MACULAR AND RETINAL NERVE FIBER LAYER ANALYSIS IN MAIN BUMIPUTERA ADULTS IN SARAWAK

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DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF THE MASTER OF MEDICINE (OPHTHALMOLOGY)

SCHOOL OF MEDICAL SCIENCES
UNIVERSITI SAINS MALAYSIA
2015

DISCLAIMER

I hereby certify that the work in this dissertation is my own except for quotations and summaries which have been duly acknowledged.

Dated: …………..………..………………………

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ACKNOWLEDGEMENT

First and foremost, I would like to thank God, who made all things possible.

I would like to convey my utmost gratitude to my supervisor, Professor Dr. Shatriah Ismail, who has provided me with proper guidance, moral support, and invaluable comments and ideas throughout the entire course of my thesis.

I also sincerely thank my co-supervisor, Dr. Mohamad Aziz Salowi (Ophthalmologist, Hospital Umum Sarawak), who has helped me in the completion of this dissertation.

My sincere appreciation as well to all the lecturers, consultants and specialists in the Ophthalmology Department from Universiti Sains Malaysia (USM) for providing their outstanding teachings, and guidance along the course of my work.

Last but not least, this dissertation could not have been completed without the patience and support from my beloved wife, Dr. Choy Yee Yi, my mother, Mdm. Liew Siew Ha, and my father, Mr. Chong Yam Hwa.

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ABSTRAK

Pengenalan

Tomografi koheren optik (OCT) diguna secara meluas dalam pengukuran ketebalan makula dan ketebalan lapisan gentian saraf retina (RNFL). Variasi ketebalan makula yang normal dan pangkalan data normatif ketebalan RNFL diketahui berbeza mengikut etnik. Walau bagaimanapun, faktor etnik masih belum dikaji dengan teliti. Sehingga kini, belum ada lagi kajian yang diterbitkan berkenaan data makula dan RNFL untuk kumpulan etnik utama bagi Bumiputera dari Sarawak, Malaysia.

Objektif

Tujuan kajian ini adalah untuk menentukan dan membandingkan ketebalan makula dan RNFL di kalangan kumpulan etnik utama Bumiputera di negeri Sarawak, Malaysia.

Kaedah Kajian

Kajian ini merupakan kajian berasaskan populasi keratan rentas yang dijalankan di Hospital Umum Sarawak dari Mac 2012 hingga November 2013. Sejumlah 338 subjek yang sihat darpada tiga kumpulan etnik utama Bumiputera di Sarawak (129 Melayu, 112 Iban, dan 97 Bidayuh) berumur dari 21 hingga 70 tahun telah direkrut. Ketebalan makula dan RNFL diukur menggunakan OCT Spectralis. Min ketebalan retina telah diperolehi mengikut peta sembilan Kajian Rawatan Awal Retinopati

Kencing Manis. Min ketebalan RNFL diperolehi mengikut keseluruhan kawasan, dua kuadran (nasal dan temporal), dan empat sub-kuadran (superior dan inferior).

Keputusan

Ketebalan makula pusat min adalah 272.64 ± 26.29 μm, 276.87 ± 27.48 μm, dan 275.80 ± 23.13 μm untuk subjek Melayu, Iban dan Bidayuh masing-masing. Terdapat perbezaan yang signifikan ketebalan makula min antara subjek Melayu dan subjek Iban di zon 'superior dalaman' (p = 0.014), 'inferior luaran' (p = 0.007), dan 'temporal luaran' (p = 0.014). Keseluruhan ketebalan RNFL min adalah 102.73 ± 11.92 μm, 104.73 ± 10.40 μm, dan 103.28 ± 11.34 μm untuk subjek Melayu, Iban, dan Bidayuh masing-masing. Terdapat perbezaan yang signifikan ketebalan RNFL min di kuadran temporal antara subjek Melayu dan subjek Iban (p = 0.016).

Kesimpulan

Ketebalan makula min adalah secara signifikan lebih nipis dalam kumpulan etnik Melayu berbanding dengan kumpulan etnik Iban di zon 'superior dalaman', 'inferior luaran', dan 'temporal luaran'. Ketebalan RNFL min dalam kuadran temporal adalah secara signifikan lebih nipis dalam kumpulan etnik Melayu berbanding dengan kumpulan etnik Iban.

