Comparison of intraocular pressure measured by ocular response analyzer and Goldmann applanation tonometer after corneal refractive surgery: a systematic review and meta-analysis

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Research article

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Abstract

Background: Accurate measurement of intraocular pressure (IOP) after corneal refractive surgery is of great significance to clinic, and comparisons among various IOP measuring instruments are not rare, but there is a lack of unified analysis. GAT is currently the internationally recognized gold standard for IOP measurement, while ORA is said to take into account the biomechanical properties of cornea. In this study, we conducted this meta-analysis to systematically assess the differences and similarities of IOP values measured by ORA and GAT in patients after corneal refractive surgery from the perspective of evidence-based medicine. Methods: The authors searched electronic databases (MEDLINE, EMBASE, Web of science, Cochrane library and Chinese electronic databases of CNKI and Wanfang) from Jan 2005 to Jan 2019, studies describing IOP comparisons measured by GAT and ORA after corneal refractive surgery were included. Quality assessment, subgroup analysis, meta-regression analysis and publication bias analysis were applied in succession. Results: Among the 273 literatures initially retrieved, 8 literatures (13 groups of data) with a total of 724 eyes were included in the meta-analysis, and all of which were English literatures. In the pooled analysis, the weighted mean difference (WMD) between IOPcc and IOPGAT was 2.67 mmHg (95% CI: 2.20~3.14 mmHg, $p < 0.0001$), the WMD between IOPg and IOPGAT was -0.27 mmHg (95% CI: -0.70~0.16 mmHg, $p = 0.2174$). In the subgroup analysis of postoperative IOPcc and IOPGAT, the heterogeneity among the data on surgical procedure was zero, while the heterogeneity of other subgroups was still more than 50%. The comparison of mean-ΔIOP is: mean-ΔIOPg > mean-ΔIOPGAT > mean-ΔIOPcc. Conclusions: IOPcc may be more close to the true IOP after corneal refractive surgery compared with IOPg and IOPGAT, and the recovery of IOPcc after corneal surface refractive surgery may be more stable than that after lamellar refractive surgery. Keywords: corneal refractive surgery; intraocular pressure; ocular response analyzer; Goldmann applanation tonometer; meta-analysis;

Background

Corneal refractive surgery has become an extremely popular procedure to correct ametropia, such as myopia and hyperopia[1]. Corneal refractive surgery is mainly divided into surface refractive surgery and lamellar refractive surgery. The former mainly includes Photorefractive Keratectomy (PRK), Laser-assisted Subepithelial Keratomileusis (LASEK) and Epipolis Laser in Situ Keratomileusis (EPI-LASIK), while Laser-assisted in Situ Keratomileusis (LASIK) and Femtosecond Laser-assisted LASIK (FS-LASIK) belong to the latter[2].

No matter what kind of refractive surgery the patient had undergone, their central corneal thicknesses (CCT) decreased, and corneal thickness affected the measured intraocular pressure (IOP)[3]. Therefore, the measurement of IOP after refractive surgery is one of the most challenging problems. In addition, there are risks of steroid-induced glaucoma and secondary keratoconus after corneal refractive surgery, so it is of great clinical significance to accurately measure postoperative IOP for the diagnosis and treatment of ophthalmology[4].

At present, there are several devices for measuring IOP, such as Goldmann applanation tonometer (GAT), noncontact tonometer (NCT)iCare rebound tonometer (iCare RBT) and Ocular Response Analyzer (ORA) etc.[5]. The measurement of GAT (IOP_{GAT}) is the internationally recognized golden standard for IOP measurement[6].

Measured values of IOP are affected by CCT as well as corneal biomechanical properties[5]. Both GAT and NCT have been reported to underestimate the IOP after the refractive surgery[1], while ORA is claimed to measure IOP independent of CCT[7]. During the measurement process, due to the dynamic characteristics of the pulsed airflow and the attenuation of corneal viscosity, the IOP values of the two flattening operations are inconsistent. The average value of these two flattening IOP measurements is Goldmann-correlated Intraocular Pressure (IOPg) and the difference is the corneal hysteresis (CH). The correction of IOP according to CH could reduce the measurement of IOP by corneal factors, that is, Corneal-Compensated Intraocular Pressure (IOPcc)[7, 8].

