# THE EVALUATION AND THE EFFECT OF SURGICALLY INDUCED ASTIGMATISM IN PHACOEMULSIFICATION SURGERY

BY

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A thesis submitted in fulfilment of the requirement for the degree of Master of Health Sciences (Optometry)

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NOVEMBER 2020

# ABSTRACT

Three issues regarding surgically induced astigmatism (SIA) include the choice of SIA calculators, the relationship between SIA consistency with phacoemulsification technique variation, and the effect of SIA prediction error on toric IOL calculation. Phase I compared the individual SIA value and analysis report from SIAC, SIA2.1, SIA3.1, OC6.0 and VVC calculators. Mean difference and agreement between calculators were assessed. No significant differences in mean SIA between the calculators ($p$ = 0.71) were found. The 95% limit of agreement between calculators ranged from -0.006 to 0.005D. OC6.0 and VVC reported astigmatism analysis according to Alpins method, whereas SIAC, SIA2.1 and SIA3.1 were based on Holladay method. Holladay method calculators provided surgeons' SIA centroid which is the actual SIA. SIAC and SIA3.1 provided subset analysis of SIA. SIA2.1 and SIA3.1 provided coherence analysis which is a clinically relevant value to evaluate SIA consistency. Thus, SIA2.1 were used in Phase II and III of this study for its suitability to the study objective. In Phase II study, the relationship between SIA consistency and phacoemulsification technique variation were evaluated. The actual SIA and coherence of four surgeons were calculated. A questionnaire (PTechSIA) was developed, validated and used to collect information on the surgeons' surgical technique. Input from the PTechSIA were used to quantify the surgeons' phacoemulsification technique variation using technique variation score (TVS). Strong negative correlation between SIA coherence and TVS (Spearman's $r$=-0.95, $p$=0.05) were found, indicating that a consistent phacoemulsification technique contributed to a better SIA consistency. In Phase III, we evaluated the surgeons' SIA prediction error and its effect on toric IOL selection. SIA prediction error was observed in all four surgeons. Two surgeons had a statistically significant SIA prediction error in X and Y value ($p$ <0.01). This error resulted in different toric IOL selection in 85% of subjects. Furthermore, underestimation of SIA had resulted in higher IOL toricity selection and vice versa. From the three-phase study, all issues were addressed accordingly. SIA calculator with centroid and coherence analysis are suggested to determine surgeons' actual SIA and monitor the SIA consistency. A consistent surgical technique contributes to a high SIA consistency, and SIA prediction error significantly affects toric IOL selection. These findings justified the clinical significance and relevance of SIA value.

# خلاصة البحث

.

