INTRODUCTION

Most clinicians are familiar with the term “tomography” as in Computerized Tomography (CT) scanning. While the distinction between a standard X-ray and a CT scan is clearly understood, there is a generalized misunderstanding of the differences between standard corneal “topography” and corneal “tomography.”

Tomography is an imaging technique where a series of cross-sectional images are merged to allow for a computer generated three-dimensional reconstruction. The advantages of anterior segment tomography compared to corneal topography are similar to the advantages of CT scanning compared to standard roentgenograph. Anterior segment tomography allows not only the visualization of the anterior corneal surface, but the posterior corneal surface, the anterior chamber, the corneal thickness, portions of the angle of the eye, and the lens. The computer generated three-dimensional reconstruction allows for a much expanded range of applications. Measurements such as anterior chamber depth, corneal thickness, and lens density are samples of measurements available with anterior segment tomography that were not available with older devices that just measured the anterior corneal surface.

In order to generate a three-dimensional reconstruction a series of planar optical cross-sectional images are merged (similar to creating a three-dimensional retinal photograph by merging a stereo pair of photographs). While the earlier systems used a series of vertical optical cross sections, more recent systems have utilized a rotating Scheimpflug camera which increased the accuracy of the tomography devices. The added information supplied by anterior segment tomography has expanded the medical and surgical applications of these devices. While screening patients for refractive surgery, operative planning and the diagnosis of post-LASIK ectasia remain the most frequent use of these devices; other applications include uses such as: surgical planning for toric intraocular lenses, surgical planning for intra-corneal segments (e.g. INTACS), surgical planning for phakic intraocular lenses, postoperative management of DS(A)EK patients, and pre-operative evaluation of the cataract patient. While there is more than one commercially available rotating Scheimpflug system, the OCULUS Pentacam (OCULUS Optikgeraete GmbH, Wetzlar, Germany) represents the vast majority of the systems currently in use, though the discussion that follow would apply to all Scheimpflug devices.

REFRACTIVE SURGERY

The most frequent application of anterior segment tomography is in the evaluation of the potential refractive surgery candidate and identifying patients with early or sub-clinical keratoconus. It is important to identify these patients, who may be asymptomatic, because refractive surgery in these patients may lead to a rapid deterioration in vision, corneal distortion and progressive thinning. In order to identify patients who may have early or sub-clinical changes, we need to look at more than just visual acuity, central corneal thickness and anterior corneal curvature. The value of new technology is that it provides information on both anterior and posterior corneal surfaces and allows for the generation of a full pachymetric distribution map. The example below (Figure 1) demonstrates the benefit of this technology and the limitation of relying solely on older technology that was limited to measuring just anterior corneal curvature. In this example, while the anterior curvature appears completely normal, the tomography reveals a significant “ectasia” or island of positive elevation on the posterior surface and a marked inferior displacement of the thinnest point.
on the pachymetry map. Changes on the posterior surface and/or changes in pachymetric distribution or progression will typically predate any changes of the anterior corneal surface and the use Scheimpflug imaging reconstruction will identify “at risk” patients who would otherwise be missed by conventional topographic screening.

In addition to screening for ectatic disease, refractive planning involves computation of the predicted minimal residual bed. The traditional method of estimating the residual bed involves taking the pre-operative corneal thickness by ultrasonic pachymetry and subtracting both the flap thickness and the ablation depth. It has always been assumed that the largest potential source of error was in the estimation of flap thickness. The estimated ablation depth is probably the measure with the least amount of variability.

For corneal thickness, most practitioners utilize a hand-held ultrasonic pachymeter to determine thickness. Ultrasound, however, has a number of significant limitations, one of which is that it fails to give a complete picture of the entire corneal surface. The assumption is that the center of the cornea is the thinnest zone, and while this assumption is reasonably true in “normal” corneas, it is often wrong in eyes with keratoconus or “sub-clinical” disease (exactly the cases we are trying to eliminate) (Figure 1). Residual bed computation should utilize the thinnest point in the treated portion of the cornea and not just a central apical reading. For these reasons and others, I have abandoned the routine use of ultrasonic pachymetry in favor of an automated optical device that allows me to measure the corneal thickness over the entire corneal surface. Instead of using a single ultrasound reading determined at the “ apex”, I utilize the thinnest corneal thickness reading on the pachymetric map.

