Comparison of optical coherence tomography models OCT1 and Stratus OCT for macular retinal thickness measurement

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Aims: To compare the values measured for retinal macular thickness with the first and last generations of the optical coherence tomograph (OCT1 and Stratus OCT, Zeiss, Humphrey Division).

Methods: This was a cohort study. 59 eyes were examined: 17 had a normal macula and 42 had a diabetic macular oedema. In each eye, mean retinal thickness (RT) was measured automatically in the nine macular Early Treatment Diabetic Retinopathy Study areas and at the foveal centre, using OCT1 and Stratus OCT. The paired mean RT values for each area and the type and proportion of artefacts were compared.

Results: Of the 590 automatic measurements, 505 had no artefact, either with OCT1 or Stratus OCT. The mean difference between the OCT1 and Stratus OCT measurements was 25 (SD 26.2) µm (p<0.0001). With Stratus OCT, RT values were significantly higher, by 8.1% (7.8%), than with OCT1. Artefacts were only observed in cases of diabetic macular oedema and were significantly more frequent with OCT1 than Stratus OCT (10.5% versus 4.4, p<0.0001).

Conclusion: The macular retinal thickness values measured with Stratus OCT were significantly higher than those measured with OCT1. Stratus OCT has the advantage of producing fewer artefacts than OCT1 in pathological cases.

The introduction of optical coherence tomography (OCT) in clinical practice in 1996 made it possible to measure retinal thickness (RT) routinely. The first version, OCT1 (Carl Zeiss Meditec, Humphrey Division, Dublin CA, USA), had an axial resolution of about 15 µm. In 2002, the new Stratus OCT came into use and reduced axial resolution by up to 7 µm. The repeatability and reliability of RT measurements with OCT1 have been demonstrated in several studies. Artefacts were defined as the discordance between the automatically detected anterior and posterior retinal boundaries and the boundaries detected by the examiner. Such artefacts can either increase or reduce the RT values measured manually in the quadrants concerned (fig 3).

Artefacts

The proportion of artefacts on radial B-scans was also compared for OCT1 and Stratus OCT. Artefacts were defined as the discordance between the automatically detected anterior and posterior retinal boundaries and the boundaries detected by the examiner. Such artefacts can either increase or reduce the RT values measured manually in the quadrants concerned (fig 3).

Data analysis

Comparison of OCT1 and Stratus OCT macular RT estimations was based on quadrant by quadrant paired comparison. The coefficient of correlation and the mean difference between RT measurements with OCT1 and Stratus OCT were calculated. Results are expressed as means (SD). Fisher’s
exact test was used for the correlation studies, and paired Student t test, for the comparative studies. Statistical analysis was performed with Apple iMac StatView software (SAS Institute Inc, Version 5.0). All analyses were performed on the two complete sets of 590 values and also on the sets of values that remained after the exclusion of quadrants with artefactual measurements. The type and proportion of the artefacts obtained with OCT1 and Stratus OCT were also compared ($\chi^2$ test).

**Retinal outer boundary reference line**
Careful examination of the outer boundary reference line, automatically aligned by the mapping software of OCT, showed that, in Stratus OCT, it was constantly located on the inner segment/outer segment (IS/OS) photoreceptor line rather than on the retinal pigment epithelium (RPE) line. This misalignment was not noted in OCT1, which did not distinguish between these two lines because of its lower axial resolution. To evaluate and quantify this error more accurately, we measured the mean distance between the IS/OS and the RPE lines, at the foveal centre of healthy maculas mapped with Stratus OCT, using the “Scan Profile” protocol of the software. The outer boundary of the retina was characterised by two peaks, the outermost being the signal of the RPE. Callipers easily allowed measurement of the distance between the two peaks. This measurement was
repeated at the five contiguous pixels on each side. The average of the 11 measurements performed was considered as the distance between the two lines at the foveal centre.

RESULTS
Artefacts
Of the two sets of 590 paired values, 85 exhibited artefacts with either OCT1 or Stratus OCT or both. With OCT1, artefacts were present in 19 eyes, and with Stratus OCT, in nine. They were only observed in eyes with diabetic macular oedema (DMO). Of the two sets of 420 values obtained with OCT1 and Stratus OCT in the 42 eyes with DMO, 62 (10.5%) and 26 (4.4%), respectively, exhibited artefacts \((p<0.0001)\). Artefacts resulting in lower RT values than with manual measurement were observed in 44/62 quadrants (71%) in the OCT1 scans, and in 16/26 quadrants (61.5%) in the Stratus OCT scans. These underestimations were mainly the result of the presence of intraretinal hard exudates, or by erroneous analysis of cystoid macular oedema (fig 4A, B, and C). There were a few overestimated artefacts, the result of erroneous positioning of the inner boundary of the retina. The detached posterior hyaloid was, for example, misinterpreted as the internal limiting membrane (fig 4D and E).

Retinal thickness values
On the basis of the two complete series of 590 values—that is, including the artefacts, the mean RT in the 6 mm diameter area was 322.3 (126.3) \(\mu\)m with OCT1 and 358.9 (156) \(\mu\)m with Stratus OCT. There was good agreement between the two instruments \((r=0.899, p<0.0001)\). However, the RT values obtained with Stratus OCT were always higher than those obtained with OCT1, by 11.6% (23.1%) (mean difference: 36.6 (70.1) \(\mu\)m \(p<0.0001\)); the greater the retinal thickness, the greater the difference.