اللابؤرية الناجمة جراحيا (surgically induced astigmatism, SIA) لها تأثير مباشر على نتائج ما بعد الجراحة لعملية سحب الماء الأبيض بتقنية الفاكو. هناك ثلاث قضايا متعلقة بالـ SIA وهي: اختيار حاسبات SIA، والعلاقة بين اتساق الـ SIA مع تباين طرق سحب الماء الأبيض، وتأثير خطأ التنبؤ بالـ SIA على حساب العدسة البارزة (toric IOL) داخل العين. قارنت المرحلة الأولى للدراسة تقرير التحليل وقيمة الـ SIA الفردي لـ SIAC، و SIA2.1، و SIA3.1، و OC6.0، و VVC. تم حساب قياس القرنية لـ 80 شخصًا في الحاسبات، وتم تقييم متوسط الفرق والاتفاق بين الحاسبات. لم يتم العثور على فروق ذات دلالة إحصائية في متوسط الـ SIA بين الحاسبات ($p$=0.71). تراوح حد الاتفاق بنسبة 95٪ بين الحاسبات من -0.006 إلى 0.005 D. أبلغت OC6.0 و VVC عن تحليل للابؤرية وفقًا لطريقة ألباينس، واستندت SIAC و SIA2.1 و SIA3.1 على طريقة هولاداي. قدمت حاسبات طريقة هولاداي النقطة الوسطى لـ SIA الجراحين وهو الـ SIA الفعلي. قدم كل من SIAC و SIA3.1 تحليلا للمجموعة الفرعية لـ SIA. قدم SIA2.1 و SIA3.1 تحليلا للتماسك وهو قيمة ذات صلة إكلينيكية لتقييم اتساق الـ SIA. وبالتالي فقد تم استخدام SIA2.1 في المرحلتين الثانية والثالثة من هذه الدراسة لملاءمتها وفقًا لهدف الدراسة. تم في دراسة المرحلة الثانية تقييم العلاقة بين اتساق الـ SIA وتباين طرق سحب الماء الأبيض. تم حساب الـ SIA الفعلي والتمسك النهجي لأربعة جراحين. تم إنشاء استبيان والتحقق من صحته واستخدامه لجمع المعلومات حول الطريقة الجراحية للجراح. تم استخدام المدخلات من الاستبيان لتحديد تباين طرق سحب الماء الأبيض بين الجراحين من خلال طريقة تسجيل النقاط المعروفة باسم درجة اختلاف الطرق (technique variation score, TVS). تم العثور على علاقة سلبية قوية بين تمسك الـ SIA وTVS ($r$=-0.95 ، $p$= 0.05 لسبيرمان)، مما يشير إلى وجود طريقة متسقة لسحب الماء الأبيض والتي ساهمت في اتساق أفضل لـ SIA. في المرحلة الثالثة ، قمنا بتقييم خطأ توقع الـ SIA للجراحين وتأثيره على اختيار العدسة البارزة داخل العين. تمت ملاحظة أخطاء في التنبؤ بالـ SIA عند الجراحين الأربعة كلهم. كان لدى اثنين من الجراحين خطأ تنبؤ ملحوظ ($p$<0.01) مع خطأ تنبؤ SIA حسابي بلغ 0.31 D و -0.44 D على التوالي. أدى هذا الخطأ إلى اختيار مختلف للعدسة البارزة داخل العين في 85٪ من المرضى، بالإضافة إلى أن التقليل من تقدير الـ SIA قد أدى إلى اختيار عدسة بارزة أعلى، والعكس صحيح. من خلال هذه الدراسة المكونة من ثلاث مراحل، تم النظر في المسائل المتعلقة بالـ SIA وفقًا لذلك. تم اقتراح حاسبات SIA مع نقاط مركزية لـ SIA وتحليل التمسك الـ SIA الفعلي للجراحين ومراقبة اتساق SIA. ساهمت الطرق الجراحية المتسقة في زيادة اتساق الـ SIA ، واتضح أن الخطأ في تنبؤ الـ SIA قد يؤثر بشكل كبير على اختيار العدسة البارزة داخل العين. بررت هذه النتائج الأهمية الإكلينيكية والعلاقة القوية لقيمة الـ SIA.

# APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Health Sciences (Optometry).

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# DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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# ACKNOWLEDGEMENT

All glory to Allah the Almighty, whose Grace, Mercies, and Guidance have enlightened me throughout this study. The prayers and salams are always offered for our beloved Prophet Muhammad p.b.uh, and his relatives and companions.

I am deeply grateful to my respected supervisor, Asst. Prof. Dr. Md. Muziman Syah bin Md. Mustafa and Assoc. Prof. Dr. Khairidzan Mohd. Kamal for the golden opportunity to pursue this study under their supervision. All the endless guidance and support throughout the ups and downs were precious, so as the trust given to me. Thank you for the inspiration to be an enthusiast, as well as for all the support in terms of facilities, knowledge and guidance. Forever I will be indebted to both of you and only Allah could repay your kindness.

My heartfelt gratitude goes to all staff of IIUM Eye Specialist Clinic who have been very supportive throughout the whole data collection process making it smooth and finally able to be completed successfully. Also to all members of Department of Optometry and Visual Science for the direct and indirect contribution to my study progress.

