Macular imaging by optical coherence tomography in the diagnosis and management of glaucoma

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► Additional material is published online only. To view please visit the journal online (http://dx.doi.org/10.1136/bjophthalmol-2017-310869).

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Received 11 June 2017
Revised 4 September 2017
Accepted 6 October 2017
Published Online First 21 October 2017

ABSTRACT

The macular area is important to the detection of glaucomatous retinal ganglion cell (RGC) damage. Macular thickness complementary to peripapillary retinal nerve fibre layer (RNFL) thickness can well reflect glaucomatous damage, given that the macula contains more than 50% of the RGCs in a multilayered pattern and larger RGC bodies compared with their axons. Thus, macular ganglion cell thickness parameters recently have been considered to be an effective glaucoma-diagnostic tool comparable to RNFL thickness parameters. Furthermore, spectral-domain optical coherence tomography ganglion cell–inner plexiform layer thickness and deviation maps can provide additional information essential for distinguishing glaucomatous changes from other, myopia-associated or macular disease-associated changes. Therefore, our aim with this study was to review the clinical application of macular imaging by optical coherence tomography and to provide essential clinical tips for its use in the diagnosis and management of glaucoma.

INTRODUCTION

Optic nerve head (ONH) and retinal nerve fibre layer (RNFL) analyses have been the mainstays for diagnosis and management of glaucoma. Their outstanding diagnostic abilities notwithstanding, the advent of spectral-domain optical coherence tomography (SD-OCT) has driven investigations into the clinical significance of detecting glaucomatous damage in the alternative form of ganglion cell damage in the macular area.

The macular area is important in the detection of glaucomatous retinal ganglion cell (RGC) damage.[1] Macular thickness can reflect glaucomatous damage, given that the macula contains more than 50% of the RGCs in a multilayered pattern and the larger size of RGC bodies there, which are up to 20 times larger than the diameter of their axons.[2 3] The macular area also has been noted for its consistency, especially the fact that, relative to the peripapillary RNFL (pRNFL), it is less affected by interindividual structural variability and non-neural structures including blood vessels.[4 5] Furthermore, with regard to the pathophysiology of glaucoma including RGC degeneration and axonal damage, macular thickness can reflect glaucomatous damage in a more fundamental way.

Macular OCT imaging in glaucoma mostly measures inner retinal layer thickness in the macular area, which consists of the RNFL, ganglion cell layer (GCL) and inner plexiform layer (IPL). These are the most commonly used macular parameters for prediction of RGC damage in the macular area. They have supported efficient detection and monitoring of the disease along with other important glaucoma-related parameters. Ever since the importance of the macular area to glaucoma detection and progression was recognised,[6] various investigations have evaluated the diagnostic value of macular inner retinal layer thickness and its applications in the field of glaucoma.[7–14] This article reviews the literature and its findings to date on the application of macular parameters to glaucoma diagnostics and management.

Principles and interpretation of macular imaging

Currently, several commercially available SD-OCT protocols provide data on macular ganglion cell damage based on different thickness measurements. Although the protocols for detection of macular ganglion cell damage differ between SD-OCTs, as indicated in table 1, most of them present changes in the aforementioned three inner retinal layer thicknesses in the macular area. One of the commonly used macular parameters is the macular ganglion cell complex (GCC), the sum of the macular RNFL, GCL and IPL, which is provided by devices such as RTVue (Optovue, Fremont, California, USA) and Topcon SD-OCT (Topcon, Tokyo, Japan). Another algorithm of Cirrus SD-OCT (Carl Zeiss Meditec, California, USA), which provides macular ganglion cell–inner plexiform layer (GCIPL) thickness, is known as macular ganglion cell analysis (GCA).[4] To explain briefly, the macular GCA performs 200 horizontal B-scans x 200 A-scans (or 528×128 scans) in over 1024 samplings to detect and measure macular GCIPL thickness within a 6×6×2 mm cube centred on the fovea. Thereby, it provides macular GCIPL thickness in the elliptical shape, within the annulus of the inner vertical and horizontal diameters of 1 and 1.2 mm and outer vertical and horizontal diameters of 4 and 4.8 mm, respectively. It identifies the outer boundaries of the RNFL and IPL, and yields the GCIPL thickness in the form of the difference between them.