On the basis of the two series of 505 values—that is, excluding the artefacts, the mean RT in the 6 mm diameter area, was 308.8 (116.8) \(\mu\)m with OCT1 and 333.8 (126.7) \(\mu\)m with Stratus OCT. The agreement between the OCT1 and Stratus OCT measurements was better than when the artefactual quadrants were included \((r=0.98, p<0.0001)\). However, these measurements still remained unequal (fig 5A). The mean difference between Stratus OCT and

| Table 1 | Distribution of (1) the retinal thickness (RT) measured with OCT1 and with Stratus OCT, (2) the difference between the RT values measured with Stratus OCT and OCT1, and (3) the RT ratio (Stratus OCT – OCT1)/OCT1 based on the 505 non-artefactual RT measurements for 42 eyes with diabetic macular oedema and 17 eyes with healthy maculae |
|---------|-----------------------------------|--------------------------------|-----------------|-----------------|
| OCT 1 \(\mu\)m | Stratus OCT \(\mu\)m | Stratus OCT – OCT 1 \(\mu\)m | (Stratus OCT – OCT 1)/OCT 1 |                      |
| Number of values | 505 | 505 | 505 | 505 |
| Mean | 308.8 | 333.8 | 25.0 | 0.08 |
| SD | 116.8 | 126.7 | 26.2 | 0.078 |
| Error of mean | 5.2 | 5.6 | 1.2 | 0.003 |
| Minima | 124 | 126 | –68 | –0.192 |
| Maxima | 761 | 824 | +216 | +0.557 |
using Stratus OCT. In both OCT instruments, computer image processors measure RT from retinal tomograms as the distance between the highly reflective inner and outer boundaries of the retina, which are located by a thresholding algorithm. \(^5\)

The mapping software of OCT1 has been shown to have good reproducibility for RT measurements in healthy subjects, and in patients with DMO. \(^1\) It also appeared to be a sensitive tool for detecting early retinal thickening in diabetic patients. \(^5\) We therefore compared the RT measurements obtained with OCT1 (software A6.2) and Stratus OCT (software 2.0) and showed that both give measurements that are highly correlated but nevertheless slightly different. We do not know which OCT gives RT values closest to the in vivo reality, and can only compare the macular RT measured with both instruments. Stratus OCT tended to overestimate the RT measured with OCT1, by 25 (26.2) \(\mu m\) (p<0.0001). As stated in Results, the greater the RT, the greater the difference between OCT1 and Stratus OCT values. The equation: 

\[
RT(\text{Stratus OCT}) = 1.064 \times RT(\text{OCT1}) + 5.43
\]

was extrapolated from the regression graph “RT(\text{Stratus OCT}) = f(RT(\text{OCT1}))” (fig 5A) obtained with StatView software. The mean percentage by which Stratus OCT exceeded OCT1 was 8.1% (7.8%) (fig 5B). Despite the wide range observed for this ratio (−19% to +56%), the standard error of the mean was only 0.3%—that is, in 95% of the RT measures, Stratus OCT exceeded OCT1 by 7.5% to 8.7%. This means that by adding 8% to our OCT1 values, we can estimate the Stratus OCT values with an error of less than 0.6% in 95% of cases. Conversely, by reducing the Stratus OCT values by 7%, the OCT1 values can be estimated with an error of less than 0.6% in 95% of cases.

Because of its better axial resolution, Stratus OCT displays two different outer hyper-reflective lines. The innermost is generated by the IS/OS junction, as shown by Drexler et al\(^6\) with an ultra high resolution OCT prototype, and the outermost, by the RPE. Stratus OCT takes the IS/OS line as the outer boundary of the retina, thus underestimating RT. The difference between the RT measurements obtained with the two OCT instruments would have been greater if the outer boundary line of the Stratus OCT had been correctly located at the RPE level.

The significantly lower artefact rate with Stratus OCT than with OCT1 for DMO (4.4% v 10.5%) may be the result of the better definition of A-scans with the former instrument. Artefact locations were also different. Most of the artefacts encountered in OCT1 were not seen in Stratus OCT and vice versa. Maculopathies with hard exudates are the most likely to generate artefacts. However, even in these eyes, artefacts were fewer with Stratus OCT than with OCT1.

In conclusion, retinal thickness measured with Stratus OCT (version 2.0) was significantly greater than with OCT1 (version A6.2). Therefore, extrapolation of retinal thickness measurements from OCT1 to Stratus OCT should take into account a correcting value. This value would be even higher, by up to 46 \(\mu m\), if the outer reference line for macular thickness measurement were correctly located at the RPE and not on the IS/OS line. Although Stratus OCT has the advantage of being more accurate and producing fewer artefacts than OCT1 in pathological cases, the retinal thickness values provided by its mapping software should be carefully reappraised.

**DISCUSSION**

Axial resolution is twice as good with Stratus OCT as with OCT1 (about 7 \(\mu m\) with 1000 pixels for each A-scan versus 13 \(\mu m\) with 500 pixels for OCT1). Longitudinal resolution is also better with Stratus OCT (512 axial profiles per tomographic line, instead of 100 with OCT1). In the present study, RT was therefore measured in each 6 \(\mu m\) diameter area at a total of 600 points using OCT1 and 3072 points using Stratus OCT.
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