Abstract
Optical Coherence Tomography is now a clinical mainstay in hundreds of ophthalmology practices worldwide. In an effort to promote standards of imaging that ensure consistency of data and quality, a systematic protocol of OCT macular scanning is discussed in detail.

Key Words
MacPac, 7 mm Post. Pole, Cross Hair, scan/panning, retinal thickness/volume change, free-scanning, spikes and dips

Introduction
In the relatively short period of time since Optical Coherence Tomography (OCT) has been available to the worldwide ophthalmology market, its impact on clinical photography departments has been significant. In use at the Duke University Eye Center since 1997, OCT eclipsed fluorescein angiography as the second most-ordered imaging procedure by a significant margin in 2001. Well over 3900 patients were scanned with this newer diagnostic modality compared to almost 3300 angiograms acquired. Stereo color fundus photography remains the top imaging procedure at Duke. It is almost always performed along with angiography, in addition to being a stand-alone procedure. Many patients receive both angiographic and OCT tests, but a significant number of patients have OCT scans as their sole imaging procedure with no traditional fundus photography, particularly those patients with a form of macular edema. The great majority of these patients have macular disease. In a lesser but significant number of glaucoma patients, macular thickness and nerve fiber layer are analyzed with various glaucoma scanning modes. The Zeiss Stratus OCT 3000 (Figure 1), arguably the most significant retinal imaging device released in recent years, provides physicians and imagers with a number of interesting and potentially helpful scanning modes. These enable the acquisition of two-dimensional, cross-sectional images, in addition to measurable and therefore, quantifiable data statistics. To ensure accuracy of data and consistency of testing over long periods of time, it is important to implement and follow set scanning standards. The purpose of this article is not intended to be a “how to” scanning manual (the Zeiss OCT user’s manual is quite good), but rather to provide OCT users with a standard set of scanning modes for obtaining quality images and data on almost all macular pathologies in a timely and efficient fashion to be used over time. In the description to follow, a systematic method of OCT macular imaging referred to as “MacPac” is suggested in order to provide comprehensive scanning and data gathering of most macular disease. The MacPac consists of three powerful scanning modes: 7mm Posterior Pole, Cross Hair, and...
Fast Macular Thickness Map, all offering a solid platform for baseline macular imaging whether used alone or in conjunction with traditional fundus photography and angiography.

**Scanning the Posterior Pole**

For decades, the standard for fundus photography has been 30° disc/macula stereo photographs; the baseline images used to document the posterior pole. The use of seven stereo standard field protocols, ETDRS/DCCT (Early Treatment Diabetic Retinopathy Study, Diabetic Controls and Complication Trial) and wide angle fundus cameras offer substantial documentation beyond the posterior pole to image diseases such as diabetic retinopathy, vascular occlusions, choroidal nevi and tumors. While the OCT is capable of mid-periphery scanning and, at times, far periphery scanning (per patient compliance), its primary use is to scan the optic nerve, peripapillary and macular areas. Provided with an almost overwhelming array of scanning modes, line numbers, lengths and angles, the choices for any given user seem infinite and to newer users, rather daunting (Figure 2). If a user were to be limited to just one scan for whatever reason, the 7mm Posterior Pole Scan (7mm Post. Pole) just may be the single most useful OCT image for any given macular disease. Though 10 mm is the maximum line length allowed by the device, a 7mm line easily encompasses the area leading from the optic nerve well past the macula temporally and provides good magnification. Using the Custom Scan function of the Stratus OCT, users are enabled the option of programming their own defined scanning modes. At Duke, this so-called “7mm Post. Pole” mode was created to capture a wide, high-resolution, cross-sectional image emanating at the optic nerve and terminating temporally to the macula. In addition to the 7mm length, a 5° negative angle offset is programmed for both eyes. This offset enables the user to begin the scan at the center temporal edge of the typical optic nerve and, by default, the scan almost always cuts directly through the fovea given the anatomic inclination for it to reside just below a horizontal line drawn through the optic nerve, under this described “photographic equator” (Figure 3).1