A macular GCA report provides (1) average, minimum and six-sector (superotemporal, superior, superonasal, inferonasal, inferior and inferotemporal) GCIPL thickness parameters, (2) a GCIPL thickness map and (3) a GCIPL deviation map. These thickness parameters present not only the thickness values themselves but also colour codes (ie, green, normal range; yellow, outside 95% normal limit; red, outside 99% normal limit) for comparison with the internal normative database. The GCIPL thickness map provides a colour-coded display of GCIPL thickness along with a reference

To cite: Kim KE, Park KH. *Br J Ophthalmol* 2018;**102**:718–724.

Table 1 Comparison among different spectral-domain optical coherence tomographs detecting glaucomatous damage in macular area

	Cirrus HD-OCT	Spectralis OCT	RTVue FD-OCT	Topcon 3D-OCT	Swept-source DRI OCT	RS-3000 OCT
Manufacturer	Carl Zeiss Meditec, Dublin, California	Heidelberg Engineering, Hidelberg, Germany	Optovue, Fremont, California, USA	Topcon, Tokyo, Japan	Topcon, Tokyo, Japan	Nidek, Gamagori, Japan
Scan speed (A-scans/s)	27 000	27 000	26 000	27 000	100 000	53 000
Axial resolution (µm)	5	3.9	5	5–6	20	7
Transverse resolution (µm)	15	14	15	20	8	20
Grid dimensions (mm)	6×6	8×8	7×7	6×6	12×9 (wide scan)	9×9
Centre	Fovea	Fovea	1 mm temporal to the fovea	Fovea	Fovea	Fovea
Measurement layer	GCL+IPL	Separate measurement of entire retinal layers	GCL+IPL+RNFL	RNFL/GCL+IPL/GCL+IPL+RNFL	RNFL/GCL+IPL/GCL+IPL+RNFL	GCL+IPL+RNFL

GCL, ganglion cell layer; IPL, inner plexiform layer; OCT, optical coherence tomography; RNFL, retinal nerve fibre layer.

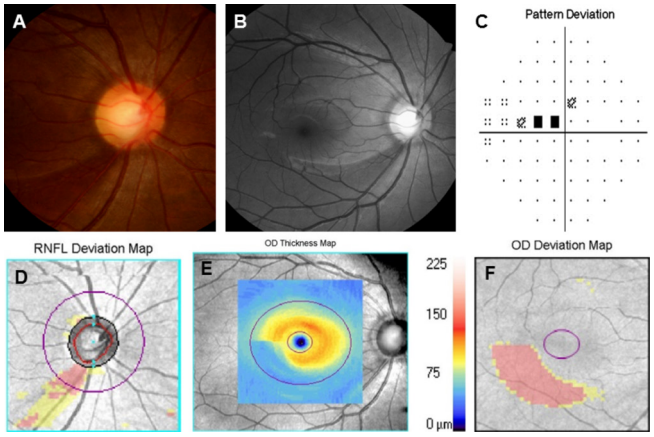

Figure 1 Images of right eye diagnosed with open-angle glaucoma. (A, B) Note the inferior neuroretinal rim notching with disc haemorrhage and inferior retinal nerve fibre layer (RNFL) defect with (C) corresponding superior visual field defect. Corresponding (D) RNFL defect and (E, F) macular ganglion cell–inner plexiform layer (GCIPL) defect demonstrated on optical coherence tomography. Glaucomatous macular GCIPL defect on macular ganglion cell analysis demonstrates a typical arcuate shape that appeared to be related with the peripapillary RNFL defect.

colour bar. The GCIPL deviation map represents the status as deviated from the internal normative database, indicating yellow or red to represent GCIPL thickness less than the lower 5% or 1% of normative data, respectively, and uncoloured areas within the normal limits. Diagnostic classification by colour coding provides intuitive results, enabling clinicians to effectively judge the presence and characteristics of macular damage in an at-a-glance view.

