Next-Generation Technology for the Cataract & Refractive Surgeon

Produced under an unrestricted educational grant from Oculus, Inc., and Oculus Optikgeraete GmbH.

This monograph is based on an educational seminar presented at the 2004 AAO meeting in New Orleans. In it, users of the new Pentacam Comprehensive Eye Scanner describe how the system allows them to perform a wide range of clinical services, from monitoring intraocular changes to treating a wider range of cataract and refractive patients than they could previously.

JACK T. HOLLADAY, MD, MSEE, FACS (MODERATOR)

MICHAEL W. BELIN, MD, FACS

ARTURO S. CHAYET, MD

MATTHIAS MAUS, MD

PAOLO VINCIGUERRA, MD

JACK HOLLADAY, MD, MSEE, FACS

IOL CALCULATION AFTER REFRACTIVE SURGERY

Here I discuss one of my favorite topics, IOL calculations after refractive surgery. Approximately 1 year ago, I acquired the Pentacam Comprehensive Eye Scanner (Oculus, Inc., Lynnwood, WA) (Figure 1), because it performs countless functions to aid surgeons in refractive surgery. In particular, I wanted to measure the posterior surface of the cornea to see if I could use the calculations for IOL implantation.

OTHER METHODS FALL SHORT

There are two problems associated with most modern techniques of measuring the power of the cornea. First, topographers and keratometers only measure the front surface of the cornea, but corneal power comprises both front and back surface power. These instruments assume the back surface of the cornea is approximately 82% of the radius of the front surface, and they use this value to

Figure 1. The Pentacam Comprehensive Eye Scanner.

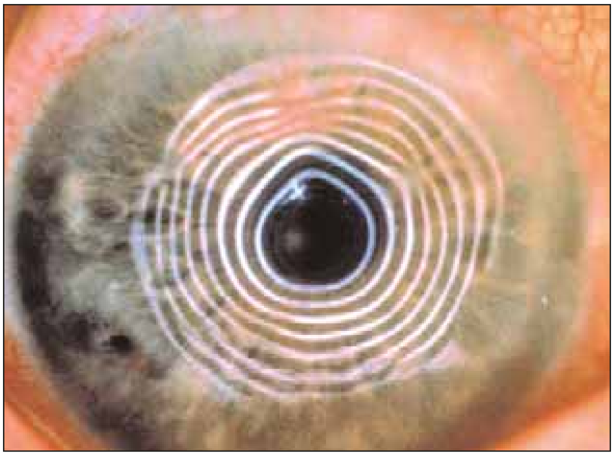

Figure 2. The topography of a radial keratotomy patient shows the difference in the mires centrally out to the periphery.

report the net power of the cornea. Because current corneal refractive surgical procedures affect only the front surface of the cornea, the physiologic ratio is no longer true, and a significant error results. Second, these devices also cause error by measuring the cornea paracentrally rather than centrally. In virgin corneas, the difference is negligible, but corneas that have undergone refractive surgery usually have a big difference from the center to the periphery, so another significant error is made.

THE IMPORTANCE OF THE CENTRAL CORNEA

Our goal is to determine the power of the cornea over the area of the pupil projected onto the cornea (entrance pupil). For example, the topography of a radial keratotomy patient with a 4.5-mm optical zone shows that the mires out in the periphery do not relate to the change in the calculated power centrally (Figure 2). An eye that is plano (20/20) has a very nice reflex in the center but has distorted mires in the periphery. No single study has ever been able to correlate keratometric measurements on the surface of the cornea from RK with the actual refractive change.

Even topographers have a blind spot that can leave from 1.3 to 2.1mm of unmeasured central area and prevent us from knowing the true power of the corneal center. The larger the central scotoma, the greater the error.

COMPETING TECHNOLOGIES

The Orbscan

The Orbscan topographer (Bausch & Lomb, Rochester, NY) accurately performs tomography and yields good values for pachymetry, but moves through space over a 2.1-second period to measure the cornea. Because an eye makes many compensatory saccadic movements to maintain fixation within 2.1 seconds, the unit never knows exactly where the eye is during that 2.1-second period and therefore produces poor measurements of the posterior corneal power.

The Pentacam Comprehensive Eye Scanner, in contrast, maintains a fixed point on the vertex of the cornea during the examination. The patient places his head in the headrest, and the slit-lamp camera rotates, taking measurements over 360º. This fixed point allows the system to maintain a common point in the solution as well as to measure in the center of the cornea. The Pentacam can detect any movement, however slight, and compensate for it using a central registration of all measurements.

The Artemis

Another modality that uses high-frequency, digital ultrasound is the Artemis 2 VHF Digital Ultrasound Eye Arc-Scanner (Ultralink LLC, St. Petersburg, FL). The Artemis 2 maps the anterior segment using ultrasound. Although its measurements are not as precise as the Pentacam's, the advantage of ultrasound is that it measures through opaque media, such as the ciliary body and structures behind the iris. I think that there will be a place for both of these devices in refractive surgery. Digital, high-frequency ultrasound may be best for mapping the area behind the iris, but light is always the most precise measurement when it comes to measuring structures that can be seen optically, because light's wavelength is so much shorter than that of ultrasound. The same principle explains why the IOLMaster (Carl Zeiss Meditec Inc., Dublin, CA), which uses light, is 10µm in its tolerance, whereas the best digital ultrasound is 100µm. Light has a much shorter wavelength than ultrasound, and the wavelength of the media used to make the measurement is always the limiting factor in the accuracy of these instruments.