Massive gratitude to my parents, Marzuki bin Ahmad and Dyg Jemaah binti Awg Ibrahim of whom without I will not be where and what I am today. Thank you for the endless unconditional support, love and faith in me. To my dearest husband Darmadi bin Sahminan who have been my backbone to pass through all this, your understanding and sacrifices throughout this journey is something I will never able to repay, May Allah bless you in this world and hereafter. May we continue to share dreams and visions together while supporting each other endlessly. To Muhammad and Maryam, you both might not remember those moments where we had to leave everything and start a new life all over again, all so that your Mak could pursue her dream. But really without both of you, this journey will be much harder. Lastly for my dearie baby Mustofa, perhaps this thesis is your twin. Thank you for enduring the journey with me.

Once again, Alhamdulillah for His endless mercies bestowed upon us, in which this study has successfully come to completion.

# TABLE OF CONTENTS

Abstract ..... ii
Approval page ..... iv
Declaration ..... vi
Acknowledgement ..... viii
Table of Contents ..... ix
List of Tables ..... xiii
List of Figures ..... xiv
List of Symbols ..... xvi
List of Abbreviations ..... xviii

**CHAPTER ONE: INTRODUCTION ..... 1**
1.1 Study Background ..... 1
1.2 Justification ..... 4
1.3 Thesis Structure and Overview ..... 4
1.4 Aims ..... 7

**CHAPTER TWO: LITERATURE REVIEW ..... 8**
2.1 Astigmatism in Ocular Optical System ..... 8
2.1.1 Cornea Anatomy and Corneal Astigmatism ..... 8
2.1.2 The Crystalline Lens and Lenticular Astigmatism ..... 11
2.2 Cataract Surgery and Intraocular Lens ..... 13
2.2.1 Type of Cataract Surgery ..... 14
2.2.2 Intraocular-lenses Variation ..... 16
2.3 Surgically Induced Astigmatism ..... 18
2.3.1 Methods of SIA Calculation ..... 18
2.3.2 Graphical Representation, Consistency and Predictability Analysis of SIA ..... 27
2.3.3 Factors Associated with SIA Magnitude in Phacoemulsification ..... 34
2.3.4 Other Factors Influencing the Magnitude of SIA ..... 41
2.3.5 Clinical Relevance of SIA ..... 42
2.4 Current Practice of Qualitative Questionnaire Validation ..... 44
2.4.1 Face Validity ..... 44
2.4.2 Content Validation ..... 45

**CHAPTER THREE: PHASE I: THE COMPARISON OF SURGICALLY INDUCED ASTIGMATISM (SIA) VALUES AND SIA ANALYSIS REPORTS BETWEEN FIVE SIA CALCULATORS ..... 47**
3.1 Introduction ..... 47
3.2 Objectives ..... 48
3.2.1 General Objective ..... 48
3.2.2 Specific Objectives ..... 48
3.3 Research Hypothesis ..... 49
3.4 Study Area ..... 49
3.5 Study Design ..... 49

3.6 Sampling and Study Population ..... 49
3.6.1 Inclusion Criteria ..... 50
3.7 Sample Size Calculation ..... 50
3.8 Ethical Approval ..... 51
3.9 Tools and Instrumentation ..... 52
3.9.1 IOLMaster 700 ..... 52
3.9.2 SIA Calculator ..... 53
3.9.3 SIA Calculator Version 2.1 ..... 56
3.9.4 SIA Calculator Version 3.1 ..... 59
3.9.5 Peyman's Ophthalmology Calculator ..... 61
3.9.6 VECTrAK™ Vector Calculator Version 2.4.2 ..... 63
3.10 Procedures of the Measurement ..... 65
3.10.1 Corneal Power Measurement ..... 66
3.10.2 SIAC ..... 67
3.10.3 SIA2.1 ..... 67
3.10.4 SIA3.1 ..... 67
3.10.5 OC6.0 ..... 68
3.10.6 VVC ..... 68
3.11 Data Presentation ..... 69
3.12 Data Management and Analysis ..... 69
3.13 Results ..... 70
3.13.1 Distribution of Subjects ..... 70
3.13.2 Inter-Calculator Agreement ..... 71
3.13.3 Comparison of Calculator's Analysis Report ..... 72
3.14 Discussion ..... 75
3.14.1 Inter-calculator Agreement ..... 76
3.14.2 Comparison of Calculator's Analysis Report ..... 77
3.15 Conclusion ..... 79