Interpretation of the macular GCA deviation map does not differ significantly from that of RNFL analysis. Characteristic glaucomatous damage on the macular GCA deviation map is usually represented as follows (figure 1): yellow-coloured and red-coloured areas indicating decreased macular GCIPL thickness presented in arcuate to crescent shape, predominantly located in the temporal macular regions along the horizontal raphe and usually located within the same hemifield as corresponding RNFL defect and optic disc damage.[15 16] However, false-positive findings in GCIPL diagnostic classifications for normal healthy populations have been reported; this suggests that optical coherence tomography diagnostic classifications should be interpreted with caution, especially in eyes with long axial lengths, large fovea–disc angles and small optic discs.[15] Hwang *et al*[17] also reported abnormal GCIPL deviation map patterns for cases with various diseases such as macular degeneration (ring-shaped pattern), epiretinal membrane (irregular colour-coded pattern) and compressive optic neuropathy (vertical hemifield abnormality), which call for careful interpretation of GCIPL deviation maps.

Relationship between RNFL and macular parameters

Because pRNFL analysis has been predominantly employed in routine patient management, better understanding of the relationship between pRNFL and macular parameters would certainly extend the range of macular thickness application. Indeed already, most studies that have investigated such relationship have confirmed strong correlations between the two parameters.[13 18] A population-based study conducted in Singapore found a strong association between average GCIPL and RNFL

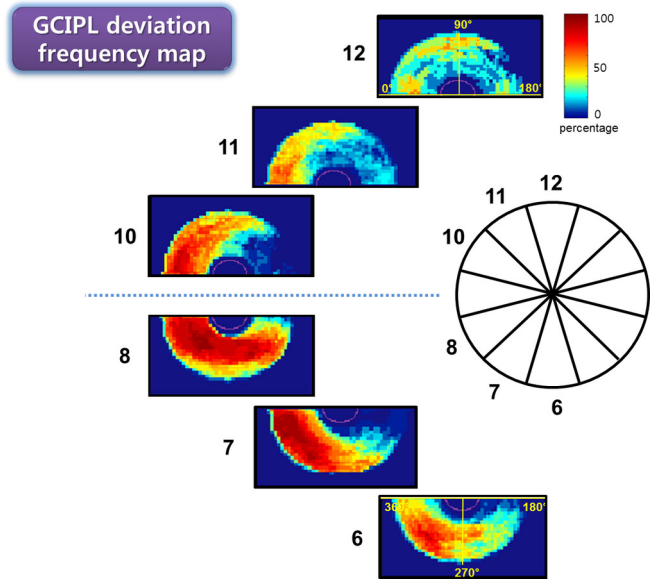

Figure 2 Topographic relationship between localised peripapillary retinal nerve fibre layer (pRNFL) and macular ganglion cell–inner plexiform layer (GCIPL) defects according to clock-hour location of pRNFL defect. A 'GCIPL deviation frequency map' was obtained by merging the GCIPL defects shown on the GCIPL deviation map corresponding to pRNFL defects at different clock-hour (from 6 to 12 o'clock) locations. The red-coloured region indicates GCIPL defects detected at the highest frequency in the pRNFL clock-hour group; the blue-coloured region, close to zero frequency. Distinctive patterns of GCIPL defect among six clock-hour groups in regard to location, shape and area were noted. The GCIPL defect, located in the same hemifield as the corresponding pRNFL defect, mostly showed an arcuate pattern. The defects in the inferior hemifield were relatively larger and closer to the fovea than those in the superior hemifield, and the GCIPL deviation frequency maps had the temporal macular area as the most frequently damaged area in common (adapted and modified from Kim *et al*[16]).