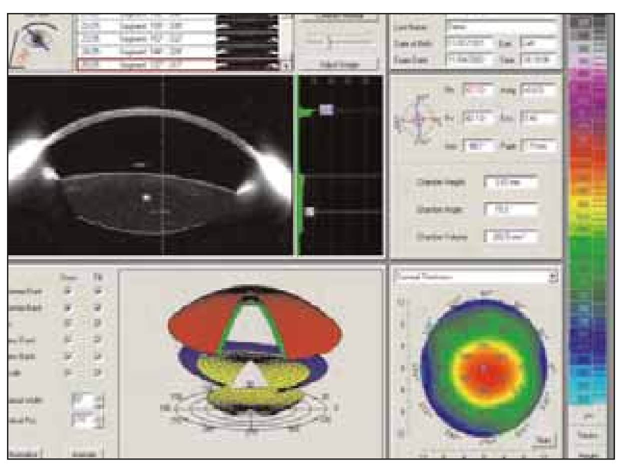

Figure 3. A typcial Pentacam map shows the crystalline lens in a cross section of the eye.

PENTACAM MAPPING

A typical map produced by the Pentacam shows the surface of the cornea with high resolution of the lens (Figure 3). The front view reveals all the ocular properties that a slit lamp does. It is also possible to do some tremendous work with the system's software, such as mapping in three-dimensional sections. The Pentacam's maps offer great detail, such as the density of the crystalline lens.

The high resolution of the Pentacam allows us to objectively determine, quantitate, and provide objective data for peer-review organizations and other documentation for the existence of a cataract. The densitometer measures the amount of density and variation within the crystalline lens, such as the increase in density of a nuclear sclerotic cataract. In addition to pachymetry maps, the Pentacam features many display options, including maps for front- and back-surface power, the iris, and the front and back surfaces of the lens. It also allows us to change the scale and obtain cut-out widths and many other display features.

A typical Pentacam picture of a keratoconic eye will show a hot spot (area of steepening on the anterior surface) to indicate the shape of a cone. A similar appearance can develop from years of contact-lens wear resulting in corneal warpage, but there is no thinning in the area of steepening, unlike keratoconus. The only way to verify the presence of a cone is to identify thinning in its area. A back-surface map of keratoconus demonstrates a cone, similar to the front surface. Warpage from a contact lens shows no change in the posterior surface. The Pentacam's pachymetry map will not show a circular, thin area, but rather a displacement of the circular pattern in the direction of the cone, because the cornea normally thickens as we move from the center to the periphery.

CLINICAL USE

My colleagues and I are conducting a study measuring refractive surgery patients pre- and postoperatively in order to determine the parameters obtained from the Pentacam. These data will allow us to correlate the actual refractive change with the change in power measured with the Pentacam.

In this study, it appears that the power of the central 4.5-mm zone of the cornea has the highest correlation with the actual refractive change. Oculus, Inc., has allowed me to access the Pentacam's software, and I am in the process of examining various areas of the cornea from 1-, 2-, 3-, 4-, 5-, and 6-mm rings. From previous studies, I know that it should be approximately the 4.5-mm region. For example, with wavefront analyzers, even with a 6- or 7-mm pupil, the peripheral rays around that diameter are weighted by the Stiles-Crawford effect in a way that they become almost negligible with a 6-mm pupil. In fact, one of the conclusions from Stiles and Crawford's original study in 1933 was that a model eye built for night vision should never use an aperture larger than 5.5mm, because the peripheral rays do not contribute to the peripheral part of the image but do cause glare, nighttime images, halos, streaks, etc.

My colleagues and I have studied approximately 100 eyes of 50 patients. We only used one eye from each patient because we wanted to determine the symmetry between the two eyes. Using both eyes from a patient in any study is not statistically valid in the population because two eyes from one person have a lot of cross-correlation. Ideally, investigators should only use one eye from a patient and randomize it, which is what we did in this study in order to avoid a statistical bias.

At this time, we are using the 4-mm zone and plotting that change against the actual change that we measured in the patients between the third- and fourth-month postoperative visits. By that time, patients are stable to within 0.25D, except for the 2% who may have regression and whose data we exclude. As for range, we took patients all the way from +5.00D hyperopia to approximately -10.00D of myopia. Interestingly, the patient with the largest prediction error had a sphero-equivalent change of nearly zero with substantial mixed astigmatism. The average difference in the actual versus the predicted is approximately 0.37D, with a maximum error of 0.50D.

IN SUMMARY

No previous technology has ever allowed us to predict the refractive change that a virgin cornea will experience from refractive surgery. The Pentacam's technology will be the breakthrough that allows refractive surgeons to abandon the historical method, contact-lens method, and other preoperative measurement methodologies by measuring the postoperative refractive surgery cornea directly. If a postoperative refraction has been contaminated by a change in the patient's crystalline lens since surgery, the historical method does not work. For example, an RK patient may experience a hyperopic drift that flattens his cornea over time, and the historical method will no longer apply. With these methods, surgeons are always trying to ferret out such problems in order to obtain the right answer, and no easy solution exists.

Within a few months, I will have finished analyzing and will publish the data from our study. I expect our results to show that the Pentacam measures the true corneal power in postoperative LASIK and PRK patients to an accuracy of ±0.50D. This variable is about as good as we will be able to achieve until excimer lasers become more precise. Currently, variations in the asphericity of the cornea and irregularities induced by the lasers make the tolerance approximately 0.25 to 0.50D. This research has been very exciting for me, because I think it will markedly improve the technique and accuracy with which we can determine post-refractive corneal power.

QUESTIONS

Dr. Chayet: Will this be available in the Pentacam software?

Dr. Holladay:

Yes, as soon as I determine, with the help of the company, the specific parameters I have found in their software to give a net refractive power for patients' corneal power. This would be the value that you plug into the program you are using for the calculation.

Audience: Do you think there will be a correlation with RK patients?

