EXTENDED REPORT

Optical coherence tomography in photodynamic therapy for subfoveal choroidal neovascularisation secondary to age related macular degeneration: a cross sectional study

J Sahni, P Stanga, D Wong, S Harding

Aim: To introduce new terminology and validate its reliability for the analysis of optical coherence tomography (OCT) scans, compare clinical detection of cystoid macular oedema (CMO) and subretinal fluid (SRF) with OCT findings, and to study the effect of photodynamic therapy (PDT) on the foveal morphology.

Methods: Patients with subfoveal, predominantly classic choroidal neovascularisation (CNV) secondary to age related macular degeneration (AMD) undergoing PDT were evaluated with refraction protocol best corrected logMAR visual acuity (VA), slit lamp biomicroscopy, routine fluorescein angiography (FFA), and OCT. New terminologies introduced to interpret the OCT scans were: neuroretinal foveal thickness (NFT), bilaminar foveal thickness (BFT), outer high reflectivity band thickness (OHRBT), intraretinal fluid (IRF), subretinal fluid (oSRF), vitreomacular haemoid attachment (VMAH). Results: Fifty-six eyes of 53 patients were studied. VA was better in eyes with a thinner outer high reflectivity band (OHRBT) (p = 0.02) and BFT (p = 0.05). BFT was less in eyes that had undergone a greater number of PDT treatments (p = 0.04). There was poor agreement between OCT and clinical examination in the detection of CMO and subretinal fluid (κ = 0.289 and κ = 0.165 respectively). To validate the interpretation and measurements on OCT, two groups of 20 scans were analysed by two independent observers. There was good agreement between the observers in the detection of IRF, oSRF, and VMHA (p<0.001). Measurements of NFT and BFT had a high reproducibility, and of OHRBT reproducibility was low.

Conclusions: New terminology has been introduced and tested. OCT appears to be superior to clinical examination and FFA in the detection of AMD in this study. Better vision was associated with a thinner OHRBT and/or the absence of SRF giving insight into the biological effect of PDT.

PATIENTS AND METHODS

This was a non-randomised prospective cross sectional study of eyes with predominantly classic subfoveal CNV secondary to AMD attending the St Paul’s Clinical Eye Research Centre. All patients underwent refraction and visual acuity measurement using TAP protocol. The Early Treatment Diabetic Retinopathy Study (ETDRS) chart (Lighthouse Television Products, NY, USA) was used. Best corrected visual acuity was measured at 2 m. The score was the total number of letters read correctly plus 15. If the patients saw fewer than 20 letters, they were tested with the top three lines at 1 m. The score then was the total number of letters read at 2 m plus the number of letters read at 1 m. Clinical and fundus fluorescein angiography (FFA) evaluation was by a retina specialist or a fellow experienced in clinical studies. The presence or absence of cystoid macular oedema (CMO) and subretinal fluid (SRF) was determined on slit lamp biomicroscopy.

Abbreviations: AMD, age related macular degeneration; BFT, bilaminar foveal thickness; CMO, cystoid macular oedema; FFA, fundus fluorescein angiography; ICC, intraclass correlation coefficient; IRF, intraretinal fluid; NFT, neuroretinal foveal thickness; OCT, optical coherence tomography; OHRBT, outer high reflectivity band thickness; PDT, photodynamic therapy; RPE, retinal pigment epithelium; SRF, subretinal fluid; TAP, Treatment of AMD with Photodynamic therapy study; VA, visual acuity; VMHA, vitreomacular haemoid attachment.
biomicroscopy using a 60 dioptre Volk (Volk Opticals, Mentor, OH, USA) lens and a standard Mainster (Ocular Intruments Inc, Bellevue, USA) contact lens with 1.5 magnification and on FFA by interpretation of 10 minute late frames. Patients with CNV secondary to non-AMD aetiologies were excluded.