thicknesses after adjusting for age, gender, disc area, signal strength and axial length.[19] In line with this, all of the GCIPL sectors have shown statistically significant correlations with corresponding pRNFL thicknesses in patients with glaucoma.[18] In addition to thickness measurements, the topographic relationship between localised pRNFL defect and GCIPL defect has been revealed, this time in a study by Kim *et al*.[16] They generated a 'GCIPL deviation frequency map' using computer software and demonstrated GCIPL defects corresponding to six different clock-hour locations of pRNFL defect (figure 2). They discovered that the GCIPL defects had an arcuate shape that appeared as a continuation of the RNFL defect in the same hemisphere; they also noted that the temporal macular region was the most frequently damaged site in either hemifield and was larger in the inferior hemifield than in the superior. Significantly, a strong correlation between pRNFL and GCIPL measurements in terms of both thickness and topographic characteristics can provide clinicians a basis for interpreting glaucomatous damage in a combined manner.

Factors affecting macular parameters

Peripapillary RNFL thickness offers high diagnostic performance on account of its having the highest density of RGC axons in the entire retina. However, its major drawback is that it is affected by various factors such as age,[5] disc size,[5] disc tilt,[20 21] retinal vessel position[22] and axial length.[5 15 22] Macular GCIPL thickness measurements have shown excellent interindividual and intraindividual reproducibility during the courses of both short-term and long-term follow-ups.[4 23 24] More importantly, they have been reported to be less influenced by interindividual variability. Ocular or systemic demographic factors do affect GCIPL thickness, but to relatively smaller magnitudes.[5 25 26] A study conducted with 282 normal subjects found that thinner RNFL, older age, longer ocular axial length and the male gender were associated with thinner GCIPL.[25] A similar study conducted for a Chinese population showed the same results except that the female gender, not the male, was correlated.[26] These factors should be taken into consideration when interpreting GCIPL thickness measurements, notwithstanding the relatively less interindividual variance of GCIPL thickness.

Comparison of glaucoma-diagnostic ability between macular and RNFL parameters

In everyday clinical practice, the vast majority of glaucoma diagnoses consist of uncertain disc findings among which one particular diagnostic measurement alone might not be sufficient for determination of the diagnosis or further treatment plan. Because RNFL parameters have been preferred for OCT-based glaucoma diagnosis, macular parameters have been considered only as supplementary or alternatives to pRNFL or ONH parameters. However, a large number of investigations have compared the diagnostic ability between the two parameters and concluded that they might in fact be comparable to each other (see online supplementary table 1). Mwanza *et al*[27] first reported the diagnostic abilities of GCIPL thickness in comparison with RNFL and ONH in patients the macular GCIPL parameters were comparable with the pRNFL and ONH ones and also, in agreement with other studies published later on,[13 28] that the minimum GCIPL thickness demonstrated the best diagnostic ability, followed in order by the inferotemporal, average, superotemporal and inferior sectors. GCC thickness, complementary to pRNFL thickness, also showed good glaucoma-diagnostic ability.[7] A recent meta-analysis by Oddone *et al* revealed that the glaucoma-diagnostic ability of the macular parameters is comparable to that of the RNFL ones for diagnosis of manifest glaucoma.[29] Their results for GCIPL thickness showed that the best parameters were inferior RNFL thickness and minimum GCIPL thickness, with sensitivities of 0.80 (95% CI 0.68 to 0.89) and 0.78 (95% CI 0.66 to 0.86), respectively, and for GCC thickness, the best parameters were global loss volume (for RTVue OCT) and the inferior sector (for Topcon 3D-OCT) with sensitivities of 0.64 (95% CI 0.46 to 0.79) and 0.67 (95% CI 0.57 to 0.76), respectively. Whether macular parameters can be used as a primary diagnostic tool independent of RNFL thickness is another question. However, most of the reports published to date indicate that macular parameters, with their acceptable diagnostic performance, can be considered a comparable diagnostic tool to RNFL parameters.