**CHAPTER FOUR: PHASE II: THE ASSOCIATION BETWEEN PHACOEMULSIFICATION SURGICAL TECHNIQUES VARIATION WITH SIA CONSISTENCY ..... 81**
4.1 Introduction ..... 81
4.2 Objective ..... 82
4.2.1 Specific Objectives ..... 82
4.3 Hypothesis ..... 84
4.4 Study Area ..... 84
4.5 Study Design ..... 84
4.6 Sampling and Study Population ..... 84
4.7 Sample Size Determination ..... 85
4.8 Study Tools ..... 86
4.8.1 PTech-SIA Questionnaire ..... 86
4.8.2 IOLMaster ..... 86
4.8.3 SIA2.1 ..... 86
4.9 Study Procedure ..... 87
4.9.1 Development, Validation and Administration of PTech-SIA questionnaire ..... 89
4.9.2 Determination of Surgeons' Actual SIA and SIA Coherence ..... 91
4.10 Data Presentation ..... 91

4.11 Data Management and Analysis ..... 91
4.12 Results ..... 94
4.12.1 PtechSIA Questionnaire Development and Validation ..... 94
4.12.2 Phacoemulsification Technique Variation ..... 99
4.12.3 SIA Consistency ..... 99
4.12.4 The Relationship Between the Phacoemulsification Technique Variation with SIA Consistency ..... 105
4.13 Discussion ..... 107
4.13.1 PTechSIA Questionnaire Development and Validation ..... 107
4.13.2 Phacoemulsification Technique Variation Calculation ..... 109
4.13.3 SIA Consistency ..... 110
4.13.4 The Relationship Between the Phacoemulsification Technique Variation with SIA Consistency ..... 111
4.14 Conclusion ..... 112

**CHAPTER FOUR: PHASE III: THE INFLUENCE OF SURGICALLY INDUCED ASTIGMATISM PREDICTION ERROR ON TORIC INTRAOCULAR LENS SELECTION ..... 113**
5.1 Introduction ..... 113
5.2 Objectives ..... 114
5.2.1 General Objective ..... 114
5.2.2 Specific Objectives ..... 114
5.3 Hypothesis ..... 114
5.4 Study Area ..... 114
5.5 Study Design ..... 115
5.6 Sampling and Study Population ..... 115
5.7 Sample Size Determination ..... 116
5.8 Study Tools ..... 117
5.8.1 IOLMaster ..... 117
5.8.2 SIA2.1 ..... 117
5.8.3 Toric IOL Calculator ..... 117
5.9 Study Procedure ..... 120
5.9.1 Corneal Power Measurement and Determination of Surgeon's Actual SIA ..... 120
5.9.2 SIA Prediction Error ..... 120
5.9.3 Toric IOL Calculation ..... 121
5.10 Data Presentation ..... 122
5.11 Data Management and Analysis ..... 123
5.12 Results ..... 123
5.12.1 SIA Prediction Error ..... 123
5.12.2 Toric IOL Selection ..... 124
5.13 Discussion ..... 134
5.13.1 SIA Prediction Error ..... 134
5.13.2 Toric IOL Selection ..... 135
5.14 Conclusion ..... 138

**CHAPTER SIX: SUMMARY AND CONCLUSIONS ..... 139**
6.1 Introduction ..... 139
6.2 Summary of the Research Findings ..... 139

6.3 Contributions of the Study ..... 141
6.4 Limitation of the Study ..... 143
6.5 Suggestion for the Future Study ..... 144
6.5.1 Inclusion of Measured Posterior Keratometry ..... 144
6.5.2 Multicentre Studies ..... 144
6.5.3 Different IOL Platform ..... 144
6.6 Disclaimer ..... 144

