

# TABLE OF CONTENTS

## CHAPTER 1- INTRODUCTION:

1. Motivation of the study.....	1
2. The crystalline lens and the accommodative system.	
2.1 Human and primate crystalline lens.....	4
2.1.1. Human Crystalline lens.	
2.1.2. Primate Crystalline lens.	
2.2 The accommodative mechanism.....	8
2.2.1. Different accommodative mechanism theories.	
2.2.2. Biometric changes during accommodation.	
2.3. The aging of the crystalline lens: presbyopia and cataracts.....	12
2.3.1. The aging lens.	
3. Imaging technique of the anterior segment of the eye: an overview.	
3.1. Tecnicas based on specular reflections from the ocular components	17
3.1.1. Corneal videokerastocopy.	
3.1.2. Keratometry.	
3.1.3. Purkinje imaging phakometry.	
3.2. Ultrasound based techniques.....	20
3.2.1. A-scan Biometry.	
3.2.2. Ultrasound biomicroscopy.	
3.3. Techniques based on low coherence interferometry.....	22
3.3.1. Partial coherence interferometry.	
3.3.2. Optical Coherence Tomography (OCT).	
3.4. Magnetic Resonance Imaging (MRI).....	24
3.5. Slit lamp biomicroscopy.....	25
3.4.1. Scanning slit corneal topography.	
3.4.2. Scheimpflug imaging.	
4. The optical quality of the normal human eye	
4.1. Optical Aberrations.....	28
4.2. Aberrometry.....	30
4.3. Total Aberrations.....	33
4.4. Corneal Aberrations.....	34
4.5. Interaction between Total and Corneal Aberrations.....	36
4.6. Misalignment of the ocular components.....	37
4.7. Sources of optical aberrations in the normal eye: state of the art	38
4.7.1. Ocular surface misalignments.	
4.7.2. Pupil centration.	
4.7.3. Corneal shape, corneal irregularities and refractive index.	
4.7.4. Crystalline lens shape, structure and refractive index.	

<b>5. The optical quality of the pseudophakic eye</b>	
<b>5.1. Cataract surgery.....</b>	<b>41</b>
<b>5.2. New designs of intraocular lenses.....</b>	<b>42</b>
<i>5.2.1. Monofocal intraocular lenses: spherical and aspheric surfaces.</i>	
<i>5.2.2. Multifocal intraocular lenses.</i>	
<i>5.2.3. Accommodative lenses.</i>	
<i>5.2.4. Other innovative pseudophakic IOL designs.</i>	
<i>5.3.5. Phakic lenses.</i>	
<b>5.3. Optical quality of eyes after cataract surgery.....</b>	<b>46</b>
<b>6. Hypothesis and goals of this thesis.....</b>	<b>47</b>

**CHAPTER 2- METHODS: CUSTOM-DEVELOPED PURKINJE APPARATUS FOR PHAKOMETRY AND LENS TILT AND DECENTRATION MEASUREMENTS.**

<b>1. Introduction.....</b>	<b>57</b>
<b>2. Purkinje Imaging.....</b>	<b>59</b>
<b>2.1. Optical Set Up.....</b>	<b>59</b>
<b>2.2. Purkinje image processing.....</b>	<b>62</b>
<b>2.3. Phakometry.....</b>	<b>63</b>
<i>2.3.1. The merit function.</i>	
<i>2.3.2. First Purkinje image height.</i>	
<i>2.3.3. Third double image height.</i>	
<i>2.3.4. The equivalent mirror theorem.</i>	
<i>2.3.5. Lens tilt and decentration.</i>	
<b>3. Validation of the technique by computer simulations.</b>	
<b>3.1. Test of phakometry methods using computer eye models.....</b>	<b>72</b>
<i>3.1.1. Effect of lens tilt and decentration.</i>	
<i>3.1.2. Effect of anterior and posterior corneal curvature.</i>	
<i>3.1.3. Effect of Anterior Chamber depth.</i>	
<i>3.1.4. Effect of lens thickness.</i>	
<b>3.2. Test of lens tilt/decentration methods using computer eye models....</b>	<b>75</b>
<b>3.3. Test of the validity of the assumptions in the model eye.....</b>	<b>76</b>
<i>3.3.1. Effect of anterior corneal asphericity.</i>	
<i>3.3.2. Effect of corneal irregularities.</i>	
<i>3.3.3. Effect of anterior and posterior lens asphericities.</i>	
<i>3.3.4. Effect of refractive gradient index in a realistic eye model.</i>	
<b>4. Preliminary tests in phakic and pseudophakic eyes</b>	
<b>4.1. Data acquisition.....</b>	<b>81</b>
<b>4.2. Subjects.....</b>	<b>83</b>

