Ophthalmologists have numerous technologies at their disposal for imaging and investigating the cornea and anterior chamber. For years, conventional slit-lamp, keratometry, ultrasound pachymetry, and Placido disc-based topography systems have served clinicians and researchers as helpful tools for evaluation and diagnosis. However, each of those modalities has performance limitations and new informational requirements have arisen as a result of recent advances in the field of ocular surgery.

The Pentacam system from Oculus is a powerful, multifunctional tool for cornea and anterior chamber imaging that can be used in a broad range of clinical applications to meet the needs of the contemporary ophthalmologist while offering the potential to overcome the shortcomings of existing technologies. In a symposium held during the XXII Congress of the European Society of Cataract & Refractive Surgeons, an international faculty of noted clinicians and researchers gathered to discuss the benefits and applications of this versatile, advanced technology in clinical practice and research.

**Interpretation of Scheimpflug Based Anterior Segment Imaging and Mapping**

**Burkhard Dick, MD**

**Novel Applications of Digital Scheimpflug Analysis**

Burkhard Dick, MD has been using the Pentacam for more than 18 months in the setting of routine patient evaluation and as an adjunct in clinical research. He explained the features of the Pentacam that make it a user- and patient-friendly system for evaluating refractive surgery patients, and provided some examples of novel and future applications.

Dr. Dick pointed out that the Pentacam examination can be delegated to a trained technician without requiring ophthalmologist involvement since its performance is intra- and inter-observer independent. Importantly, the scanning procedure has been met with excellent patient acceptance since it takes a very short time and is completely comfortable. Also, critical to users, the Pentacam generates results immediately and offers highly reliable performance so that it can facilitate rapid decision-making in clinical practice.

"Since the fixation target in the Pentacam is in the centre of the rotation axis, useful results are obtained with a single examination in approximately 95% of patients."

The Pentacam has several other unique benefits. Corneal haze does not invalidate its measurements, and the system can accurately characterise even the most irregular corneas because the sharp, crisp Scheimpflug images allow perfect edge detection and therefore highly accurate refractive power calculations.

Since it provides topography maps of the anterior and posterior surfaces of the cornea, the Pentacam is a valuable aid in LASIK screening for diagnosing corneal anomalies that would exclude patients from surgery. For example, with the Pentacam maps, the invagination of the posterior surface of the cornea and forward movement of Bowman’s membrane that are hallmark’s of early keratoconus can be identified.

Dr. Dick described several examples of where the Pentacam is being used in the evaluation of refractive surgery patients. Since the system is able to quantify corneal haze, he is using it for that purpose in a prospective clinical trial randomising patients to epikeratoplasty or LASEK. The data will be analysed to compare the amount of haze associated with those two procedures and also to investigate correlations between haze severity and ablation depth.

The pachymetry function of the Pentacam also makes it a useful tool in the evaluation of patients seeking retreatment for determining if there is sufficient residual stromal tissue to allow a safe enhancement procedure.

"Our testing shows the pachymetry measurements obtained with the Pentacam correspond well to those determined using various ultrasound systems. The maximum difference has been <10 microns, and when there are discrepancies, the Pentacam-generated values are thinner and so allow surgeons to err on the side of safety."

In another refractive surgery application, the optical and topographical analyses features of the Pentacam have been applied for the evaluation of corneal striae in post-LASIK eyes. Dr. Dick explained that the striae reflect compressed corneal lamellae with V-shaped indurations and can result in patient discomfort and blurred vision. Evaluation with the Pentacam enables the clinician to identify the presence of that pathological correlate for the patient’s symptoms.

The high-resolution Scheimpflug image also permits detailed characterisation of incisional architecture. Based on that capability, Dr. Dick noted the Pentacam is a useful tool in research investigating new surgical blades and surgical wound creation techniques. In another research application, he has used it to evaluate accommodation achieved with a dual optic IOL when varying the power combinations of the anterior and posterior lenses.