This one scan is somewhat analogous to an establishing shot: the low-magnification wide-angle photograph of the anterior eye using a photo slit-lamp camera as the starting point in documenting the overall health in which further documentation is gathered with higher magnifications and various lighting techniques. The 7mm Post. Pole scan provides a good representation of the overall health of the macular area. It is often the only magnification needed to document prominent cystic appearances and the presence of vitreomacular traction (VMT) in high-resolution. This composite image is comprised of 512 A-scans, the highest possible resolution offered by the current OCT 3. This was not the case with the earlier OCT models 1 and 2, where long scans did not have adequate resolution to sufficiently document foveal detail at the lower magnification. Prominent cysts can be scanned at higher resolution and magnification if so desired, but scanning the macula only at short line lengths, such as 3mm, can potentially miss the presence of VMT often seen at the nerve in addition to the macular area, nasally or temporally, superiorly or inferiorly.

A major advantage of using the 7mm Post. Pole scan is reproducibility. Using the temporal center margin of the optic nerve as a landmark start point, different users can repeat scans on subsequent visits with a high degree of confidence that they are scanning the previous area. This provides more consistent visual representation of disease progression. Not having any landmarks in simple horizontal line scans makes accuracy difficult to achieve with a high degree of confidence. This is especially true if foveal detail is compromised by the presence of any given pathological process, making it difficult to visualize and image. Also, often times patient fixation is non-existent, making the fovea difficult to locate and scan. This custom mode often gives the user a “fighting chance” of

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**Figure 2:** Scan mode options including the custom “7mm Post. Pole” mode.

**Figure 3:** Digital color fundus image of normal retina w/ MacPac overlays depicting “blanketing” scan coverage; horizontal yellow line (“photographic equator”) illustrates natural, inferior macular location, blue circle pattern represents Retinal Map field, red lines indicate 7mm Post. Pole coverage obtained with Scan/panning and the green lines represent Cross Hairs. Overlays not drawn exactly to scale. (Illustration by Russell Burns, Duke Eye Imaging.)
locating the fovea independent of a patient’s ability to fixate or comply.

One 7mm Post. Pole scan of the posterior pole through the nerve and fovea is often sufficient documentation in many cases but may not encompass all the needed information in that macular region. The OCT user should perform aggressive and deliberate offset horizontal “scan/panning” scans superior and inferior to the fovea, within the arcades, to search for VMT or any other abnormal pathologic findings such as subretinal fluid/blood, cysts, holes and pigment epithelial detachments in neighboring areas. Scan panning is easily done by clicking onto the active line scan on-screen with the mouse and slowly dragging or raking the live OCT scan across the macular area in a systematic fashion while searching for abnormal pathology. The enormously helpful “review buffer mode” should be used to study all non-saved scan passes to ensure that the most helpful scans are saved. It should be confirmed that no abnormal pathology was actually scanned only to be deleted in favor of a scan mistakenly thought to be more helpful. With the economy of digital storage space, it would be unwise to discard potentially significant diagnostic images in favor of saving space. OCT Super Luminescent Diode (SLD) range and noise settings are left at default settings for almost all scanning situations to ensure consistency. Figures 4-7 illustrate various 7mm scans; a normal macula, sarcoid uveitis with chronic edema and detached fovea, a partial-thickness macular hole with vitreomacular traction and operculum, and vitreomacular separation.

