• Clinical Research •

A pilot study of the precision of digital intraocular pressure measurement during vitrectomy

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Abstract

• **AIM:** To evaluate the precision of digital intraocular pressure (IOP) measurement in silicone oil (SO) filled eyes during vitrectomy.

• **METHODS:** This is a retrospective, single-blind study. Patients who were diagnosed with retinal detachment and scheduled for vitrectomy with SO injection were consecutively enrolled. During the vitrectomy, IOP was digitally measured and then by a rebound tonometer (IcarePRO). The rebound tonometer readings were masked to the surgeons. The digitally measured IOP and that of rebound tonometer were compared, and the inter-methods agreement was assessed. The absolute deviation in IOP values between these two methods (ΔIOP) was also calculated, and correlations between ΔIOP and refractive status, lens status and levels of surgeons' experience were analyzed.

• **RESULTS:** A total of 131 patients (131 eyes) were recruited, with a mean age of 51.0±16.1y. There was no significant difference in IOPs between digital measurement and the rebound tonometer (15.6±4.3 *vs* 15.7±5.1 mm Hg; t=0.406, P=0.686). Intraclass correlation coefficients (ICC) analysis indicated a strong correlation between these two measurements (ICC=0.830, P<0.001). The mean ΔIOP was 2.0±1.9 mm Hg (range: 0-12.8 mm Hg), with 98 eyes (74.8%) had the ΔIOP within 3 mm Hg. ΔIOP was found to be negatively correlated with levels of surgeons' experience (r=-0.183; P=0.037), but not with the refractive status or lens status of the patients (both P>0.05).

• **CONCLUSION:** For experienced surgeons, the digital IOP measurement may be an acceptable technique for IOP measurement in SO filled eyes during vitrectomy. However, its use by inexperienced surgeons should be taken with caution.

• **KEYWORDS:** digital intraocular pressure measurement; intraocular pressure; silicone oil; vitrectomy

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INTRODUCTION

Silicone oil (SO) is commonly used in a variety of vitreoretinal surgeries, and as a well-tolerated substance, its vital role in the treatment of the retinal detachment (RD) and ensuring ideal functional and anatomical outcomes has been widely accepted[1-2]. During the vitrectomy, to ensure successful retinal reattachment and reduce postoperative complications, surgeons adjust the amount of SO injected based on the intraocular pressure (IOP). However, due to the supine position of the patients, most tonometers are not available during the vitrectomy, which makes the regulation of intra-operative IOP very difficult. According to our clinical observation and previous reports, a tactile assessment of the IOP based on the bare cornea, namely, the digital IOP measurement, was adopted by many vitreoretinal surgeons at the end of the cases[3-4]. Although the utilization of this traditional technique dates back for decades, digital IOP measurement was considered as an unreliable method due to its highly subjective nature and lack of standardization. Besides, its accuracy has never been validated.

Therefore, in the present single-blind study, we investigated the reliability of digital IOP measurement during vitrectomy in comparison to rebound tonometer, which is tolerable in many conditions. Besides, potential influence factors such as the level of surgeons' experience, lens status, and refractive status were also evaluated.

SUBJECTS AND METHODS

Ethical Approval This is a retrospective, single-blind study

conducted at the Peking University Third Hospital from February 2018 to June 2018. The protocol was approved by the Ethics Committee of the Peking University Third Hospital and followed the Declaration of Helsinki requirements. All patients provided written informed consent before the surgery.

Subjects and Clinical Examination Patients who were diagnosed with RD and scheduled for vitrectomy with SO injection were consecutively enrolled. Patients with primary glaucoma, ocular hypertension, uveitis, corneal diseases, a history of steroid use, as well as patients scheduled for combined surgical procedures such as scleral buckling, lens phacoemulsification or intraocular lens (IOL) implantation, were all excluded.

All the patients underwent a detailed, comprehensive ophthalmic examination, including best-corrected visual acuity, IOP, slit-lamp biomicroscopy, gonioscopy, binocular indirect ophthalmoscopy, fundus photography, and B-ultrasound scanning.

Surgical Procedure All the participants underwent 23-gauge standard 3-port pars plana vitrectomies under the retrobulbar anesthesia. After a complete vitrectomy and relief of vitreous traction, the posterior retina was flattened with perfluorocarbon liquid, and air-fluid exchange was performed if there was any subretinal fluid. Retinopexy was achieved by laser endophotocoagulation. All of the eyes were moderately filled with SO (Siluron 5000, Geuder AG, Heidelberg, Germany) and IOPs were adjusted to a normal range. Then the cannulas were withdrawn and the sclerotomies were sutured.

