GOLDMANN APPLANATION TONOMETRY AND CENTRAL CORNEAL THICKNESS:

A COMPARISON OF FOUR CORRECTION FACTOR FORMULAS

by

Leslie Cucuzza and Tracy Mills

This paper is submitted in partial fulfillment of the

requirements for the degree of

Doctor of Optometry

Ferris State University

Michigan College of Optometry

March 2005

ABSTRACT

PURPOSE: It is now widely accepted that measured intraocular pressure (IOP) varies in relation to central corneal thickness (CCT). This study compares four proposed formulas for adjusting the measured pressure to determine what, if any, statistical difference exists between the various methods when applied to matched sets of IOP and CCT measurements.

SUBJECTS AND METHODS: IOP and CCT values were measured in 66 eyes using Goldmann Applanation Tonometry (GAT) and ultrasound pachymetry. From the matched data sets obtained, correction values were calculated using four different formulas. The results were then compared using single factor analysis of variance and the Tukey-Kramer honestly significant difference (HSD) test to determine any statistical difference between the results of the four formulas.

RESULTS: No statistical difference exists between the results of the formulas proposed by Shimmyo, Herndon, and Stodtmeister. The results of the Ehlers formula were statistically different from the other three.

CONCLUSIONS: The results of three different formulas for the correction of measured IOP based on CCT are statistically the same. These formulas provide a more conservative adjustment of the measured pressure and are based on an assumed thicker "normal" average CCT.

ACKNOWLEDGEMENTS

Special thanks to the MCO Classes of 2005, 2006, and 2007, without whom we would not have a research paper, and also to Javier Falcon who re-taught us all the statistics we know.

TABLE OF CONTENTS

LIST OF TABLES

Introduction

Nearly 50 years ago Goldmann and Schmidt were the first to acknowledge that central corneal thickness could theoretically influence the measurement of intraocular pressure[1]. Although Goldmann discussed CCT as a possible source of error in measuring IOP, he dismissed the effect as insignificant[1,2]. Ehlers in 1975 proposed that the effect of CCT on GAT was noteworthy[3]. A thin cornea produces falsely low readings and a thick cornea causes falsely high measurements[3-9, 12]. While a subject of debate in the past[10], it has since become apparent that CCT is an important factor in the management and treatment of glaucoma and it is now widely accepted that the pachymeter is an essential tool. More recently, the results of the Ocular Hypertension Treatment Study[11] have inspired many experimental investigations aimed at quantifying the effects of CCT on measured pressures. Four proposed formulas are applied in this study.

Ehlers proposed a regression equation for the error of the GAT reading at 20 mmHg, as well as a table providing additive correction values for a give corneal thickness at GAT= 10, 15, 20, 25, and 30 mmHg. He also made the assumption that average corneal thickness was 520 microns. His regression equation at 20mmHg is as follows:

$$Y = 35.51 - 0.06833 * CCT$$

where Y is the correction factor and CCT is the measured corneal thickness[3].

Stodtmeister provided a slightly different nomogram:

$$Y= -(CCT-X)*5/70$$

In this formula, the number X is the mean CCT in microns found with the instrument used in a measurement series, with the assumption that the this will cancel differences in measurement by different pachymeters[5]. Y is the correction factor.

Herndon proposes the linear function:

$$Y= -0.05*CCT+27.5$$

This formula is based on an assumed "normal" CCT of 545 and proposes an adjustment of 1mmHg for each 20 micron difference[6]. Y is the correction factor.

Finally, Shimmyo[4] proposed the formula:

$$P= A+((550-CCT)/(18.1*e^{\wedge}-0.0122*A))$$

P is the adjusted IOP and A is the IOP. The correction factor (Y) is calculated using:

Y= adjusted pressure – measured pressure.

The above formulas are just four of many proposed methods of adjusting GAT readings for CCT. The clinician is left to decide which formula will be used in everyday practice. This study is designed to highlight any differences between the above methods when applied to matched data sets with the assumption that there is no statistical difference between them.

Methods

Thirty-three volunteers from the Michigan College of Optometry for a total of 66 eyes were involved in this study. The subjects were required to be at least 18 years of age with no sex or ethnicity requirements. Seven males and twenty-six females constituted the study. One drop of topical benoxinate HCl .4% with fluorescein sodium .25% was instilled prior to the procedures. Intraocular pressure (IOP) measurements were made using Goldmann Applanation Tonometry (GAT). Central Corneal Thickness (CCT) was measured using an ultrasound pachymeter (insert model here). In all methods it was randomized which eye was measured first. One of the researchers performed each GAT measurement and the other performed all of the pachymetry to ensure consistency of readings. The arithmetic mean of two measurements was used as the measured IOP, and the arithmetic mean of five measurements was used as the measured CCT. All calculations were performed using the Microsoft Excel for Office program available with the Windows 2000 Professional software package. The matched Measured IOP and CCT values are listed in Appendix A, Table 1.

