Influence of pupil dilation on the Barrett Universal II (new generation), Haigis (4th generation), and SRK/T (3rd generation) intraocular lens calculation formulas: a retrospective study

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Research article

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Abstract

Background: We investigated the effect of pupil dilation on predicted postoperative refraction (PPR) and recommended intraocular lens (IOL) power calculated using three different generations of IOL power calculation formulas: Barrett Universal II (Barrett) (new generation), Haigis (4th generation), and SRK/T (3rd generation). Methods: This retrospective study included 150 eyes. All variables were measured and calculated using a ZEISS IOL Master 700. The following variables were measured before and after dilation: anterior chamber depth (ACD), lens thickness (LT), white-to-white (WTW). PPR and recommended IOL power were calculated by Barrett, Haigis, and SRK/T IOL calculation formulas. The change in each variable before and after dilation, and correlations between all changes were analyzed using the Wilcoxon signed-rank test and the Spearman's rank-order correlation test, respectively. The influence of pupil dilation on recommended IOL power calculated by each formula was also analyzed. Results: The mean absolute change (MAC) in PPR before and after dilation was highest in Barrett, followed by Haigis and SRK/T. Significant differences were found among each MACs ($P < 0.0001$). Significant changes were observed before and after dilation in ACD and LT ($P < 0.0001$) but not in WTW. In Barrett and Haigis, there was a significant positive correlation between change in PPR and change in ACD ($P < 0.0001$) and a negative correlation between change in PPR and change in LT ($P < 0.0001$). Correlations were strongest in Barret followed by Haigis, especially in LT. Change in PPR in Barrett also demonstrated a significant positive correlation with change in WTW ($P = 0.022$). The recommended IOL power using Barrett and Haigis changed before and after dilation in 23.3% and 19.3% cases; SRK/T showed no change. Conclusions: In PPR and recommended IOL power, pupil dilation influenced Barrett most strongly, followed by Haigis and SRK/T. Given the stronger correlation between the change in PPR in Barrett and the change in ACD, LT, and WTW, the change of ACD, LT, and WTW is more important to the influence of dilation on Barrett. The influence of dilation on each formula and variable, including ACD, LT, and WTW, is key to improving IOL calculation.

Background

As patient expectations about the outcome of a cataract surgery increase, ophthalmologists need to pay special attention to the accuracy of predicted postoperative refraction (PPR). Various intraocular lens (IOL) calculation formulas are available, such as the third generation formula, SRK/T[1)]; the fourth generation formula, Haigis[2)]; and the new generation formula, Barrett Universal II.[3)] Many research papers studying the accuracy of the predictability of different IOL calculation formulas have been published.[4,5)] Most researchers state that Barrett Universal II is one of the most reliable IOL calculation formulas. [4,5)] Some studies have analyzed the influence of preoperative anterior chamber depth (ACD) on PPR in different IOL calculation formulas.[6,7)] They concluded that the influence of pre-operative of ACD on PPR varies from formula to formula. Other studies have examined the influence of pupil dilation on biometric parameters such as ACD, lens thickness (LT), white-to-white (WTW), and recommended IOL power using different IOL calculation formulas.[8,9,10)]. Thus, there are a small number of research papers which have compared the influence of pupil dilation on PPR and recommended IOL power calculated using the different generations of IOL calculation formulas, and different biometric parameters, such as ACD, LT and WTW. However, to the best of our knowledge, this is the first study to investigate the correlation between PPR and recommended IOL power in three different generations of IOL calculation formulas, and changes in the biometric parameters, ACD, LT and WTW. Given that the different generations of IOL calculation formulas include different biometric parameters, and they can be influenced by pupil dilation, further research in this area is of interest.

The purpose of this study was to analyze the influence of pupil dilation on biometric variables and recommended IOL power calculated using the Barrett Universal II, Haigis, and SRK/T formulas. Additionally, the correlation among all variables was investigated.

Methods

150 eyes in 81 patients were analyzed in this retrospective study. The average age was 72.9 ± 7.7 years (range: 51-87 years), and 39.6% of patients were men (Table 1). Cataract operations without any unexpected events were performed at two eye clinics (Yokosuka Chuoh Eye Clinic and Tsurumi Chuoh Eye Clinic). For all patients, monofocal acrylic single piece IOLs (SN60WF, Alcon Laboratories, Inc., Fort Worth, TX, USA) were inserted.