IOP Measurement After removal of the last trocar, all the patients had their IOPs digitally measured and then by a rebound tonometer in the supine position. Briefly, all surgeons were requested to gently palpate the corneal apex using their right index fingertips. By measuring the resistance of the eye to an applied force, the IOP values were estimated and then recorded as integer values. The IOP was subsequently measured with a rebound tonometer (IcarePRO, Tiolat Oy, Helsinki, Finland) by a trained examiner who was masked to the patient's clinical information. By automatically calculating an average of 6 sequential IOP measurements, the objective IOP values were obtained and blinded to the surgeons.

Data Collection The demographics, indications for surgery, refractive status, lens status, pre-existing eye disease, IOP measured by digital measurement and rebound tonometer during the vitrectomy as well as the experience of performing vitrectomy of the surgeons were collected. Patients were classified into subgroups according to their refractive status (with or without high myopia), lens status (phakic, aphakic, pseudophakic), and the levels of their surgeons' experience. Eyes requiring -6.0 diopters or more of lens correction were defined as having high myopia, and the levels of surgeons' experience were defined based on the years of performing vitrectomies.

Statistical Analysis Statistical analysis was performed using SPSS version 26.0 (SPSS Inc., Chicago, IL, USA). Continuous variables were presented as mean±standard deviation (SD); categorical variables were presented as frequencies and percentages (*n* and %). Paired *t*-test was used to compare the digitally measured IOP and the rebound tonometer readings. Correlations and agreement of IOP measured by these two methods were evaluated by intraclass correlation coefficient (ICC) analysis and Bland-Altman plot analysis. The ICC was defined as the absolute agreement to reduce systematic errors, and the two-way random-effects model was chosen so both people and measures effects are random. In a second step, the absolute deviation in IOP values measured by two methods was calculated and recorded as ΔIOP. Bivariate correlation analysis was used to evaluate the correlations between the ΔIOP and refractive status, lens status, levels of surgeons' experience. If significant correlations were detected, scatter plots and regression analysis were furtherly employed to quantify the strength and direction of these correlations. Independent *t*-test and one-way analysis of variance were used to compare the ΔIOP among different subgroups, Two-tailed values of $P<0.05$ were considered statistically significant.

RESULTS

A total of 131 patients (131 eyes) were consecutively recruited, with a mean age of 51.0±16.1y, among whom 85 were male (64.9%) and 46 were female (35.1%). RD occurred in the right eyes in 59 patients (45.0%) and the left eyes in 72 patients (55.0%). Indications for surgery included rhegmatogenous RD in 79 eyes (60.3%), recurrent RD in 15 eyes (11.5%), diabetic tractional RD in 17 eyes (13%) and traumatic RD in 20 eyes (15.3%). Seven surgeons who performed all the vitrectomies were allocated to four groups based on their levels of experience (years of performing vitrectomy). Concerning years of performing vitrectomy, two surgeons with less than 1 decade, two surgeons with 1 to 2 decades, two surgeons with 2 to 3 decades, and a single surgeon with more than 3 decades. Detailed basic demographics and clinical information are summarized in Table 1.

No significant difference was detected between the IOP readings of digital measurement and rebound tonometer (15.6±4.3 mm Hg *vs* 15.7±5.1 mm Hg; paired *t*-test, $t=0.406$; $P=0.686$). ICC analysis showed strongly correlation between these two measurements [ICC=0.830, 95% confidence interval (CI): 0.767-0.876; $P<0.001$]. Bland-Altman plot analysis also indicated a good inter-measurements agreement, with 95% limits of agreement ranging from -5.3 to 5.5 mm Hg (Figure 1). The mean absolute deviation between these two methods (ΔIOP value) was 2.0±1.9 mm Hg (range: 0-12.8 mm Hg), with 58