Dr. Holladay:

Yes. The problem is that there is no easy way to perform a prospective study on RK patients because no refractive surgeon performs RK anymore. Also, I would not know whether the changes were in the patients' crystalline lens or the cornea. I am testing RK patients to see if their ratio of front and back corneal surfaces is 82% or a smaller value. I know from LASIK and PRK patients that this ratio correlates with the amount of treatment delivered with the procedure. In other words, the greater the treatment, the flatter the front surface becomes, and thus the front-to-back ratio changes dramatically from 82% sometimes down to 70%. There is no way to predict that ratio prospectively now, however, because of a lack of RK patients for us to study pre- and postoperatively.

MICHAEL W. BELIN, MD, FACS
KERATOCONUS AND PREOPERATIVE SCREENING

I will address preoperative surgical screening for keratoconus. Why is screening for keratoconus important? We must identify these patients, because performing refractive surgery in them can lead to rapid visual deterioration and progression of the disease. More importantly, we must identify those who were previously undiagnosed, as well as those who have what we call *forme fruste* (patients who may have keratoconus but whose postoperative results may not fall within the acceptable range for thinning of the cornea).

PLACIDO DISK TECHNOLOGY SHORTFALLS

Going back to the birth of refractive surgery (and this report is based on Placido disk technology), as many as 17% of refractive surgery candidates had a topographic map suspicious for keratoconus. Why? Placido disk technology makes a lot of assumptions, including that the corneal apex, the line of sight, and the V-K normal (the normal line off the video keratoscope off which the measurements are actually made) are all identical. They are not, and this approach led to many erroneous conclusions. Realize that Placido disk topography represents twenty-first-century technology applied to eighteenth-century science, in that it digitizes a Placido disk measurement, similar to the idea of installing GPS positioning on a horse and buggy. It no longer makes sense to base our corneal analyses on Placido disk topography. It is time that we move beyond 300-year-old science.

When other surgeons call me with questions about their topographic maps, I always hear, "I have this abnormal curvature map...." The question is, on which patients may we perform surgery? It is important to realize that we cannot rely on corneal curvature to diagnose keratoconus. Given two seemingly identical shapes, if the reference axis is different (ie, the line of sight is not through the corneal apex), then the curvature maps will be different (Figure 4), regardless of the fact that they are identical shapes. This variation is typically what happens with false-positive inferior steepening. A decentered apex will always lead to focal areas of curvature steepening (when no true abnormality exists). True elevation maps do not make these assumptions and are independent of the reference axis.

Looking at a series of curvature maps, one may ask: "Is this keratoconus? Is this eye normal? Is this eye abnormal?" In fact, the images may be of the same eye but taken at slightly different angles (Figure 5). Such is the limitation of Placido disk technology.

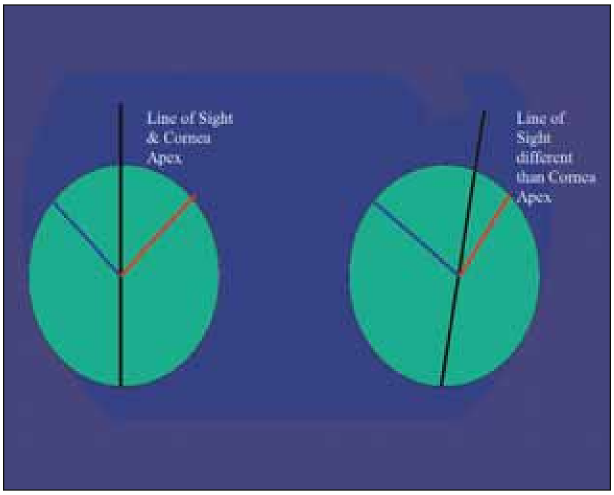

Figure 4. Two seemingly identical shapes may have different reference axes that skew their curvature maps.

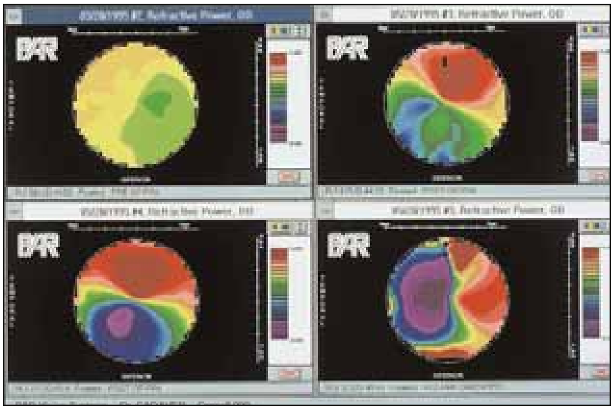

Figure 5. An eye imaged with curvature analysis at four different angles may not appear normal.

CASE REPORTS

Case 1

A routine patient presented for LASIK evaluation. In a topographic map produced by a Humphrey Atlas Corneal Topographer (Carl Zeiss Meditec Inc., Dublin, CA), which uses Placido disk technology, the eye looked fairly normal. It displayed normal SIM K values and only a small, slightly steep inferior area. The front Pentacam elevation map showed the best-fit sphere and approximately 14µm of a slightly decentered, positive elevation off the best-fit sphere, indicating a mildly decentered apex. Fourteen microns falls within the suspicious range of keratoconus. The corneal thickness map for this eye also looked normal. The anterior elevation and curvature maps of the left eye appeared even less suspicious, with only approximately 6µm of positive elevation from the best-fit sphere. The pachymetry map, however, showed a thin area inferiorly of 501µm versus a central thickness of 519µm, which equals approximately 20µm of inferior thinning in the pachymetry. Again, the front elevation appeared normal, but the back elevation showed 33µm of positive elevation. Positive elevation means an apex. In light of a drop to 501µm inferiorly and a significant posterior elevation apex, I did not perform refractive surgery on this patient, in spite of his fairly normal curvature map.

