

Role of Optical Coherence Tomography In Macular Disorders**Abstract-**

The macula is a small area less than $\frac{1}{4}$ inch in the center of the retina at the back of the eye. It is responsible for sharp, clear central vision and the ability to perceive color. Like the film in a camera, the retina receives light rays from the front of the eye and transmits those light rays through the optic nerve to the brain where the rays are converted into images.

High resolution cross-sectional imaging of the retina is useful for identifying, monitoring and quantitatively assessing macular diseases. Optical coherence tomography (OCT) is a new medical diagnostic imaging technology which can perform micron resolution cross-sectional or tomographic imaging in biological tissues. Cross-sectional images of the retina are obtained at the resolution of 10 micron. OCT uses low coherence or white light interferometer to perform high resolution measurements and imaging. This article explains the role of OCT in various macular disorders as diagnostic and therapeutic.

Introduction

The macula is a small area less than $\frac{1}{4}$ inch in the center of the retina at the back of the eye. It is responsible for sharp, clear central vision and the ability to perceive color. Like the film in a camera, the retina receives light rays from the front of the eye and transmits those light rays through the optic nerve to the brain where the rays are converted into images. The densely packed photoreceptor (light-sensitive) cells in the macula control all of the eye's central vision and are responsible for the ability to read, drive a car, watch television, see faces, and distinguish detail. The rest of the retina handles peripheral vision that enables your eyes to see objects off to the side while you are looking forward. There are two types of photoreceptor cells in the retina, rods and cones. The rods provide vision at low light levels,

29 while the cones provide sharp vision and discrimination. Because the macula contains a high
30 concentration of cones, straight-ahead vision is in sharp focus, particularly in bright light.
31 Most of the rods are located in the periphery of the retina, so faint objects are more visible if
32 you do not look directly at them. A dim star, for instance, is best seen when your eyes are not
33 aimed directly at it.

34 High resolution cross-sectional imaging of the retina is useful for identifying, monitoring and
35 quantitatively assessing macular diseases. Optical coherence tomography (OCT) is a new
36 medical diagnostic imaging technology which can perform micron resolution cross-sectional
37 or tomographic imaging in biological tissues. Cross-sectional images of the retina are
38 obtained at the resolution of 10 micron. OCT uses low coherence or white light
39 interferometer to perform high resolution measurements and imaging. The infra-red light
40 beam has a wave length of 820nm.oct has made it possible to understand better the
41 vitreoretinal relationship at the macula. OCT has a great potential as a diagnostic and
42 research tool. However it has its own limitations in the presence of media opacities like
43 vitreous hemorrhage, corneal edema and dense cataract, which attenuate the incident and
44 reflected light. Also, it cannot assess function and can only provide details about structural
45 alterations. Hence, an attempt has been made to study the role of OCT in diagnosis of
46 macular disorders.

47 **Literature**

48 **Anatomy of the macula**

49 The macula lutea is an oval, yellowish area of the center of the posterior part of the
50 retina. It measures about 5.5 mm in diameter and lies about 3mm to the lateral side of the
51 optic disc.

52 The yellowish coloration of the macula is caused by a yellow carotenoid pigment,
53 xanthophylls, which is present in the retinal layers from the outer nuclear layer inward.

54 Parts of the macula

55 ❖ Umbo

56 ❖ Foveola

57 ❖ Foveal avascular zone

58 ❖ Fovea

59 ❖ Parafoveal area

60 ❖ Peri foveal area

61 **Umbo**

62 It is a tiny depression in the very centre of the Foveola .which corresponds to the
63 ophthalmoscopically visible foveola reflex.

64 **Foveola (350microns)**

65 It is the small central region in which the thickness of the retina is reduced so as to
66 contain only photoreceptors, glial cells and Mullers cells

67 **Foveal avascular zone (800 microns)**

68 It is located inside the fovea but outside the foveola.

69 **Fovea (1500microns)**

70 It is a small depression where the retina is reduced to about half its normal thickness
71 moving towards the centre of the retina. The inner nuclear layer is reduced to a double row of
72 cells at the edge of the fovea.