Four correction methods were utilized in this study. Mean correction factor values for each set were evaluated using single factor analysis of variation (ANOVA), with the null hypothesis of no difference between each of the data sets. A post hoc Tukey-Kramer HSD test was administered to determine the mean or means that were statistically different, utilizing JMP 5.1.1 statistics software for Windows.

Results

The mean unadjusted IOP was 15.05 +/- 2.40 mmHg (range 11.0-19.5). Mean CCT was 548.47 +/- 33.19 microns. ANOVA of the four data sets gives F (15.68) > F_{crit} (2.64) indicating that there is a statistically significant difference between the mean correction factors. ANOVA of the four equations is presented in Appendix B, Table 2. A post hoc Tukey-Kramer HSD indicated that the results of the Ehlers formula were significantly different from the results of all others. (Appendix C, Table 3)

Discussion

The formula proposed by Ehlers provides the least conservative adjustment to the measured IOP for each patient. He proposes an adjustment of approximately 5mmHg for each 70 microns difference thickness from his assumed average CCT of 520 microns[3]. Doughty and Zaman[7] performed meta-analysis of 300 data sets from eyes designated as normal and found normal CCT to have a mean of 535 +/- 11.6% (474-597 microns). They also found that ultrasound pachymetry yields slightly higher average CCT (544 +/- 34 microns) than do slit-lamp (optical) based techniques (530 +/- 29 microns)[7]. Ehlers' formula was the only one based on optical pachymetry, and also the only formula assuming a mean CCT of less than 545 microns. This may explain the statistical difference from the other formulas used to calculate the correction factor.

The formula by Shimmyo is the only logarithmic formula included in the comparison. The lack of statistically significant difference between this formula and those by Herdon and Stodtmeister may be explained by realizing that throughout the "normal" range of CCT vs IOP, the regression line is virtually linear. It is only at extremely low or extremely high values of CCT and IOP that the non-linearity is appreciable.

One aspect discussed in the literature as useful in developing the correction factor for CCT verses IOP is corneal curvature. Shimmyo provides a formula for taking this into account, however as this is not included as a variable in all of the formulas we compared, it was not considered in this study.

Another point to consider is the inclusion in our data two matched sets of measurements from a post-LASIK cornea. This data was not excluded as the corneas in question were otherwise in apparent health, and the data points extended the range over which each formula was applied.

It is important to note that our data was obtained from a significantly younger population that that of the majority of other studies, not excluding those from which the IOP adjustment formulas were obtained. In the authors' opinion, any nomogram widely accepted for use in clinical practice should be applicable across all age ranges, as the literature at this point is inconclusive as to the effect of age on CCT. Note, however, that studies have demonstrated a decline in average CCT with age in Asian populations.

Of clinical importance is the difference between the formulas with regard to outcome significant adjustments. An outcome significant adjustment is defined by

Shih et. al.[13] as an adjustment of greater than 3.0 mmHg in either direction. The Ocular Hypertension Treatment Study suggests a 30% reduction in the risk of glaucoma with a 3 mmHg decrease in IOP[11]. The Ehlers formula results in outcome significant adjustments for a full 1/3 of the data sets, verses only three when utilizing the Herndon formula. These differences in outcomes emphasize the clinical importance of familiarity with the clinical research behind an adjustment formula prior to its application in clinical practice.

Overall, these authors believe that in clinical practice any adjustment to the measured IOP derived from the premise that thin corneas be adjusted up and thick be adjusted down is beneficial in the management of the various types of glaucoma. Based on our comparison of four proposed correction formulas we believe that in cases involving the classification and management of patients where IOP is a piece of the decision-making process, central corneal thickness values should be measured and measured intraocular pressures adjusted using a conservative nomogram.

APPENDIX A

MATCHED DATA SETS

Table 1

Measured IOP with Measured CCT

IOP	CCT	IOP	CCT	IOP	CCT	IOP	CCT
18	598	16.5	483	13	559	11	535
19	634	15.5	478	13.5	562	11.5	541
15.5	554	17.5	552	14.5	553	11.5	583
16	556	18	526	14	546	13.5	578
12	512	11.5	509	15	571	14.5	559
16	575	16.5	573	17.5	550	17	553
18	614	8	491	18	523	14	573
19.5	602	16	574	18	533	16	516
16	545	16	572	15.5	497	16	505
16	543	11.5	528	15	511	14	535
7.5	495	12.5	528	14.5	572	14	529
17	498	16	532	16	542	16	554
16	557	15	569	13	514	16	532
17	581	13	536	13	537	12	607
12.5	605	17.5	502	16	543	16	587
14	582	17	531	17.5	552	16	568
16.5	565	16	579				

Table 1: IOP are reported in mmHg. CCT are reported in microns.

