Retinal Thickness Measurement Using OCT

We read with interest the paper published by Payne et al., in the November 2011 issue, in particular the statement that the ratio of OCT thicknesses measured at different time points is machine invariant because of the cancellation of the baseline thickness. We believe that this statement is incorrect, because of the nature of the calculation of retinal thickness using OCT. We present the reasons below.

The retinal thickness is the distance between the inner retinal surface and the reference plane. This distance represents interval data, as there is no natural zero, and the retinal thickness assumes a numerical value only when the reference plane is defined. As a result, the retinal thickness value contains information about the reference plane for each particular machine.

Consider two OCT machines A and B, each of which measures from different reference planes, \(a\) and \(b\), respectively. Let plane \(c\) be the position of the inner retinal plane and the retinal thickness \(d\) be measured at two different times, \(t_1\) and \(t_2\). During this time interval, let the position of the retinal layers change because of the effect of disease or intervention (Figs. 1A, 1B).

If the ratio of two measurements performed at different times is independent of the OCT machine used, then these values will be equal in the same individual.

For machine A we have

\[
\begin{align*}
d_{a1} &= c_1 - a_1 \quad \text{and} \quad d_{a2} = c_2 - a_2.
\end{align*}
\]

Similarly, for machine B

\[
\begin{align*}
d_{b1} &= c_1 - b_1 \quad \text{and} \quad d_{b2} = c_2 - b_2.
\end{align*}
\]

In the general case, at time \(t_2\) it is best to assume that the positions of all retinal layers have changed, so that \(c_1 \neq c_2, a_1 \neq a_2,\) and \(b_1 \neq b_2\).

Thus, the ratio of thicknesses measured at times \(t_1\) and \(t_2\) for both machines is

\[
\frac{d_{a2}}{d_{a1}} = \frac{(c_2 - a_2)}{(c_1 - a_1)}
\]

and

\[
\frac{d_{b2}}{d_{b1}} = \frac{(c_2 - b_2)}{(c_1 - b_1)}.
\]

The condition for machine invariance (i.e., the ratio of two thickness measurements made at different times on different machines) is

\[
\left(\frac{d_{a2}}{d_{a1}}\right) - \left(\frac{d_{b2}}{d_{b1}}\right) = 0.
\]

However, it is clear that the values of retinal thickness derived by the two machines will be different, because the planes \(a\) and \(b\) are different and also because the planes \(a\) and \(b\) may have moved from their original positions at time \(t_2\).

The difference between the ratios can be 0 only if the condition \(a = b\) is applied, but this is not the case with the various OCT machines.

Therefore, neither the ratio of the thicknesses nor the log ratio can be machine invariant. This observation is illustrated by the example below. Assume that the reference planes are 50 \(\mu m\) apart, so that \(b - a = 50 \mu m\), and they do not move during the time interval:

![Figure 1](http://iovs.arvojournals.org/pdfaccess.ashx?url=/data/journals/iovs/933463/)
As an alternative to ratio calculation, we can also explore whether the linear difference between thickness measurements is machine invariant. Consider the difference between the thicknesses at the different time points:

$$\Delta d_\lambda = d_{t_2} - d_{t_1} = (c_2 - a_2) - (c_1 - a_1) = (c_2 - c_1) - (a_2 - a_1)$$
and, similarly,

$$\Delta d_\beta = d_{t_2} - d_{t_1} = (c_2 - b_2) - (c_1 - b_1) = (c_2 - c_1) - (b_2 - b_1).$$

The condition for machine invariance here is that

$$\Delta d_\lambda - \Delta d_\beta = 0.$$

From this calculation, we have

$$(b_2 - b_1) - (a_2 - a_1) = 0.$$

which is the case only if the reference planes do not change position during the time interval or if the difference between the two planes is negligibly small.

It may be that for some diseases, such as diabetic retinopathy and other retinal vascular diseases, that only the inner retinal layer moves and the reference planes (e.g., the tips of the outer segment or the first bright RPE reflection) do not move, in which case the linear difference between measurements will be machine invariant (as $(b_2 - b_1)$ is zero and $(a_2 - a_1)$ is zero).

However, in florid cystoid macular edema, where the photoreceptor layer itself detaches from the RPE or where the position of the RPE layer moves (e.g., RPE detachment reducing after intravitreal ranibizumab), then the linear difference between different machines will not be invariant.

In summary, retinal thicknesses derived from OCT measurements are interval data. There is no natural zero, and the numerical value of the thickness always depends on the choice of reference plane. The ratio of two thickness measurements made at different time intervals and the logarithm of this ratio varies from machine to machine. The linear difference between thicknesses at these different times may be machine independent, but only if the position of the reference plane remains unchanged with the passage of time.

We therefore warn the retinal community against performing studies in which different OCT machines are used and ratios of thicknesses are calculated and treated as comparable. Such comparisons would introduce errors in the data that are collected. We hope that our analysis explains this concern.

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References


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Author Response: Retinal Thickness Measurement in OCT

The authors thank Davies and Parvizi1 for their thoughtful comments about our paper published in the November 2011 issue.2 We are grateful for the opportunity to respond to their comments.

We believe that each of the approaches is correct; however, it is critical to understand the meaning, limitations, and potential biases of using a difference in the logarithmically transformed optical coherence tomography (OCT) data. As shown mathematically in our paper, a given ratio change (e.g., a change from 320 to 400 μm or 400 to 500 μm) yields a fixed change in the logOCT (in these examples, $-0.1 = \log_{10}[320/400] = \log_{10}[400/500]$) regardless of the choice of a normalizing baseline (e.g., 200 for logOCT or 250 for SD-logOCT).

We acknowledge that these changes in the logOCT value do not represent the same absolute change in retinal thickness across machines. We also recognize that if the same patient were to be measured on two different devices, then two different logOCT measurements would be obtained, as we discussed in our paper. However, we can still envision situations in which this method would be useful and advantageous. For example, if a study were designed to determine the number of patients who achieve a 20% reduction in retinal thickness (about a $-0.1$ logOCT change as illustrated above) and if the study outcome were based on repeated measures of each patient on their same OCT device, then the change in logOCT would indeed be invariant to the machine’s reference plane. As illustrated by Davies and Parvizi, a machine that includes additional retinal layers will measure greater retinal thicknesses on average and is therefore at a relative disadvantage in such a study because greater absolute changes would be necessary to achieve a given percentage of reduction. However, if a cohort of patients were described as a single whole or if there were no imbalance in the variety of machines used between the groups compared, then it would be reasonable to use multiple devices in a single study. Because randomization should balance the measurement devices used across the interventions, such an approach would be reasonable in a randomized clinical trial. While these same considerations would also make it reasonable to use the absolute change in retinal thickness across devices in certain situations, we