73 The foveal sides of the depression are called the clivus ,the floor of the depression is the
74 foveola. There are no blood vessels overlying the fovea and no rod cells in the floor of the
75 fovea. It is here that there is the highest concentration of cones

76 **Parafoveal area (500 microns)**

77 It is characterized by the densest accumulation of the nerve cells in the entire retina
78 especially ganglion cells and the inner nuclear layer. The outer boundary is the point where
79 the ganglion cell layer has four rows of the nuclei.

80 **Peri foveal area (1500microns)**

81 It ends where the ganglion cells are reduced to a single layer.

82 **Histology of the macula**

83 The centre of the macula is the fovea containing the following layers

- 84 • Internal limiting membrane
- 85 • Outer plexiform layer
- 86 • Outer nuclear layer
- 87 • Layer of cones
- 88 • Retinal pigment epithelium.

89 Mandeep Singh(2008)(10) studied a retrospective case, study,is that they reviewed cases of
90 patients with macular disorders whose eyes had been imaged using spectral domain optical
91 coherence tomography (SD-OCT) (Cirrus HD-OCT; Carl Zeiss Meditec, Inc., Dublin, CA).
92 SD-OCT images were obtained from patients with a variety of ocular conditions attending a
93 tertiary retinal clinic in Singapore from August 2007 to December 2007, according to
94 standardized protocols. Images of 428 eyes from 301 patients were reviewed. Ocular

diagnoses included diabetic macular edema, exudative age-related macular degeneration, central serous chorioretinopathy, cystoid macular edema, retinal vein and artery occlusions, infective chorioretinitis, and others. The authors concluded that OCT is much interest to illustrate how SD-OCT was useful in complementing the clinician's assessment of macular diseases.

Kato Chiako (2000) examined 4 eyes in 4 patients of macular degeneration by optical coherence tomography (OCT). The series comprised one eye of Alport syndrome and 3 eyes of cone or cone-rod dystrophy(1). In Alport syndrome, OCT showed thinning of sensory retina and high-reflective layer corresponding to retinal pigment epithelium and choriocapillaris. In 3 eyes of cone or cone-rod dystrophy, OCT showed absence of low-reflective layer corresponding to the photoreceptors. The foveal thickness in the 4 eyes ranged from 25 to 73 .MU.m, average 56.0+-.21.4 .MU.m. It averaged 136.3+-.12.3 .MU.m in normal eyes. The difference was significant ($p<0.05$). The diameter of macular depression averaged 1,452.8+-.149.3 .MU.m in the 4 eyes and 1,258.5+-.47.1 .MU.m in normal eyes. The difference was significant ($p<0.05$).²

Optical coherence tomography

Optical coherence tomography (OCT) allows characterization of the profile and the intra-retinal structural changes of many macular disorders (Haouchine et al 2004).(3)

Diabetic macular edema

This has five distinct patterns on OCT (Hee et al 1998)(4,5)

- Sponge-like retinal thickness
- Cystoid macular edema

117 ▪ Subfoveal serous detachment

118 ▪ Vitreomacular traction

119 ▪ Taut posterior hyaloid

120 OCT is very useful in defining treatment options and for monitoring response to intervention

121 (Massin et al 2003).(7)

122 **Macular hole:** OCT is extremely use for assessing the following:

123 ▪ Early macular holes

124 ▪ Presence of PVD

125 ▪ Size of macular holes

126 ▪ Closure pattern following Vitrectomy (Johnson 2002)(6)

127 **ARMD:** OCT has become very popular in ARMD because of early disease detection,

128 monitoring of therapy and early evidence of reactivation (Rogers et al 2002).(9)

129 **ERM:** These are clearly visible on the vitreoretinal interface on OCT (Wilkins et al,

130 1996).(11)

131 **CSR:** OCT allows detection of early CSR that is clinically observe (HEE et al, 1995).(4,5)

132 **OCT scan protocols in macular disease**

133 The protocols that are helpful in macular diseases are the following:

134 **1. Line scan**

135 The line scan gives an option of acquiring multiple line scan without retaining to main

136 window. The length of the line scan and the angle can be altered, though one has to keep in

137 mind that as the scan length increases the resolution decreases.

138 **2. Radial lines**

139 The scan protocol consists of 6-24 equally spaced line scan that can be varied in size and
140 parameters. All the lines pass through a central common axis. The radial lines are useful for
141 acquiring macular scan and retinal thickness or volume analysis.³

142 **3. Macular thickness map**

143 This is the same as radial lines except that the aiming circle has a fixed diameter of 6mm.
144 This helps in measuring the retinal thickness.