ABSTRACT

Introduction

Optical coherence tomography (OCT) is widely used in the measurement of macula thickness and retinal nerve fiber layer (RNFL) thickness. The normal variation of macular thickness and the normative database of RNFL thickness are known to vary according to ethnicity. However, the ethnic influence has not been thoroughly evaluated. To date, there are no published studies on macular and RNFL data for the main Bumiputera ethnic groups from Sarawak, Malaysia.

Objective

The aim of this study is to determine and compare the macular and RNFL thickness among the main Bumiputera ethnic groups in the state of Sarawak, Malaysia.

Methods

This is a cross-sectional population-based study conducted in Hospital Umum Sarawak from March 2012 to November 2013. A total of 338 healthy subjects from three main Bumiputera ethnic groups in Sarawak (129 Malay, 112 Iban, and 97 Bidayuh) aged from 21 to 70 years old were recruited. The macular and RNFL thickness were measured using Spectralis OCT. The mean retinal thickness was obtained according to the nine areas of the Early Treatment Diabetic Retinopathy Study map. The mean RNFL thickness was acquired according to overall area, two quadrants (nasal and temporal), and four sub-quadrants (superior and inferior).

Results

The mean central macular thickness was 272.64 ± 26.29 µm, 276.87 ± 27.48 µm, and 275.80 ± 23.13 µm for Malay, Iban and Bidayuh subjects respectively. There was significant difference of mean macular thickness between the Malays subjects and Iban subjects in the superior inner (p = 0.014), inferior outer (p = 0.007), and temporal outer (p = 0.014) region. The overall mean RNFL thickness was 102.73 ± 11.92 µm, 104.73 ± 10.40 µm, and 103.28 ± 11.34 µm for Malay, Iban, and Bidayuh subjects respectively. There was significant difference of mean RNFL thickness in the temporal quadrant between the Malays subjects and Iban subjects (p = 0.016).

Conclusion

The mean macular thickness was significantly thinner in the Malay ethnic group compared to the Iban ethnic group in the superior inner, inferior inner, and temporal outer areas. The mean RNFL thickness in the temporal quadrant was significantly thinner in the Malay ethnic group compared to the Iban ethnic group.

Chapter 1

Introduction

1.1 OPTICAL COHERENCE TOMOGRAPHY

Within the last ten years, optical coherence tomography (OCT) has been gradually emerging as an objectively important non-invasive imaging modality providing high-resolution quantitative measurements of the macular thickness and retinal nerve fiber layer (RNFL) thickness under ideal condition. It is therefore becoming an important evolving tool in the diagnosis and monitoring of macular diseases and glaucoma (To *et al.*, 2011).

The time-domain (TD) OCT was the initial conventional OCT used in the management of retinal diseases. Beginning year 2002, the introduction of third generation OCT have seen major improvement in terms of providing higher scan resolution and faster scan speed as compared to conventional OCT (Mincheol *et al.*, 2010). In May 2002, the third-generation Stratus OCT received Food and Drug Administration clearance (Budenz *et al.*, 2007). In July 2003, the normative values for RNFL thickness were approved (Donald *et al*, 2007). In terms of measurement of macular thickness in healthy eyes, the values obtained from the third-generation OCT are higher than the values obtained using previous generations (Chan *et al.*, 2006).

Subsequently, the higher resolution spectral-domain OCT (SD-OCT) was introduced in clinical practice. SD-OCT also known as Fourier-domain OCT, collects data 100 times faster than conventional time-domain (TD) OCT, resulting in improved resolution (Grover *et al.*, 2009). Basically, this Fourier transformation–based technology is capable of simultaneous measurement of the light echoes. In the case of TD-OCT technology, the light echoes are measured sequentially. Thus, with the advent of SD-OCT, there is increased amount of data acquired at one point of time during the scanning session. The Cirrus OCT scans at 27,000 A-scans per second with 5µm axial resolution (Leung *et al.*, 2012). A Spectralis OCT scans at 40,000 A-scans per second with 7 µm axial resolution. This invariably prevents frequent interruption between individual scans. Eventually, the data obtained is adequate for three-dimensional imaging and volumetric analysis (Kiernan *et al.*, 2010).