**High-Magnification Scanning of the Fovea**

A long 7mm line scan through the posterior pole will only tell most of the story in some cases, certainly not the whole story. This is why it is important to supplement long scans with higher magnification short scans to analyze the macular areas in more vivid detail. The Cross Hair mode has proven to be a very effective tool for assessing fine foveal detail and offers the advantage of a default scan at both the horizontal and vertical settings (mode settings of 0° and 270°, respectively). These scans, like the 7mm Post. Pole scans, are very high-resolution. 512 A-scans are used to build these high-magnification images, only the 512 A-scans are more densely stacked, providing even higher tissue resolution than longer scans. 3mm is the default length (and shortest possible line length for any scan) for Cross Hair scans, but this number can be increased if so desired. However, modifying length is not recommended as it complicates the procedure and would have to be repeated on future visits for consistency. The first scan in the Cross Hair mode scans horizontally at 3mm, then defaults to a 3mm vertical scan once the horizontal image is scanned and saved. Scan/panning technique, up/down and sideways, should be employed at this hi-magnification setting so as not to miss juxta/extrafoveal pathology. Also, at times, for reasons unknown at this writing, greater scan saturation and focus seems to be acquired more easily when scanning vertically and should be considered if encountering difficulty with the initial horizontal scans. The 3mm scans of the fovea are quite helpful in imaging intra-retinal fluid, lamellar/pseudo/partial thickness/full thickness macular holes, small cysts, and epiretinal membranes. As stated earlier, it may not always be necessary to scan at the 3mm range as no significant information will be gathered beyond what was captured with the 7mm scan. Cases such as chronic diabetic or macular edema, uveitis, epiretinal membranes, large PEDs, subretinal hemorrhages and retinal detachments may not require such high magnification scanning to illustrate their presence and destructive effects. Figures 8-10 illustrate high magnification scans obtained with Cross Hair scans; lamellar hole, spontaneously sealed Stage 1 macular hole with pseudopericulum and posterior vitreous separation, and an extremely small cyst corresponding with central serous chorioretinopathy initially misdiagnosed as a full thickness macular hole scanned with an OCT 1.
VOLUMETRIC SCANNING OF THE MACULAR REGION

The Fast Macular Thickness Map (FMTM) mode is the third and final mode in this proposed MacPac protocol, and it is a powerful one considering that it utilizes lower resolution scans to comprise interpolated Retinal Maps. This is perhaps the most comprehensive scanning mode of the three described. Cystoid macular edema, a common retinal finding, is just one of many diseases that can be accurately imaged with FMTM. Macular edema is often present in patients with diabetes, uveitis, vein occlusions, Irvine-Gass Syndrome, age-related macular degeneration and macular holes (the two latter are not often correlated with macular edema). Though each of the six scans are comprised of only 128 A-Scans (768 total) and are of a lower resolution than the Cross Hair and 7mm Post. Pole scans (each of 512 A-scans), the fact is that six good 6mm scans can be acquired at each clock hour in less than two (1.92) seconds. Most pathology can be imaged quite well at this lower resolution (approximately the same resolution of OCT 1 and 2) including subtle VMT. These Retinal Maps, now used in more and more practices worldwide, provide clear, objective data in the form of a false-color aerial graphic as well as sectoral thickness and volumetric statistics, a two-pronged method of tracking macular edema and retinal thickness over time. From the patient’s perspective, this mode provides a higher “Star Wars” factor than other modes, almost hypnotic, with the hi-tech scan alignment or “spinning wheel array” of the preview diodes seen before active scan acquisition mode is engaged. This somewhat hypnotic effect may actually promote testing compliance and scan placement accuracy. Some users prefer initiating all scanning sessions with the FMTM mode as it functions as a lower resolution screening mode and has the ability to detect pathology lying within the circular scan area subsequently imaged in higher resolutions using Cross Hair or the 7mm Post. Pole scans. Also, although of lower resolution, the scans obtained with FMTM have the capability at times to actually exaggerate subtle pathologic findings through large pixel effect, which again, may be imaged later using the higher resolution modes.

Some experienced OCT users prefer the Macular Thickness Map (MTM) or Radial Lines (RL) modes instead of the FMTM mode and the reasons are numerous. One, in the MTM or RL modes, the 6 or more (user can choose to increase the number of radial scans from 6-24) individual lines are made of 512 A-Scans compared to the 128 in the FMTM, offering much higher resolution per scan. Two, experienced users often like to have total control of each scan through the fovea and prefer to have the ability to scan at certain clock hours when encountering difficulty or artifacts on one particular scan. If the desired outcome is 6-24 high resolution scans at each clock hour, then MTM and RL are indeed excel-

Figure 8:
3 mm Cross Hair scan of lamellar hole with posterior vitreous detachment and operculum.

Figure 9:
3 mm Cross Hair scan of spontaneously sealed Stage 1 macular hole with settling neurosensory retina at layer abutting RPE, w/PVD and pseudo-operculum. Of note, this patient was scheduled for vitrectomy surgery the next day which was cancelled upon review of scans, referring physician purchased an OCT unit the next week.