The Pentacam also has a number of applications for surgical planning and follow-up in cases of phakic IOL implantation. Anterior chamber depth, which is one of the criteria for selecting candidates for implantation of the iris-fixed Artisan phakic IOL, can be accurately measured with the Pentacam. Not only does the device provide information about the central anterior chamber depth, but it also measures depth at the periphery.
The Pentacam system uses a rotating Scheimpflug camera and an ultrafast processor to obtain 50 slit images and provide a comprehensive, 3-dimensional (3-D) scan of the anterior chamber from the anterior surface of the cornea up to the posterior surface of the crystalline lens. The examination is comfortable, rapid, and accurate. It is a non-contact procedure and takes less than 2 seconds to complete. During the scan, fixation control is achieved via a second camera focused on the pupil that monitors size and orientation; detected eye movements are corrected for automatically after the scan is completed.

The Pentacam scans and measures the cornea and anterior chamber. It does a rotating scan but captures the images only in the temporal area in 180°. For example, for a right eye it scans from approximately 130° to 310°. This procedure avoids the nose shadow.

With its rotating principle, the number of data points in the centre of the cornea is optimised and any influence of nose shadow is avoided. The data are analysed with sophisticated software to produce multiple representations of the anterior segment and an extensive list of key measurement values that make the Pentacam useful in a broad spectrum of applications. The Pentacam generates the following outputs:

- A clear, sharp Scheimpflug image, depicting the entire anterior segment from the cornea to the posterior lens surface, including the angle area up to the most distal 100 - 150µm. This image can also be reviewed with 3-D animation

- Topography maps of the anterior and posterior surfaces of the cornea based on measurement of approximately 25,000 true elevation points. The Pentacam measures 25,000 true elevation points while doing a 50 image scan. Topography information is provided as tangential and sagittal (axial) curvature maps, true elevation maps from limbus-to-limbus with free selectable reference bodies, and a true net power map

- A colour-coded corneal pachymetry map displaying the entire cornea from limbus-to-limbus and with measurement precision of ±5 microns

- An anterior segment analyser providing data on chamber angle, chamber height, chamber volume and orientation along with a manual measurement function

- Densitometry data for the cornea and the entire crystalline lens, including the subcapsular layer

Using a prototype for that application, Dr. Dick and colleagues studied the simulated postoperative anatomy of a -15.0 D myope with a 6.0-mm optic in place. An anterior chamber depth value measured with ultrasonography or partial coherence interferometry indicated the patient was a good candidate for implantation of an anterior chamber IOL. However, the Pentacam simulation revealed a future risk for endothelial cell loss occurring secondary to age-related increase in crystalline lens causing anterior displacement of the phakic IOL.

“For now, the Pentacam is helpful for patient follow-up post-implantation of a phakic IOL. It can be used to evaluate safety distances between the posterior side of the implant and the crystalline lens and from the anterior optic side to the corneal endothelium. The latter measurement can be made using the vertical distance to the central endothelium. More importantly, the Pentacam can also be used to determine the shortest distance from the edge of the optic rim to the endothelium, which may be regarded as the most critical distance for determining endothelial safety and in most cases is represented by a diagonally oriented line.”

JAN NOVAK, MD, PHD
Pentacam in Clinical Practice and in Scientific Investigation

Jan Novak, MD, PhD has been using the Pentacam since November 2003, and so far has performed about 1,200 examinations. He discussed its benefits and use in daily practice and research studies.

“We have used the Pentacam in a broad spectrum of applications that take advantage of its capabilities to image and analyse the cornea, anterior chamber, crystalline lens, IOLs, and secondary cataract. Based on our experience, we consider the Pentacam to be the most comprehensive method for investigating the anterior segment available to ophthalmologists today.”

Dr. Novak noted that the Pentacam can be readily integrated into clinical practice because the examination is easy and affordable. The non-contact measurement takes only about two seconds, and quality images are obtained in any cooperative patient with a clear cornea and a pupil at least 1.5-mm in diameter, independent of tear film condition. However, maximum pupil dilation is needed in order to fully visualise the...
We consider the Pentacam to be the most comprehensive method for investigating the anterior segment available to ophthalmologists today.

We believe new users will quickly appreciate the broad range of information provided by this multifunctional system and it easy-to-use interface.

ALAN-NICOLAS GILG, MD
Pentacam in Routine Practice for the Cataract and Refractive Surgeon

Alan-Nicolas Gilg MD, has also been relying on the Pentacam for evaluation and management of patients in routine clinical practice. He described some of those applications along with methods for selecting and reviewing available diagnostic information.

“We believe new users will quickly appreciate the broad range of information provided by this multifunctional system and it easy-to-use interface.”