145 **4. Fast macular thickness map**

146 It is designed for use with retinal thickness analysis. When done in both the eyes, it can be
147 used for comparative retinal thickness or volume analysis. It is a quick protocol that takes
148 only 1.92sec to acquire six scans of 6mm length each.

149 **5. Raster line**

150 This provides an option of acquiring a series of line scans that are parallel, equally spaced
151 and are 6-24 in numbers. These multiple line scans are placed over rectangular regions, the
152 area of which can be adjusted so as to cover the entire area of pathology. This is especially
153 useful in conditions like choroidal neovascular membrane where one wishes to obtain scan at
154 multiple levels.

155 **6. Repeat**

156 Repeat protocol enables one to repeat any of the previously saved protocols using same
157 set of parameters that includes scan size, angle, placement of fixation, light emitting diode
158 and land mark. (Gupta 2004)(2)

159 **Principles**

160 It uses light rather than ultrasound. The speed of light is almost a million times faster
161 than sound and this difference allows the measurement of structures with resolution of ≤ 10
162 microns compared to 100 micron scale of ultrasound. Ultrasound needs contact with tissue
163 under study, whereas OCT does not require any contact.

164 It is a non-contact, non-invasive device where a broad band width of near infra-red light
165 beam (820nm) is projected on to the retina. The light gets reflected from the boundaries
166 between the microstructure and also gets scattered differently from tissues with different
167 optical properties. It then compares the echo time delay of the same wavelength that is
168 reflected from a reference mirror at a known distance.

169 Optical coherence tomography uses low coherence or white light interferometry to perform
170 high resolution measurements and imaging.

171 An optical beam from a laser or light source which emits short optical pulses or short
172 coherence length light is directed on to a partially reflecting mirror (optical beam splitter). The
173 partially reflecting mirror splits the light into two beams, one beam is reflected and the other
174 is transmitted. One light beam is directed on to patient's eye and is reflected from intraocular
175 structures at different distances.

176 The reflected light beam from the patient's eye consists of multiple echoes which give
177 information about the range or distance and thickness of different intra-ocular structures. The
178 second beam is reflected from a reference mirror at a known spatial position. This retro-
179 reflected reference optical beam travels back to the partial mirror (beam splitter) where it
180 combines into the optical beam reflected from the patient's eye.

181 When the two light pulses coincide, they produce a phenomenon known as interference
182 which is measured by a light sensitive detector (photo detector). Thus the interferometer can
183 precisely measure the echo structure of reflected light and perform high resolution
184 measurements of the distance and the thickness of different tissue structures.

185 The light source for the interferometer is a compact super luminescent diode, which is
186 coupled directly into an optical fibre. This light source is similar to laser diode used in optical
187 compact disc layers, except in OCT, the diode source is designed to emit short coherence
188 length light. The interferometer is constructed using a fibre optic coupler which functions,
189 analogous to a beam splitter. The arm of the interferometer which consists of reference mirror
190 is located within the instrument, while the optical fibre in the second arm of the
191 interferometer is connected to the OCT ophthalmic instrument resembling a slit lamp
192 biomicroscopy or fundus camera.

193 **Image resolution(11)**

194 The image resolution of OCT in the axial (or longitudinal) versus transverse directions
195 is determined by different mechanisms. The resolution of the image in the axial (longitudinal)
196 direction is determined by the resolution of the optical ranging measurement.

197 This is determined by the physical properties of light source which is used for the
198 measurement. If a short pulse laser source is used, the axial resolution is determined by the
199 pulse duration. Conversely, if a continuous, low coherence light source is used, axial
200 resolution is determined by the 'coherence length' of the light source. It is important to note
201 that the measurement of distance or tissue thickness can, in practice, be performed with
202 significantly higher resolution than this limit.

203 The transverse of the image is determined by the size of the focused optical beam. This is a
204 function of the optics used to project the beam on to the eye and this is determined by factors
205 such as whether imaging is performed over a large depth, such as in the anterior eye, or
206 whether the focusing angle is restricted, as in imaging the retina. The image resolution is also
207 a function of the size of the tomogram that is desired.