Relationship between macular parameters and macular perfusion status

Recent studies using OCT angiography have found a strong correlation between inner retinal layer thickness and macular capillary perfusion status in patients with glaucoma.[30–32] In a recent investigation by Takusagawa *et al*,[30] the GCC map showed thinning in the same area as the superficial vascular complex capillary dropout. More interestingly, they observed that macular perfusion defects were more prominent in the superficial vascular complex supplying most of the GCC than in

the intermediate and deep capillary plexus. In another study by Chen *et al*,[31] decreased macular GCC thickness was significantly associated with decreased macular superficial vessel density in treated glaucomatous eyes. Decreased macular GCIPL thickness also was significantly correlated with large foveal avascular zone area (representing microcirculatory deficiency), as was decreased central visual field (VF) sensitivity, in glaucomatous eyes with central VF defect.[32] Although the causal relationship between inner retinal layer thickness and vascular–structural change in glaucoma remains for further elucidation, the current evidence demonstrates that decreased macular inner retinal thickness is associated with macular perfusion defects.

Structure–function relationship: correlation between central VF sensitivity and macular parameters in glaucoma

Understanding the relationship between structure and function is important in glaucoma, as the two factors reflect one another. Macular GCIPL thickness shows a strong correlation ($r^2=0.67$) with estimated macular RGC counts and, as such, currently represents one of the best imaging estimates of it.[33] Thus, it would be expected to reflect central VF sensitivity better than pRNFL thickness, and accordingly, previous reports have shown stronger central (parafoveal) functional damage associations with macular GCIPL change than with pRNFL.[18 34 35] Rao *et al* reported a significant structure–function relationship between GCIPL thickness and 10-2 standard automated perimetry (SAP), though the strength of the coefficient of determination (r^2) was rather moderate (range, 0.16–0.60), depending on the thickness parameters and the VF sensitivity scale. Their results demonstrated that, according to the linear model, the best fit was for the inferior and average GCIPL thicknesses.[36] In a different study, the structure–function relationship at the temporal parafoveal location was significantly greater than that at the central or nasal parafoveal location, and greater in the inferior hemimacula than in the superior hemimacula.[37] Among the six GCIPL sectors, the strongest observed association has been that between inferotemporal GCIPL thickness and superonasal centre mean sensitivity.[18] In addition, a stronger relationship with macular mean sensitivity in advanced stages of glaucoma has been demonstrated for GCIPL thickness than for pRNFL thickness.[38] In that study, macular GCIPL thickness reflected macular functional damage well in more advanced glaucoma, the stage wherein structural change is thought to be less sensitive and informative for indicating disease status. Recently, a pattern of correlation between GCIPL thickness and 10-2 SAP test points, presented by Lee *et al*, showed localised arcuate characteristics in the central macula, which were well matched with the patterns of GCIPL defect themselves.[39] All of the reports above noted have provided strong evidence that VF function can be relatively well inferred from macular parameters, especially in the central macular region.

Application of macular parameters for glaucoma population with diverse characteristics

The advantages of macular parameters are significant for glaucoma populations with diverse characteristics such as mild/preperimetric disease severity or high myopia. Moreover, they can be more beneficial in situations where clinical diagnoses are uncertain. Herein, we aim to present the diverse applications of macular parameters in various situations.

Diagnostic ability in preperimetric and early glaucoma

It is well known that the glaucoma-diagnostic ability of SD-OCT is affected by disease severity and the more so as disease progresses to more advanced stages. Therefore, investigators have been more interested in validating the diagnostic performance of macular parameters for early stages of the disease. In the results obtained, macular parameters have shown excellent, RNFL-comparable diagnostic sensitivity in patients with glaucoma suspect or preperimetric glaucoma.[8 10 12 13 27 35 40–42] Kim *et al*[40] reported that the diagnostic performance (presented as area under receiver operating characteristic curve (AUROC)) of the best parameter in macular GCIPL was 0.823 (inferotemporal sector), which result showed no significant difference from those of the best parameters for pRNFL (7 o'clock sector, 0.764) and ONH (rim area, 0.767) in preperimetric glaucoma. Moreover, in preperimetric glaucoma, the macular GCIPL deviation map has demonstrated diagnostic performance comparable to that of the pRNFL deviation map.[41] Relevantly too, macular GCA maps have shown good early-glaucoma detection ability (−6 dB <VF mean deviation), the detection rate ranging from 79.4% (thickness map) to 87.8% (deviation map).[12] However, as GCA maps are, as above noted, limited to the elliptical measurement annulus centred on the fovea, clinicians should be aware that glaucomatous eyes showing a large angular distance between the fovea and the RNFL defect could be missed.[12 40]