Table 1. Sex and age distribution

Parameters	Mean* [range]
Male, %	39.60%
Age, years	72.9±7.7 years [51 to 87]

* Data are presented as means ± standard deviations.

The ethical committees of both eye clinics approved this study. Consent to use their medical data for this research was given by all patients whose postoperative best-correction vision was higher than 20/40 without any history of eye problems and intraocular or corneal operations. This research followed the tenets of the Declaration of Helsinki in the entire data collection process.

All biometric variables, including ACD, LT, WTW, PPR, and recommended IOL power, were measured and calculated before and after pupil dilation using a ZEISS IOL Master 700 (Carl Zeiss Meditec AG, Jena, Germany). PPR and recommended IOL power were calculated using three different generations of IOL power calculation formulas: Barrett Universal II, Haigis, and SRK/T for SN60WF (Alcon Laboratories, Inc.), using a constant of 119.0 provided by the User Group for Laser Interference Biometry.

After the pre-dilation examination, topical tropicamide and phenylephrine (Midrin-P®, Santen, Osaka, Japan) were applied every 15 minutes. After full dilation, the post-dilation examination was performed.

The mean change in ACD, LT, and WTW, and the mean absolute change (MAC) in PPR for each formula was analyzed. The correlation of the variables above was also investigated. Additionally, the difference between the coincidence rate of recommended IOL power for each formula before and after pupil dilation was checked. Finally, based on the collected data above, the influence of pupil dilation on all variables was analyzed.

The Wilcoxon signed-rank test was used to compare changes in ACD, LT, and WTW and change in PPR for each formula before and after dilation. The Spearman's rank-order correlation test was used to investigate the correlation of the variables. The difference in recommended IOL power within ±0.5D was regarded as coinciding. Fisher's exact test was used to compare recommended IOL power. $P < 0.05$ was regarded as statistically significant. The Bell Curve for Excel, version 1.03 (Social Survey Research Information Co, Ltd., Tokyo, Japan) was used to analyze statistical data.

Results

The mean pre-dilation ACD, LT, and WTW were 3.08 ± 0.40 mm (range: 2.08–4.28 mm), 4.57 ± 0.46 mm (range: 3.44–5.87 mm), and 11.87 ± 0.37 mm (range: 10.8–12.8 mm), respectively (Table 2).

Table 2. Effect of pupil dilation on anterior chamber depth, lens thickness, and white-to-white

Parameters	Mean*, mm		Mean difference post- minus pre-dilation, mm	Number of eyes			
	Pre-dilation	Post-dilation		D** < 0	D = 0	D > 0	*P*
ACD	3.08 ± 0.40	3.14 ± 0.41	0.06 ± 0.03	0 (0.0%)	0 (0.0%)	150 (100.0%)	< 0.0001
LT	4.57 ± 0.46	4.55 ± 0.41	-0.02 ± 0.01	124 (82.7%)	24 (16.0%)	2 (1.3%)	< 0.0001
WTW	11.87 ± 0.37	11.88 ± 0.38	0.02 ± 0.11	49 (32.7%)	39 (26.0%)	62 (41.3%)	0.16

* Data are presented as means ± standard deviations.

** D is the difference post- minus pre-dilation.

ACD, anterior chamber depth; LT, lens thickness; WTW, white-to-white

Table 2 indicates the influence of pupil dilation on ACD, LT, and WTW. ACD and LT significantly changed after dilation ($P < 0.0001$), but WTW did not. There was a significant positive correlation between pre-dilation ACD and change in ACD (Spearman's rho = 0.25, $P = 0.0017$); however, a significant correlation was not seen between LT and WTW (Spearman's rho = 0.092, $P = 0.26$, and Spearman's rho = -0.016, $P = 0.85$, respectively) (Figure 1). MAC in PPR using each formula is shown in Table 3. MAC in PPR using Barrett Universal II was highest (0.047 ± 0.029), followed by Haigis (0.035 ± 0.019), and then SRK/T (0.0052 ± 0.0053). Significant differences were found among each MAC in PPR ($P < 0.0001$).

Table 3. Mean absolute change in predicted postoperative refraction between pre- and post-pupil dilation in the three formulas

Formulae	Mean absolute change*,
SRK/T	0.0052 ± 0.0053 D
Haigis	0.035 ± 0.019 D
Barrett	0.047 ± 0.029 D
* Data are presented as means ± standard deviations.	