<b>4.3. Results of phakometry measurements in young eyes and on eyes of patients with IOLs.....</b>	<b>83</b>
<b>4.4. Crystalline lens tilt and decentration.....</b>	<b>84</b>
<b>4.5. Intraocular lens tilt and decentration.....</b>	<b>85</b>

## **5. Discussion.**

<b>5.1. Comparison with previous studies.....</b>	<b>86</b>
<b>5.2. Limitations of the technique and implication of the results.....</b>	<b>88</b>

## **CHAPTER 3- SCHEIMPFLUG IMAGING: OPTICAL DISTORTION CORRECTION**

<b>1. Introduction.....</b>	<b>99</b>
<b>2. Methods.</b>	
<b>2.1. Obtaining images from the raw data.....</b>	<b>103</b>
<b>2.2. Obtaining information about the Pentacam's configuration.....</b>	<b>103</b>
<b>2.3. Applying the distortion's correction algorithm.....</b>	<b>105</b>
<b>3. Results.</b>	
<b>3.1. Nodal points.....</b>	<b>107</b>
<b>3.2. Correction distortion algorithms.....</b>	<b>107</b>
<b>4. Conclusions .....</b>	<b>110</b>

## **CHAPTER 4- CRISTALLYNE LENS RADII OF CURVATURE FROM PURKINJE AND SCHEIMPFLUG IMAGING.**

<b>1. Introduction.....</b>	<b>119</b>
<b>2. Methods.</b>	
<b>2.1. Purkinje imaging.....</b>	<b>119</b>
<b>2.2. Scheimpflug imaging.....</b>	<b>120</b>
<b>2.3. Subjects.....</b>	<b>121</b>
<b>2.4. Experimental procedures.....</b>	<b>121</b>
<b>2.5. Statistical analysis.....</b>	<b>122</b>
<b>3. Results.</b>	
<b>3.1. Lens radii of curvature of the unaccommodated eye.....</b>	<b>123</b>
<b>3.2. Lens radii of curvature during accommodation.....</b>	<b>126</b>
<b>4. Discussion.....</b>	<b>128</b>

## **CHAPTER 5 - IOL TILT AND DECENTRATION MEASUREMENTS:. PURKINJE IMAGING VERSUS SCHEIMPFLUG IMAGING.**

<b>1. Introduction.....</b>	<b>139</b>
<b>2. Methods</b>	
<b>2.1 Purkinje imaging.....</b>	<b>140</b>
<b>2.2 Scheimpflug imaging.....</b>	<b>141</b>
<b>2.3 Physical model eye.....</b>	<b>141</b>
<b>2.4 Patients.....</b>	<b>142</b>
<b>2.5 Experimental protocols.....</b>	<b>142</b>

<b>3. Results.</b>	
<b>3.1. Purkinje imaging and Scheimpflug raw data.....</b>	<b>143</b>
<b>3.2. IOL tilt and decentration in the physical model eye.....</b>	<b>145</b>
<b>3.3 IOL tilt and decentration in patients' eyes.....</b>	<b>145</b>
<b>4. Discussion.</b>	
<b>4.1. Limitations of the techniques.....</b>	<b>148</b>
<b>4.2. Comparisons to previous studies and implications.....</b>	<b>149</b>

**CHAPTER 6 - CHANGES IN CRYSTALLINE LENS RADII OF CURVATURE AND CURVATURE AND LENS TILT AND DECENTRATIONS DURING DYNAMIC ACCOMMODATION IN RHESUS MONKEY.**