Diagnostic ability in highly myopic eyes

Detecting glaucomatous damage in patients with a high degree of myopia has always been challenging due to their unique ocular characteristics. Macular inner retinal thickness relative to pRNFL thickness is reported to be less affected by the degree of myopia and the ONH morphology related to myopic change.[5 41] And as expected, macular parameters have demonstrated satisfactory, comparable-to-RNFL diagnostic performance even in myopic eyes.[9 11 13 43 44] Choi *et al* reported that the best parameters for discriminating normal from glaucomatous eyes were inferior RNFL (AUROC 0.90) and inferotemporal GCIPL (0.852) thickness in their highly myopic group, and average RNFL (0.929) and minimum GCIPL (0.908) thickness in their non-highly myopic group.[11] Inferotemporal macular GCIPL thickness has been found to be the best parameter for glaucoma detection also in myopic preperimetric glaucoma.[9] In that study, moreover, its diagnostic ability was significantly better than those of average and inferior RNFL thicknesses and rim area. Thus far, most of the relevant studies have agreed that macular parameters provide reliable diagnostic parameters, even for highly myopic eyes. However, when interpreting glaucomatous change in such cases, consideration should always be given to segmentation error,[45] artefacts or false-positive innate abnormality arising from comparison with the internal normative database.[15 17 44]

Clinical tips for the use of different macular GCA maps in cases of diagnostic uncertainty

In addition to GCIPL thickness measurements, the pearls of macular GCA are the thickness map and deviation map showing GCIPL defect. The significant advantage of thickness and deviation maps is that they represent the characteristics (eg, location, size, shape, angular width) of the GCIPL defect,[16] thereby compensating for the impossibility of direct confirmation of macular ganglion cell damage through clinical examination. These maps, in presenting the topographic patterns of GCIPL defect to clinicians, facilitate interpretation in relation with other signs of structural and functional glaucomatous damage. In addition, the characteristics of GCIPL defect can help clinicians to differentiate glaucoma from other macular diseases or optic neuropathies.[17 46] Interestingly, Kim *et al*,[43 47] based on