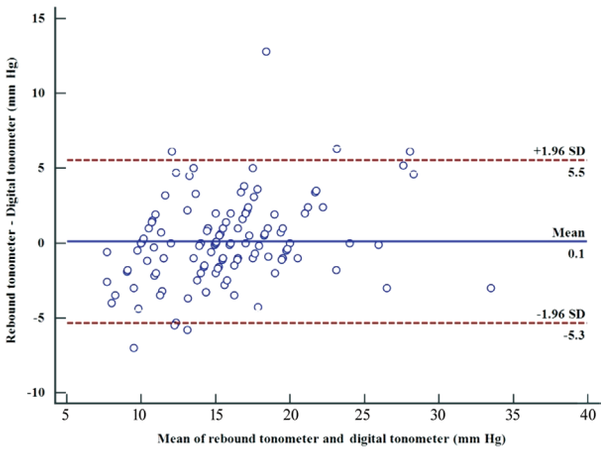

Figure 1 Bland-Altman plot of IOP measured by the rebound tonometer and digital tonometer The y-axis depicts the mean differences in IOP between the rebound tonometer and digital tonometer (rebound tonometer-digital tonometer) and the x-axis indicates the mean IOP measured by these two methods. The mean difference of rebound tonometer and digital tonometer was 0.1 mm Hg (the dark blue line), with 95% limits of agreement (±1.96 SD) ranging from -5.3 to 5.5 mm Hg (the reddish-brown lines). SD: Standard deviation.

Table 1 Basic demographic and clinical information of the patients

Parameters	Data
Age (y, mean±SD)	51.0±16.1
Gender, *n* (%)	
Male	85 (64.9)
Female	46 (35.1)
Eyes, *n* (%)	
Right	59 (45.0)
Left	72 (55.0)
Refractive status, *n* (%)	
With high myopia	32 (24.4)
Without high myopia	99 (75.6)
Lens status, *n* (%)	
Phakic	88 (67.2)
Aphakic	13 (9.9)
Pseudophakic	30 (22.9)
Level of surgeons' experience, *n* (%)	
Less than 1 decade	11 (8.4)
1 to 2 decades	61 (46.6)
2 to 3 decades	40 (30.5)
More than 3 decades	19 (14.5)

High myopia defined as eyes requiring -6.0 diopters or more of lens correction; Level of surgeons' experience: defined as the years of performing vitrectomy.

eyes (44.3%) have ΔIOP within 1 mm Hg, 98 eyes (74.8%) within 3 mm Hg, and 122 eyes (93.1%) within 5 mm Hg.

As to the subgroup analysis, significant correlations between these two measurements were also detected regardless of refractive status, lens status and levels of surgeons' experience.

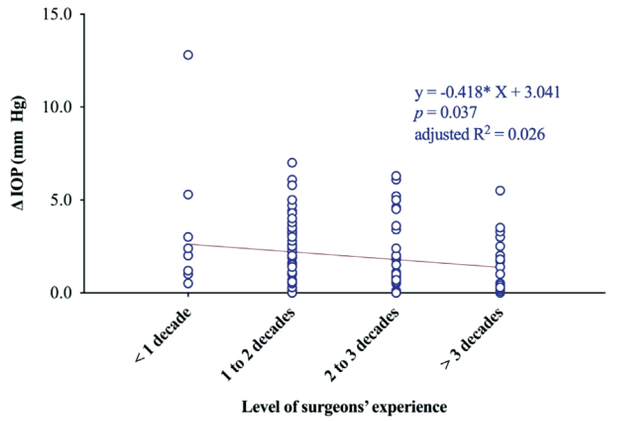

Figure 2 Scatter plot and linear regression analysis of the correlation between ΔIOP values and levels of surgeons' experience The linear regression analysis revealed a negative correlation between ΔIOP values and levels of surgeons' experience. The y-axis depicts ΔIOP values, indicating the absolute deviation in IOP values measured by the rebound tonometer and digital measurement. The x-axis indicates the levels of surgeons' experience defined as the years of performing vitrectomies. The reddish-brown line represents the regression equation: y=-0.418x+3.041 (adjusted R^2=0.026, P=0.037) indicating a weak negative correlation between levels of surgeons' experience and ΔIOP.

However, for pseudophakic eyes and cases performed by surgeons with less than 10y of experience, the correlations were not so strong as in other subgroups (ICC=0.594, ICC=0.752, respectively; Table 2).

Bivariate correlation analysis was performed to evaluate the correlations between ΔIOP and variables, including refractive status, lens status, and levels of surgeons' experience. The results showed that ΔIOP was negatively correlated with the levels of surgeon's experience (Pearson, r=-0.183, P=0.037), with the most experienced surgeon having the minimum ΔIOP values (1.6±1.5 mm Hg), consistent with the scatter plot and linear regression analysis (Figure 2). On the contrary, refractive status and lens status were found to have no significant correlations with ΔIOP (Spearman, both P>0.05).