208 **Normal macular scan**

209 On a 10mm horizontal line scan passing through the foveal centre, one can clearly
210 demarcate major landmarks namely optic disc and fovea. The optic disc is seen towards the
211 right of the tomogram and is easily identifiable by its contour. The central depression
212 represents the optic head cup and stalk continuing behind is the anterior part of the optic
213 nerve. The fovea is seen to the left and is easily identifiable by the characteristic thinning of
214 retinal layers. The vitreous anterior to the retina is non –reflecting vitreous and back
215 scattering retinal layers is the vitreo retinal interface.

216 The retinal nerve fibre layer (NFL) is highly reflective and increases in thickness
217 towards the optic nerve. The posterior boundary of the retina is marked by a hyper reflective
218 layer that represents retinal pigment epithelium (RPE) and choriocapillaris.

219 Just anterior to RPE and choriocapillaries complex is a minimally reflective layer that
220 represents photoreceptor. Above this layer of photoreceptor, are alternating layers of
221 moderate and low reflectivity that represents different layers of neuro sensory retina. The
222 retinal blood vessels within the neurosensory retina shows back scatter and also cast a
223 shadow behind (Gupta, (2004).

224

225

226 **Macular disorders**

227 **Age-related macular degeneration**

228 Age-related macular degeneration (ARMD), also called senile macular degeneration, is a
229 bilateral disease. It is a leading cause of blindness in developed countries, in population
230 above the age of 65 years.

231 It is of two types

- 232 • Non-neovascular(Dry)
- 233 • Neovascular(Wet or exudative)

234 **Non-neovascular ARMD**

235 **Drusen**

236 Drusen can be hard drusen or soft drusen.

237 **Hard drusen in OCT**

238 On OCT they are seen as focal elevation of the RPE with mildly thinned overlying retina.
239 The elevated RPE does not shadow the reflection.

240 **Soft drusen in OCT** images show small modulation in the contour of the retinal pigment
241 epithelium with lack of shadowing below the contour changes, similar to serous RPE
242 detachment. However, unlike a PED, soft drusen have shallow margins and mild back scatter
243 into the choroid.

244 **Geographic atrophy**

245 OCT shows a thinned out overlying retina and decreased reflectivity of RPE with enhanced
246 choroidal layer.

247 **Neovascular ARMD (exudative)**

248 OCT shows retinal thickening with mild back scattering from outer retinal layers, with
 249 disruption in the RPE in an area of moderate reflectivity with fusiform thickening of the
 250 reflective band corresponding to the CNVM. The lesions merge with RPE choriocappileries
 251 layer.

252 **Occult CNVM**

253 OCT shows an enhanced optical scatter signal at the choroidal level extending into sub-RPE
 254 space which is thicker than the adjacent reflection from the pigmented epithelium and
 255 choriocappileries, consistent with a neovascular membrane. The retina overlying the lesion
 256 appears thickened and elevated, with reduced reflectivity, suggesting fluid accumulation.

257 **Retinal pigment epithelium detachment(PED)**

258 PED can be differentiated into the following type

259 Serous PED

260 Fibro vascular PED

261 Hemorrhagic PED

262 Drusenoid PED

263 **Serous PED**

264 Serous PED-clinically seen as an area of RPE detachment.

265 OCT reveals an elevation of the retina and RPE above an optically clear space. The
 266 reflections from the choroid below the detachment are attenuated due to shadowing from the

267 highly reflective, detached PED. It may have associated overlying serous detachment of the
268 neurosensory retina, which will be seen as elevated neurosensory retina with underlying
269 optically clear space followed by the elevated RPE denoting the PED

270 **Fibro vascular PED**

271 OCT shows elevated RPE, along with mild to moderate back scatter persisting
272 beneath the RPE, consistent with the Fibro vascular PED. It may have associated overlying
273 neurosensory detachment or overlying cystoid macular edema.

274 **Hemorrhagic PED**

275 OCT through the hemorrhagic PED shows elevated RPE with moderate back scatter,
276 which attenuates quickly with depth below the RPE. This back scatter, appearing
277 immediately below the raised RPE is consistent with the hemorrhagic. The RPE band may be
278 indistinguishable from hemorrhagic. There may be associated neurosensory elevation and
279 cystoid changes in the overlying retina.