SD-OCTs also possess the feature of enhanced measurement reproducibility. The Spectralis (Heidelberg Engineering, Vista, California, USA), one of the commercially available SD-OCT devices, which integrates the Trutrack technology, allows consistent point-to-point correlation between the OCT and the previous recent fundus images of the same individual. The scans are thus repeated in identical locations at different point of time (Grover *et al.*, 2009).

1.2 MACULA

Macula is an oval area at the center of the posterior part of the retina. The macula measures around 5mm in diameter and located 3mm to the lateral aspect of the optic disc. Conventionally, the boundary of the macula is the 5 to 6mm area with at least two layers of ganglion cells and is centred vertically between the temporal retinal vessels arcades.

The fovea is a depressed area located at the centre of the macula. The fovea measures about 1.5mm in diameter. This depressed area consists mainly of photoreceptors as the nerve cells and the fibers of the inner layers of the retina are displaced peripherally. Thus, the fovea area has the most distinct vision perceived specialising for high spatial acuity and for colour vision. Within the fovea, there is an area known as fovea avascular zone. This zone is taken as the centre of the macula. Thus, it is the point of fixation.

Surrounding the fovea is a ring of 0.5mm in diameter known as the parafoveal area. Here, the outer plexiform layer, the inner nuclear layer, and the ganglion cell layer are the thickest. Then, surrounding this parafoveal area is a ring of about 1.5mm wide. This area is known as the perifoveal zone.

1.3 RETINAL NERVE FIBER LAYER

The RNFL is formed by the expansion of the fibers of the optic nerve. These fibers are the extension of the ganglion cell layer. The axons of the ganglion cells course along the inner portion of the retina to aggregate in the posterior portion of the globe to form the optic nerve.

The axons of the ganglion cells converge towards the optic disc from superios, nasal, inferior and temporal direction in particular patterns. The superior, inferior, and nasal fibers of the ganglion cells enter in a fairly straight course. Temporal axons which originate from above and below the horizontal raphe will take an arching course towards the optic disc. The axons of the ganglion cells that arised from the nasal macula will course directly towards the optic disc. These nasal fibers form the papillomacular bundle prior entering the optic disc.

1.4 BUMIPUTERA IN SARAWAK

Bumiputera is a Malaysian term to describe the Malay race and other indigenous peoples of Malaysia. It defines only "Malay" and "indigenous peoples", "natives" of Sarawak, and "natives" of Sabah. Sarawak has more than fourty ethnic groups. Sarawak generally has seven major ethnic groups – Iban, Chinese, Malay, Bidayuh, Melanau, Orang Ulu and others. The minor ethnic groups would include Murut, Kedayan, Indian, Javanese and Bugis.

The Iban ethnic group comprise almost 30 percent of the total population of Sarawak. The Chinese community in Sarawak make up at least 24 percent of the total population and are classified as non-Bumiputera ethnic The Malays represent about 24 percent of the Sarawak population followed by the Bidayuh and Melanau ethnic group representing 8 percent and 5 percent of Sarawak population respectively. Orang Ulus, which consist of Kayan, Lun Bawang, Kelabit, Kenyah, Penan and Bisaya, represent only about 6 percent of the total population.

In terms of Bumiputera population, this includes the Iban, Malay, Bidayuh, Melanau, Orang Ulu, and the minority ethnic groups excluding Indian. Ibans are the main Bumiputeras, comprising 40 percent. Malay ethnic group make up 32 percent of Sarawak Bumiputeras and Bidayuh represent 11 percent of Bumiputeras in Sarawak.

1.5 OPTICAL COHERENCE TOMOGRAPHY IN RETINAL IMAGING

OCT is a non-invasive, non-contact imaging modality. It produces high resolution, cross-sectional images of ocular structures. OCT is based on imaging reflected light. The technique produces image from the backscattered light from different layers in the retina, while B-scan and radar imaging produce images from ultrasound waves. OCT measures the optical reflectivity using the principle of low-coherence interferometry while B-scan and radar imaging depends on acoustic or radio wave reflectivity.

