Between Changes of Measured IOP and CCT

Two studies have investigated the correlation between measured IOP by Tonopen and corneal thickness.<sup>9,12</sup> Hamed Azzam and Garzozzi have demonstrated significant correlation between CCT and the change in IOP after operation by Tonopen.<sup>12</sup> A less prominent correlation between change of IOP by Tonopen P and percentage change in CCT and keratometry was found when compared with Tonopen C.

### Tonopen versus Goldmann Applanation Tonometer

All studies suggested that the difference in measured IOP before and after PRK was greater in Goldmann applanation tonometer when compared with Tonopen P and Tonopen C.<sup>9-12</sup> The study by Levy found that the mean measured IOP by Goldmann applanation tonometer was significantly lower than Tonopen C in post PRK eyes ( $P = 0.012$ ).<sup>11</sup> This suggests that the IOP measurement by Tonopen is more accurate than Goldmann tonometer in eyes after performing PRK.

### Dynamic Contour Tonometry in Post PRK Eyes

Dynamic contour tonometry is a device for the measurement of IOP by a non-applanating method.<sup>13</sup> The measurement is based on corneal contour matching and a solid state sensor. The measurement is independent from the corneal factors and can be mounted on a slip lamp for the measurement of IOP.<sup>13</sup> A total of five studies have

studied the use of dynamic contour tonometry in eyes performed with PRK.<sup>13–16,38</sup>

#### Changes in Measured IOP After Operation

No significant change in the measured IOP by dynamic contour tonometry was found when comparing pre-PRK eyes and 3 months post PRK eyes in the study by Chen.<sup>38</sup>

#### Relationship Between Changes of Measured IOP and CCT

No significant correlation between the change in CCT and the change in IOP measured by dynamic contour tonometry was reported in two studies.<sup>13,15</sup> Sadigh has shown that there was no significant correlation between CCT changes and IOP measured by dynamic contour tonometry, but a significant correlation was found between CCT changes and changes in IOP measured by Goldmann applanation tonometer, before and 6 months after operation ( $P=0.44$  vs  $P<0.001$ ).<sup>13</sup> A similar result was also shown in Roshowska, showing that the measurement of IOP by dynamic contour tonometry is independent from CCT.

#### Dynamic Contour Tonometry versus Other Tonometers

All studies had demonstrated that the measured IOP in post PRK eyes by Goldmann applanation tonometer was lower than dynamic contour tonometry.<sup>13–16,38</sup> The result is within expectation as dynamic contour tonometry is theoretically independent from corneal factors. Study performed by Aristeidou showed that the mean IOP measured by Goldmann applanation tonometer was significantly lower than IOP measured by dynamic contour tonometry after the 1st month, 3rd month, 6th month and 12th month after PRK, showing that dynamic contour tonometry may be a better device for IOP measurement when compared with Goldmann applanation tonometer.<sup>16</sup> Furthermore, there was a lack of agreement between Goldmann applanation tonometer and dynamic contour tonometry measured IOP in 6 months postoperative eyes, showing a mean difference of  $-2.4\text{mmHg}$ .<sup>15</sup>

Roszkowska compared the measured IOP in eyes performed with PRK by different devices, showing that no significant difference in measured IOP was found between dynamic contour tonometry and Corvis ST, but a significant difference was found between the IOP measured by Goldmann applanation tonometer and Corvis ST.<sup>15</sup>

#### Dynamic Scheimpflug Analyser (Corvis ST) in Post PRK Eyes

Corvis ST is a new noncontact tonometer, which uses a 455 nm wavelength light-emitting diode and 4330 frames

per second Scheimpflug camera to record the dynamic reaction of cornea to a high-intensity air impulse.<sup>27</sup> Various dynamic corneal response parameters measured by the dynamic Scheimpflug analyzer will be used to analyse the loading and unloading pattern of deformation of cornea at the highest concavity and applanation.<sup>26</sup> New corneal biomechanical response parameters such as deformation amplitude ratio 2.0mm, integrated inverse radius, stiffness parameter at first applanation and Ambrosio relational thickness are introduced recently. The parameters will be used for calculation of biomechanically corrected IOP.<sup>26,27</sup> A total of five studies investigating the use of Corvis ST in post PRK eyes were found<sup>14,26,27,38,39</sup>.

#### Changes in Measured Biomechanically Corrected IOP After Operation

No significant difference is found in biomechanically corrected IOP measured by Corvis ST in post PRK eyes when compared with the baseline ( $P=0.101$ ).<sup>26,38</sup> Chen 2020 has demonstrated an insignificant change in the biomechanically corrected IOP (bIOP) when comparing preoperative and 3 months postoperative eyes ( $P=0.6784$ ).<sup>38</sup> Hassan demonstrated significant differences in pachymetry, second applanation velocity, radius in 1-month post PRK eyes when compared with preoperative baseline. However, no significant differences in found in other parameters such as IOP, first applanation time, first applanation velocity.<sup>28</sup> The study also suggests that Corvis ST is a handy and accurate device for assessing ocular biomechanical properties and biomechanically corrected IOP after PRK.