Figure 10:
A 1.99 mm OCT 1 Cross Hair scan of tiny intraretinal cyst secondary to central serous chorioretinopathy initially misdiagnosed by referring ophthalmologist with macular hole. The cysts did, in fact have a hole-like appearance when viewed on examination with OCT and with a Zeiss FF-3 fundus camera. However, it was almost a half disc-diameter temporal to the foveal pit, also seen on examination.

Figure 11:
Normal Retinal Map with information display containing Center Deviation value and retinal thickness sector graphs illustrating thickness/volume values per sector; note “0” +/- Center Deviation, a perfectly registered Retinal Map obtained with the FMTM mode.
lent. However, they will usually not render as accurate a Retinal Map as the FMTM mode since the rapid acquisition of the six scans in this mode negates most problems of patient fixation and foveal registration at the midpoint of each scan. This is especially true with patients who have difficulty fixating and/or following instructions. Registration flux is illustrated on each Retinal Map in the form of the +/- Center Deviation (CD) value (Figure 11). When using the manual modes of radial scanning and comparing the Center Deviation value to a set of scans obtained with the FMTM mode on the same eye, the CD value is almost always lower and thus, proof of higher quality foveal registration and volumetric data. For these reasons, the FMTM mode is an ideal application for use on children (Figure 12). If a patient fixates perfectly with every scan in the manual modes using more than six radial line scans with the fovea in the exact middle of each radial scan, then the subsequent Retinal Map may be more accurate than the FMTM map as it is constructed with less reliance on interpolation to build the map. The users of these manual modes can overcome problems, but only with more scan time, highly skilled scanning technique and acute attention to fixation with highly capable patients. Therefore, for accuracy and repeatability, the FMTM mode is preferable to the manual modes especially if the resultant Retinal Map is the primary reason for performing these scans. Also, in computing the Retinal Map and assessing retinal thickness/volume, the OCT program only needs to render the anterior surface of the definable nerve fiber layer (NFL) and the anterior surface of a cohesive lower retinal pigment epithelium (RPE). The lower resolution scans can perform this task with ease. Increased data points captured between these layers by the higher resolution scans of the MTM or RL modes add nothing to the overall computation of thickness/volume values within the NFL and RPE. Also, worthy of note, the FMTM modes are the preferred macular edema scanning modes of The Fundus Photograph Reading Center (University of Wisconsin) and The OCT Reading Center at Duke, who both use this data for clinical trial analysis and databasing.

Before OCT 3, objectively assessing macular edema and/or thickness with photographs was possible, yet somewhat difficult given variances in stereo separation and overall photographic quality discrepancies often found with both stereo fundus photographs and stereo fluorescein angiographic frames. With OCT 1 and 2, Retinal Map modes were made available giving objective numerical data measured and displayed within nine sections of a Retinal Map. Comparison of Retinal Maps obtained with OCT 1 and 2 was simply a matter of looking at one map and comparing it to another, instead of viewing only photos. Fluctuating numerical measurements were made available for the first time. OCT 3 has taken this a step further with the Retinal Thickness/Volume Change analysis program. The software performs a correlation between two different Retinal Maps obtained on different dates and displays thickness/volume change differences in both a color-coded map graphic and sectoral numerical values indicating increases and/or decreases in either average retinal thickness (microns) or volume (cubic millimeters) (Figure 13). This function can also display thickness/volume changes for both eyes on one page, more or less negating the neces-

Figure 12: FMTM of a hyperactive, noncompliant child with inferior retinal detachment (macula-on) initially diagnosed with retinoschisis, note thickness values in inferior sectors.

Figure 13: Retinal Maps obtained 1/22/03 vs. 2/12/03 (A) and subsequent Thickness/Volume Change analysis map (B) illustrating marked decreased thickness in all sectors but the bottom sector.
sity to review the previous Retinal Map in the chart or on screen. The employment of this mode on patients with macular edema has resulted in markedly fewer angiograms for this particular diagnosis. Patients who have endured numerous angiograms in the past unanimously prefer the OCT method over angiography for obvious reasons. Also worth mentioning, over the years it has been observed that patients tend to understand their retina health better when shown OCT tomograms of their eye compared to a healthy eye, even more so than showing them a digital fundus photograph or angiogram image in which some patients tend to mistakenly assume any blood vessel in the photograph is “bad”. Showing a patient a flat macular cross section compared to an eye with substantial macular edema provides a striking illustration in simple terms; i.e., flat is good, fat is bad.