OCT uses near-infrared light beam to form the measuring beam and the reference beam. The measuring beam is first directed into the posterior part of the eye where the retinal layers will reflect the beam to variable extent. The reference beam is then synchronised with the reflected reference beam returning from the retinal layer surface to create constructive interference. On the other hand, destructive interference is created from the reflections from the deeper structures. The interference will be interpreted as depth. The amplitude of reflection will be interpreted as brightness.

The indications of OCT in retinal imaging in clinical practice are mainly for detection of retinal diseases and monitoring of those diseases. It is indicated in the detection and monitoring of macular pathology such as macular hole and macular oedema. The macular morphology can be evaluated quantitatively and qualitatively (Tariq *et al.*, 2011). In the management of glaucoma, it is useful for detection of glaucomatous RNFL and optic disc changes.

The cross-section images of the retinal layers are represented by colour scheme. The colour range from red to white signifies highly reflective while the colour range from blue to purple shows that the particular layer is poorly reflective. The resolution for the Spectralis SD-OCT is 8μm.

1.6 MACULA THICKNESS

Macular oedema commonly causes visual loss due to abnormal fluid accumulation within the retina and increase in retinal thickness as a result of the breakdown of the blood-retina barrier (Chan *et al.*, 2006). Conventional method of evaluating for macular oedema with slit lamp biomicroscopy is relatively insensitive to small changes in retinal thickness and is only qualitatively assessed. The introduction of OCT will enable reliable detection and measurement of small changes in the macular thickness (Chan *et al.*, 2006) and quantitatively evaluate the efficacy of different therapeutic modalities (Song *et al.*, 2010). Due to its high resolution and reliability, OCT has become an important tool for diagnosing and monitoring various macular diseases (Kelty *et al.*, 2008).

When utilising OCT as an imaging tool in assisting the diagnosis of macula diseases, the imaging sessions would need the age-match normogram as point of reference. Prior to labeling the macula as abnormal, it is important to determine this range of normal macular thickness and the determinants of the macular thickness (Pradhan *et al.*, 2014).

In the past and at present, many studies have been conducted in various countries within the Asian continent in generating the normative data and establishing the determinants of the macular thickness. Most of the studies concluded that gender is the demographic determinant for the macular thickness. However, only a small number of similar studies established the association of age with macula thickness.

In India, Pradhan *et al.* (2014) conducted a study on 189 healthy Indians aged 25 to 79 concluded that females have thinner macula and the foveal thickness reduces with advancing age. In Pakistan, a study by Adhi *et al.* (2012) on 200 healthy subjects aged 16 to 18 years old suggested male have thicker macula but identified age is not associated with macula thickness. Choovuthayakorn *et al.* (2012) in Thailand studied 368 normal Thai people from 18 to 88 years old concluded males having thicker macula but found no association with age. In contrast, the study by Oshitari *et al.* (2007) comprising 31 healthy Japanese eyes aged 27 to 77 years old reported that gender is not a macula thickness determinant but described age as the determinant with positive correlation.

It has been reported that ethnicity has the influence on macular morphology (Huang *et al.*, 2009, Kelty *et al.*, 2008, Asefzadeh *et al.*, 2007, El Dairi *et al.*, 2009, Oshitari *et al.*, 2007). All these previous studies evaluated the differences of macular thickness in the Caucasians with the East Asians (Huang *et al.*, 2009, Oshitari *et al.*, 2007) and the African Americans (Kelty *et al.*, 2008, Asefzadeh *et al.*, 2007, El Dairi *et al.*, 2009). Therefore, at present, there is no studies published that directly compare the ethnic groups in Malaysia or within the Southeast Asia region.