#### Corvis ST versus Other Tonometers

Lee and Lanza had compared Corvis ST with other tonometers.<sup>14,26</sup> Lanza has demonstrated that the measured IOP by Goldmann applanation tonometer is significantly lower than the corneal properties corrected IOP by Corvis ST in post PRK eyes ( $P<0.014$ ).<sup>14</sup> No significant difference is found between the IOP measured by dynamic contour tonometry and Corvis ST.<sup>14</sup> Lee has compared the biomechanically corrected IOP measured by Corvis ST and IOP measured by noncontact tonometer in post PRK eyes, showing that the corrected IOP by Corvis ST has a significantly smaller difference between pre and post PRK when compared with the measured IOP by noncontact tonometer.<sup>26</sup>

#### Repeatability and Reproducibility of Corvis ST

Chen studied about Corvis ST's the intraobserver and interobserver as well as their repeatability and



reproducibility of Corvis ST in post PRK eyes.<sup>27</sup> The results suggested good intraobserver and interobserver reproducibility in the IOP, CCT and first applanation time. A good or close to good repeatability and reproducibility were reported in terms of deformation amplitude. For the second applanation time, a close to good repeatability and yet a not good reproducibility were reported.<sup>27</sup>

### Tonopachymetry in Post PRK Eyes

Tonopachymetry is a combination of non-contact tonometry and pachymetry. The CCT is measured by Scheimpflug camera system while the IOP is measured by non-contact tonometry.<sup>25</sup> The IOP is then corrected by the measured CCT automatically. Hahn demonstrated a higher repeatability in terms of CCT and IOP measured by tonopachymetry when compared with US pachymetry and Goldmann applanation tonometer.<sup>25</sup> Significant difference is found between the corrected IOP by tonopachymetry and corrected IOP by US pachymetry and Goldmann applanation tonometer in nonsurgical and post PRK eyes. The average CCT measured by tonopachymetry was found to be significantly thicker than US pachymetry in both post PRK eyes and nonsurgical eyes (7.35 $\mu$ m vs 17.76 $\mu$ m). The overestimation in CCT was found to be greater in post PRK eyes than non-surgical eyes ( $P < 0.001$ ). However, a close agreement with clinically acceptable range of limits of agreement between the corrected IOP and CCT by tonopachymetry and US pachymetry was reported in the Bland Altman plot, which shows that tonopachymetry is one of the alternatives for US pachymetry and Goldmann applanation tonometer for measuring corrected IOP in post PRK eyes.<sup>25</sup>

### Ocular Response Analyser in Post PRK Eyes

Ocular response analyser is a form of pneumotonometer for the measurement of IOP. It uses an electro-optical detector to measure two applanation pressure for the measurement of corneal hysteresis so as to compensate for the corneal biomechanical properties.<sup>17</sup> A limited number of studies have investigated the use of ocular response analyzer in post PRK eyes.<sup>14,17,38</sup>

Chen has demonstrated a significant reduction in the corneal compensated IOP by ocular response analyzer in 3 months post PRK eyes when compared with pre PRK eyes. The study demonstrated an insignificant change in the IOP measured by Corvis ST and Dynamic Contour tonometry, showing that ocular response analyzer may

not be as accurate as the IOP measured by the two aforementioned tonometers.<sup>38</sup>

Another study performed by Lanza showed that the measured IOP by ocular response analyzer in post PRK eyes was found to be significantly higher than Goldmann applanation tonometer ( $P < 0.0001$ ).<sup>14</sup> No significant correlation between CCT measures, corneal curvature and ocular response analyzer measures were found in eyes performed with PRK.<sup>14</sup> Further studies are required to investigate the use of ocular response analyzer in terms of accuracy for measurement of IOP in post PRK eyes.

The study performed by Landoulsi had underwent 10 ocular response analyzer measurements in the included eyes for the calculation of intraclass correlation coefficients, which is for the assessment of the agreement level.<sup>17</sup> It showed that in post PRK patients, none of the parameters have reached 0.6, the lower limit of substantial agreement.<sup>17</sup>

### Small Incision Lenticule Extraction Corneal Biomechanical Properties After SMILE

Eight studies have demonstrated the change in corneal biomechanical properties in post SMILE eyes. However, the resulting conclusion of corneal biomechanical properties varies in different studies.<sup>40–42,45–49</sup>

Hosny, Li and Shen demonstrated a significant decrease in corneal hysteresis and corneal resistance factor in post SMILE eyes when compared with preoperative eyes.<sup>40–42</sup> Pedersen demonstrated that CH and CRF in post SMILE eyes were significantly lower when compared with healthy eyes by ocular response analyzer.<sup>45</sup> However, the study by Fu only showed a significant decrease in corneal resistance factor but an insignificant change in corneal hysteresis when comparing post SMILE eyes with pre-SMILE eyes.<sup>49</sup>