We then compared ΔIOP values among different subgroups. Though pseudophakic eyes and cases performed by surgeons with less than 10y of experience had slightly higher mean ΔIOP, no significant differences in ΔIOP values were detected among subgroups with different refractive status, lens status or levels of surgeons' experience (all P>0.05). Table 3 summarized the detailed information about the ΔIOP values among different subgroups.

DISCUSSION

So far as we know, no clinical studies have specifically explored the reliability of digital IOP measurement in SO filled eyes. Therefore, we carried out the present study to determine if this technique might be an acceptable option for estimating

Table 2 Correlations between the digitally measured IOP and the rebound tonometer readings

Parameters	*n*	ICC and 95%CI	*P*
All subjects	131	0.830 (0.767-0.876)	<0.001
Refractive status			
With high myopia	32	0.812 (0.733-0.870)	<0.001
Without high myopia	99	0.875 (0.762-0.937)	<0.001
Lens status			
Phakic	88	0.883 (0.826-0.921)	<0.001
Aphakic	13	0.786 (0.427-0.930)	0.001
Pseudophakic	30	0.594 (0.302-0.784)	<0.001
Level of surgeons' experience			
Less than 1 decade	11	0.752 (0.292-0.927)	0.003
1 to 2 decades	61	0.772 (0.647-0.857)	<0.001
2 to 3 decades	40	0.863 (0.720-0.931)	<0.001
More than 3 decades	19	0.874 (0.590-0.956)	<0.001

ICC: Intraclass correlation coefficients; CI: Confidence interval. High myopia defined as eyes requiring -6.0 diopters or more of lens correction; Level of surgeons' experience: defined as the years of performing vitrectomy. $P<0.05$ was considered statistically significant.

Table 3 Comparison of the ΔIOP values among different subgroups

Parameters	*n*	ΔIOP (mm Hg)	*t*/*F*	*P*
Refractive status			1.313	0.192[a]
With high myopia	32	2.1±2.1		
Without high myopia	99	1.6±1.4		
Lens status			0.863	0.424[b]
Phakic	88	1.8±1.7		
Aphakic	13	2.2±1.8		
Pseudophakic	30	2.4±2.6		
Level of surgeons' experience			1.677	0.175[b]
Less than 1 decade	11	2.9±3.5		
1 to 2 decades	61	2.2±1.7		
2 to 3 decades	40	1.7±1.8		
More than 3 decades	19	1.6±1.5		

High myopia defined as eyes requiring -6.0 diopters or more of lens correction; Level of surgeons' experience defined as the years of performing vitrectomies; ΔIOP: The absolute deviation in digitally measured IOP and rebound tonometer readings; [a]Independent *t*-test; [b]One-way analysis of variance; $P<0.05$ was considered statistically significant.

IOP during the vitrectomy. Our results revealed a high level of agreement between digitally measured IOP and rebound tonometer readings, and this tendency was more prominent among experienced surgeons. The absolute deviation of the IOP readings between the two measurements was 2.0±1.9 mm Hg, with 98 eyes (74.8%) had their inter-methods differences within 3 mm Hg. As the first study to investigate the precision of digital IOP measurement in SO filled eyes, our results support it as a reasonable method for experienced surgeons during vitrectomy.

Not surprisingly, ΔIOP was found to be negatively correlate with the levels of surgeons' experience in this study (r=-0.183, P=0.037), with the most experienced surgeon had the minimum ΔIOP (1.6±1.5 mm Hg) and the highest inter-methods correlation (ICC=0.874; 95%CI: 0.590-0.956). As to the cases performed by the least experienced surgeons, the correlation between digitally measured IOP and rebound tonometer readings were not as strong as it was in other subgroups (ICC=0.752; 95%CI: 0.292-0.927). Higher ΔIOP was also observed in the least experienced group (2.9±3.5 mm Hg) though with no significant difference when compared with other subgroups (P=0.175). Consistent with a previous report, our findings suggested that digital assessment of IOP by palpation on the bare cornea is reliable when performed by experienced examiners, though the previous research was carried out on a cadaveric eye model[5].