Case 2

Another refractive surgery evaluation map from the Placido-based Humphrey Atlas topographer showed a steep inferior curvature map of over 48.00D and significant inferior steepening OD. Most surgeons would be alarmed by this topography and would not consider this patient an appropriate candidate for refractive surgery. The Pentacam elevation map, however, showed a normal astigmatic picture with a decentered apex. There was no apical protrusion present. The composite picture also showed normal pachymetry and posterior elevation. This case illustrates the limitation of Placido disk technology. With a decentered apex and a line of sight deviating from the center, the curvature maps looked highly abnormal. The appearance, however, was erroneous. The eye had a normal cornea with a slightly decentered apex. The patient's left eye had a similar appearance, with a slightly decentered apex but no apical protrusion (Figure 6). The composite map showed that its corneal thickness was completely normal, as were the anterior and posterior elevations. The curvature, however, showed mild inferior-nasal steepening, because the corneal apex was slightly decentered in that direction.

Curvature is not an innate property of the cornea; it will change with orientation. A slightly decentered apex will produce values that do not truly indicate the shape of the cornea. Therefore, I suggest examining an eye's elevation and pachymetry maps first and the curvature map last. I make almost all my clinical decisions based on the anterior and posterior elevation and pachymetry maps.

Case 3

A third case represented a distinctly abnormal map. The Pentacam composite picture revealed a decentration of the apex and of the thinnest area of the cornea. The front elevation map showed 30µm of apical protrusion, which was well outside the normal range, as well as a huge amount of posterior elevation. The elevation maps depicted positive deviation off the best-fit sphere, which is a cone, compatible with the diagnosis of keratoconus.

The front elevation map of the patient's left eye (+17µm) was not as alarming as that of his right. However, the posterior curvature map displayed a huge amount of posterior elevation, up to 45µm, coinciding with the thin area of the cornea. Both eyes of this patient were abnormal, and he was not a candidate for any type of refractive intervention.

Case 4

The composite picture of a patient's right eye showed a normal-looking curvature with relatively low levels of posi-

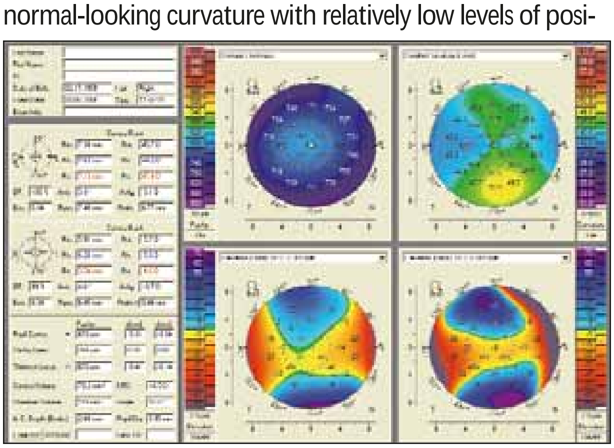

Figure 6. The Pentacam image of the patient's left eye.

tive elevation that fell well within the normal range. The curvature map indicated slight astigmatism, as did a Pentacam front elevation map. The pachymetry map showed corneal thinning down to 483µm but otherwise a fairly normal picture.

The patient's left eye (Figure 7) showed a suspicious front elevation map. However, his left eye also had a markedly thin cornea and a huge amount of posterior elevation. In spite of the fact that the right eye was relatively normal, his left eye clearly was not. I always stress that, if one eye is abnormal, both eyes should be eliminated as nonsurgical candidates.

PROPOSED SCREENING PARAMETERS

When using the Pentacam, I suggest examining patients' front elevation first. Use best-fit sphere and float and a scale that is ±75µm. Set the system to "color extension," which provides a more traditional (ROYGBIV) color scale. Look at back elevation and pachymetry next and at curvature last. The Pentacam system also has an option to set all displays at a 9-mm central corneal zone. You will find the maps easier to evaluate with the settings, as they concentrate on the areas of clinical concern and are sensitive enough without being overly noisy.

My normal values for anterior elevation are elevation differences of less than +12µm. Differences greater than +15µm typically indicate keratoconus, and those between +12 and +15µm are suspicious. Future color scales with the Pentacam are going to allow not only a quantitative but also an easier qualitative observation. Normal values for posterior elevation are approximately 5µm higher than those for anterior elevation, although experience with posterior elevation is more limited.

CLOSING COMMENTS

Keratoconus screening requires the use of topography systems that measure elevation data as their elemental measurement. Derived elevation (curvature) is not accurate; you must measure elevation directly. Although Placido disk systems will not miss many cases of keratoconus, they have a very high false-positive rate. The Pentacam is the only eye screening system that does not rely on Placido-based technology.

Preoperative corneal power measurements are never performed in a vacuum. Look at the distribution of pachymetry as well as the symmetry between the eyes. Remember, if one eye is abnormal, both are. The pachymetry and elevation maps should all coincide. The apex is usually the thinnest area of the cornea. I hope this discussion will be helpful to those who are interested in furthering their understanding of elevation corneal mapping.

I have worked with just about every topography system available, and the Pentacam is the first system that performs every measurement (curvature, front and back elevation, and corneal thickness) in an accurate and reliable fashion. My staff and I used to have our complex cases evaluated on multiple systems in two different offices. The Pentacam can do it all. It is technician- and patient-friendly and images even the irregular corneas that other systems cannot. It has become our indispensable topography system.

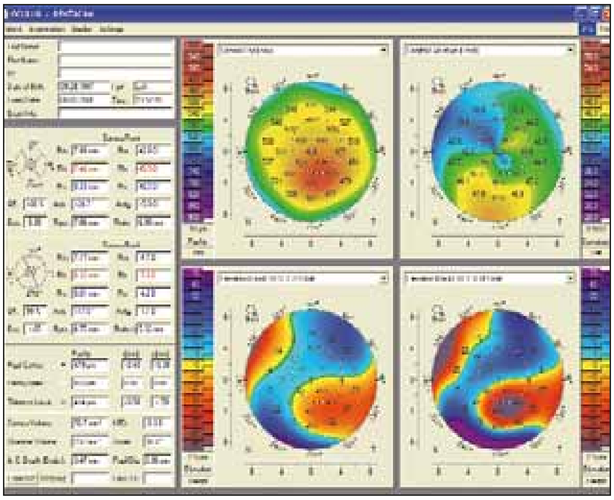

Figure 7. The front elevation map of this patient's left eye looked suspicious for keratoconus.