For CCT, Li and Shen demonstrated a significant reduction in post SMILE eyes.<sup>41,42</sup> For flat keratometry, steep keratometry, mean keratometry, Li demonstrated a significant reduction in 1 month, 3 months and 6 months after SMILE when compared with pre-operation.<sup>41</sup>

Both Fu and Pedersen have found an insignificant difference in the first applanation time, deformation amplitude of corneal apex at highest concavity phase.<sup>45,49</sup> Pedersen also suggested that there was an insignificant difference in the highest concavity radius, the highest concavity deflection length, the first and second applanation time between post SMILE eyes and healthy eyes.<sup>45</sup> Fernandez and Mastropasqua demonstrated a significant change in the first and second applanation time in post

SMILE eyes.<sup>46,47</sup> Shen demonstrated an insignificant change in peak distance, applanation time at the highest concavity, the second applanation time, the first applanation length, and the second applanation length in post 1 day SMILE eyes.<sup>42</sup>

A significant increase in deformation amplitude was reported in post SMILE eyes by Shen, Pedersen, Mastropasqua and Fernandez.<sup>42,45–47</sup> Yu demonstrated that in eyes performed with SMILE, the surrounding cornea would move slightly forward and the central posterior cornea would move slightly backward and return to normal gradually.<sup>48</sup>

### Goldmann Applanation Tonometry in Post SMILE Eyes Changes in Measured IOP After Operation

Three studies have investigated into the measured IOP by Goldmann applanation tonometer in post SMILE eyes, all showing a significant reduction in the measured IOP by Goldmann applanation tonometry.<sup>38,40,43</sup> Hosny has demonstrated a significant reduction in measured post SMILE IOP by Goldmann applanation tonometer when compared with preoperative IOP ( $P < 0.001$ ). The change in Goldmann applanation tonometer was found to be  $-5.30 \pm 2.67$  mmHg.<sup>40</sup> Chen demonstrated that the Goldmann applanation tonometer measured IOP has shown a significant reduction in measured IOP at 1 month, 3 months and 6 months after operation when compared with preoperative baseline IOP ( $P < 0.001$ ) (43). Another study by Chen has demonstrated a significant reduction in measured IOP by Goldmann applanation tonometer in eyes 3 months after SMILE when compared with the baseline IOP, a reduction of mean  $-2.83$  mmHg was reported.<sup>38</sup>

### Relationship Between Changes of Measured IOP and CCT

A significant correlation between postoperative IOP by Goldmann applanation and CCT was reported in post SMILE eyes.<sup>43</sup>

### Noncontact Tonometer in Post SMILE Eyes Changes in Measured IOP After Operation

A limited number of studies have investigated the use of noncontact tonometer in post SMILE eyes. A significant decrease in IOP measured by noncontact tonometer at 1 month, 3 months and 6 months after SMILE was demonstrated in study by Li ( $P < 0.001$ ).<sup>41</sup> Similar results were also demonstrated in Fu, showing a significant reduction in measured IOP by noncontact tonometer in eyes at 1 week, 1 month and 3 months after SMILE when compared with preoperative measured IOP ( $P = 0.006$ ).<sup>49</sup> By the multiple

linear regression models, definite regression coefficients were reported between the change in IOP by noncontact tonometer and other influencing factors, including postoperative corneal resistant factor, corneal hysteresis, Kf and preoperative IOP.<sup>41</sup> Another study by Shen showed a similar result of the IOP by noncontact tonometer, having a significant decrease in measured IOP after the SMILE procedure.<sup>42</sup>

### Noncontact Tonometry versus Other Tonometers

When compared with bIOP by Corvis ST, IOP by noncontact tonometer showed a greater reduction in measured IOP in eyes at 1 month and 3 months after SMILE. It has a smaller reduction when compared with Goldmann corrected IOP and cornea compensated IOP by ocular response analyzer at 1 week, 1 month and 3 months after SMILE.<sup>49</sup>

### Ocular Response Analyzer in Post SMILE Eyes Changes in Measured IOP After Operation

A significant reduction of corneal compensated intraocular pressure (IOPcc) by ocular response analyzer in post SMILE eyes was found when compared with pre-SMILE eyes.<sup>27,38,41</sup> The ocular response analyzer used in the study by Li included parameters including corneal resistance factor, corneal hysteresis, Goldmann correlated IOP (IOPg), and corneal compensated IOP (IOPcc).<sup>41</sup> Corneal compensated IOP is the estimated IOP by compensating corneal properties to produce a more accurate value in post-refractive surgery eyes. Both IOPg and IOPcc have a significant reduction when comparing post 1 month, 3 months, 6 months with the baseline preoperative values ( $P < 0.001$ ).<sup>41</sup>