**REFERENCES ..... 145**

**Appendix A ..... 158**
**Appendix B ..... 164**
**Appendix C ..... 166**
**Appendix D ..... 167**
**Appendix E ..... 170**
**Appendix F ..... 174**
**Appendix G ..... 176**
**Appendix H ..... 177**
**Appendix I ..... 178**
**Appendix J ..... 181**
**Appendix K ..... 183**
**Appendix L ..... 189**
**Appendix M ..... 196**

# LIST OF TABLES


| Table No. | | Page No. |
|---|---|---|
| Table 2.1 | Nomenclatures for SIA calculation | 19 |
| Table 2.2 | Summary of accepted methods to calculate SIA | 28 |
| Table 2.3 | SIA data sample | 29 |
| Table 2.4 | Summary of SIA plots characteristics | 33 |
| Table 2.5 | Summary of previous study on SIA magnitude from different incision size comparisons | 36 |
| Table 2.6 | Summary of previous study on SIA in different incision location comparison | 38 |
| Table 2.7 | Types of validity assessment | 41 |
| Table 2.8 | The Lawshe's table | 46 |
| Table 3.1 | Subject's demographic and astigmatism profile | 71 |
| Table 3.2 | The mean differences and 95% LOA of mean individual SIA values between calculators | 72 |
| Table 3.3 | Summary of all calculator's analysis reports | 74 |
| Table 3.4 | Comparison between centroid SIA calculated from SIAC, SIA2.1 and SIA3.1 | 75 |
| Table 4.1 | Content validation assessment | 96 |
| Table 4.2 | Surgeons' TVS results | 99 |
| Table 4.3 | Subject's demographic and astigmatism profile, SIA centroid and coherence of all surgeon | 101 |
| Table 4.4 | Surgeons' SIA coherence and TVS | 106 |
| Table 5.1 | Summary of predicted versus actual SIA and the SIA prediction error | 124 |
| Table 5.2 | Demographic, biometry and astigmatism profiles of the subjects | 125 |
| Table 5.3 | Toric IOL selection difference between predicted versus actual SIA for all surgeons | 127 |

# LIST OF FIGURES


| Figure No. | | Page No. |
|---|---|---|
| Figure 1.1 | Corneal incision and SIA | 2 |
| Figure 1.2 | Summary of the study flow | 6 |
| Figure 2.1 | The corneal dimension | 9 |
| Figure 2.2 | The corneal layer and thickness | 10 |
| Figure 2.3 | The crystalline lens. | 12 |
| Figure 2.4 | Astigmatic vector plot on cartesian coordinate | 22 |
| Figure 2.5 | Example of double angle plot | 29 |
| Figure 2.6 | Example of uniplot | 30 |
| Figure 2.7 | Example of Alpins single polar plot | 31 |
| Figure 3.1 | IOLMaster 700 | 53 |
| Figure 3.2 | The SIAC calculator | 55 |
| Figure 3.3 | SIAC analysis report generator interface | 56 |
| Figure 3.4 | Download page for SIA 2.1 and SIA3.1 | 57 |
| Figure 3.5 | The SIA 2.1 calculator | 58 |
| Figure 3.6 | The SIA3.1 calculat | 60 |
| Figure 3.7 | The OC6.0 calculator | 62 |
| Figure 3.8 | The VVC calculator | 64 |
| Figure 3.9 | The study flowchart | 65 |
| Figure 4.1 | Phase II flowchart | 83 |
| Figure 4.2 | Flowchart of the validation study | 87 |
| Figure 4.3 | Flowchart of the correlation study | 88 |
| Figure 4.4 | Example of PTechSIA scoring | 92 |
| Figure 4.5 | PTechSIA pilot questionnaire | 97 |

Figure 4.6 Finalized PTechSIA questionnaire 98

Figure 4.7 SIA double angle plot of Surgeon A 102

Figure 4.8 SIA double angle plot of Surgeon B 103

Figure 4.9 SIA double angle plot of Surgeon C 104

Figure 4.10 SIA double angle plot of Surgeon D 105

Figure 4.11 Scatterplot of TVS versus SIA Coherence 106

Figure 5.1 Sample of the ZCalc toric IOL calculation report/order request 119

Figure 5.2 Sample of the BTCalc toric IOL calculation report 120

Figure 5.3 Toric IOL selection difference between predicted versus actual SIA in Group 1 surgeon 128