Just like a fundus camera, all machines have limitations and OCT is certainly not immune. The FMTM mode is a highly effective method of scanning and measuring retinal thickness and tissue volume for most diseases within its given scan parameters. However, the key to rendering this data is to detect intact NFL and RPE surfaces. If the RPE is significantly compromised or detached, as with Pigment Epithelial Detachments, this mode is of little utility and can skew data. Chorioretinal scarring can also pose analysis problems, but can be overcome in some cases. Analysis problems encountered with these findings manifest themselves in the form of VOCT (volumetric OCT) graphical artifacts referred to as pie-shaped “spikes”, which indicate false elevation, and “dips”, which indicate false thinning (Figures 14 and 15). Anterior to the neurosensory retina, if the software mistakenly recognizes VMT as the NFL, major skewing of the data will result, producing errant Retinal Maps with white VMT spikes and faulty VOCT statistical data. OCT 3 is more capable of discriminating VMT from NFL than OCT 1 and 2, but cannot always differentiate. Therefore, with the presence of large PEDs and substantial VMT, these have to be considered as obstacles not likely to be overcome and another scanning mode should be used, such as 7 mm scans. When there is obvious and substantial VMT, FMTM scans should be attempted with a manual focus (overriding default focus at “0” setting) deeper into the retina, intentionally disregarding the anterior VMT. This method will yield accurate volumetric data in many cases, not all.

Similar VOCT errors can occur when measuring retinal thickness/volume of macular edema associated with full-thickness macular holes. Oftentimes six radial lines are obtained and the resultant Retinal Map displays accurate retinal thickness leading up to the hole. However, given its programmed algorithms, usually the software would quantitatively “close” these holes, resulting in inaccurate, but somewhat useful maps (Figure 16).

**CONCLUSION**

Using the three modes mentioned in this MacPac protocol will likely yield appropriate diagnostic information for most macular disorders on most patients as they literally “blanket” the peri-macular area with scans. Just as ophthalmic photographers often have to venture out into the peripheral retina to document associated clinical findings in addition to the macular appearance within the posterior pole, there will certainly be cases in which one has to deviate from these fine scanning modes and employ either other scanning modes altogether or use one of the three in a different fashion. Again, the MacPac modes discussed here are used to image the macular region within the arcades, and they do a fine job at that, but there are often cases that require a more aggressive and creative technique. Necessary deviation from set protocols, aside from standard scanning, is referred to as “free-
scanning”. Atypical line lengths and angles may have to be used to scan atypical findings, but it is important to use these very same techniques when the given patient returns. The Repeat Scan function can be used to insure the same line length and angle are used again for consistency, but scan placement is still up to the user. Whenever possible, a good technique to use when scanning beyond the macular or disk areas is to include either the foveal depression (if seen) or optic nerve as a scan landmark to help locate the pathology and plot the scan line correctly in the future. This is helpful when scanning nevi, tumors, retinoschisis or retinal detachments in the mid periphery.

Do all eyes need so many scans? No, and yes. No, if a singular, long 7mm scan tells the physician what they need to know. Yes, if the MacPac scans only serve as a baseline for even more scanning beyond this protocol in that same scanning session and in future studies. Beyond MacPac, users are certainly encouraged to explore other modes of scanning, using this protocol as a common starting point. Users should remember that a single scan is just one of infinite potential slices into retinal tissue with plenty of opportunities to miss abnormal pathology. But, armed with instructions from the physicians and knowing where to scan and what modes to use, invaluable images and quantifiable data can be obtained in an efficient time frame with minimal discomfort to the patient. OCT is truly a breakthrough technology and is already a clinical mainstay in many institutions worldwide. Perhaps, in the years to come, there will be a familiar set of scanning standards, be it MacPac or another, routinely providing consistent macular data to study.

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