Many studies have been done on comparing the IOP measured by the GAT and ORA after the corneal refractive surgery. But each study is just for one or two types of refractive surgery, so the conclusions of each study are lack of integrity. Therefore, in this work, we gave a systematic review and meta-analysis on the three types of IOP (IOPcc, IOPg, IOP_{GAT}) measured by ORA and GAT after corneal refractive surgery, and hoped to draw a more comprehensive conclusion on IOP of post operation.

Methods

Search strategy

We searched foreign language electronic databases of MEDLINE, EMBASE, Web of science, Cochrane library and Chinese electronic databases of CNKI and Wanfang. The search terms used were "ocular response analyzer" or "ORA", "Goldmann applanation tonometer" or "GAT", "intraocular pressure" or "IOP". The publication period was from Jan 2005 to Jan 2019, and references to all of the retrieved literature are supplemented.

Two investigators (HZ and ZS) independently searched the studies, screened identified abstracts and articles in duplicate, extracted the available data from eligible studies, and assessed the study quality.

Inclusion and exclusion criteria

Studies describing IOP comparisons measured by GAT and ORA in their title or abstract were retrieved for full text review. Inclusions for analysis were restricted to: 1) study participants underwent corneal refractive surgery and IOP was measured with ORA and GAT after surgery; 2) mean and standard deviation of three IOP measurements (IOPcc, IOPg and IOP_{GAT}) can be extracted from studies. Exclusion criteria applied were as follows: 1) studies done before 2005; 2) reviews or animal studies; 3) studies with no definite follow-up time; 4) studies comparing IOP with other conditions such as glaucoma, keratoconus, diabetes; 5) studies reported by other language (non-Chinese, non- English).

Data extraction and quality assessment

The following available data were extracted from eligible studies: the name of first author and the year of publication (name/y), country in which the study was carried out (country), study design (retrospective or prospective), the number of eyes included in the study (sample size), mean and standard deviation of age (mean age±SD), surgical method, surgical procedure (lamellar corneal refraction surgery or surface corneal refractive surgery), postoperative follow-up time (post-op follow-up), and mean and standard deviation of IOP measurements (IOPcc, IOPg and IOP_{GAT}) after corneal refractive surgery. Any differences in data abstraction were resolved by consensus and discussion with the other authors.

The study quality was assessed by using the Quality Assessment for Diagnostic Accuracy Studies 2 (QUADAS2) checklist[9]. The patient selection risk of bias question 2 ("Was a case-control design avoided?"), and index test risk of bias question 2 ("If a threshold was used, was it prespecified?") were excluded from the checklist because they did not apply to the current review [10].

Statistical analysis

The effect was expressed by weighted mean difference (WMD) and 95% confidence interval (CI). The heterogeneity test was performed by chi-square test, and heterogeneity index (I^2) was used to assess heterogeneity quantitatively. If $p \geq 0.05$ and $I^2 < 50\%$, multiple sets of data were considered to be homogeneous, and fixed effect model was selected for calculation and combined effect quantity. On the contrary, it was considered that there was heterogeneity, and random effect model was selected for correction[11]. Publication bias was assessed via Egger precision-weighted linear regression. We also performed subgroup analysis and univariate meta-regression to explain possible sources of statistical heterogeneity when there were differences. The prespecified subgroups of interest were study design (retrospective compared with prospective), surgical procedure (lamellar corneal refractive surgery compared with surface corneal refractive surgery), and post-op follow-up (time ≤ 1 month compared with time > 1 month, time ≤ 3 months compared with time > 3 months). And meta-regression was also performed for these three study characteristics respectively. The quality assessment process was completed by Review Manager (version 5.3), and the rest of the analysis was performed by R programming language software (version 3.5.2).

Results

Search results

The method used to select the studies is shown in Fig 1. The initial search identified 273 studies (80 from MEDLINE, 48 from EMBASE, 125 from Web of Science, 12 from Cochrane, 1 from CNKI, 5 from Wanfang and 2 studies identified from reference lists). After removing duplicates, 150 citations were reviewed. A total of 142 publications were excluded for the following reasons: 112 did not belong to the comparison for IOP after corneal refractive surgery, 9 were conducted with animals, 15 were reviews, 3 were unable to extract the mean or standard deviation of the three kinds of IOP, 2 studies were in French without an English translation, and 1 without special follow-up time. Therefore, the meta-analysis was comprised of 8 full articles.