QUESTIONS

Audience: Would you perform LASIK on an eye with a decentered apex and an otherwise normal topography?

Dr. Belin:

Yes, particularly a customized LASIK procedure. In the past, there was some question with a decentered apex, particularly in hyperopes, of whether refractive surgery would induce significant aberrations. The issue was less of a concern with myopic patients. With wavefront-guided treatments now, particularly Wavescan (Visx, Inc., Santa Clara, CA), these types of treatments are less risky. Corneas with a decentered apex are normal. The early Placido-disk mapping devices always gave a false-positive reading with decentered apexes. Although some people have significantly decentered apexes, mild-to-moderate decenration is a common finding.

Dr. Holladay:

I would add that one of the biggest concerns with performing refractive surgery is the corneal warpage from contact lenses, particularly for patients who have worn them for 15 or 20 years. Warpage does not necessarily clear after

3 to 6 months without contact-lens wear, and a Pentacam examination may detect it. If such patients are corrected to 20/20, then there is no reason not to perform refractive surgery on them.

I also wanted to ask Dr. Belin: **Do you use 15µm as your difference between the symmetric points?**

Dr. Belin:

I use 15µm of elevation difference as my cut-off for a normal cornea (>15µm positive elevation off the best-fit sphere is abnormal). Here, we are talking about the central portion of the cornea. Do not look at numbers on the periphery, because an astigmatic eye will show positive and negative deviation by definition when compared to a perfect sphere. If there is a sphere, which is a reference shape, and you are looking at an astigmatic eye, the flat axis is elevated, the steep axis is depressed, and if there is a lot of cylinder, you'll see numbers in the periphery of +50µm. It means nothing other than the patient has significant cylinder. Cones are centrally placed apexes. Consider an island of central power in that central cornea. If coinciding to the area of maximal thinness and pachymetry is +15µm or above, I will not consider those patients candidates for refractive surgery.

ARTURO S. CHAYET, MD
PENTACAM FOR THE COMPREHENSIVE ANTERIOR SEGMENT AND REFRACTIVE SURGEON

I will explain why and how I use the Pentacam Comprehensive Eye Scanner. The maps that I use most frequently with my patients include front elevation, curvature from the back of the cornea, corneal thickness, and subjective curvature, which is a map similar to what we used to see with Placido disc topography systems. These four maps provide me with a lot of information.

USE WITH IOLs

Besides its applications in keratoconus screening, I was also interested in using the Pentacam as a Scheimpflug camera. I am performing an increasing amount of intraocular refractive surgery, and the visibility of the inside of the eye that the Pentacam provides is very useful. For example, when implanting a Verisyse lens (Advanced Medical Optics, Inc., Santa Ana, CA), I want to see, follow, and document the amount of intraocular space available from the front surface of the IOL to the cornea and the periphery, as well as between the IOL and the crystalline lens and the IOL and the endothelium. At the same time, I would like to record that the surgery is not inducing any cataracts.

Another nice feature of the Pentacam is the ability to see the anterior chamber depth map (Figure 8). This map provides another view of the space from the endothelium to the anterior surface of the crystalline lens. This map is particularly useful when I screen patients for phakic IOL implantation.

When implanting a Visian ICL (Staar Surgical Company, Monrovia, CA), the Pentacam gives me an excellent view through the dilated pupil by which I can calculate the IOL's vault. If there is 200µm of vault between the implant and the crystalline lens (Figure 9), I know from experience that the patient will not develop cataracts from the IOL. The Pentacam allows me to document the amount of space from the most elevated part of the Visian ICL to the endothelium. And at the same time, it also records changes in the crystalline lens, which allows the surgeon to monitor the progression of cataracts. For example, if a Pentacam image shows that the anterior chamber in the periphery is slightly shallow due to significant vaulting from the Visian ICL, then I know to keep documenting this effect periodically and to monitor the patient for any rise in IOP over time.

The Pentacam has also proved helpful with the Light Adjustable Lens (LAL; Calhoun Vision, Inc., Pasadena, CA), by documenting the IOL's power change intraocularly after implantation and adjustments. This documenting ability has helped me as a surgeon as well as the company to follow the progress of these patients.

OTHER APPLICATIONS

The Pentacam also takes very nice white-to-white and angle-to-angle measurements. Unfortunately, at this time, the device cannot measure anything that is not optically visible, so it does not provide a perfect sulcus-to-sulcus measurement. I can perform some correlations, however, that will help me calculate

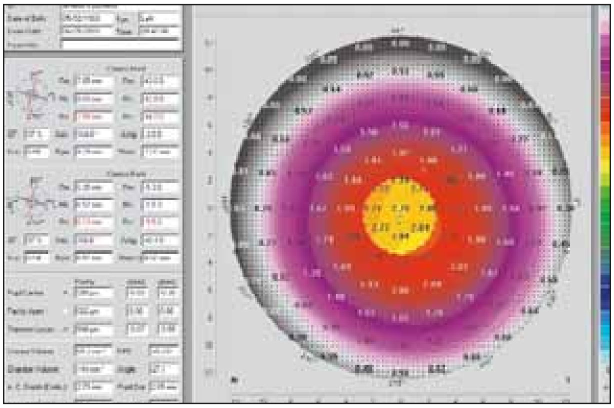

Figure 8. An anterior chamber depth map generated by the Pentacam is shown.

measurements for some of the IOLs that we use. I also find the Pentacam useful for measuring and documenting the depth of Intacs corneal rings (Addition Technology, Inc., Des Plaines, IL) implanted in the cornea. Over the years, I have seen some corneal rings shift a little too superficially, and the Pentacam allows me to document how the rings are behaving. Also, I am able to see the centration of the Intacs in relation to the pupil, which no other technology has allowed me to do.