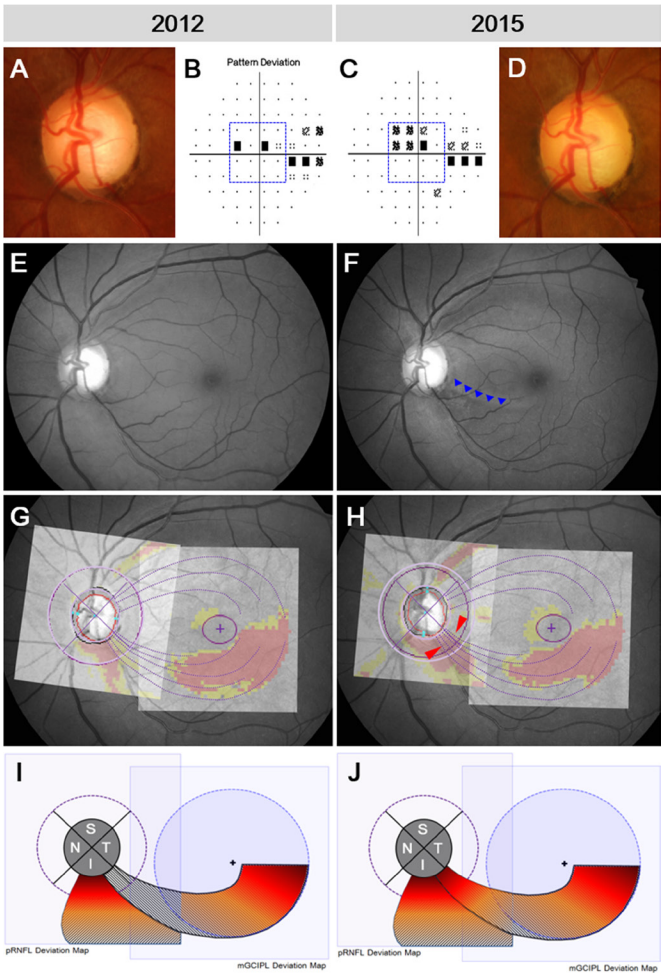

Figure 3 Representative case of early glaucomatous eye (left eye of a 43-year-old man) at baseline (year 2012; A, B, E, G and I) and follow-up (year 2015; C, D, F, H and J) examinations. (A) Stereo disc photograph showing glaucomatous optic neuropathy. (B) Pattern deviation map derived from central 30-2 Humphrey visual field test showing defects in both superior and inferior hemifields. (G) Integrated map combining macular ganglion cell–inner plexiform layer (GCIPL) and peripapillary retinal nerve fibre layer (pRNFL) deviation maps from spectral-domain optical coherence tomography superimposed on RNFL photography. Both inferoinferior pRNFL defect and inferior macular GCIPL loss were detected by the integrated deviation map. (I) Schematic representation showing inferoinferior pRNFL defect with inferior macular GCIPL (mGCIPL) loss. (C) After 3 years, note the increased superior paracentral scotoma. (F) The RNFL defect's temporal border was thickened and sharpened in the red-free RNFL photograph in year 2015 (blue arrowhead) relative to the baseline. (H) The integrated deviation map for year 2015 shows the subsequent emergence of pRNFL defect (red arrowhead) in the macular vulnerability zone (MVZ).[1] (J) Schematic representation of both inferoinferior and MVZ–pRNFL defects in eye showing inferior mGCIPL loss (adapted from Kim *et al*[51]).

their detection of superior–inferior GCIPL thickness difference across the temporal horizontal raphe, were able to offer a practical tip on the use of the GCIPL thickness map: such hemifield difference positivity suggests a strong likelihood of glaucomatous damage. This can be useful, especially in patients who are highly myopic with depigmented fundus whose RNFL defect is not visible[43] or in patients with preperimetric or early perimetric glaucoma for discrimination of early structural damage.[47]

GCIPL thickness and deviation maps, despite their limitations, can be convenient and handy, enabling time-saving and effective decision-making in busy clinical settings.

Detection of glaucoma progression

It still is not fully understood whether damage to the RGC body and RGC axonal loss occurs simultaneously or sequentially (one preceding the other). Understanding the temporal relationship of these parameters is essential for earlier detection of progression as well as earlier diagnosis. The macular vulnerability zone (MVZ), introduced by Hood *et al*,[1] is a temporal portion of the inferior quadrant of the optic disc where glaucomatous damage predominantly occurs. Since most of the inferior region of the macula projects into this MVZ of the disc, that macular area is just as susceptible to the glaucomatous damage as the inferotemporal part of the disc. Thus, studies have been gradually highlighting the importance of scrutinising the damage in the MVZ of the optic disc and corresponding macular areas for diagnosis and detection of glaucoma progression.[1 48–50] Kim *et al*[51] recently reported the temporal relationship between RNFL and GCIPL loss based on OCT deviation maps. Their results showed that in early-glaucoma eyes, macular GCIPL change was frequently detected earlier than corresponding RNFL change (figure 3), in line with their previous findings.[48] Their findings could be associated with the superior sensitivity of the GCIPL deviation map relative to the RNFL alternative; it is more likely, though, that they reflect the fact that detectable structural change in the macular RGCs can precede that in the pRNFL. In any case, they recommended combined examination of pRNFL and macular RGC imaging for enhanced detectability of glaucoma progression.