280 **Drusenoid PED**

281 OCT defines a RPE elevation with optical back scatter below the RPE, with small
282 modulations in the RPE contour with moderate optical reflectivity below the lesion.

283 **Feeder vessels**

284 OCT may reveal areas of increased back scatter corresponding to the scarring
285 membrane, with associated thickening of RPE choriocapillaries layer.

286

287

288 **Loculated fluid**

289 OCT shows a well defined region of hyper-reflectivity at the level of the RPE-
290 choriocappileries, consistent with the CNVM. The neurosensory retina above the membrane
291 shows thickening as well as focal areas of reduced opticality, corresponding with the fluid.

292 **RPE rip**

293 OCT through the lesion shows the elevated neurosensory retina and RPE which
294 shadows the reflections from the choroid below. In the area of RPE rip two highly reflective
295 layers are seen below the sensory retina corresponding with a folded double layer of pigment
296 epithelium, with attenuation of reflections below the layer. In the area corresponding with
297 absent RPE, enhanced reflectivity and optical penetration of the choroid is noted.

298 **Disciform scar**

299 OCT reveals a focal area of enhanced back scatter corresponding to the chorioretinal
300 scar. The overlying neurosensory retina shows thinning throughout. (Natarajan et al 2005)

301 **Central Serous ChorioRetinopathy (CSCR)**

302 OCT shows an elevated neurosensory retina with an optically clear space
303 underneath and a reflective layer corresponding to the RPE and choriocappileries underneath
304 it, corresponding to the CSR. With the advent of OCT the existence of PED with CSR has
305 been shown to be much more than thought previously. In cases of associated PED; below the
306 elevated neurosensory retina lies an optically clear space below which a highly reflective dome
307 shaped elevation with attenuated shadows below it suggest the presence of PED. There may
308 be hyper reflective spots in the optically clear space below the neurosensory retina
309 corresponding with the sub retinal exudation and fibrin seen in resolving or chronic

310 CSCR.CSCR may also have associated choroidal neovascular membrane (CNVM). In such
311 situations, there will be a delineated hyper fluorescence on angiogram corresponding with
312 the CNVM. OCT will show high reflectivity at the level of RPE choriocapillaries suggestive
313 of a CNVM.

314 **Epi retinal membrane (ERM)**

315 OCT is very useful tool in grading the ERM, and providing information about the
316 underlying retinal traction and secondary changes in the retina. OCT reveals a hyper-
317 reflective membrane at the vitreoretinal interface, adherent to the underlying retina, with
318 distortion of the inner retinal layer. The traction on the underlying retina is seen as folds in the
319 inner retinal layer. On OCT, ERMs are seen as clearly separable where clear space is visible
320 between the epiretinal membrane and inner retinal surface and global ERM where no area of
321 separation is seen between the ERM and inner retinal surface. An increased thickness of
322 retina with optically empty spaces in retinal layers along with reduced back scattering from
323 outer retinal layers will indicate Cystoid macular edema; a lamellar macular hole may be
324 associated with ERM. A macular pseudo hole formed by the ERM needs to be differentiated
325 from a true macular hole. A macular pseudo hole will show an abnormally steep foveal
326 contour resembling a partial thickness macular hole, but the outer retinal layer is seen intact
327 throughout the image ruling out a full thickness macular hole. It is important to distinguish an
328 ERM from a detached posterior hyaloid as both appear as a reflective band anterior to the
329 retina on OCT. The posterior hyaloid has a weak, patchy reflection that is inner than an ERM.

330 **Macular hole**

331 In OCT the following are seen:

332 1. stage IA of the macular hole is seen as foveal pseudo cyst in the retinal layers.

333 2. stage IB is seen as partial disruption of the outer retinal layers. The posterior vitreous seen
334 attached to its edges. It may develop to a lamellar macular hole.

335 3. stage II reveals as a full thickness macular dehiscence with attached posterior vitreous. The
336 surrounding retina may show thickening and cystic changes.

337 4. Stage III .reveals a large macular hole with attached posterior vitreous.