P < 0.0001 for SRK/T vs. Haigis, SRK/T vs. Barrett, and Haigis vs. Barrett.

Using Barrett Universal II and Haigis, there was significant positive correlation between change in PPR and change in ACD (Spearman's rho = 0.95, *P* < 0.0001, and Spearman's rho = 0.93, *P* < 0.0001 respectively); however, this correlation was not observed with SRK/T (Spearman's rho = 0.029, *P* = 0.63) (Figure 2). On the other hand, when using Barrett Universal II and Haigis, there was a significant negative correlation between change in PPR and change in LT (Spearman's rho = -0.89, *P* < 0.0001, and Spearman's rho = -0.78, *P* < 0.0001, respectively); nonetheless, this tendency was not found with SRK/T (Spearman's rho = -0.063, *P* = 0.45) (Figure 3). There was a significant positive correlation between change in PPR and change in WTW using Barrett Universal II (Spearman's rho = 0.19, *P* = 0.022); this correlation was not found with Haigis and SRK/T (Spearman's rho = 0.14, *P* = 0.082, and Spearman's rho = 0.15, *P* = 0.067, respectively) (Figure 4).

The coincidence rates of recommended IOL power before and after pupil dilation in each formula are displayed in Table 4. The recommended IOL power changed after dilation in 23.3% of cases when using Barrett Universal II and in 19.3% of cases using Haigis. In all cases, recommended IOL power coincided before and after dilation when using SRK/T. The inconsistency rate when using Barrett Universal II and Haigis was significantly higher than SRK/T (*P* < 0.0001). The recommended IOL power changed more frequently with Barrett Universal II than with Haigis; however, the difference in coincidence rate was not significant.

Table 4. Coincidence of recommended IOL power between pre- and post-pupil dilation in the three formulas

	Number of eyes		
	SRK/T	Haigis	Barrett
Coincidence	150 (100.0%)	121 (80.7%)	115 (76.7%)
	0 (0.0%)	29 (19.3%)	35 (23.3%)

$P < 0.0001$ for SRK/T vs. Haigis or Barrett, and $P = 0.48$ for Haigis vs. Barrett.

IOL, intraocular lens; SRK/T

Discussion

In this study, PPR and recommended IOL power were differently influenced by pupil dilation when calculated using three different generations of formulas: Barrett Universal II, Haigis, and SRK/T. Barrett Universal II was the most sensitive to pupil dilation, followed by Haigis, whereas SRK/T was not influenced by pupil dilation. The change in ACD and LT before and after pupil dilation were more closely involved in influencing Barrett Universal II and Haigis. The change in WTW before and after pupil dilation only influenced Barrett Universal II.

Improvements in the accuracy of biomechanical measurements and PPR has gained attention, as they are important in choosing the most suitable IOL.[4),5)] Therefore, we must consider all factors that influence biomechanical variables and PPR.

Regarding the biomechanical parameters, different generations of IOL calculation formulas have different parameters to estimate the effective lens position (ELP), an important factor for PPR.[1-3)] Although the detailed components of the formulas are complex, the vital part for their comprehension is as follows. SRK/T uses corneal curvature radius and axial length (AL) to estimate ELP, which was published by Retzlaff et al. in 1990.[1)] ELP is estimated based on the ACD and AL in Haigis,[2)] and Barrett Universal II (new generation formula) uses AL, corneal curvature radius, ACD, LT, and WTW. [3)] Many studies have investigated the influence of pupil dilation on these biometric measurements.[8,10-16)] In a clinical setting, pupil dilation is a vital process of preoperative examination. Therefore, it is important to analyze its possible influence on PPR and recommended IOL power in third, fourth, and new generation IOL power calculation formulas, and to investigate the correlation between variables.

In many studies, AL and corneal curvature radius are not affected by pupil dilation.[10-12)] However, ACD has been reported to be influenced by pupil dilation.[10-14)] Compared to ACD, few studies have dealt with the influence of pupil dilation on LT and WTW. Wang X et al.[8)] demonstrated that LT was significantly affected by pupil dilation. The influence of pupil dilation on ACD and LT is logical because the ciliary and dilator muscles relax and contract, respectively, through pupil dilation, causing the lens to become thinner and the ACD to become deeper. It is controversial whether pupil dilation influences WTW. While Huang et al.[10] and Arriola-Villalobos et al.[15] have insisted that WTW is affected by pupil dilation, the opposite result has been reported by Wang et al.[8] Although the researchers attributed the discrepancy in the influence of pupil dilation on WTW to the examination error and imaging artifact, the real mechanism remains unknown.