Study characteristics

The characteristics of the studies included in our analysis are presented in Table 1. Of the 8 articles, Kirwan's, Qazi's and Denise's all included data of different follow-up time, so there were 13 groups of data in this study. 5 of the 8 studies included were prospective and 3 were retrospective. Three of the studies were conducted in America and two studies were conducted in China, others were each in Ireland, Korea, and Iran. The sample sizes varied from 28 to 148, and the total was 724. The average age is between the 20 and 40 years old. The longest follow-up time was 12 months, the shortest was only 1 week, and the rest were 1 month, 3 months and 6 months respectively.

Quality assessment

The QUADAS2 tool was applied to assess for bias and the quality evaluation results of the included literatures are shown in Fig 2. The reference standard in five articles was highly biased[12-14, 17, 18] and the patient selection in only one article was highly biased [17]. For flow and timing, all literatures showed lowly biased[12-19]. In general, the quality of the included literatures is relatively high.

Analysis of postoperative IOPcc and IOP_{GAT}

Fig. 3 gave the forest plot of the correlation between postoperative IOPcc and IOP_{GAT}. There was significant heterogeneity among the groups of data ($p < 0.0001$, $I^2 = 71\%$), so the random effect model was used for analysis. In the pooled analysis, the WMD between IOPcc and IOP_{GAT} was 2.67 mmHg (95% CI: 2.20~3.14 mmHg, $p < 0.0001$, Fig 3). The Egger statistic ($p = 0.028$) revealed there was certain publication bias.

We performed subgroup analysis using the study design, surgical procedure and postoperative follow-up time as sub-group criteria respectively. In the subgroup analysis of postoperative IOPcc and IOP_{GAT}, as shown in Table 2, the heterogeneity among the data on surgical procedure was zero, while the heterogeneity of other subgroups was still more than 50%.

The meta-regression results showed no statistical significance for the effect of three characteristics (study design, surgical procedure, post-op follow-up) on heterogeneity, namely, study design ($p = 0.9747$), surgical procedure ($p = 0.0976$), post-op follow-up ($p = 0.2983$ (1 month), $p = 0.5096$ (3 months)).

Analysis of postoperative IOPg and IOP_{GAT}

Fig. 4 gave the forest plot of the correlation between postoperative IOPg and IOP_{GAT}. There also was little heterogeneity among the data of groups ($p = 0.0025$, $I^2 = 60\%$), and random effect model was used for analysis. In the pooled analysis, the WMD between IOPg and IOP_{GAT} was -0.27 mmHg (95% CI: -0.70~0.16 mmHg, $p = 0.2174$, Fig 4) and Egger statistics ($p = 0.1339$) showed no publication bias.

Although the Fig. 4 showed that there was some heterogeneity between IOPg and IOP_{GAT} after operation, there was no significant difference between them in general, so the heterogeneity between IOPg and IOP_{GAT} had not been analyzed.

Comparison of IOP pre- and post-operative surgery

In the 8 studies, only four groups of data[15-18] contain preoperative IOP and ΔIOP, where ΔIOP refers to the difference between the value IOP obtained from pre- and post-operation. The data were summarized in Table 3. Through the meta-analysis, the WMD between preoperative IOPcc and IOP_{GAT} was 1.52 mmHg (95% CI: 0.97~2.07 mmHg, $p < 0.0001$), and the WMD between preoperative IOPg and IOP_{GAT} was 1.16 mmHg (95% CI: 0.60~1.73 mmHg, $P < 0.0001$). And the three ΔIOP values from the largest to the lowest were shown as: mean-ΔIOPg = 3.83 mmHg, mean-ΔIOP_{GAT} = 2.65 mmHg, mean-ΔIOPcc = 1.43 mmHg.

Discussion

With the rapid development of corneal refractive surgery technology and the improvement of social living standards, more and more myopic patients choose to undergo the refractive surgery to improve their vision. Meanwhile, the importance of accurately measuring the IOP after corneal refractive surgery for guiding clinical medication and timely discovering secondary diseases is gradually recognized by more and more ophthalmologists [1, 3]. Therefore we conducted a systematic review and meta-analysis on comparison of IOPcc, IOPg and IOP_{GAT} after corneal refractive surgery to gain a more comprehensive conclusion on postoperative IOP.