1.7 RETINAL NERVE FIBER LAYER THICKNESS

The deterioration of RNFL thickness is an early sign of glaucoma, and the degree of deterioration indicates the degree of progression (Manassakorn *et al.*, 2008). RNFL damage in early glaucoma is known to precede optic disc change and visual field damage (Hong *et al.*, 2010, Alasil *et al.*, 2011). The RNFL is also known as a sensitive indicator of structural damage (Hong *et al.*, 2010). Although standard automated perimetry is considered as the gold standard, it is believed that about 20 to 40 percent of the retinal ganglion cells are lost during the pre-perimetric period (Manassakorn *et al.*, 2008). Recently, the availability of OCT would be a promising tool to detect early RNFL defects in glaucoma (Peng & Lin, 2008) as it generally show good sensitivity and specificity for the detection of glaucomatous damage (Hong *et al.*, 2010). This structural evaluation technology provides quantitative measurement (Manassakorn *et al.*, 2008) which is reproducible and more objective (Peng & Lin, 2008).

Similar to the interpretation of the macular thickness using the OCT, the RNFL thickness produced from the OCT is measured by referring to the normative databases of the age-matched normal RNFL thickness values from the OCT. However, majority of these databases are derived from the measurements done on the Caucasians (Bendschneider *et al.*, 2010, Alasil *et al.*, 2013, Budenz *et al.*, 2007, Wexler *et al.*, 2010). But in recent years, many investigators started to study and had published their results on Asian normative databases (Qu *et al.*, 2014, Appukuttan *et al.*, 2014). Although these studies were done in highly and densely populated Asian countries, India (Appukuttan *et al.*, 2014) and China (Qu *et al.*, 2014), the normative databases available may not be applicable for the population with the Southeast Asia or other Asia sub-continents.

With regards to the RNFL determinants, multiple studies have analysed and reported the outcome of the age, gender, and ethnicity on RNFL morphology in normal population using OCTs (Bendschneider *et al.*, 2010, Alasil *et al.*, 2013, Budenz *et al.*, 2007, Wexler *et al.*, 2010, Qu *et al.*, 2014, Appukuttan *et al.*, 2014, Oshitari *et al.*, 2007). Most of the studies evaluated only the effect of age and gender on RNFL parameters (Bendschneider *et al.*, 2010, Wexler *et al.*, 2010, Qu *et al.*, 2014, Appukuttan *et al.*, 2014). When the effects of ethnicity on RNFL were evaluated, Studies by which evaluated the effects of ethnicity on RNFL parameters, the reported comparisons were mainly of those between the Caucasians and the Asians (Budenz *et al.*, 2007, Alasil *et al.*, 2013), the Hispanics (Budenz *et al.*, 2007, Alasil *et al.*, 2013), and the Japanese (Oshitari *et al.*, 2007).

1.8 RATIONALE OF STUDY

In our study, we seek to determine and compare the macular and RNFL thickness amongst the Sarawakians since no study has been published. By conducting this study, the preliminary data for the mean macular and RNFL thickness can be established for the three main Bumiputera ethnic groups in the state of Sarawak, which are the Ibans, Malays and Bidayuhs. The data available can be used as reference in future to establish the normative database for these three races. In terms of clinical application, it can be helpful in future utilizing the data to predict any early changes of the macula and optic nerve head pathology among these three Bumiputera ethnic groups.

Chapter 2

Objective

2.1 GENERAL OBJECTIVE

To analyse the macular thickness and retinal nerve fiber layer (RNFL) thickness in three main Bumiputera ethnic groups from Sarawak, namely Malay, Iban and Bidayuh.

2.2 SPECIFIC OBJECTIVES

1. To determine the macular thickness in Malay, Iban, and Bidayuh ethnic groups in Sarawak
2. To determine the RNFL thickness in Malay, Iban, and Bidayuh ethnic groups from Sarawak
3. To compare the macular thickness among Malay, Iban, and Bidayuh from Sarawak
4. To compare the RNFL thickness among Malay, Iban, and Bidayuh from Sarawak

2.3 RESEARCH HYPOTHESIS

1. There is significant difference in the mean macular thickness parameters among Malay, Iban, and Bidayuh ethnic groups in Sarawak
2. There is significant difference in the mean RNFL thickness parameters among Malay, Iban, and Bidayuh ethnic groups in Sarawak