In our study, while ACD significantly increased after dilation, LT significantly decreased, which are both consistent with other studies.[16] WTW did not significantly change. Regarding the influence of pupil dilation on PPR and recommended IOL power, the outcomes of previous studies are inconsistent, and also vary from formula to formula.[10,12,16,17],[18]

Rodriguez-Raton et al. showed that PPR was not affected by pupil dilation when using SRK/T, but was when using Haigis.[12] Adler et al. also indicated similar results.[17] These results were reasonable since SRK/T does not include ACD as a biometric parameter, which is significantly affected by pupil dilation, whereas, Haigis does. Our research also showed that while PPR did not change after pupil dilation when using SRK/T, PPR significantly changed when using Haigis. Concerning Barrett Universal II, although many studies have demonstrated its superior accuracy in calculating PPR compared to other formulas[4,5], studies investigating the influence of pupil dilation on PPR and recommended IOL power on Barrett Universal II have not been published. Our research indicated that the MAC in PPR was largest when calculated using Barrett Universal II, followed by Haigis, and SRK/T. This suggests that Barrett Universal II was the most sensitive to pupil dilation, followed by Haigis, and then SRK/T. The difference in the sensitivity to pupil dilation among the formulas was significant. This tendency was also seen in the coincidence of recommended IOL power in each formula before and after dilation. The recommended IOL power calculated by Barrett Universal II changed most frequently among the formulas, although it was not statistically significant between Barrett Universal II and Haigis. Although some studies have demonstrated that the recommended IOL power calculated with Haigis is significantly affected by pupil dilation, but not if calculated using SRK/T[10,12,16], our research is the first to show that Barrett Universal II may be even more sensitive to pupil dilation than Haigis, considering PPR and recommended IOL power.

The analysis of correlation between the change in PPR and the biometric variables indicated that the newer generation formula is more sensitive to pupil dilation. The change in PPR using Barrett Universal II and Haigis showed a significant positive correlation with the change in ACD and a significant negative correlation with the change in LT, but not with SRK/T. This tendency was more remarkable in Barrett Universal II. This result indicated that the change in ACD and LT significantly influenced the change in PPR in the formulas, which included ACD as a biometric parameter, and it was even more influential on the formula that included both ACD and LT as biometric variables. Additionally, the change in PPR when using Barrett Universal II indicated a significant positive correlation with the change in WTW, but not when using Haigis and SRK/T. This outcome was persuasive since Barrett Universal II was the only formula that included WTW as a biometric factor. Given the fact that all biometric factors, ACD, LT, and WTW, could be significantly influenced by pupil dilation, it is convincing that the more biometric parameters IOL calculation formula includes, the more influential pupil dilation is on the formula. As a result, recommended IOL power calculated by Barrett Universal II changed in many more cases after pupil dilation compared to Haigis and SRK/T.

Thus, there are biometric factors in the IOL calculation formula that are influenced by pupil dilation. In general, the more modern the generation formula is, the more biometric parameters are included. Barrett Universal II is said to be one of the most reliable IOL calculation formulas.[4),5)] However, this study demonstrated that since it includes more biometric variables compared to previous generation formulas, eye specialists must be familiar with these phenomena to improve the accuracy of IOL calculation.

This study has some limitations. First, the inclusion of data from both eyes of some patients in the study may have had a coupling effect in the statistical analysis. Second, different surgeons performed the surgeries, which may have affected the postoperative IOL position. Third, the influence of pupil dilation on prediction error in refraction was not analyzed, which would enable optimization of the constant for measurement with or without pupil dilation. This idea may be more useful to improve the accuracy of IOL power calculation. We plan to analyze this in our future research.

Conclusions

In our study, pupil dilation influenced Barrett most strongly, followed by Haigis and SRK/T, in terms of both PPR and recommended IOL power. Given the stronger correlation between the change in PPR when using Barrett and the change in ACD, LT, and WTW, the change of ACD, LT, and WTW is essential for the influence of dilation on Barrett. The influence of dilation on each formula and variables including ACD, LT, and WTW is key to improving the accuracy of IOL calculation.