I also appreciate the Pentacam's tomographic capabilities. For example, because one RK patient I treated was able to see his anterior corneal map, he was better able to understand how against-the-rule astigmatism was affecting his vision (in his case, the wound was gaping).

In conclusion, I am grateful to have the Pentacam for screening patients for various intraocular procedures.

QUESTIONS

Audience: In the case of ICL implantation, how does one differentiate between the implant and the opacification of the lens with the Pentacam?

Dr. Chayet:

We can see changes in the lens, such as nuclear sclerosis, with the anterior chamber maps that the Pentacam provides, both before and after ICL implantation.

MATTHIAS MAUS, MD
THE ROLE OF THE PENTACAM IN REFRACTIVE SURGERY

I practice in a busy refractive office. My colleagues and I use the Pentacam Comprehensive Eye Scanner for LASIK calculations, topography measurements, phakic IOL planning, densitometry, and marketing.

LASIK CALCULATIONS

In LASIK calculations, an eye's corneal thickness is one of the most important data points to obtain. The Pentacam´s camera captures the cornea's pachymetry in 25,000 locations, including the pupil's center, the apex, the thinnest local point of the cornea, and its deviation from the apex. You can also measure the corneal thickness of any location manually on the screen. However, my colleagues and I wanted to know whether we could examine postoperative flap thickness with the Pentacam. We were only able to measure the LASIK flap in three of 100 patients immediately postoperatively, due to postoperative tissue hydration, and the obtained data were of no great value.

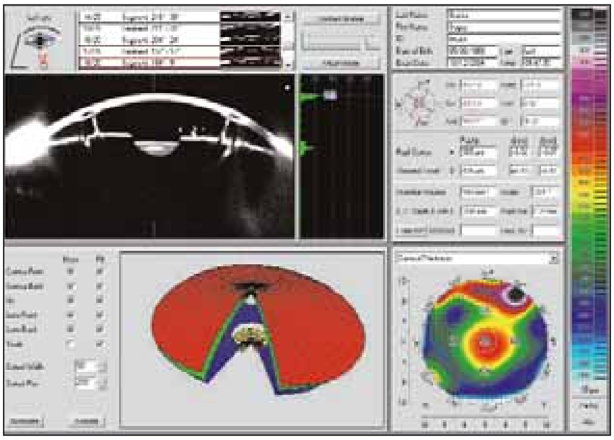

Figure 9. A Pentacam image shows the measurement from the posterior surface of the Visian ICL to the anterior surface of the crystalline lens.

TOPOGRAPHIC MEASUREMENTS

T-CAT is a topography-guided treatment program for the Allegretto Wave excimer laser (Wavelight Laser Technologie AG, Erlangen, Germany). As Dr. Holladay discussed, normal topography cannot measure the corneal center, where there is a blind spot. My staff and I use T-CAT treatments to validate the topography of central disorders, and then we use this verification as the basis for topography-guided treatments. In contrast to the keratometer, the Pentacam provides a lot of data from the central cornea. If the topographic and Pentacam maps look similar, then we feel confident in treating the topographic reading. For example, in the case of a highly irregular surface following a +6.00D treatment after an incomplete flap cut, the Wavelight Topolyzer examination showed a peak of irregularity in the central corneal area. In this case, the central "topography" obtained by the Pentacam, with its highest density of measured points in the central area, supported the Topolyzer´s interpolation (Figure 10).

T-CAT and other topography-guided treatments usually remove a greater amount of tissue, which increases the risk of inducing keratoconus. The Pentacam informs the surgeon of the degree of surgical risk with these types of treatments by mapping the corneal thickness over the complete ablation zone.

PHAKIC IOL PLANNING

As Dr. Chayet described, it is easy to simulate the location of a Verisyse IOL and its distance to the endothelium in the center and in the periphery, depending on the size of the implant.

The Pentacam's measurement of the anterior chamber depth correlates well to that of the IOLMaster; the only difference between the two is that the IOLMaster measures from the epithelium and the Pentacam from the endothelium or the epithelium to the lens. Correcting the difference by the corneal thickness produces a very straight line of correlation between the two systems.

DENSITOMETRY

Those of us who perform intraocular refractive surgery sometimes have to decide between implanting an additional lens and performing clear lens extraction. With the Pentacam, it is easy to obtain a densitometry reading of the lens, for documentation as well as for deciding whether or not to perform early cataract surgery instead of implanting an additional lens. If the patient develops an early cataract, he will always think that this occurred because of the lens we implanted.

MARKETING

Using a Pentacam clearly shows patients that you employ high-end technology. There is no better descriptive tool than colorful printouts that you can show to the patient while explaining his disorders. Such tools reinforce your competency in patients' minds. Visual maps also foster patient comprehension better than showing them a laser and talking about speed, etc. Patients are even able to see their keratoplasty scars and lens implants.

CONCLUSION

It is clear to my colleagues and me that the Pentacam has made us more competent in the eyes of our patients, allowed us to treat a greater number of complicated cases, and increased the safety of our procedures. It is in such demand in our office that it has no chance to cool down!

QUESTIONS

Dr. Holladay: Dr. Maus, you made a good point and perhaps you could clarify about the actual thickness measurement. How does the Pentacam measure pachymetry?

Dr. Maus:

For corneal thickness, it measures from the top of the epithelium to the anterior surface of the endothelium. Importantly, it does not measure the tear film.