In the matter of comparison between IOPg and IOP_{GAT} after corneal refractive surgery, our result showed that there was no significant difference between IOPg and IOP_{GAT}. That was consistent with most previous studies [3, 14-17, 19]. In addition, almost all studies have suggested that IOP_{GAT} was highly dependent on corneal thickness [14, 18-20], so it was reasonable to believe that IOPg was also associated with corneal thickness.

In terms of the comparison between IOPcc and IOP_{GAT} after corneal refractive surgery, our study showed that IOPcc was 2.56 mmHg higher than IOP_{GAT} in general, and the difference between IOPcc and IOP_{GAT} was statistically significant. The relationship between IOPcc and IOP_{GAT} after surgery was also consistent with the existing studies [14-17, 21]. This might be because IOPcc was a measurement of IOP that removed the effect of corneal thickness [21].

After refractive surgery, in spite of the cornea became thinner, there was no significant change in the generation and flow of aqueous humor, that is, there had little effect on the aqueous humor circulation, so the IOP should not have a great change[22]. That is to say, it was feasible to compare the difference of IOP before and after surgery to indicate which IOP measurement was more in line with the real IOP postoperative. Our study showed the comparison results of the mean-ΔIOP were: mean-ΔIOPg > mean-ΔIOP_{GAT} > mean-ΔIOPcc, and mean-ΔIOP_{GAT} was 1.645 times that of mean-ΔIOPcc. So we could assume that IOPcc might be closer to real IOP after corneal refractive surgery. With regard to this aspect, previous studies[4] have also mentioned lower percent change in IOPcc measured before and after surgery, and it suggested that IOPcc could partially compensate for the biomechanical properties of the cornea.

The choice of the type of corneal refractive surgery is limited by many factors such as the diopter of patient and corneal thickness[23]. Generally, the corrected diopter of corneal lamellar refractive surgery is higher than that of surface refractive surgery. Moreover, the higher the corrected diopter is, the larger the amount of corneal cutting need to take, and the thinner the residual bed thickness of cornea is left. And relatively, the greater the amount of corneal cutting is, the more significant the changes of corneal biomechanical properties will be[2,24]. In addition, previous studies[25, 26] have proved IOP measurements were not only associated with CCT, but also affected by corneal mechanical properties. In the subgroup analysis of postoperative IOPcc and IOP_{GAT} on surgical procedures, the heterogeneity among the data after corneal surface refractive surgery was zero, while the heterogeneity after corneal lamellar refractive surgery was 87%. Compared with the IOPcc after the corneal lamellar refractive surgery, IOPcc after corneal surface refractive surgery was relatively stable. This result reminded us that the stability of IOPcc after different refractive surgery may be related to corneal biomechanics. Therefore, it was assumed that the biomechanical properties of cornea after surface refractive surgery may be more stable than those after lamellar surgery. Of course, more clinical data are needed to further substantiate the conclusion.

The use of hormones after corneal refractive surgery is the main influencing factor of steroid-type glaucoma, so monitoring of IOP is particularly important during the postoperative use of hormones [27]. Although the types of hormones used and the time of administration for different surgical methods are not the same, our literature-based research showed that there was no significant correlation between the follow-up time and the size of heterogeneity, regardless of the follow-up time of dividing line for one month or 3 months. Considering that there are many factors influencing the occurrence of glaucoma after corneal refractive surgery, the conclusion of this paper needs further verification of clinical cases.

Our reporting also had certain limitations. For instance, we did not consider the effect of sample size on the combined effect size, which might lead to the relatively dominant effect of large sample size data on the results. We also did not conduct meta-regression or subgroup analysis on the age of patients, the main reason was the corneal refractive surgery for patients with a certain age requirements. In general, 18 to 45 was the optimal age for the procedure, so the age of the patients in this study was too concentrated to be grouped again.

Conclusions

In summary, IOPcc may be more close to true IOP after corneal refractive surgery compared with IOPg and IOP_{GAT}. Moreover, In terms of postoperative recovery of IOP, IOPcc after corneal surface refractive surgery may be more stable than that after lamellar refractive surgery. Further research and validation through more clinical data are needed.