### Relationship Between Changes of Measured IOP and Biomechanical Properties of Cornea

No significant correlation was found between changes in IOPcc in post SMILE eyes and changes in CCT, flat keratometry, steep keratometry, mean keratometry, and corneal resistant factor by Li.<sup>41</sup> Only significant correlation was found between the change in IOPcc in post SMILE eyes and the change in corneal hysteresis. Similar results were demonstrated in Hosny, showing the decline of post SMILE IOP and the post SMILE pachymetry, lenticule thickness or CCT.<sup>40</sup>

### Ocular Response Analyzer versus Other Tonometers in Post SMILE Eyes

Fu showed that both Goldmann correlated IOP and cornea compensated IOP by ocular response analyzer had a

significant decrease in post SMILE eyes at 1 week, 1 month and 3 months (49). The reduction was shown to be greater than bIOP by Corvis ST and IOP by noncontact tonometer.<sup>49</sup> Hosny has demonstrated a significantly lower postoperative IOP than the preoperative IOP by Goldmann applanation tonometer and ocular response analyzer (IOPcc).<sup>40</sup> The measured IOP by Goldmann applanation tonometer was significantly lower than ocular response analyzer in post SMILE eyes ( $P<0.001$ ).<sup>40</sup>

### Pentacam Scheimpflug Images with Noncontact Tonometer in Post SMILE Eyes

The study by Li has used the measured IOP by noncontact tonometer, with the measured corneal thickness and curvature by Pentacam to calculate the corrected IOP in post SMILE eyes, using the five different formulas.<sup>41</sup> The five formulae include Ehlers, Shah, Dresden, Kohlhaas, Orssengo/Pye formulae. All of the IOP by the formulae showed an insignificant reduction in IOP at 1 month after SMILE, except for Ehlers. An insignificant reduction in IOP at 3 months and 6 months after SMILE was reported in Dresden, Orssengo, and Kohlhaas while a significant reduction was reported in Ehlers and Shah.

### Dynamic Contour Tonometer in Post SMILE Eyes

A study performed by Chen has demonstrated a significant reduction in measured IOP by dynamic contour tonometry in post 3 months SMILE eyes when compared with preoperation.<sup>38</sup> Further studies are required to investigate into the use of Dynamic contour tonometer for the measurement of IOP in post SMILE eyes.

### Dynamic Scheimpflug Analyzer Tonometry (Corvis ST) in Post SMILE Eyes

#### Changes in Measured IOP Before and After Operation

The IOP measured by the standard dynamic Scheimpflug analyzer was shown to have a significant reduction after SMILE when compared with preoperative baseline IOP.<sup>43–46</sup> Shen investigated into the change in IOP measured by Corvis ST in the early phase after SMILE. A significant reduction in the measured IOP by Corvis ST at 20 minutes and 24 hours after SMILE was recorded, when comparing with preoperative baseline. The study also suggested that the main predictors of postoperative Corvis ST IOP value were postoperative first applanation time value, preoperative CCT value and postoperative PD value. No significant association was found between postoperative Corvis ST IOP and age, postoperative

CCT, manifest refraction spherical equivalent, corneal curvature or other parameters.<sup>42</sup>

As for the biomechanically corrected IOP, which makes use of the new algorithm by Corvis ST, studies have shown that it was better in measuring the IOP after SMILE when compared with the IOP measured by the standard Scheimpflug analyzer.<sup>43</sup> Chen reported an insignificant correlation between post SMILE bIOP and CCT, but a significant correlation between the postoperative IOP by conventional Scheimpflug analyzer.<sup>43</sup> No significant reduction of bIOP in post SMILE eyes, when compared with preoperative baseline bIOP, was reported by Chen.<sup>43</sup> However, Fernandez demonstrated that biomechanically corrected IOP showed a significant difference after SMILE. bIOP showed a smaller reduction when compared with conventional IOP measured with dynamic Scheimpflug analyzer.<sup>46</sup>

### Corvis ST versus Other Tonometers

Another study by Chen demonstrated that the biomechanically corrected IOP has a significant reduction of  $-1.46$  mmHg after SMILE when compared with preoperative bIOP. When compared with Goldmann applanation and ocular response analyzer measured IOPcc, the IOP measured by dynamic contour tonometry has a smaller reduction.<sup>38</sup> Fu also showed that bIOP has no significant difference between pre-SMILE eyes and post SMILE eyes, while IOP measured by the noncontact tonometer, ocular response analyzer showed significant reduction after SMILE.<sup>49</sup>

## Discussion

IOP was found to be major risk factors for glaucoma.<sup>5,51</sup> Studies have shown that in eyes performed photorefractive keratectomy or small incision lenticule extraction, the corneal biomechanical properties will be altered.<sup>12,31,37,40–42,45–49</sup> The measured IOP of tonometers such as Goldmann applanation tonometry, noncontact tonometer, Tonopen were found to be correlated with the corneal biomechanical properties such as central corneal thickness and corneal curvature.<sup>9–13,21,22</sup> This suggest that accuracy for measuring IOP in eyes performed with PRK or SMILE is of paramount importance. Therefore, this review will focus on discussing the accuracy of different tonometers in post PRK or SMILE eyes.