List Of Abbreviations

ACD: anterior chamber depth; AL: axial length; ELP: effective lens position; IOL: intraocular lens; LT: lens thickness; MAC: mean absolute change; PPR: predicted postoperative refraction; WTW: white-to-white.

Declarations

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was approved by the ethical committee at Yokosuka Chuoh Eye Clinic and Tsurumi Chuoh Eye clinic.

CONSENT FOR PUBLICATION

Written informed consent for publication of their clinical details and/or clinical images was obtained from the patients. A copy of the consent form is available for review by the editor of this journal.

AVAILABILITY OF DATA AND MATERIALS

The datasets used and/or analysed during the current study are available from the corresponding author upon reasonable request.

COMPETING INTERESTS

The authors declare that they have no competing interests.

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AUTHORS' CONTRIBUTIONS

TT conceived the concept, designed, analyzed and interpreted the data, and was a major contributor in writing this manuscript. AM analyzed the data and interpreted the analyzed data. NM supervised the entire process in this study. All authors approved the final manuscript.

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Figures

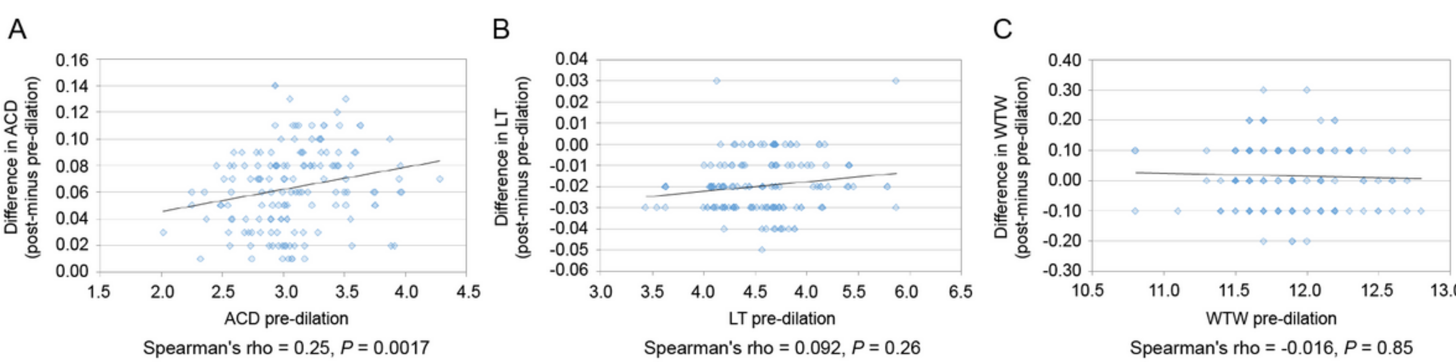

Figure 1

Correlation between change in ACD (A), LT (B), and WTW (C) and pre-dilation ACD (A), LT (B), and WTW (C).

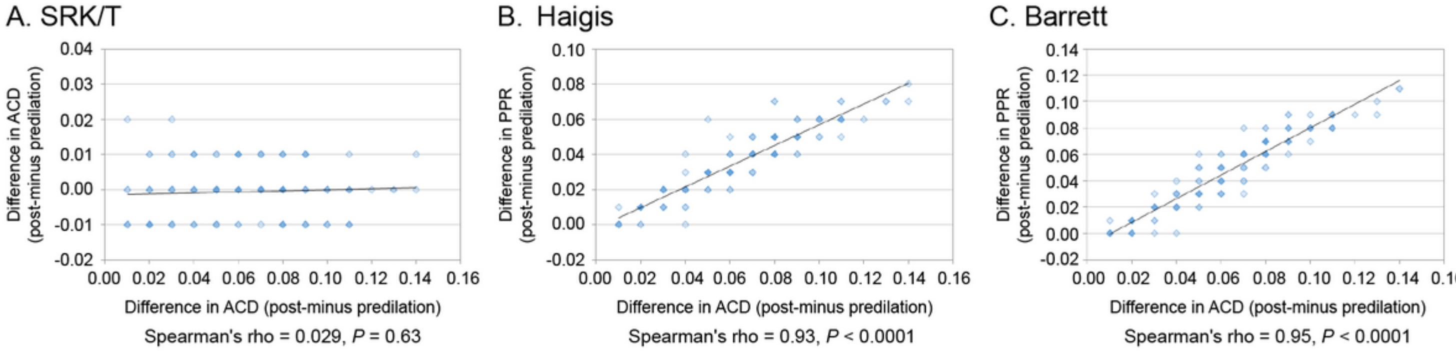

Figure 2

Correlation between change in ACD and change in PPD in SRK/T (A), Haigis (B), and Barrett (C).