Abbreviations

PRK: Photorefractive Keratectomy; LASEK: Laser-assisted Subepithelial Keratomileusis; EPI-LASIK: Epipolis Laser in Situ Keratomileusis; LASIK: Laser-assisted in Situ Keratomileusis; FS-LASIK: Femtosecond Laser-assisted LASIK; CCT: Central corneal thickness; IOP: Intraocular pressure; GAT: Goldmann applanation tonometer; NCT: Noncontact tonometer; iCare RBT: iCare rebound tonometer; ORA: Ocular Response Analyzer; IOP_{GAT}: Intraocular pressure measured by GAT; IOPcc: Corneal-Compensated Intraocular Pressure; IOPg: Goldmann-correlated Intraocular Pressure; WMD: Weighted mean difference; CI: Confidence interval;

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

ZH and S-ZT independently searched and screened the literatures, extracted the available data from eligible studies, and assessed the study quality. ZH did the whole statistical analysis and article drafting. LL helped supervise the project and gave suggestions on revision of article. SR provided guidance for clinical knowledge of refractive surgery. Z-HX conceived the original idea, and gave critical revision of article.

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Tables

Table 1 Characteristics of studies included in the meta-analysis

Name/y	Country	Retrospective or prospective	Sample size	Mean age ±SD (years)	IOP(mmHg)			Surgical method	Lamellar or surface	Follow-up time
					IOPcc	IOPg	IOP_{GAT}			
Kirwan_a/2008[12]	Ireland	Prospective	90	35.6±9.3	13.1±1.9	10.2±2.1	9.6±1.7	LASIK	Lamellar	3 months
Kirwan_b/2008[12]	Ireland	Prospective	35	37.3±11.7	13.8±2.7	10.7±2.5	11.0±2.1	LASEK	surface	3 months
Fan/2011[13]	China	Retrospective	148	22.9±4.64	13.91±2.26	10.7±2.5	11.0±2.1	LASIK	Lamellar	6 months
Hong/2015[14]	China	Retrospective	50	21.8±5.9	15.3±2.4	12.5±2.1	13.0±2.3	LASIK	Lamellar	3 months
Pepose/2007[15]	America	Prospective	66	39.6±11.4	13.1±2.0	10.6±2.6	12.0±2.7	LASIK	Lamellar	1 week
Qazi_a/2009[16]	America	Prospective	28	39.0±12.0	13.37±2.53	11.29±3.08	11.53±2.45	LASIK	Lamellar	6 months
Qazi_b/2009[16]	America	Prospective	30	41.0±9.0	14.24±2.82	10.07±3.55	11.86±2.74	LASEK	surface	6 months
Denise_a/2011[17]	America	Prospective	51	36.0±8.0	16.40±2.43	13.16±3.08	13.82±2.56	EPI-LASIK	surface	1 month
Denise_b/2011[17]	America	Prospective	51	36.0±8.0	16.00±2.60	13.09±3.25	13.34±2.58	EPI-LASIK	surface	3 months
Denise_c/2011[17]	America	Prospective	51	36.0±8.0	14.66±2.30	11.73±2.56	11.86±2.71	EPI-LASIK	surface	6 months
Denise_d/2011[17]	America	Prospective	51	36.0±8.0	15.09±2.30	12.11±2.54	12.40±2.67	EPI-LASIK	surface	12 months
Shin/2015[18]	Korea	Retrospective	40	26.25±7.23	13.64±2.09	10.27±2.26	10.83±2.83	FS-LASIK	Lamellar	1 month
Zare/2012[19]	Iran	Prospective	33	26.9±5.0	15.25±3.24	14.15±2.73	12.42±2.14	PRK	surface	3 months

LASIK=Laser-assisted in Situ Keratomileusis; LASEK= Laser-assisted Subepithelial Keratomileusis; EPI-LASIK= Epipolis Laser in Situ Keratomileusis; FS-LASIK=Femtosecond Laser-assisted LASIK; PRK= Photorefractive Keratectomy