Digital IOP measurement is somewhat like the digital palpation (finger tension). Digital palpation is a traditional technique performed by gently pressing both index fingertips onto the superior eyeball through the upper eyelid. So far as we know, digital palpation has been regarded as the most convenient and least expensive technique for IOP determination and still plays roles in many conditions, such as the diagnosis of IOP elevation in emergency settings, the approximate IOP evaluation for very young children, and remains the mainstay for IOP measurement among eyes with keratoprosthesis implantation[6-9]. Though there are doubts about its reliability, digital palpation remains as a reliable technique when performed by experienced examiners, and its accuracy could be improved through training[10-12]. Therefore, we assume that a similar IOP measurement should be available on the cornea. In our study, all the surgeons were masked to the study design and the rebound tonometer readings, and no train was made before performing the digital IOP assessment. It is reasonable to believe that if surgeons routinely perform digital IOP measurement and assess their estimation using an objective tonometer, a more accurate digital IOP evaluation may be acquired.

The latest vitrectomy machines have a built-in IOP control system, which can provide real-time evaluation of IOP and maintain the desired IOP values during the vitrectomy[13]. However, surgical procedures after SO injection, such as removing the trocars and sealing sclerotomies, all could cause unwanted leakage and IOP alterations. Therefore, even with the active pressure control design, IOP measurement may still

be necessary immediately after closure of the sclerotomies to renormalize the IOPs [14]. We believe that digital measurement may remain as an acceptable candidate for IOP estimation during the vitrectomy, especially in primary care settings where instruments are unavailable. Notably, though digital IOP measurement may be a reliable technique when performed by experienced surgeons, cautions should be taken when it is utilized by young surgeons with comparatively less experience.

No correlations between the ΔIOP and lens status or refractive status were detected, though relatively higher ΔIOP values (2.4±2.6 mm Hg) and weaker correlation between these two IOP measurements (ICC=0.594; 95%CI: 0.302-0.784) were observed in pseudophakic eyes[15]. The underlying explanations are unclear. It has been reported that corneal biomechanical properties such as corneal hysteresis and corneal resistance factor affect the IOP measurement[16-18]. For patients with pseudophakic eyes, the corneal incision during the cataract surgeries may affect the corneal hysteresis and corneal resistance factor, and thus may influence the accuracy of IOP estimation. However, these influences have only been observed during the early postoperative period[19]. Besides, with the vitreoretinal surgical procedure and SO injection[20], the influence of previous cataract surgeries may be minimized or even eliminated. We assume that, when the cornea is palpated by a fingertip, an implanted IOL may and interfere with the IOP evaluation by affecting the alteration of the cornea. However, the precision of rebound tonometer may not be influenced for its tiny probe (weighing about 24 mg), a limited radius of contact with the cornea (0.9 mm), and rapid measurement (within 0.25-0.35ms)[21-22]. Thus, the presence of IOL may help explain the weaker correlation between the two IOP readings in pseudophakic eyes.

The results also suggested that the precision of digital IOP measurement may not be affected by the presence of high myopia, which is relatively common in rhegmatogenous RD eyes. Exact explanation about this issue is unclear since little research has investigated these topics, and our results need to be confirmed by further studies.

In our study, the rebound tonometer (Icare PRO) was used as a criterion. Although Goldmann applanation tonometry (GAT) is the golden-standard method for measuring IOP, it is not available for patients with supine positions. Rebound tonometer has an excellent agreement with GAT readings in various conditions[21,23-27]; besides, we also detected a reasonably good correlation between the rebound tonometer and GAT in SO filled eyes previously[28]. As an updated version of rebound tonometer, it is reasonable to assume that the Icare PRO correlates well with GAT in SO filled eyes as its predecessors. Besides, the Icare PRO has advantages for its portable design and applicationin both the upright and horizontal positions[24,29-30], all of the above enabled the current study.

There are some limitations to this study. First, the relatively smaller sample size of the most and least experienced surgeon groups may bring bias to the study. Second, the retrospective nature of the study limited its evaluation of other factors that may influence IOP measurement, such as central cornea thickness. Third, our results might not generalize to all conditions as the surgeons in our study are all retinal specialists with relatively rich experience. Our results need to be confirmed by prospective, multi-center studies with larger sample size. Despite all these limitations, our study firstly investigated the precision of digital IOP measurement in SO filled eyes during vitrectomy and highlighted the necessity of considering specific conditions when incorporating it into clinical practice.

In conclusion, the present study suggests that, for experienced surgeons, digital IOP measurement may be a reliable technique for IOP evaluation during the vitrectomy. However, its precision may be influenced by the experience of the surgeons and the lens status. Digital IOP measurement performed by young surgeons with limited experience or among the pseudophakic eyes should be taken with cautions.

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