<b>1. Introduction.....</b>	<b>161</b>
<b>2. Methods.</b>	
<b>2.1. Animals.....</b>	<b>162</b>
<b>2.2. Measurements of current stimulus/accommodative response.....</b>	<b>162</b>
<b>2.3. Dynamic measurement of accommodation. ....</b>	<b>162</b>
<b>2.4. Dynamic biometric measurements.....</b>	<b>163</b>
<b>2.5. Dynamic measurement of phakometry and lens tilt and decentration</b>	<b>163</b>
<b>2.6. Experimental protocols.....</b>	<b>165</b>
<b>3. Results.</b>	
<b>3.1. EW stimulated accommodation.....</b>	<b>166</b>
<b>3.2. Dynamic photorefraction and biometry.....</b>	<b>167</b>
<b>3.3. Changes in lens tilt and decentration with accommodation.....</b>	<b>171</b>
<b>4. Discussion.....</b>	<b>172</b>

**CHAPTER 7 - CHANGE OF OPTICAL QUALITY WITH INTRAOCULAR LENS IMPLANTATION.**

<b>1. Introduccion.....</b>	<b>185</b>
<b>2. Methods</b>	
<b>2.1. Patients.....</b>	<b>187</b>
<b>2.2. Anterior corneal aberrations.....</b>	<b>188</b>
<b>2.3. Statistical analysis.....</b>	<b>189</b>
<b>3. Results.....</b>	<b>189</b>
<b>4. Discussion.....</b>	<b>198</b>

**CHAPTER 8 - CUSTOMIZED COMPUTER MODELS OF EYES WITH INTRAOCULAR LENSES.**

<b>1. Introduccion.....</b>	<b>209</b>
<b>2. Methods</b>	
<b>2.1. Subjects.....</b>	<b>211</b>
<b>2.2. Experimental measurements.....</b>	<b>212</b>
<b>2.2.1. Total aberrations measurements.</b>	
<b>2.2.2. Corneal topography.</b>	
<b>2.2.3. Optical biometry.</b>	
<b>2.2.4. IOL tilt and decentration.</b>	

2.2.5. Computer simulations.	
2.2.6. Physical eye model and computer simulations.	
<b>3. Results.</b>	
3.1. Individual geometrical data.....	<b>218</b>
3.2. Wave aberrations. Simulations vs real measurements.....	<b>218</b>
3.3. Individual Zernike coefficients.....	<b>223</b>
<b>4. Discussion.</b>	
4.1. Validation of the eye model and limitations.....	<b>227</b>
4.2. Relative contribution of cornea, IOL geometry and misalignment to eye rotation to ocular aberrations.....	<b>229</b>

**CHAPTER 9 - BALANCE OF CORNEAL HORIZONTAL COMA BY INTERNAL OPTICS IN EYES WITH INTRAOCULAR ARTIFICIAL LENSES: EVIDENCE OF A PASSIVE MECHANISM.**

<b>1. Introducción.....</b>	<b>239</b>
<b>2. Methods</b>	
2.1. Subjects.....	<b>241</b>
2.2. Corneal aberrations.....	<b>242</b>
2.3. Total aberrations measurements.....	<b>243</b>
2.4. Angle $\lambda$ , IOL tilt and decentration.....	<b>243</b>
2.5. Computer eye modelling.....	<b>244</b>
2.6. Data analysis.....	<b>244</b>
<b>3. Results.</b>	
3.1. Average compensation.....	<b>245</b>
3.2. Individual compensation.....	<b>246</b>
3.3. Effect of angle $\lambda$ .....	<b>248</b>
3.4. Effect of IOL tilt and decentration.....	<b>251</b>
<b>4. Discussion.....</b>	<b>253</b>
<b>CHAPTER 10 - CONCLUSIONS .....</b>	<b>259</b>
<b>CHAPTER 11 - BIBLIOGRAPHY. ....</b>	<b>275</b>

**PUBLICATIONS.**