Table 2 Analysis results for each subgroup of IOPcc and IOP_{GAT}

Subgroup factor	Group standard	Number of data group	Q-value	p-value	I^2	95% CI
study design	retrospective	3	8.90	0.0117	77.5%	3.04 (2.02~4.05)
	prospective	10	25.86	0.0022	65.2%	2.54 (2.02~3.07)
surgical procedure	lamellar	6	38.97	0.0001	87.2%	2.61 (1.73~3.50)
	surface	7	0.37	0.9991	0%	2.69 (2.28~3.09)
post-op follow-up	>1 month	10	18.85	0.0265	52.3%	2.90 (2.48~3.32)
	1 month	3	8.23	0.0163	75.7%	2.12 (1.01~3.24)
	>3 months	5	12.36	0.0149	68.0%	2.83 (2.07~3.60)
	3 months	8	24.72	0.0009	72.0%	2.57 (1.96~3.18)
total		13	40.92	0.0001	71.0%	2.67 (2.20~3.14)

Table 3 Preoperative IOP and the change of IOP, the unit is mmHg

Name/y	Preoperative			Postoperative			IOPcc	IOPg	IOP_{GAT}
	IOPcc	IOPg	IOP_{GAT}	IOPcc	IOPg	IOP_{GAT}			
Pepose/2007[15]	15.4±3.2	15.2±3.4	13.8±3.3	13.1±2.0	10.6±2.6	12.0±2.7	2.1±2.6	4.6±2.7	2.6±2.2
Qazi_a/2009[16]	15.52±3.43	15.72±3.70	14.40±3.27	13.37±2.53	11.29±3.08	11.53±2.45	2.66±3.54	4.41±3.74	4.46±3.68
Denise_d/2011[17]	15.50±2.50	14.70±2.70	13.40±2.20	15.09±2.30	12.11±2.54	12.40±2.67	0.27±1.91	2.34±2.09	0.95±3.30
Shin/2015[18]	14.31±2.42	14.19±2.54	13.43±2.19	13.64±2.09	10.27±2.26	10.83±2.83	0.67±2.07	3.92±2.19	2.60±2.51

Figures

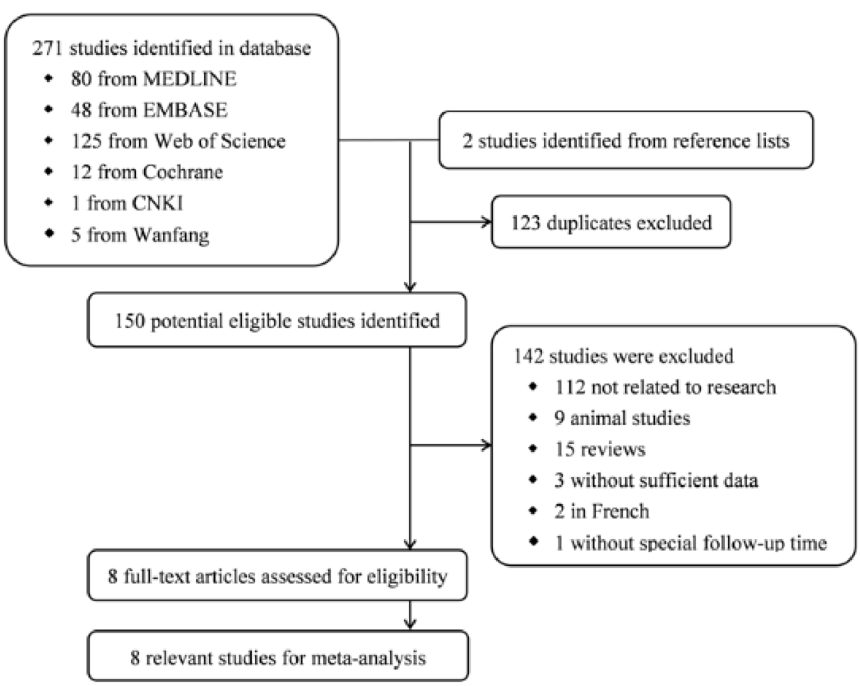

Figure 1

Flow chart of study identification, exclusion, and inclusion in the meta-analysis