In post PRK eyes, previous studies have shown that a significant change in the measured IOP by Goldmann applanation tonometer, noncontact tonometer, Tonopen



and ocular response analyser. Dynamic contour tonometry and Corvis ST are found to have no significant changes in eyes performed with PRK. This shows that Corvis ST and Dynamic contour tonometry have a better performance in terms of accuracy. The result is expected as the two devices corrected the measured IOP by the biomechanical properties of the cornea, which is a major cause of inaccuracy.

In post SMILE eyes, similar results are also obtained, showing that Goldmann applanation tonometer, noncontact tonometer, ocular response analyser and dynamic contour tonometer have a significant change in measured IOP after operation. The biomechanically corrected IOP by Corvis ST was found to be more accurate and have less reduction in measured IOP than the aforementioned devices.

Despite there may be inaccuracy in the measurement of IOP using tonometers other than Corvis ST and Dynamic contour tonometry, other tonometers also have their own advantages and shall be considered for the measurement of IOP in post PRK eyes or post SMILE eyes. Goldmann applanation tonometer is the gold standard in IOP measurement and is commonly used for the measurement of IOP. Ophthalmologists may have an easier access to the device. Study by Schipper has demonstrated the IOP measured by Goldmann applanation tonometer at the temporal cornea may have a better accuracy when compared to central cornea in post one and three months PRK eyes.<sup>10</sup> Furthermore, ophthalmologists can take the results from pachymetry of the operated eye into consideration while interpreting the IOP measured by Goldmann applanation tonometer in operated eyes.

Noncontact tonometry is known for its convenience and safety, hence it is commonly used for screening. Tonopen is also commonly used due to its portable size and its inaccuracy can be improved by measuring the IOP at the temporal peripheral region of the cornea instead of the central cornea.<sup>12</sup> A greater difference in measured IOP before and after PRK was found in Goldmann applanation tonometer when compared with Tonopen P and Tonopen C.<sup>9–12</sup> This shows that Tonopen may have a more accurate result in measured IOP in post PRK eyes. Ocular response analyzer is also demonstrated to have a better accuracy in terms of IOP measurement when compared with Goldmann applanation tonometer in post PRK and post SMILE eyes.<sup>14</sup>

Accurately knowing the IOP value is helpful for diagnosing glaucoma and glaucoma screening as it is a major

risk factor. It is important for ophthalmologists to appreciate the chances of discrepancies in the measurement of IOP in eyes performed with PRK or SMILE. Dealing with this, Corvis ST or dynamic contour tonometry might be able to provide a more accurate IOP value. Other measures such as indirect fundoscopy, visual field assessment, ocular coherence tomography should also be performed once there is a raise of suspicion of glaucoma. While for following post PRK or SMILE eyes with glaucoma over time, any IOP tool, such as Goldmann applanation tonometry or noncontact can be used, because the change of IOP during follow-up matters for monitoring glaucoma cases. By reducing the IOP by 30–50% from baseline, the progression of glaucoma would usually stop.<sup>52</sup> Therefore, the change of IOP is more important during glaucoma follow-up. During the use of noncontact tonometer, ophthalmologists should also be aware of the chances of inaccuracy in high IOP eyes, as previous studies have shown that noncontact tonometer was found to be less reliable between 20 and 30 mmHg.<sup>53</sup>

## Conclusion

The biomechanically corrected IOP measured by Corvis ST and IOP measured by Dynamic contour tonometry were found to be accurate in post PRK eyes. For eyes performed with SMILE, Corvis ST was found to be more accurate for measuring IOP than other tonometers. Other tonometers such as Goldmann applanation tonometer, noncontact tonometry, Tonopen, ocular response analyzer can also be used for measuring IOP in eyes performed photorefractive keratectomy or small incision lenticule extraction in clinical practice; however, it is important for ophthalmologists to take note of the chances of discrepancies.

## Disclosure

The authors report no conflicts of interest in this work.