Chapter 3

Materials and Methods

3.1 STUDY DESIGN

A cross-sectional study was performed to analyse macular thickness and RNFL thickness

3.2 POPULATION, TIME AND PLACE

3.2.1 Period of Study

The study was conducted from March 2012 to November 2013

3.2.2 Place of Study

The study was carried out in the Outpatient Clinic Department, Hospital Umum Sarawak, Kuching, Sarawak

3.2.3 Study Population

This subjects recruited are aged from 21 years old to 70 years old who are from Malay, Iban or Bidayuh ethnic group from Sarawak that fulfilled the selection criteria

3.3 SAMPLING METHOD AND SAMPLE SIZE

3.3.1 Sampling Method

The sampling method was conducted using non-probability sampling method whereby those who walk-in to Eye Clinic, Hospital Umum Sarawak that fulfill the selection criteria were selected. Both of the eyes of each subject were examined and the right eye of each subject was included in the study.

3.3.2 Sample Size Calculation

The sample size calculation for all four specific objectives was calculated based on 2-mean comparison using independent design. The approach was achieved using the PS (Power and Sample Size) Software as per quoted by Dupont and Plummer (1990). The result is in close agreement with Pearson and Hartley (1970).

Formula:

$n = 2\sigma^2 / \Delta^2 (Z\alpha + Z\beta)^2$

Whereby α – 0.05

β – power (stat with 80% - 0.8)

σ – SD/standard deviation

Δ – detectable difference (clinically important)

when m = 2.862 (Ratio of Malay population to Bidayuh population as per 2010 census) α - 0.05

power - 0.8

Δ - 35.0

σ - 61.0 (Jusoh *et al.*, 2011)*

m - 2.862 (Ratio of Malay population to Bidayuh population as per 2010 census)

Therefore, n Bidayuh = 30 ≈ 33

n Malay = 86 ≈ 95

Total population by ethnic group, administrative district and state in Sarawak year 2010

Malay = 568,113

Iban = 713,421

Bidayuh = 198,473

Therefore, the final sample size that fulfill the ratio of population among the three main Bumiputera races for both the mean macular thickness and mean RNFL thickness are

n (Malay) = 95

n (Iban) = 95

n (Bidayuh) = 33

Total (n) = 223

3.4 SELECTION CRITERIA

3.4.1 Inclusion criteria

1. Age from 21 years old to 70 years old

2. Malay, Iban or Bidayuh ethnic groups in Sarawak

3.4.2 Exclusion criteria

1. Axial length less than 22.00mm and more than 25.00mm

2. Refractive of spherical equivalent of more than +4.00D and -4.00D

3. Presence of media opacity

4. Retinal diseases such as diabetic retinopathy, hypertensive retinopathy, previous retinal laser photocoagulation, retinitis pigmentosa, and retinal nerve fiber layer defects

5. Macular disorders such as macular oedema, macular hole, macular scar, and abnormal Amsler grid testing

6. Optic nerve pathologies such as optic neuritis, optic neuropathy, optic atrophy, congenital optic disc anomalies, and glaucomatous optic disc changes

3.5 DEFINITION OF TERMS

3.5.1 Macula

The macula boundary is defined histologically by an area with 2 or more layers of ganglion cells, from 5-6 millimeters in diameter, and located centrally in a vertical distance between the two temporal vascular arcades. The macula is defined clinically as an area of 5.5mm in diameter, 3.5 disc diameter or 18 degree of visual angle, centered at 4.0mm temporal and 0.8mm inferior to the center of the optic disc.

3.5.2 Retinal Nerve Fiber Layer

The RNFL is an extension of the ganglion cell layer, which are actually the axons. Within the layers of the retina, the nerve fiber layer is situated between the ganglion cell layer and internal limiting membrane. This layer courses along the inner portion of the retina and aggregates in the posterior portion of eyeball to form the optic nerve. The nerve fibers from the temporal retina follow an arcuate course around the macula to enter the superior and inferior poles of the optic disc. The papillomacular fibers travel straight to the optic nerve from the fovea. The nasal nerve fibers also pursue a radial course.