OCT was performed and analysed by a single observer (JS) on the OCT3 masked to visual acuity (VA) clinical and FFA findings. All scans were performed prior to FFA and slit lamp biomicroscopy. Pupils were dilated with tropicamide (1%) and phenylephrine (2.5%) drops. Internal fixation guided by the video image was used to ensure that scans passed through the fovea. Scans that did not pass through the fovea were excluded. Horizontal single line A scans through the fovea of default length 5 mm at 0° and a fast macular thickness map consisting of six simultaneous 6 mm radial line scans were obtained. With each single line scan pass, 512 longitudinal range samples were captured—each consisting of 1024 data points over 2 mm of depth, giving 524 288 data points, which are integrated to construct a cross sectional anatomical image (tomogram). In cases with poor central fixation, the scan was manually positioned on the anatomical fovea as viewed on the black and white video image.

All thickness measurements were made on the single line horizontal scans. The measurements were done by manual positioning of the callipers using the retinal thickness (single eye) quantitative analysis protocol offered by Stratus OCT3. New terminology was defined and used in interpreting OCT images as shown in table 1 and figures 1, 2, and 3. The foveal centre was defined as the maximum depression within the depression or pit within the neuroretina and the fovea was defined as the surrounding area, the diameter of which was 500 μm. Measurements were obtained from acquired scans using these definitions and compared against clinical

**Figure 1** Optical coherence tomogram passing through the fovea of a normal eye illustrating retinal layers and terminology developed for the study. RNFL, retinal nerve fibre layer; PRL, photoreceptor layer; RPE, retinal pigment epithelium; NFT, neuroretinal foveal thickness (distance between inner high reflectivity band and inner margin of outer high reflectivity band at foveal centre); OHRBT, outer high reflectivity band thickness; NFT = 181 μm and OHRBT = 58 μm in this scan.

**Figure 2** (A) Colour fundus photograph of the right eye of an 83 year old male patient demonstrates a green-grey subfoveal lesion with haemorrhage. The arrow indicates the location and direction of the optical coherence tomographic (OCT) scan. (B) OCT image demonstrates loss of foveal depression with cystoid spaces and vitreoretinal hyaloid attachment. NFT, neuroretinal foveal thickness; OHRBT, outer high reflectivity band; IRF, intraretinal fluid. NFT = 406 μm and OHRBT = 307 μm in this scan.

**Figure 3** (A) Colour fundus photograph of the left eye of a 54 year old female patient shows a subfoveal green-grey lesion with minimal haemorrhage. The arrow indicates the location and direction of the optical coherence tomographic (OCT) scan. (B) OCT passing through the fovea illustrating bilaminar foveal thickness (BFT), intraretinal fluid (IRF), and subretinal fluid (SRF). BFT is the distance between the inner high reflectivity band and the inner margin of the outer high reflectivity band at the foveal centre in the presence of subretinal hyporeflective area. NFT = 473 μm and BFT = 722 μm in this scan.
Table 1 Terms and definitions used within this paper

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tr>
<td>Neuroretinal foveal thickness (NFT)</td>
<td>Distance between the inner high reflectivity band and the outer high reflectivity band at the foveal centre</td>
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<tr>
<td>Bilaminar foveal thickness (BFT)</td>
<td>Distance between the inner high reflectivity band and the inner margin of the outer high reflectivity band at the foveal centre</td>
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<tr>
<td>Outer high reflectivity band thickness (OHRBT)</td>
<td>Distance between the inner margin of the outer high reflectivity band and the outer margin of the outer high reflectivity band at the fovea</td>
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<tr>
<td>Vitreomacular hypoidal attachment (VMHA)</td>
<td>Complete separation of the posterior hyaloid from the macula in the OCT scan</td>
</tr>
<tr>
<td>Posterior vitreous detachment (PVD)</td>
<td>Complete separation of the posterior hyaloid from the macula in the OCT scan</td>
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<tr>
<td>Intrafoveal fluid (IRF)</td>
<td>Well defined intraretinal hyporeflective spaces at the fovea separated by reflective septae</td>
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<tr>
<td>Subretinal fluid (SRF)</td>
<td>Separation of the neuroretina from the outer high reflectivity band by a well defined hyporeflective space at the fovea</td>
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**RESULTS**