Figure 5.4 Toric IOL selection difference between predicted versus actual SIA in Group 2 surgeon 128

Figure 5.5 IOL toricity selection in surgeons with SIA overestimation using ZCalc and BTCalc 129

Figure 5.6 IOL toricity selection in surgeons with SIA underestimation using ZCalc and BTCalc 129

Figure 5.7 IOL selection of surgeons according to astigmatism profile using ZCalc and BTCalc 131

Figure 5.8 IOL toricity selection according to astigmatism profile for Surgeon D using ZCalc and BTCalc 132

Figure 5.9 IOL toricity selection according to astigmatism profile for Surgeon C using ZCalc and BTCalc 132

Figure 5.10 Percentage of matched IOL selection according to astigmatism type for all surgeons using ZCalc and BTCalc 133

Figure 5.11 Simplified important findings on the effect of SIA prediction error towards toric IOL selection 133

Figure 5.12 Selection pattern difference between calculators 134

# LIST OF SYMBOLS

| | |
|---|---|
| % | Percentage |
| - | negative sign/ minus |
| μ | Micro |
| ° | Degree |
| ± | plus-minus |
| Hz | Hertz |
| α | Direction in degrees of the steeper corneal principal plane |
| ϕ | Direction in degree of the flatter corneal principal plane |
| M | Difference in power, expressed in diopters (D), between the steeper and the flatter principal corneal plane |
| X | X-axis value of astigmatic vector according to cartesian-coordinate based vector analysis |
| Y | Y-axis value of astigmatic vector according to cartesian-coordinate based vector analysis |
| Ω | The directions of planes under examinations using polar value methods |
| KP | The difference of dioptric components between two perpendicular keratometric/refractive planes using polar value methods |
| $^2$ | Square |
| + | positive sign/ plus |
| x | multiply |
| > | more than |
| < | less than |
| ≥ | more than and equal to |

| | |
|---|---|
| = | equal to |
| √ | square root |
| sin | sine |
| cos | cosine |
| tan | tangent |
| arctan | arc-tangent |
| Δ | difference/ detectable difference |
| ® | registered |
| ™ | trademark |
| $p$ | significant level |
| $n_e$ | number of SMEs rating a measurement item as *"essential".* |
| $N$ | the total number of SMEs who are involved in the content validity process. |
| n | sample size required |
| $Z_{\alpha/2}$ | 95% confidence interval with significant level of 0.05 |
| $Z_{1-\beta}$ | power of study |
| $\sigma$ | standard deviation |
| $r$ | coefficient of correlation |
| $J_0$ | Jackson cross-cylinder power, axes at 90° and 180° |
| $J_{45}$ | Jackson cross-cylinder power, axes at 45° and 135° |

# LIST OF ABBREVIATIONS

| | |
|---|---|
| ACD | anterior chamber depth |
| AE | angle of error |
| AL | axial length |
| ANOVA | analysis of variance |
| ATR | against the rule |
| BTCalc | Barrett Toric Calculator Version 2.0 |
| CI | correction index |
| CVI | content validity index |
| CVR | content validity ratio |
| D | dioptre |
| DC | dioptric cylinder |
| DS | dioptric sphere |
| DTC | distance to centroid |
| DV | difference vector |
| ECCE | extracapsular cataract extraction |
| EDOF | extended depth of focus |
| FI | flattening index |
| HTAA | Hospital Tengku Ampuan Afzan |
| ICCE | intracapsular cataract extraction |
| ID | identification |
| IESC | International Islamic University Malaysia Eye Specialist Clinic |