We recently looked at 1,436 pre-operative eyes using the Oculus Pentacam and recorded corneal thickness at the apex, pupillary center and the thinnest reading (Table 1).

The average thickness readings at the apex (539.3µm), pupil center (538.8µm) and the thinnest reading (536.3 µm) were similar. The differences between the apex and both the pupillary center and the thinnest region were also small with a relatively tight standard deviation (1.06 +/- 1/73, 2.99 +/- 4.34 respectively). The range, however, did show a few significant outliers. At least one patient had a 31 µm difference between their apex and pupil center reading and up to 93 µm comparing the thinnest region to the apex. The use of the full pachymetric map and the thinnest point reading allows for the identification of these outliers, that otherwise would have been missed.

In addition to screening preoperatively for early or sub-clinical keratoconus, it is essential to be able to separate decreased vision after LASIK due to undercorrection, abnormal healing response or surface abnormalities from iatrogenic ectasia. While earlier
This postoperative LASIK patient exhibits a normal anterior corneal surface (both curvature and elevation), but shows a prominent positive para-central island indicative of iatrogenic ectasia.

Figure 2. (4 map refractive display (Oculus Pentacam)).

Figure 3. (Corneal thickness or Pachymetric map (Oculus Pentacam)).

While changes on the anterior surface may be seen in all of the above conditions (including post-LASIK ectasia), only iatrogenic ectasia (or pre-existing keratoconus) show changes on the posterior corneal surface. Comparing the posterior corneal surface pre-operatively to the postoperative map is the most sensitive method to identify early ectatic change. Forward protrusion or displacement of the posterior corneal surface is found in eyes with post-LASIK ectasia (Figure 2). Patients exhibiting such changes should be cautioned about any further ablative surgery that may further weaken the cornea.

**INTRACORNEAL RING SEGMENTS**

Scheimpflug imaging has become invaluable in the preoperative, operative and post-operative management. Elevation based tomography more accurately characterizes true cone morphology. Many surgeons determine the type of segment, the number of segments and the placement of the segments based on cone morphology. Traditionally, the morphology of the cone was categorized by descriptions based solely on anterior curvature analysis. Sagittal curvature, however, is a very poor indicator of cone location and morphology. Curvature maps, whether generated by placido systems or generated by elevation systems, do not depict shape and convey false information about the size and location of the cone. Elevation maps more accurately locate the cone and give the surgeon a more reliable road map to plan their surgery. The complete pachymetric map (Figure 3) is useful for determining the depth of the tunnel (either mechanical or femtosecond). A circle can be drawn on the pachymetric map corresponding to the location and size of the proposed segment tunnel. The thinnest reading in the tunnel area may then be used to compute the desired depth (e.g. 75% of the thinnest reading). Using the full pachymetric map is a more reliable way to compute the proposed tunnel depth as there may be significant variation in corneal thickness in different regions of the cornea. This is even truer in abnormal corneas.

Postoperatively, the Scheimpflug images themselves may be evaluated to determine the placement of the ring segments (Figure 4). The quality of the individual images is often of sufficient quality to determine the shape of the insert and to measure the depth of the placement.
DESCEMETS' STRIPPING ENDOTHELIAL KERATOPLSTY - DSE(A)K

Descemets’ stripping endothelial keratoplasty is becoming the treatment of choice for corneal edema secondary to endothelial dysfunction. One of the advantages of this surgery compared to full-thickness penetrating keratoplasty is the preservation of the anterior corneal architecture. Even though the anterior corneal surface is unchanged, patients often have a hyperopic shift secondary to changes to the posterior corneal surface. Standard reflective (Placido) topography is incapable of imaging the posterior surface. Scheimpflug cross-sectional imaging can clearly demonstrate the minus lens effect of the donor lenticule (Figure 5).