## References

1. Casas Luque L, Naidoo K, Chan VF, et al. Prevalence of refractive error, presbyopia, and spectacle coverage in Bogotá, Colombia: a rapid assessment of refractive error. *Optom Vis Sci*. 2019;96(8):579–586. doi:10.1097/OPX.0000000000001409
2. Harb EN, Wildsoet CF. Origins of refractive errors: environmental and genetic factors. *Annu Rev Vis Sci*. 2019;5:47–72. 1 doi:10.1146/annurev-vision-091718-015027
3. Spadea L, Giovannetti F. Main complications of photorefractive keratectomy and their management. *Clin Ophthalmol*. 2019;13:2305–2315. doi:10.2147/OPTH.S233125

4. Wong AHY, Cheung RKY, Kua WN, Shih KC, Chan TCY, Wan KH. Dry eyes after SMILE. *Asia Pac J Ophthalmol (Phila)*. 2019;8(5):397–405. doi:10.1097/01.APO.0000580136.80338.d0
5. Sihota R, Angmo D, Ramaswamy D, Dada T. Simplifying “target” intraocular pressure for different stages of primary open-angle glaucoma and primary angle-closure glaucoma. *Indian J Ophthalmol*. 2018;66(4):495–505. doi:10.4103/ijo.IJO\_1130\_17
6. Wang KJ, Wang WW, Tsai CL, Wang IJ. Intraocular pressure changes in eyes with small incision lenticules and laser in situ keratomileusis. *Clin Exp Optom*. 2019;102(4):399–405. doi:10.1111/cxo.12861
7. Tsai AS, Loon SC. Intraocular pressure assessment after laser in situ keratomileusis: a review. *Clin Exp Ophthalmol*. 2012;40(3):295–304. doi:10.1111/j.1442-9071.2011.02641.x
8. Schallhorn JM, Schallhorn SC, Ou Y. Factors that influence intraocular pressure changes after myopic and hyperopic LASIK and photorefractive keratectomy: a large population study. *Ophthalmology*. 2015;122(3):471–479. doi:10.1016/j.ophtha.2014.09.033
9. Garzosi HJ, Chung HS, Lang Y, Kagemann L, Harris A. Intraocular pressure and photorefractive keratectomy: a comparison of three different tonometers. *Cornea*. 2001;20(1):33–36. doi:10.1097/00003226-200101000-00006
10. Schipper I, Senn P, Oyo-Szerenyi K, Peter R. Central and peripheral pressure measurements with the Goldmann tonometer and tonopen after photorefractive keratectomy for myopia. *J Cataract Refract Surg*. 2000;26(6):929–933. doi:10.1016/S0886-3350(99)00461-7
11. Levy Y, Zadok D, Glovinsky Y, Krakowski D, Nemet P. Tono-pen versus Goldmann tonometry after excimer laser photorefractive keratectomy. *J Cataract Refract Surg*. 1999;25(4):486–491. doi:10.1016/S0886-3350(99)80044-3
12. Hamed-Azzam S, Briscoe D, Tomkins O, Shehede-Mashor R, Garzosi H. Evaluation of intraocular pressure according to corneal thickness before and after excimer laser corneal ablation for myopia. *Int Ophthalmol*. 2013;33(4):349–354. doi:10.1007/s10792-012-9701-7
13. Sadigh AL, Fouladi RF, Hashemi H, Beheshtnejad AH. A comparison between Goldmann applanation tonometry and dynamic contour tonometry after photorefractive keratectomy. *Graefes Arch Clin Exp Ophthalmol*. 2013;251(2):603–608. doi:10.1007/s00417-012-2142-1
14. Lanza M, Iaccarino S, Mele L, et al. Intraocular pressure evaluation in healthy eyes and diseased ones using contact and non contact devices. *Cont Lens Anterior Eye*. 2016;39(2):154–159. doi:10.1016/j.clae.2015.10.001
15. Roszkowska AM, De Grazia L, Cirone M, Ferreri G. Comparison of Goldmann applanation tonometry and dynamic contour tonometry in the measurement of intraocular pressure in eyes with different corneal thicknesses. *Ophthalmologica*. 2009;223(4):244–249. doi:10.1159/000209253
16. Aristeidou AP, Labiris G, Katsanos A, Fanariotis M, Foudoulakis NC, Kozobolis VP. Comparison between Pascal dynamic contour tonometer and Goldmann applanation tonometer after different types of refractive surgery. *Graefes Arch Clin Exp Ophthalmol*. 2011;249(5):767–773. doi:10.1007/s00417-010-1431-9
17. Landoulsi H, Saad A, Haddad NN, Guilbert E, Gatineau D. Repeatability of ocular response analyzer waveform parameters in normal eyes and eyes after refractive surgery. *J Refract Surg*. 2013;29(10):709–714. doi:10.3928/1081597X-20130919-04
18. Tamburrelli C, Giudiceandrea A, Vaiano AS, Caputo CG, Gullà F, Salgarello T. Underestimate of tonometric readings after photorefractive keratectomy increases at higher intraocular pressure levels. *Invest Ophthalmol Vis Sci*. 2005;46(9):3208–3213. doi:10.1167/iov.04-1240