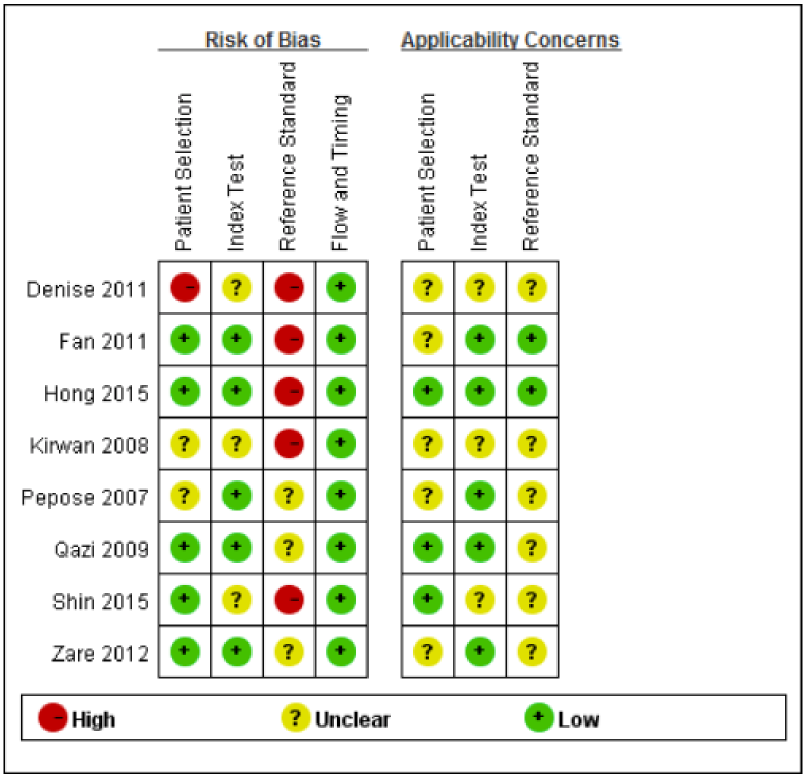

Figure 2

Quality assessment of studies included in the meta-analysis

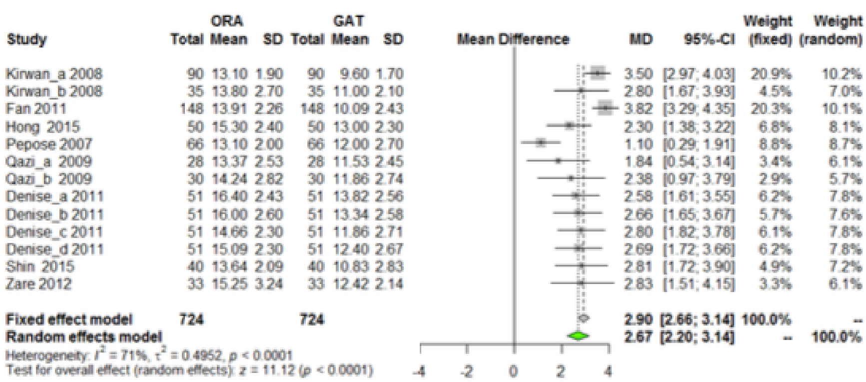

Figure 3

Forest plot of the correlation between postoperative IOPg and IOPGAT

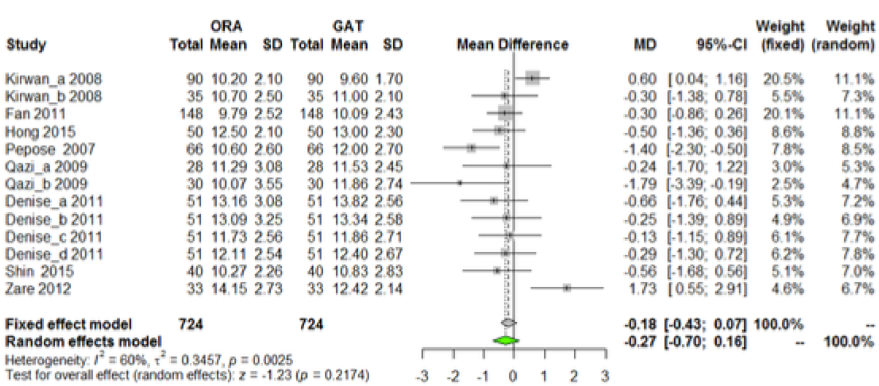

Figure 4

Forest plot of the correlation between postoperative IOPg and IOPGAT

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- supplement1.tiff
- supplement2.tiff
- supplement3.tiff
- supplement4.tiff
- supplement5.tiff
- supplement6.tiff