Anterior segment tomography can also be used to document and follow corneal deturgescence, for documenting areas where the lenticule may not be adherent and to see fluid accumulation between the donor lenticule and the recipient posterior stroma. In short, Scheimpflug imaging allows the surgeon to follow the rate of healing, the refractive effect and the position and health of the graft.

PHAKIC INTRAOCULAR LENSES

Current phakic IOLs fall into three main categories (anterior chamber, iris supported, and posterior chamber). While the clearance (distance) between the IOL and the endothelium is important in all three, it is of critical importance in the surgical planning for
anterior and iris supported lenses. This is even more problematic with hyperopic phakic lenses as their overall thickness is greater. Central anterior chamber depth readings are often inadequate to adequately access the risk of endothelial touch or compromise, as (depending on the lens style and eye anatomy) the minimal lens-cornea distance may often occur in the periphery. Anterior segment tomography allows for the generation of a three-dimensional reconstruction of the anterior segment and the generation of an anterior chamber depth map. This map shows the anterior chamber depth not only at the center but almost out to the limbus (Figure 6).

With knowledge of the anterior segment and information on the geometry of the phakic lens it is possible to simulate the lens in the eye and to generate the approximate clearances that would exist between the endothelium and different parts of the eye. With this capability, different lenses can be evaluated to determine suitability (Figure 7).

**IOL COMPUTATIONS IN THE POST REFRACTIVE PATIENT**

Standard IOL formulas assume a normal relationship between the anterior and posterior corneal surface. In fact, all of our measurements, such as keratometry, have assumed the same relationship that was described in Gullstrand’s reduced eye. The accuracy of modern IOL formulas is a testament to how well this assumptions work in normal patients. Refractive surgery, however, has changed the playing field. Modern laser refractive surgery alters the anterior corneal surface while normally leaving the posterior surface unchanged. This, however, dramatically changes the relative relationship between the two surfaces. The assumptions that worked so well in normal (not post refractive surgery) eyes, do not apply to eyes that have been surgically altered. It is not uncommon to see “refractive surprises” of 3 D or more in post refractive surgery eyes that undergo cataract and implant surgery. Anterior segment tomography, by independently measuring the two surfaces allows for the computation of a corneal power map that does not rely on a presumed posterior surface, but on one that is directly measured. There are a number of approaches that have been taken to IOL computation in the refractive surgery patient. Two of the more common ones are; true or net corneal power (Figure 8), and Jack Holladay’s effective keratometry reading (EKR) (Figure 9). Both of these have been useful in cases where pre-refractive surgery keratometry (historical method) is not available.
TORIC IOL AND ASTIGMATIC SURGERY

The amount and direction of astigmatism is most often approximated by the subjective refraction. The standard refraction, as well as a wavescan analysis measures the total refraction and not its components. Particularly in cataract patients, the lens opacity or change in lens density often contributes to the total astigmatism. Astigmatic surgery, whether by a toric IOL or incisional should correct the non-lens astigmatism. Anterior segment tomography is capable of measuring the anterior and posterior cornea, anterior chamber depth, anterior lens surface and lens density or transmission. This information allows, at least in part, a breakdown of the total refraction into its components. Often, especially in eyes with significant lens change, the subjective astigmatism and the corneal astigmatism can differ greatly. Noel Alpins, MD has been a proponent of astigmatic vector analysis for years and has recently released a software program (Assort©) that can be incorporated directly into a number of topographic devices including the Oculus Pentacam.

CONCLUSION

Rotating Scheimpflug cross-sectional analysis allows for a three-dimensional reconstruction of the anterior segment. Just as computerized tomography (CT scanning) represented a huge advancement over standard X-rays, anterior segment tomography represents a major advance compared to standard reflective topography.

References

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