Dr. Holladay: So, the Pentacam does not measure the thickness of the endothelium. It lights upon Decemet's membrane, and then, does it measure to the back of the endothelium or the front?

Dr. Maus:

It measures to the back of the endothelium.

PAOLO VINCIGUERRA, MD
DAILY USE OF THE PENTACAM AND INTERPRETATION AND USE OF THE MAPS

In my daily practice, my colleagues and I often concentrate on the connection between the cornea's pachymetry and curvature when determining patients' candidacy for refractive surgery. The key is to locate the thinnest point of the cornea, so we examine the connection between the cornea's pachymetry and curvature.

USING THE DEVICE

The Pentacam is able to create Scheimpflug images that can be interpreted in many different ways. For instance, overview maps that the system generates allow you to examine particular sections of each Scheimpflug image via a zoom function and a three-dimensional view.

In addition to creating a pachymetry map, the Pentacam offers many other displays, such as an instantaneous map with a central and posterior view of the cornea. These viewing options allow you to see the difference between the anterior and posterior surfaces of normal eyes. Comparing these data to the posterior elevation map then enables you to calculate the real power of the eye. No topographer can calculate the true corneal power in this way.

In addition, in normal eyes, the difference between the calculations from the posterior-elevation and the normal-view maps shows the safety at 6mm. For example, 2µm of elevation in the center of the cornea is safe, but 15µm is not. Thus, looking at the correlation

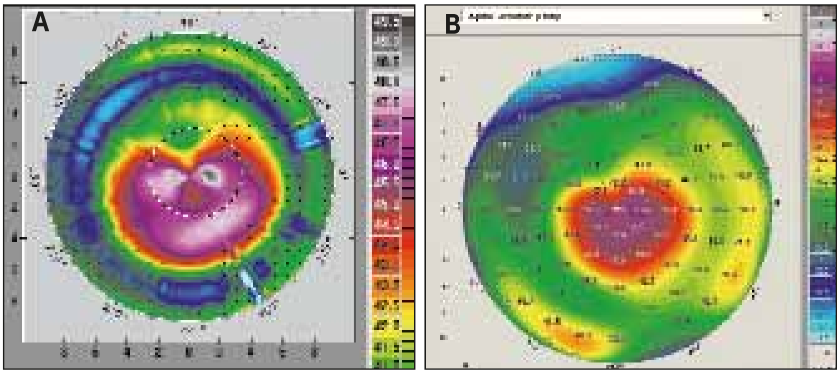

Figure 10. Corneal topography (A) correlates well with Pentacam measurements (B).

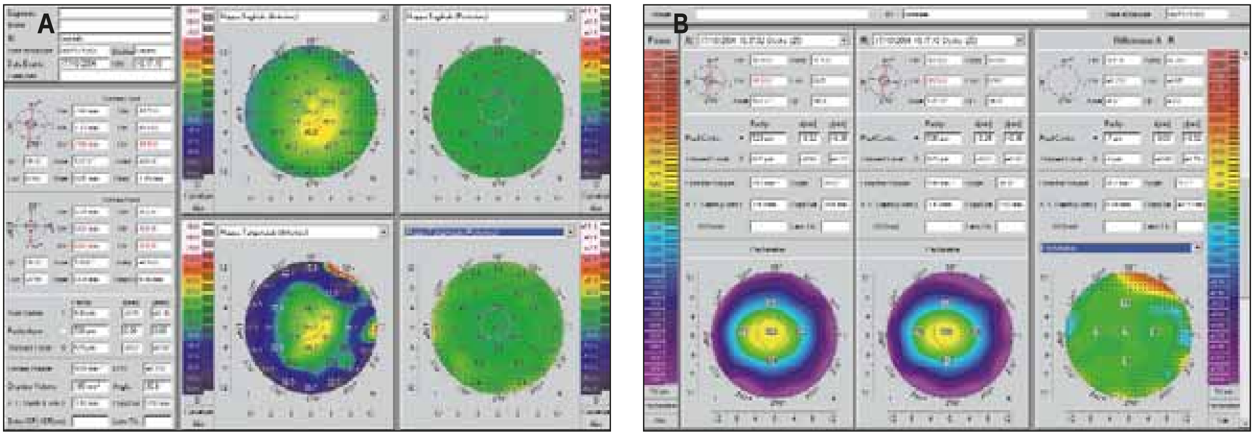

Figure 11. These pachymetry maps show the subject's corneal thickness before the instillation of artificial tears (A) and after (B).

between the corneal thickness and curvature is useful in determining patients' candidacy for surgery.

TESTING THE SYSTEM'S SENSITIVITY

To demonstrate the precision of the Pentacam, I examined the eyes of my 11-year-old daughter. I measured her corneal thickness prior to (Figure 11A) and after (Figure 11B) instilling artificial tears. I was able to measure 7µm of difference between the pre- and post-artificial tear measurement with the Pentacam. Artificial tears, of course, do not affect corneal curvature, only pachymetry. I saw no change in the posterior curvature, a finding that indicated that the machine was not biased by the introduction of artificial tears.

The Pentacam assists surgeons in other important diagnostic areas. As addressed previously in this monograph, the device can help detect keratoconus and forme fruste eyes by revealing corneal warpage and increasing corneal curvature. Note that there is no relationship between the change in corneal curvature and pachymetry, a feature that enhances safety for these patients. In keratoconus detection, it is very important to locate the thinnest point of the cornea, because it corresponds perfectly to the most elevated area. There is a direct relationship between steepening and thinning that the Pentacam identifies.

ADDITIONAL APPLICATIONS

My colleagues have described how the Pentacam can help measure the evolution of a cataract by identifying a relationship between the patient's symptoms and an increased scattering of light.