Other investigators have examined progressive loss of macular ganglion cell damage using macular GCIPL thickness parameters. Among healthy eyes, for example, a significantly faster rate of average RNFL decrease (−0.52 µm/year) relative to that of average macular GCIPL (−0.32 µm/year) has been reported.[52] Recently, Lee *et al*[53] demonstrated a significantly faster GCIPL thinning rate in progressors than in non-progressors. They also found that GCIPL thinning rate was significantly correlated with pRNFL thinning rate, which suggests that trend-based analysis of GCIPL thickness can be useful for assessment of glaucoma progression. Another report, this one by Hammel *et al*, showed that the rate of average RNFL thickness decrease (−0.98 µm/year) was significantly faster than that of average macular GCIPL change (−0.57 µm/year) in glaucomatous eyes, but that the difference was insignificant in healthy eyes (−0.48 and −0.14 µm/year for RNFL and GCIPL, respectively).[54] In addition, their separate analysis for an advanced-glaucoma group showed that only macular GCIPL loss, in all sectors except the temporal superior, was statistically significant, which results are in line with an earlier study, which found that structural changes in the macular area can be detected in advanced-glaucoma eyes.[55] Therefore, detecting progressive loss of macular parameters can be useful throughout the entire course of the disease, even in advanced glaucoma.

LIMITATIONS

Macular parameters, despite their high diagnostic ability and advantages over pRNFL measurements, have several limitations that should be considered. First, unlike the situation with ONH or RNFL change, clinicians have no clues to the confirmation of the authenticity of macular inner retinal layer abnormality other than those presented by OCT maps. Indeed, since direct

comparison between clinical examinations (or photographs) and OCT findings for the presence of macular ganglion cell abnormality is impossible, careful interpretation of macular parameters in combination with other diagnostic measurements is suggested. Second, various diseases other than glaucoma can result in macular GCIPL thickness change that affects the yellow-coloured and red-coloured areas on the deviation map. For example, any retinal diseases involving macular areas such as the epiretinal membrane, age-related macular degeneration, drusen, or macular oedema and optic neuropathies (eg, non-arteritic ischaemic optic neuropathy, post-optic neuritis or compressive optic neuropathies) can affect macular GCIPL thickness and, so too, the patterns of macular GCA abnormality on the deviation map.[17 46] Therefore, clinicians need to be aware of such diseases when ruling out causes of macular GCIPL abnormality. Third and lastly, limitations related to the restricted macular scanning area of at least some OCT devices have to be considered. As mentioned earlier, glaucomatous eyes showing RNFL defect with a large angular distance from the fovea should be observed with caution, as their corresponding macular damage could be located outside the scanning area.[12 40]

CONCLUSIONS

Macular parameters have shown high diagnostic ability and outstanding performance, which qualities make them a reliable choice for detection and monitoring of glaucomatous change. In consideration of the different diagnostic sensitivities and specificities among eyes with diverse ocular characteristics (eg, disease severity, optic disc characteristics, degree of myopia), combining macular parameters with other diagnostic modalities would certainly enhance their glaucoma-diagnostic capability as well as that for progression monitoring. Thus, we hope that clinicians take full advantage of the potential of macular OCT imaging in this way. In the future, technologically advanced iterations of the macular scanning algorithm would strengthen the accuracy and precision of its application, thus enabling more personalised diagnosis and treatment for patients with glaucoma.

Correction notice This article has been corrected since it published Online First. The reference citation at the end of the Figure 2 caption has been corrected from 8 to 16.

Contributors Design of review: KEK, KHP. Collection and management of data/references: KEK. Interpretation of data: KEK, KHP. Preparation of manuscript: KEK, KHP. Review/approval of manuscript: KHP.

Competing interests None declared.

Provenance and peer review Not commissioned; externally peer reviewed.

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