19. Cennamo G, Rosa N, La Rana A, Bianco S, Sebastiani A. Non-contact tonometry in patients that underwent photorefractive keratectomy. *Ophthalmologica*. 1997;211(6):341–343. doi:10.1159/000310825
20. Montés-Micó R, Charman WN. Intraocular pressure after excimer laser myopic refractive surgery. *Ophthalmic Physiol Opt*. 2001;21(3):228–235. doi:10.1046/j.1475-1313.2001.00581.x
21. Zhang X, Pan C, Li L, Ding J. Correlations between factors and intraocular pressure following photorefractive keratectomy. *Zhonghua Yan Ke Za Zhi*. 1998;34(5):385–387.
22. Cernák A, Sisková E, Durcová T, Cernák M. Is it possible to accurately measure intraocular pressure after refractive surgery?. *Cesk Slov Oftalmol*. 2003;59(6):397–401.
23. Chatterjee A, Shah S, Bessant DA, Naroo SA, Doyle SJ. Reduction in intraocular pressure after excimer laser photorefractive keratectomy. Correlation with pretreatment myopia. *Ophthalmology*. 1997;104(3):355–359. doi:10.1016/S0161-6420(97)30308-X
24. Abbasoglu OE, Bowman RW, Cavanagh HD, McCulley JP. Reliability of intraocular pressure measurements after myopic excimer photorefractive keratectomy. *Ophthalmology*. 1998;105(12):2193–2196.
25. Hahn IK, Kim JY, Kim MJ, Tchah H, Moon CH. Validity of tonopachymetry for measuring corrected intraocular pressure in non-surgical and post-photorefractive keratectomy eyes. *Korean J Ophthalmol*. 2017;31(1):44–51. doi:10.3341/kjo.2017.31.1.44
26. Lee H, Roberts CJ, Kim TI, Ambrósio R Jr, Elsheikh A, Yong Kang DS. Changes in biomechanically corrected intraocular pressure and dynamic corneal response parameters before and after transepithelial photorefractive keratectomy and femtosecond laser-assisted laser in situ keratomileusis. *J Cataract Refract Surg*. 2017;43(12):1495–1503. doi:10.1016/j.jcrs.2017.08.019
27. Chen X, Stojanovic A, Hua Y, et al. Reliability of corneal dynamic scheimpflug analyser measurements in virgin and post-PRK eyes. *PLoS One*. 2014;9(10):e109577. doi:10.1371/journal.pone.0109577
28. Hassan Z, Modis L Jr, Szalai E, Berta A, Nemeth G. Examination of ocular biomechanics with a new scheimpflug technology after corneal refractive surgery. *Cont Lens Anterior Eye*. 2014;37(5):337–341. doi:10.1016/j.clae.2014.05.001
29. Munger R, Hodge WG, Mintsoulis G, Agapitos PJ, Jackson WB, Damji KF. Correction of intraocular pressure for changes in central corneal thickness following photorefractive keratectomy. *Can J Ophthalmol*. 1998;33(3):159–165.
30. Mardelli PG, Piebenga LW, Whitacre MM, Siegmund KD. The effect of excimer laser photorefractive keratectomy on intraocular pressure measurements using the Goldmann applanation tonometer. *Ophthalmology*. 1997;104(6):945–948. doi:10.1016/S0161-6420(97)30202-4
31. Munger R, Dohadwala AA, Hodge WG, Jackson WB, Mintsoulis G, Damji KF. Changes in measured intraocular pressure after hyperopic photorefractive keratectomy. *J Cataract Refract Surg*. 2001;27(8):1254–1262. doi:10.1016/S0886-3350(01)00971-3
32. Rosa N, Cennamo G, Breve MA, La Rana A. Goldmann applanation tonometry after myopic photorefractive keratectomy. *Acta Ophthalmol Scand*. 1998;76(5):550–554. doi:10.1034/j.1600-0420.1998.760508.x
33. Gimeno JA, Muñoz LA, Valenzuela LA, Moltó FJ, Rahhal MS. Influence of refraction on tonometric readings after photorefractive keratectomy and laser assisted in situ keratomileusis. *Cornea*. 2000;19(4):512–516. doi:10.1097/00003226-200007000-00022
34. Wu F, Jin X, Xu Y, Yang Y. Treatment of corneal perforation with lenticules from small incision lenticule extraction surgery: a preliminary study of 6 patients. *Cornea*. 2015;34(6):658–663. doi:10.1097/ICO.0000000000000397
35. Faucher A, Grégoire J, Blondeau P. Accuracy of Goldmann tonometry after refractive surgery. *J Cataract Refract Surg*. 1997;23(6):832–838. doi:10.1016/S0886-3350(97)80239-8
36. Tamburrelli C, Vaiano AS, Salgarello T, Caputo CG, Scullica L. Tonometric changes of latanoprost-induced intraocular pressure reduction after photorefractive keratectomy. *Invest Ophthalmol Vis Sci*. 2004;45(3):846–850. doi:10.1167/iov.03-0625