3.5.3 Malay

Article 160 of the Constitution of Malaysia defines a Malay as a person who satisfies two sets of criteria. First, the person must be one who professes to be a Muslim, habitually speaks the

Malay language, and adheres to Malay customs. Second, the person must have been domiciled in the Federation or Singapore on Merdeka Day, born in the Federation or Singapore before Merdeka Day, born before Merdeka Day of parents one of whom was born in the Federation or Singapore (collectively, the "Merdeka Day population"), or, is a descendent of a member of the Merdeka Day population.

3.5.4 Iban

An Iban must be from a family of at least three generations of Iban ethnic, habitually speaks Iban language and adheres to Iban customs.

3.5.5 Bidayuh

A Bidayuh must be from a family of at least three generations of Bidayuh ethnic, habitually speaks Bidayuh language and adheres to Bidayuh customs.

3.5.6 Optical coherence tomography

A non-invasive, non-contact trans-pupillary, and low coherence interferometry imaging technique that produces cross-sectional images of the retina to visualize and measure anatomic layers of the retina and to assess RNFL. The images are produced by measuring the round trip travel time of the relatively long wave length infra-red light reflected from a biologic target and then scanning the optical beam in the transverse direction to produce a 2- or 3-dimensional image of tissue reflection and scattering.

3.5.7 Macular Thickness Parameters

Thickness of the retina layer measured nine areas of the Early Treatment Diabetic Retinopathy Study map. These 9 divided subfields are central, superior-inner, nasal-inner, inferior-inner, temporal-inner, superior-outer, nasal-outer, inferior-inner, and temporal-outer.

3.5.8 Retinal Nerve Fiber Layer Thickness Parameters

Thickness of the RNFL within the peri-papillary region measured in 6 divided areas. The 6 divided areas are nasal-superior, temporal-superior, temporal, temporal-inferior, nasal-inferior, and nasal region. An average retinal nerve fiber layer thickness of all 6 areas known as global thickness was also included.

3.6 RESEARCH TOOLS

3.6.1 Snellen Visual Acuity Chart

The Snellen eye chart (Figure 3.1) is made up of dark, square-shaped capital letters on a white background. There is typically a large “E” at the top of the chart. Each row of letters below it is progressively smaller than the previous one. The letters can be replaced with pictures or numbers.

3.6.2 Goldmann Applanation Tonometer

Haag-Streit Goldmann Applanation Tonometer AT900 (Haag-Streit International, Switzerland) (Figure 3.2) was used to measure intraocular pressure.

3.6.3 Slit Lamp Biomicroscope

The slit lamp biomicroscope, Topcon SL-3F (Topcon, Japan) (Figure 3.3) was used for anterior segment examination of the eye.

3.6.4 Slit lamp biomicroscope with Superfield and 78D Lenses

The posterior segment examination was done with a hand-held lens of either Superfield lens (Volk, USA) (Figure 3.4) or 78D lens (Volk, USA) (Figure 3.5).

3.6.5 Binocular Indirect Ophthalmoscope with 20D or 28D lenses

Binocular indirect ophthalmoscope (Heine Omega 500) (Figure 3.6) and a hand-held +20D (Figure 3.7) or +28D (Figure 3.8) condensing lens (Volk, USA) are used to perform binocular indirect ophthalmoscopy.

3.6.6. A-Scan Biometry Device

A-scan biometry was done by the principle investigator using ultrasound biometer Sonomed, PACSCAN Plus, Model: 300A+ (Sonomed Inc., USA) to measure the axial length of the eyeball selected for the study.

3.6.7 Spectral Domain Optical Coherence Tomography Device

The newer Spectral domain optical coherence tomography (SD-OCT) (SPECTRALIS SD-OCT, Heidelberg Engineering) (Figure 3.9) was used to measure the macular thickness parameters and RNFL thickness parameters.

Figure 3.1: Snellen Visual Acuity Chart

Figure 3.2: Goldmann Applanation Tonometer

Figure 3.3: Slit Lamp Biomicroscope

Figure 3.4: Super Field Lens