APPENDIX B

CALCULATED CORRECTION FACTORS

Table 2

Calculated Correction Factors

IOP	CCT	Correction Factors			
		Stodtemeister	Shimmyo	Ehlers	Herndon
18	598	-3.53571429	-3.30319134	-5.2588	-2.4
19	634	-6.10714286	-5.85153992	-7.6564	-4.2
15.5	554	-0.39285714	-0.26699707	-2.3284	-0.2
16	556	-0.53571429	-0.4029461	-2.4616	-0.3
16.5	483	4.678571429	4.52709603	2.4002	3.35
15.5	478	5.035714286	4.80594734	2.7332	3.6
17.5	552	-0.25	-0.13679597	-2.1952	-0.1
18	526	1.607142857	1.65159567	-0.4636	1.2
13	559	-0.75	-0.58269735	-2.6614	-0.45
13.5	562	-0.96428571	-0.78168355	-2.8612	-0.6
14.5	553	-0.32142857	-0.19781962	-2.2618	-0.15
14	546	0.178571429	0.26215546	-1.7956	0.2
11	535	0.964285714	0.94775264	-1.063	0.75
11.5	541	0.535714286	0.57213096	-1.4626	0.45
11.5	583	-2.46428571	-2.09781352	-4.2598	-1.65
13.5	578	-2.10714286	-1.82392828	-3.9268	-1.4
13	536	0.892857143	0.90641809	-1.1296	0.7
13	537	0.821428571	0.84167394	-1.1962	0.65
12	607	-4.17857143	-3.64566697	-5.8582	-2.85
12.5	605	-4.03571429	-3.53927267	-5.725	-2.75
12	512	2.607142857	2.43044464	0.4688	1.9
11.5	509	2.821428571	2.60637438	0.6686	2.05
15	571	-1.60714286	-1.39321009	-3.4606	-1.05
14.5	559	-0.75	-0.59345887	-2.6614	-0.45
17.5	502	3.321428571	3.2831032	1.1348	2.4
17	498	3.607142857	3.53506533	1.4012	2.6
16	532	1.178571429	1.2088383	-0.8632	0.9
16	542	0.464285714	0.53726147	-1.5292	0.4
16	554	-0.39285714	-0.26863073	-2.3284	-0.2
16.5	565	-1.17857143	-1.01352896	-3.061	-0.75
16	575	-1.89285714	-1.67894209	-3.727	-1.25
16.5	573	-1.75	-1.55407774	-3.5938	-1.15
17.5	550	-0.10714286	0	-2.062	0

IOP	CCT	Correction Factors			
		Stodtemeister	Shimmyo	Ehlers	Herndon
16	543	0.392857143	0.47010379	-1.5958	0.35
16	557	-0.60714286	-0.47010379	-2.5282	-0.35
18	614	-4.67857143	-4.40425511	-6.3244	-3.2
19.5	602	-3.82142857	-3.64454592	-5.5252	-2.6
16	545	0.25	0.33578842	-1.729	0.25
16	543	0.392857143	0.47010379	-1.5958	0.35
7.5	495	3.821428571	3.32982998	1.601	2.75
8	491	4.107142857	3.59385523	1.8674	2.95
16	574	-1.82142857	-1.61178441	-3.6604	-1.2
16	572	-1.67857143	-1.47746904	-3.5272	-1.1
11.5	528	1.464285714	1.39854235	-0.5968	1.1
12.5	528	1.464285714	1.41570907	-0.5968	1.1
18	523	1.821428571	1.85804513	-0.2638	1.35
18	533	1.107142857	1.16988026	-0.9298	0.85
15.5	497	3.678571429	3.53771124	1.4678	2.65
15	511	2.678571429	2.58739016	0.5354	1.95
14.5	572	-1.67857143	-1.45067725	-3.5272	-1.1
14	573	-1.75	-1.50739392	-3.5938	-1.15
16	516	2.321428571	2.28336124	0.2024	1.7
16	505	3.107142857	3.02209576	0.935	2.25
14	535	0.964285714	0.98308299	-1.063	0.75
14	529	1.392857143	1.37631619	-0.6634	1.05
16	587	-2.75	-2.48483429	-4.5262	-1.85
14	582	-2.39285714	-2.09724371	-4.1932	-1.6
17	531	1.25	1.29165849	-0.7966	0.95
17.5	552	-0.25	-0.13679597	-2.1952	-0.1
16	568	-1.39285714	-1.2088383	-3.2608	-0.9
15	569	-1.46428571	-1.26052341	-3.3274	-0.95
13	514	2.464285714	2.33078938	0.3356	1.8
16	532	1.178571429	1.2088383	-0.8632	0.9
16	579	-2.17857143	-1.94757282	-3.9934	-1.45
17	581	-2.32142857	-2.10744279	-4.1266	-1.55