| | |
|---|---|
| IIUM | International Islamic University Malaysia |
| IOS | index of success |
| IQR | interquartile range |
| K | keratometry |
| LASIK | laser in situ keratomileusis |
| LoA | limit of agreement |
| LRI | limbal relaxing incision |
| mm | milimetre |
| MSICS | manual small incision cataract surgery |
| OC6.0 | Ophthalmology Calculator 6.0 |
| PCI | partial coherence interferometry |
| PCIOL | posterior chamber intracocular lens |
| postop | postoperative |
| preop | preoperative |
| PTechSIA | Phacoemulsification technique related to SIA |
| RM-ANOVA | repeated measures analysis of variance |
| SD | standard deviation |
| SE | spherical equivalent |
| SIA | surgically induced astigmatism |
| SIA2.1 | SIA Calculator Verson 2.1 |
| SIA3.1 | SIA Calculator Version 3.1 |
| SIAC | SIA Calculator |
| SICS | small incision cataract surgery |
| SME | subject matter expert |
| SPSS | Statistical Package for the Social Science |
| SS-OCT | swept source optical coherence tomography |

| | |
|---|---|
| TIA | target induced astigmatism |
| TVS | technique variation score |
| U.K | United Kingdom |
| U.S.A | United Stated of America |
| VS | variation score |
| VVC | VECTrAK™ Vector Calculator Version 2.4.2 |
| WHO | World Health Organization |
| WTR | with the rule |
| ZCalc | ZCalc Online IOL Calculator Version 1.5.1.201511251206 |

# CHAPTER ONE

# INTRODUCTION

## 1.1 STUDY BACKGROUND

Cataract is one of the leading causes of reversible blindness (Lundström et al., 2015; Salowi, Goh, Lee, Adnan, & Ismail, 2015). Management of cataract includes removal and replacement of cataractous lens with an artificial intraocular lens (IOL) through a surgery. There are various cataract surgery techniques such as intracapsular cataract extraction (ICCE), extracapsular cataract extraction (ECCE) and phacoemulsification. The aim of cataract surgeries is to restore functional vision to cataract patients.

Despite the ability to restore functional vision, residual astigmatism remains an issue in cataract surgery. It is one of the main causes for postoperative residual refractive error (Chang, Su & Chen, 2015; Hashemi et al., 2016; Nikose, Saha, Laddha & Patil, 2018; Yoon, Kim, Lee & Nam, 2013). Several strategies employed by ophthalmic surgeons to correct pre-existing corneal astigmatism includes implanting toric IOL and performing limbal relaxing incisions (LRI). In addition, surgeons must understand that residual astigmatism can also be induced by cataract surgeries' main incision, which is known as surgically induced astigmatism (SIA).

Surgically induced astigmatism has a direct impact on postoperative astigmatism outcome and serves as an important parameter in toric IOL calculation. It is defined as the changes in both magnitude and axis of the principle meridian of corneal curvatures following a corneal incision (Hill, 2008). This happens when the cornea flattens along the incisional meridian, thus inducing astigmatism with axis 90 degrees apart from the incision location (Figure 1.1). The amount of SIA is calculated as the difference

between preoperative keratometry (K) and postoperative K. These astigmatic values are vectors that comprise of magnitude and direction, thus cannot be calculated using standard mathematical convention. Three accepted methods to calculate SIA is Naeser's polar method, Alpin's method and Holladay method of vector analysis (Hamer, Buckhurst & Buckhurst, 2017; Naeser, 2001). For clinical application of SIA, it has to be calculated using these valid calculation methods.

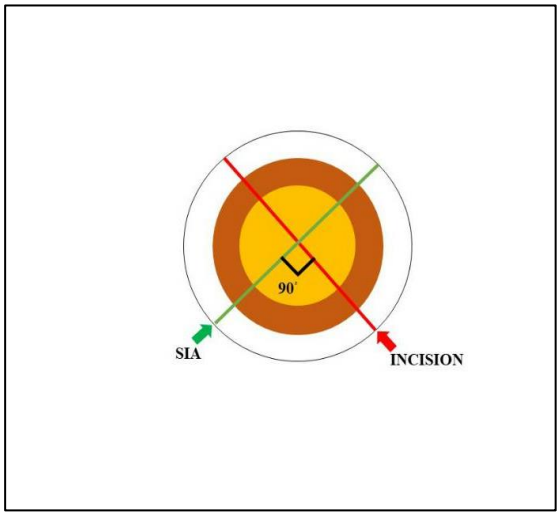


Figure 1.1 Corneal incision and SIA (Hill, 2008)