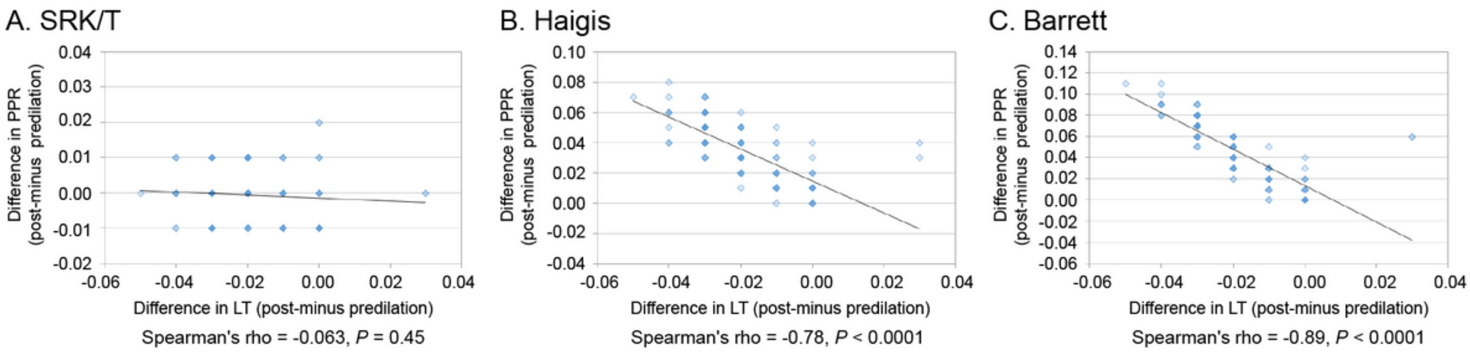

Figure 3

Correlation between change in LT and change in PPD in SRK/T (A), Haigis (B), and Barrett (C).

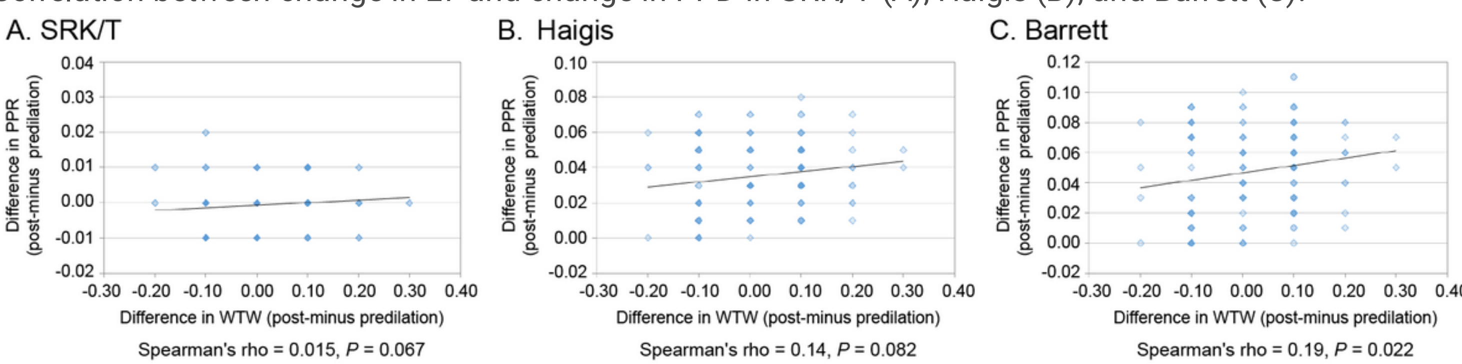

Figure 4

Correlation between change in WTW and change in PPD in SRK/T (A), Haigis (B), and Barrett (C).