APPENDIX C

SINGLE FACTOR ANALYSIS OF VARIANCE

Table 3

Single Factor Analysis of Variance

ANOVA: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ehlers	66	-129.365	-1.96008	4.886243
Herndon	66	5.05	0.076515	2.754017
Shimmyo	66	5.633332	0.085354	4.880758
Stodtmeister	66	0.142857	0.002165	5.620443

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	201.2088	3	67.06959	14.78813	6.42E-09	2.639325
Within Groups	1179.195	260	4.535365			
Total	1380.404	263				

Null hypothesis states that there is no statistically significant difference between the four formulas. $F > F_{crit}$ disproves the null hypothesis. Alpha = .05.

APPENDIX D

TUKEY-KRAMER HONESTLY SIGNIFICANT DIFFERENCE TEST

Table 4

Tukey-Kramer Honestly significant Difference Test:
Comparrison for all pairs using Tukey-Kramer HSD

	Shimmyo	Herndon	Stodtemeister	Ehlers
Shimmyo	-0.9586	-0.9498	-0.8754	1.0868
Herndon	-0.9498	-0.9586	-0.8842	1.0780
Stodtemeister	-0.8754	-0.8842	-0.9586	1.0037
Ehlers	1.0868	1.0780	1.0037	-0.9586

Values are Abs(Dif)-LSD.
Positive values show pairs of means that are significantly different.

REFERENCES

1. Goldmann VH, Schmidt TH. Uber Applanationstonometrie. Ophthalmologica. 1957; 134:221-42.

2. Goldmann VF, Schmidt TH. Weiterer Beitrag zur Applanationstonometrie. Ophthalmologica. 1961; 141: 441-56.

3. Ehlers N, Bransen T, Sperling S. Applanation Tonometry and Central Corneal Thickness. Acta Ophthalmologica 1975;53:34-43.

4. Shimmyo M, Ross AJ, Moy A, Mostafavi R. Intraocular pressure, Goldmann applanation tension, corneal thickness, and clrneal curvature in Caucasians, Asians, Hispanics, and African Americans. Am J Ophthalmol. 2003 Oct; 136(4): 603-13.

5. Stodtmeister RS. Applanation tonometry and correction according to corneal thickness. Acta Opthalmologica Scandinavica. 1998; 319-24.

6. Herndon L. Rethinking Pachymetry and Intraocular Pressure.: Central corneal thickness is more variable among clinically normal patients than was originally realized. Review of Ophthalmology.

7. Doughty MJ, Zaman ML. Human Corneal Thickness and Its Impact on Intraocular Pressure Measures: A Review and Meta-analysis Approach. Survey of Ophthalmology. 2000 Mar-Apr; 44(5): 367-408.

8. Argus WA. Ocular Hypertension and Central Corneal Thickness. Ophthalmology 1995 Dec; 102(12): 1810-12.

9. Colton T, Ederer F. The distribution of Intraocular pressures in the general population. Survey of Ophthalmology. 1980 Nov-Dec; 25(5): 123-29.

10. Feltgen N, Leifert D, Funk J. Correlation between central corneal thickness, applanation tonometry, and dirct intracameral IOP readings. BR J Ophthalmol 2001 Jan;85: 85-87.

11. Gordon, et. al. The Ocular Hypertension Treatment Study: Baseline Factors That Predict the Onset of Primary Open-Angle Glaucoma. Arch Ophthalmol. 2002 June; 120: 714-20.

12. Recep OF, Hasiripi H, Cagil N, Sarikatipoglu H. Relation Between Corneal Thickness and Intraocualr Pressure Measurement by Noncontact and Applanation Tonometry. J Cataract Refract Surg. 2001 Nov; 27: 1787-91.

13. Shih CY, Graff Zivin JS, Trokel SL, Tsai JC. Clinical Significance of Central Corneal Thickness in the Management of Glaucoma. Arch Ophthalmol. 2004 Sept; 122: 1270-5.