338 5. Stage IV reveals a macular hole larger than 400μ in diameter, with a detached posterior
339 hyaloid. There may be an associated optically empty space below the neurosensory retina at
340 the edges of the dehiscence suggestive of sub retinal fluid, along with thickening and cystic
341 changes in the retinal layer,(Natarajan 2005).

342 **Heredomacular degeneration (HMD)**

343 **Best's disease:**

344 OCT shows a characteristic dome shaped lifting of retina including the RPE layer, with
345 a high reflective deposit in the sub RPE space, corresponding to the accumulated lipo fuscin.
346 This is in contrast to the presentation of a serous PED.

347 **Foveal schisis**

348 OCT is diagnostic as it reveals an elevation of the foveal pit with peri foveal splitting of
349 the neurosensory retinal layers.

350 **Stargardt's disease**

351 OCT reveals thinned out neurosensory retina along with increased reflectivity of the
352 RPE choriocappileries layer.

353

354 **Retinitis pigmentosa**

355 OCT reveals a thinned out neurosensory retina; associated CME may be seen,
356 (Natarajan 2005).(8)

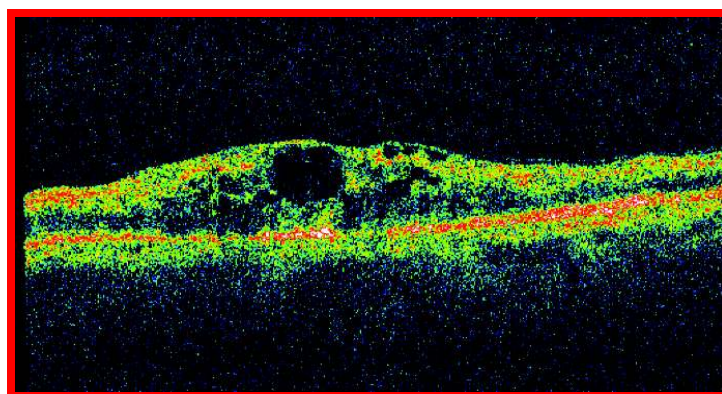
357 **CONCLUSION**

- 358 • OCT can certainly play a vital role along with the clinical examination in the diagnosis
359 and evaluation of macular disorders
- 360 • OCT can be included as a part of evaluation of any disorder affecting the macula
361 which can be performed and interpreted by an optometrist.
- 362 • It is useful for both screening and monitoring macular diseases and for deciding
363 intervention.
- 364 • It is useful for assessing response to intervention such as laser photo coagulation,
365 intravitreal injections and surgery.

367 **References**

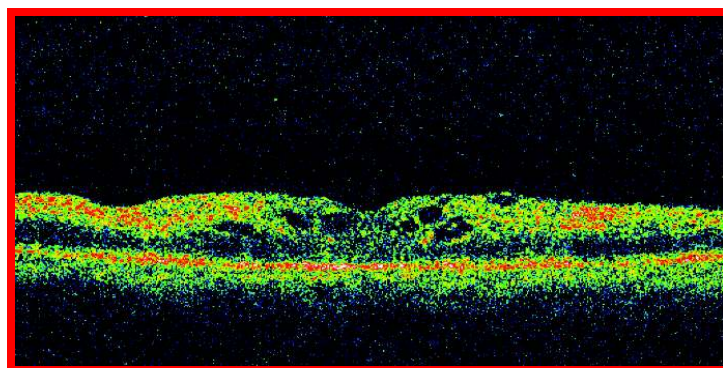
- 368 1. Chiako K, Optical coherence tomographic findings in atrophic macular
369 disorders. Japanese journal of clinical ophthalmology;(2000) 54 (8): 1429-1433.
- 370 2. Gupta V, Amod Gupta. Atlas of Optical Optical Coherence Tomography of
371 macular diseases. Jaypee, Medical publisher, first edition, (2004).
- 372 3. Haouchine B, Massin P, Tadsyoni R, Erginay A and Gaudric A. Diagnosis
373 of macular pseudoholes and lamellar macular holes by optical coherence
374 tomography. American J Ophthalmol(2004) 138:5
- 375 4. *Hee MR,Puliafito CA,Duker Js et al. Topography of diabetic macular
376 edema with optical coherence tomography, Ophthalmology (1998)105:360-70.
- 377 5. *Hee MR, Puliafito CA, Wong C et al. Optical coherence tomography of