Sixty-eight eyes of 65 patients attending St Paul’s Eye Unit, Royal Liverpool University Hospital between August 2002 and February 2003 were recruited. Twelve eyes (17%) were excluded, as scans passing through the fovea could not be obtained due to erratic and inaccurate fixation leaving 56 eyes for analysis. The median age was 76 years. Mean duration since baseline visit was 9.5 months (range 0 to 30; 24 males, 32 females). Three patients were scanned at baseline prior to receiving any treatment. Sixteen had undergone one PDT treatment application, 11 had two, 10 had three, six had four, nine had five, and one patient had seven treatment applications prior to the OCT scanning. IRF was found in 23 (42%) eyes on OCT imaging and VMHA was found in 13 (23%) eyes in the same group on slit lamp clinical examination. Kappa was 0.29 signifying a poor agreement between the two tests. There was poor agreement between slit lamp biomicroscopy and OCT in the detection of SRF (κ = 0.17).

There was no significant difference in the distance VA in eyes with and without IRF at the fovea (p > 0.5).

The mean NFT was significantly greater in patients with IRF at 223 µm compared with those without at 154 µm (p = 0.005). There was no correlation between the NFT and VA (p > 0.5) and NFT and the number of PDT applications (r = −0.23, p > 0.05).

The correlation between BFT and VA was significant (p = 0.05). There was also a significant correlation between BFT and the number of PDT applications (r = −0.28; p = 0.04) (fig 4). TAP protocol VA was significantly better in eyes with a thinner OHRBT (fig 5) (r = −0.331; p = 0.013). A VMHA was present in 20/56 patients (35.7%). No statistically significant association was found between IRF and VMHA (p = 0.4).

New observations were made from the scans in these patients. In some cases with atrophy of the retinal pigment epithelium (RPE) (on slit lamp or FFA) an optical shadow was present interfering with the identification of the outer border of the OHRBT. In cases with a large amount of intraretinal or subretinal fluid or haemorrhage, signal attenuation appears to reduce the apparent OHRBT.

**DISCUSSION**

Optical coherence tomography is a relatively new technique for cross-sectional imaging of the retina. To date, the...
For OCT to be meaningful in macular disease, scans must pass through the anatomical centre of the fovea, especially if measurements are to be compared with VA. In our study 12 (17%) of 68 eyes could not be reliably scanned through the fovea. Reliability of scans was limited by poor fixation, excessive eye movements, and difficulty identifying the true location of the fovea because of morphological changes caused by disease. Two other studies have reported on the difficulty of obtaining scans. Hee et al\textsuperscript{14} failed to obtain adequate scans in 4.2% of the study population, comprising mainly patients with diabetes with moderate to good VA (better than 20/80). Rogers et al\textsuperscript{15} reported a higher percentage (12.2%) of scans to be unobtainable/unreliable in a population of patients with AMD, a result more similar to ours but still lower. Unlike these authors our population was consecutive, often with quite low levels of vision and poor fixation, and accounting for a 17% exclusion rate: the mean VA score was 42 letters (roughly equivalent to 20/120) and scans that did not pass through the foveal centre were excluded. This significant failure rate raises the question of reliability and suitability of OCT as an objective means of measuring and monitoring retinal thickness at the fovea in some patients.

All measurements in our study were obtained by manual positioning of the callipers. Hee et al\textsuperscript{14} obtained retinal thickness measurements automatically by means of a computer algorithm that searches for the changes in reflectivity observed at the superficial and deep retinal boundaries. We therefore tested the algorithm that is supplied within the software suite of the OCT 3000. In most cases it failed to distinguish between the detached posterior hyaloid and the true inner high reflectivity band corresponding to the inner retinal border. In the presence of a subretinal hyporeflective space, the algorithm usually misread the true NFT. We believe that manual calliper placement currently remains the method of choice.