37. Zare M, Feizi S, Azimzadeh A, Esfandiari H. Effect of photorefractive keratectomy with mitomycin-C on corneal biomechanical features. *Curr Eye Res.* 2012;37(6):457–462. doi:10.3109/02713683.2012.660594
38. Chen S, Lopes BT, Huang W, et al. Effectiveness of four tonometers in measuring intraocular pressure following femtosecond laser-assisted LASIK, SMILE and transepithelial PRK. *J Cataract Refract Surg.* 2020. doi:10.1097/j.jcrs.0000000000000204
39. Svedberg H, Chen E, Hamberg-Nyström H. Changes in corneal thickness and curvature after different excimer laser photorefractive procedures and their impact on intraocular pressure measurements. *Graefes Arch Clin Exp Ophthalmol.* 2005;243(12):1218–1220. doi:10.1007/s00417-005-0072-x
40. Hosny M, Aboalazayem F, El Shiwly H, Salem M. Comparison of different intraocular pressure measurement techniques in normal eyes and post small incision lenticule extraction. *Clin Ophthalmol.* 2017;11:1309–1314. doi:10.2147/OPTH.S132578
41. Li H, Wang Y, Dou R, et al. Intraocular pressure changes and relationship with corneal biomechanics after SMILE and FS-LASIK. *Invest Ophthalmol Vis Sci.* 2016;57(10):4180–4186. doi:10.1167/iops.16-19615
42. Shen Y, Su X, Liu X, Miao H, Fang X, Zhou X. Changes in intraocular pressure values measured with noncontact tonometer (NCT), ocular response analyzer (ORA) and Corvis Scheimpflug technology tonometer (CST) in the early phase after small incision lenticule extraction (SMILE). *BMC Ophthalmol.* 2016;16(1):205. doi:10.1186/s12886-016-0381-3
43. Chen KJ, Joda A, Vinciguerra R, et al. Clinical evaluation of a new correction algorithm for dynamic Scheimpflug analyzer tonometry before and after laser in situ keratomileusis and small-incision lenticule extraction. *J Cataract Refract Surg.* 2018;44(5):581–588. doi:10.1016/j.jcrs.2018.01.023
44. Sefat SM, Wiltfang R, Bechmann M, Mayer WJ, Kampik A, Kook D. Evaluation of changes in human corneas after femtosecond laser-assisted LASIK and small-incision lenticule extraction (SMILE) using non-contact tonometry and ultra-high-speed camera (Corvis ST). *Curr Eye Res.* 2016;41(7):917–922. doi:10.3109/02713683.2015.1082185
45. Pedersen IB, Bak-Nielsen S, Vestergaard AH, Ivarsen A, Hjortdal J. Corneal biomechanical properties after LASIK, ReLEx flex, and ReLEx smile by Scheimpflug-based dynamic tonometry. *Graefes Arch Clin Exp Ophthalmol.* 2014;252(8):1329–1335. doi:10.1007/s00417-014-2667-6
46. Fernández J, Rodríguez-Vallejo M, Martínez J, Tauste A, Piñero DP. Corneal thickness after SMILE affects scheimpflug-based dynamic tonometry. *J Refract Surg.* 2016;32(12):821–828. doi:10.3928/1081-597X-20160816-02
47. Mastropasqua L, Calienno R, Lanzini M, et al. Evaluation of corneal biomechanical properties modification after small incision lenticule extraction using Scheimpflug-based noncontact tonometer. *Biomed Res Int.* 2014;2014:290619. doi:10.1155/2014/290619
48. Yu CJ, Wang Y, Su XL, Wu WJ, Wu ZQ, Wu YN. An analysis of changes in posterior corneal elevation and relevant factors after small incision lenticule extraction. *Zhonghua Yan Ke Za Zhi.* 2016;52(7):494–498.
49. Fu D, Li M, Knorz MC, Wei S, Shang J, Zhou X. Intraocular pressure changes and corneal biomechanics after hyperopic small-incision lenticule extraction. *BMC Ophthalmol.* 2020;20(1):129. doi:10.1186/s12886-020-01384-2
50. Wu X, Liu S, Huang P, Wang P. Analysis of intraocular pressure after myopic photorefractive keratectomy. *Zhonghua Yan Ke Za Zhi.* 2002;38(10):603–605.
51. Jonas JB, Weber P, Nagaoka N, Ohno-Matsui K. Glaucoma in high myopia and parapapillary delta zone. *PLoS One.* 2017;12(4):e0175120. doi:10.1371/journal.pone.0175120
52. Jonas JB, Aung T, Bourne RR, Bron AM, Ritch R, Panda-Jonas S. Glaucoma. *Lancet.* 2017;390(10108):2183–2193. doi:10.1016/S0140-6736(17)31469-1
53. Lagerlöf O. Airpuff tonometry versus applanation tonometry. *Acta Ophthalmol (Copenh)* 1990;68(2):221–224. doi:10.1111/j.1755-3768.1990.tb01909.x

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