- 378 central serous chorioretinopathy. AM J Ophthalmol (1995)120:65-73
- 379 6. Johnson MW. Improvements in understanding and treatment of macular
380 holes, Curr Opin Ophthalmol (2002) 13: 152 -160.
- 381 7. Massin P, Duguid G, Erginay A, Haouchine B, Gaudric A, Optical
382 Coherence Tomography for evaluating diabetic macular edema before
383 and after Vitrectomy. Am J Ophthalmol (2003) 135:169-77.
- 384 8. Natarajan S, Sharma S, Hitendra B Mehta HB. Diagnostics in macular
385 disorders. Jaypee, Medical publisher, First edition (2005)
- 386 9. Rogers AH, Martidis A, Greenberg PA, Puliafito CA. optical coherence
387 tomography findings following photo dynamic therapy of choroidal
388 neovascularisation, Am J Ophthalmol (2002) 134:566-576
- 389 10. *Singh M. Spectral domain optical coherence tomography imaging of
390 retinal diseases in Singapore; Ophthalmic surgery, Lasers and imaging,
391 (2008);39:S120-S125.
- 392 11. *Wilkins JR, Puliafito CA, Hee MR et al. Characterization epiretinal membranes using
393 optical coherence tomography. Ophthalmology. (1996)103:2142- 2151.
- 394