Various calculators are available to perform SIA calculation based on these methods. These calculators ease the process of SIA calculation, which can be tedious and prone to error if performed manually. However, the calculators provided different analysis report according to their respective calculation methods. To the best of our literature search, no study has compared the outcome between different calculators.

Previous studies have analysed various issues regarding SIA. It has been proven that multiple factors affected the magnitude of SIA such as incision size, incision location and corneal biomechanical properties (Chang, Su & Chen, 2015; Hashemi et

al., 2016; Nikose, Saha, Laddha & Patil, 2018; Yoon, Kim, Lee & Nam, 2013). In addition to this established knowledge, recent studies have raised concerns on the large standard deviation of SIA (Tanito, Matsuzaki, Ikeda & Fujihara, 2017; Visser, Berendschot, Bauer & Nuijts, 2012), implying SIA inconsistencies. These studies recommended that surgeons maintain a consistent surgical approach to achieve a consistent and predictable SIA, as consistent SIA could improve toric IOL prediction accuracy (Clark, 2018; Gundersen & Potvin, 2016). However, no studies have been conducted to verify the relationship between surgical technique variations with SIA consistency.

For toric IOL calculation, surgeons have the option to use predicted SIA or actual (calculated) SIA. Several recommendations and guidelines on the SIA values to be utilised were available from previous studies (Barret & Abulafia, 2014; Alcon Online Toric IOL Calculator, 2015). It was observed that these recommendations were incongruent, thus indicating that a predicted SIA might not represent the actual SIA. Therefore, recent studies have suggested the use of actual SIA and postulated that its application improved postoperative refractive outcome (Clark, 2018; Gundersen & Potvin, 2016). However, some surgeons might still adhere to the predicted SIA guidelines and recommendations, which potentially could lead to SIA prediction error. As to date, no study has been conducted to evaluate the effect of the discrepancies between predicted SIA and actual SIA on toric IOL calculation.

In order to assist the surgeon to minimise postoperative residual refractive error for their patients, the issues on SIA need to be addressed**.** This study intended to evaluate the agreement between various SIA calculators and their clinical applications. In addition to that, the relationship between surgical technique variation with the consistency of SIA was explored. Subsequently, the SIA prediction error and its effect

in toric IOL calculation were evaluated. Tackling these particular issues of SIA could contribute to the effort to achieve optimal postoperative vision in cataract surgeries.

## 1.2 JUSTIFICATION

Postoperative residual astigmatism remains as the main cause of patient's visual dissatisfaction (Chang, Su & Chen, 2015; Hashemi et al., 2016; Nikose, Saha, Laddha & Patil, 2018; Yoon, Kim, Lee & Nam, 2013). Surgically induced astigmatism is one of the crucial components in the planning of astigmatism correction (Clark, 2018; Gundersen & Potvin, 2016).

Several aspects of SIA were under-explored. The issue of SIA calculation remains a relevant concern. Due to the development of various SIA calculators which employs different methods and analysis report, an investigation is required to compare the outcome from different calculators and evaluate their suitable clinical application. In addition, the recommendations of applying a consistent surgical approach to achieve consistent SIA have not been verified through studies. A study is warranted to establish the relationship between surgical approach variations with SIA consistency. The discrepancies between predicted SIA and actual SIA have been evaluated in previous works. However, no study has evaluated the effect of this SIA prediction error on toric IOL selection, therefore, indicating a need for further investigation. Thus, this study is crucial to address these under-explored aspects of SIA.

## 1.3 THESIS STRUCTURE AND OVERVIEW

This thesis is structured into six chapters to address the issues in a stepwise manner. This is according to the nature of this study that was conducted in sequential phases.