In the clinical management of AMD the detection of CMO and SRF is important. Bressler et al\textsuperscript{19} have commented on the difficulty of correctly identifying leakage due to CNV in the presence of coexisting CMO, which can confound interpretation of FFA images. FFA and slit lamp biomicroscopy are the standard examinations used for the diagnosis of CNV in patients with AMD and these examinations are relatively insensitive at detecting small changes in retinal thickness.\textsuperscript{7} Hee et al\textsuperscript{14} reported that slit lamp biomicroscopy was unreliable in detecting an increase in thickness smaller than 250 μm in diabetic macular oedema. Browning et al\textsuperscript{16} calculated k to be 0.63 in their cohort of diabetics for the agreement between slit lamp biomicroscopy and OCT in the detection of macular oedema. In our study OCT detected IRF in more than 50% of patients in whom CMO was not seen on slit lamp biomicroscopy. The agreement between the two methods was much less in our study, k = 0.29. This may be because the majority of our patients had undergone previous PDT making clinical interpretation difficult. There was also poor agreement between the two methods in the detection of SRF (k = 0.165). The presence/absence of leakage is integral to retreatment decision making during a course of PDT.\textsuperscript{17} With OCT, a new standard for assessment of CMO and SRF have been set, which is more objective than slit lamp biomicroscopy and fluorescein angiography.

Studying the relation between VA and retinal thickness/fluid is important in increasing the understanding of retinal pathophysiology in exudative maculopathies. The presence of CMO has been reported to be associated with poorer VA in neovascular AMD.\textsuperscript{20} However in our study of patients with AMD who had undergone PDT, there was no statistically significant association between the presence or absence of IRF and SRF and VA. We could not show a statistically significant association between VA and retinal thickness.
significant association between VA and NFT or BFT. This could be because other factors such as the baseline VA and size of CNV may also affect the final VA. Using OCT, we have shown that a higher number of PDT treatments are associated with lower BFT. This observation needs further investigation in longitudinal studies but does suggest that OCT imaging may be helpful. We are currently undertaking a study to develop a new set of retreatment criteria taking these findings into consideration.

Previous studies have shown that the outer high reflectivity band corresponds to the RPE and choriocapillaris. Hee et al categorised untreated CNV on OCT tomograms as well defined, poorly defined, or as a fibrovascular PED. In our experience these characteristics were lost following PDT. We found a statistically significant inverse association between the RPE-CNV complex thickness, defined in our study as OHRBT, and VA. The suggestion from our study is that in addition to the recognised anti-angiogenic effect, PDT may preserve VA in patients with AMD by modifying the natural history of the scarring process, which in turn prevents photoreceptor loss. There was no association between the OHRBT and the number of PDT treatments or the duration since initial treatment. Measurement of OHRBT appears to have some limitations, as the absorption and scattering properties of fluid and fibrosis can attenuate the OCT signal. In contrast, RPE/chorioidal atrophy can intensify the transmission of the light and might result in a thicker OHRBT measurement.

Vitreomacular traction has been implicated in the progression of diabetic maculopathy. We looked at the pattern of vitreous interaction with the retinal surface at the fovea. VMHA was present in 20 patients, but we did not find a statistically significant correlation between CMO and VMHA. We propose that in AMD disruption of RPE metabolism by photodynamic therapy with the associated CNV is responsible for changes in the retinal architecture as opposed to vitreomacular traction (as has been implicated in other conditions).

A limitation of this study is that scans were not possible in 17% of our patient population, because of poor vision and fixation. Although we have taken great care to accurately delineate the outer high reflectivity band, errors in measuring true RPE-CNV thickness may have arisen because of light attenuation or amplification properties of the tissue. Although we have only sought correlations between vision and OCT features, baseline VA, diameter of the CNV, presence of fibrosis, atrophy, and blood may have also influenced the VA results.

Power calculations were not performed as there were no preliminary data on which to base them. In any future studies our data will be useful to perform power calculations in this specific population.

Our study shows that OCT can be a useful technique for quantitative retinal measurements in patients undergoing PDT. We were able to show that VA was better in those patients with an absence of SRF following PDT. We also showed that the favourable visual outcome following PDT might be associated with a thinner OHRBT. Thus OCT and the terminology we have developed appears to be useful in interpreting the response of the retina and can aid in evaluating the FFA when evaluating the activity of CNV treated with PDT. Further prospective longitudinal studies are needed to establish retreatment criteria based on these findings, and may improve the efficacy and cost effectiveness of PDT.

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REFERENCES