396

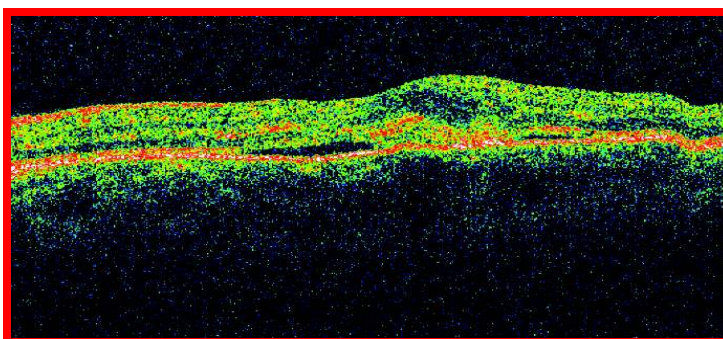
CME before Treatment



397

398

CME after Treatment

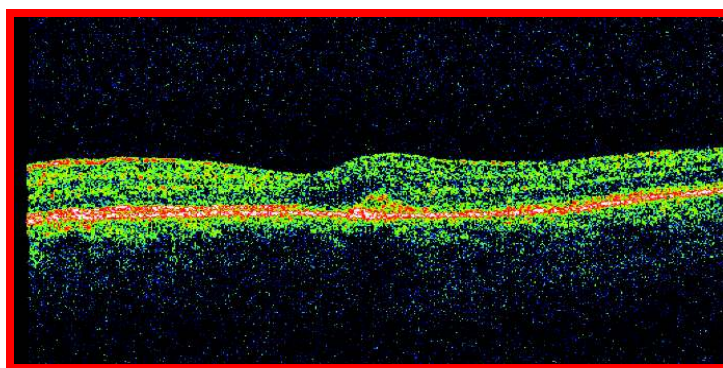


399

400

CNVM before Treatment

401



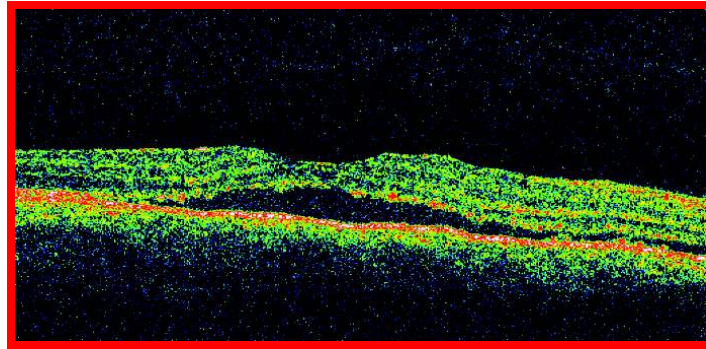
402

403

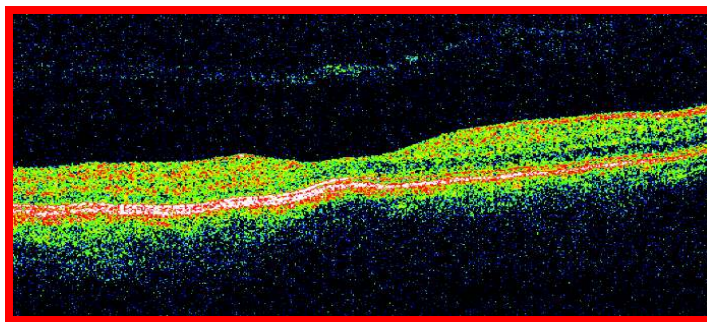
CNVM after Treatment

404

Fig 1. CME and CNVM before and after treatment

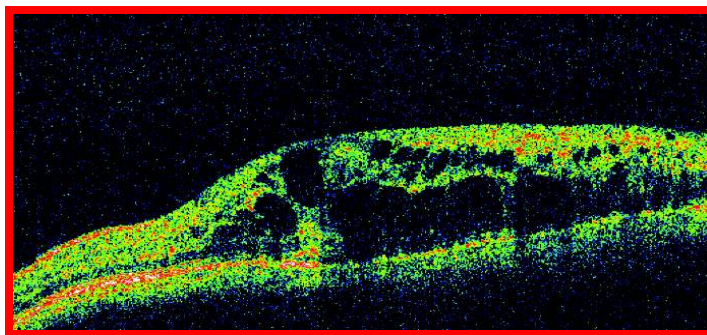


CSR before Treatment

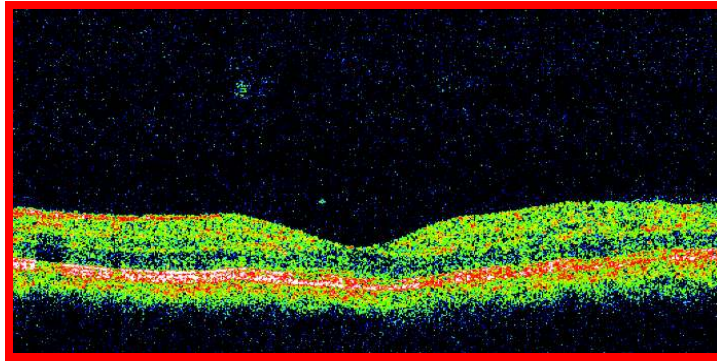


CSR after Treatment

Fig 2. CSR before and after treatment

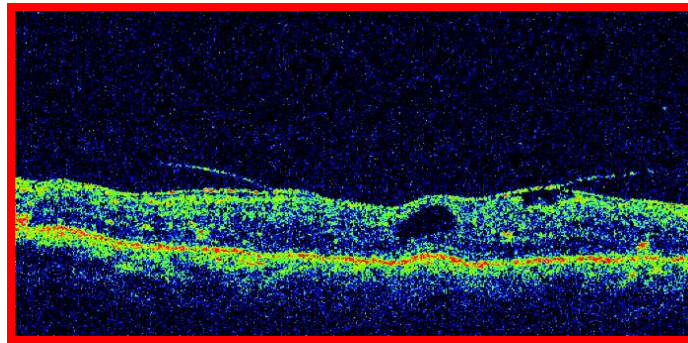


Macular Edema before Treatment

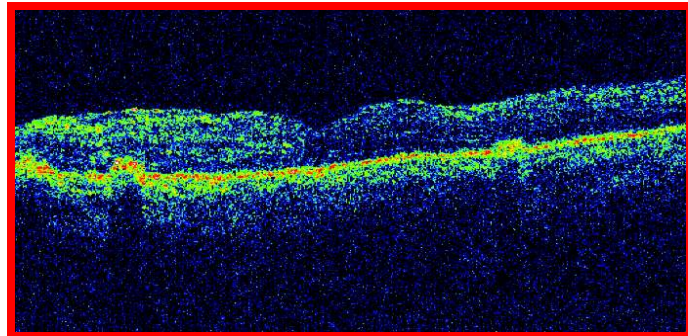


Macular Edema after Treatment

Fig 3. Macular edema before and after treatment



ERM before Treatment



ERM after Treatment

Fig 4. ERM before and after treatment