This device also facilitates the insertion of Intacs corneal rings, which are used in keratoconic eyes. With the Pentacam, I can see whether I am inserting the Intacs too superficially or too anteriorly. As most physicians know, Intacs must be placed at 80% corneal thickness.

The Pentacam recently helped me with another important case. I treated a patient who developed ectasia after LASIK. He did not have keratoconus, but the device was able to precisely measure 263µm of corneal thickness, which is uncommon in an eye with ectasia.

In deep lamellar grafts, the Pentacam can identify possible relationships between patients' symptoms and any corneal irregularities that compromise the interface between the donor lamella and the recipient's endothelial layer. Furthermore, the device's posterior surface elevation maps can provide information on the quality of the posterior cornea's optical properties, and its Scheimpflug images allow you to easily locate haze and interface problems.

Penetrating keratoplasty patients benefit from the Pentacam as well. For example, the camera may reveal the conjunction line of a donor cornea as well as any corneal thinning that is due to a mismatch between the donor and host corneas. Such discrepancies frequently result in poorly positioned sutures. Other imaging devices may miss corneal thinning in the extreme periphery in keratoplasty patients.

VARIATIONS BETWEEN SYSTEMS

I have an Orbscan topographer as well as a Pentacam, and I have noticed two differences between the two systems. First, a patient begins an Orbscan examination with the light at his side, so he does not perceive strong illumination and is able to keep his eyes open. When the Orbscan begins to scan, however, and the light shines directly through the pupil and macula, and he starts to blink or close his eyelids, thus forcing me to redo the examination. Sometimes, a patient is so sensitive to light that an Orbscan examination is difficult to perform. The Pentacam, however, has a blue light that is easier on patients' eyes. The light remains in the same position, and the examination is quite fast.

Furthermore, in cases of corneal opacities, the Orbscan always measures less than the true corneal pachymetry, because the location of the posterior cornea is induced in error by opacities, and its resolution is less than half that of the Pentacam's. Despite software that prevents the Orbscan from measuring too thin, it does not measure the true thickness of thin corneas and can in fact be off by as much as 200µm. The Pentacam, however, measures corneal opacities exactly, because it takes the image threshold location exactly.

CONCLUSION

In my practice, the Pentacam is a very helpful machine that I find easy and fast to use. It allows me to detect patients who are poor candidates for refractive surgery and helps me to make sound surgical judgments in difficult referral cases.

COMMENTS AND QUESTIONS

Dr. Belin:

I would like to repeat an important point. The use of an artificial tear, particularly a viscous one, will effect the measurements on the anterior surface of the cornea, but should have no effect on the posterior surface measurements. This is a good test to run. The Pentacam posterior maps are unchanged. This is not the case for other systems that claim to measure the posterior corneal surface.

Audience: Would eyes that show a decentered apex or some other unusual phenomenon be good candidates for a Tecnis IOL (Advanced Medical Optics, Inc., Santa Ana, CA) or other wavefront lenses that are designed based on standard corneas?

Dr. Holladay:

That's a tricky question. Remember that the cornea and the crystalline lens are on an optical axis that is tilted 5.2º, so it is normal to have a 5.2º decentration with respect to the cornea when you are looking along the visual axis. I do not know the answer to that question, because I have not treated many patients with decentration. I would say to be concerned about any eye in which the crystalline lens looks much more decentered than it is with respect to the cornea in a normal patient. If the bag and the cornea do not line up, then there will be a problem with a lens implant. Also, I think that any eye with ruptured zonules or pseudophakodonesis, where the lens looks tilted with respect to the cornea, is not a good candidate.

Audience: How does angle kappa affect the apex?

Dr. Holladay:

Angle kappa does not really affect the apex. It is what we physicians think of as the relative relationship of the pupil to the light reflex, which is the visual axis; it is a third measurement. Angle alpha is between the optical and visual axes (5.2º), which we do not measure. In addition, most pupils are positioned half way between the two axes at about 2.6º. So, when an eye is focusing, the light reflex is more nasal than the pupil, because the pupil has not moved over quite as far as the visual axis has. Thus, angle kappa does not matter much with regard to the tilt of the eye, because it appears centered over the visual axis and decentered over the optical axis. It is just an aperture that moves around. The bottom line is that tomography is the cutting edge of what we need to evaluate for refractive surgery, including phakic IOLs, and I believe that the Pentacam performs the best measurements today. ●

Jack T. Holladay, MD, MSEE, FACS, is Clinical Professor of Ophthalmology at Baylor College of Medicine in Houston. He states that he holds no financial interest in any product or technology mentioned herein, nor is he a consultant for any company. Dr. Holladay may be reached at (713) 668-7337; docholladay@docholladay.com.

Michael W. Belin, MD, FACS, is Professor and Director of Refractive Surgery at Albany Medical College as well as Medical Director of TLC Laser Eye Centers in Albany, New York. He states that he holds no financial interest in any product or technology mentioned herein but has received speaking honoraria. Dr. Belin may be reached at (518) 475-1515; mwbelin@aol.com.

Arturo S. Chayet, MD, is Director of the Codet-Aris Vision Institute in Tijuana, Mexico. He states that he holds no financial interest in any product or company mentioned herein. Dr. Chayet may be reached at +52 66 4683 5723; arturo.chayet@arisvision.com.mx.

Matthias Maus, MD, is head of Augenzentrum Maus + Heiser in Colonge, Germany. He is a paid consultant for Wavelight Laser Technologie AG, but states that he holds no financial interest in any product, technology, or company mentioned herein. Dr. Maus may be reached at +49 221 8601613; maus@augenzentrum.de.

Paolo Vinciguerra, MD, is Chairman of the Department of Ophthalmology at the Istituto Clinico Humanitas in Rozzano, Milano, Italy. He states that he holds no financial interest in any of the products or companies mentioned herein. Dr. Vinciguerra may be reached at +39 02 55211388; vincieye@tin.it.

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