The Pentacam screen displays several standard four-map printouts, or users can customise the maps shown based on their personal preference. An individual map is readily selected for further investigation with the click of a mouse, and a comparison screen is available as well to enable evaluation of serial examinations. Taking advantage of magnification, zoom, and contrast adjustment options, examiners can also more carefully investigate a specific area of interest on the Scheimpflug image, or the anatomy from the cornea to the iris and lens can be reviewed using the 3-D animation feature of the Pentacam system.

By virtue of the types of information it provides and the formats available for viewing, Dr. Gilg said he has found the Pentacam to be indispensable technology for evaluating and diagnosing external and corneal diseases, in glaucoma and refractive surgery screening and follow-up, and for characterising crystalline and artificial lens changes.

He illustrated its use to document pterygium and its progression and for visualising implanted intracorneal ring segments, corneal foreign bodies, scars, and interfaces between graft and host tissue.

Using other examples, Dr. Gilg demonstrated how the Pentacam allows accurate evaluation of anatomical relationships between implanted phakic IOLs and adjacent ocular structures, and the range of topographic information it provides.

“The topography function of the Pentacam is extremely useful for routine patient management, but we have come to especially appreciate it for guiding decisions in complex clinical cases, such as for the individual with high astigmatism after...
“Topography-guided procedures can involve significant amounts of tissue ablation and a second retreatment may be needed to correct residual refractive error.”

MATTHIAS MAUS, MD
The Role of the Pentacam in Refractive Surgery

The Pentacam has many features that make it a valuable asset to refractive surgeons. Matthias Maus, MD, discussed how it has helped to improve competency in refractive surgery planning and postoperative patient management and why it also serves as a powerful marketing tool.

“The Pentacam provides accurate, quantitative data on a range of parameters that are critical for guiding clinical decisions, but it also enables patient interactions. Not only do the Pentacam images facilitate explanations during consultation visits, but they also fascinate and impress patients and may influence them to choose our practice for their surgery.”

The Pentacam’s colour-coded pachymetry map is an asset for improving the safety of refractive surgery because it identifies corneal thickness not only in the centre of the pupil but also the thinnest location. Dr. Maus explained that the precise pachymetry function of the Pentacam is especially appreciated at his centre that specialises in topography-guided retreatments.

“The Pentacam provides the type of reliable information necessary to assess patient eligibility for surgery and to plan the procedure,” he said.

In planning surgery for implantation of the iris-claw phakic IOL, the Pentacam is useful in providing data on anterior chamber depth that is necessary for appropriate candidate selection. The anterior chamber depth value measured with the Pentacam represents the distance from the front surface of the crystalline lens to the corneal endothelium rather than the distance from the crystalline lens to the corneal epithelium measured using partial coherence interferometry (IOLMaster, Carl Zeiss Meditec). However, comparative analyses demonstrate there is good correlation between the values provided with the two techniques.

Dr. Maus pointed out that the lens densitometry function of the Pentacam is a useful aid in screening older patients who present for LASIK. For example, individuals in their 50s might note a recent myopic shift that can be documented with the Pentacam to be caused by development of nuclear sclerosis. Based on that assessment, the patient can be counselled to undergo cataract surgery rather than LASIK.

Dr. Maus believes business-minded refractive surgeons will appreciate the value the Pentacam can offer as a marketing tool. In his experience, patients are amazed at the comfort and speed of the Pentacam procedure and are delighted to view the output maps, especially with the 3-D-animation feature. In addition, using the Pentacam images for illustration and as an instructional aid, patients can more readily understand their clinical situation with respect to whether they meet the eligibility criteria for certain procedures or why they may be experiencing certain complications, such as night vision symptoms associated with corneal haze after surface ablation.

“Patients who consult with more than one refractive surgeon before deciding to undergo a procedure are likely to have a more favourable perception of a practice using the Pentacam compared with competitors who do not have such advanced technology.”

TOBIAS NEUHANN, MD
Clinical Experience with the Pentacam as a Diagnostic Tool

The multiple applications of the Pentacam make it a very useful tool in the routine management of patients undergoing cataract and refractive surgery. However, its utility expands into numerous other situations. Tobias Neuhann, MD, provided examples of his experience where he found the Pentacam a valuable asset in the evaluation of some unique cases.

The Pentacam provides a full colour-coded pachymetry map, but also highlights the thinnest part of the cornea. That latter feature has shown itself important in the management of patients with corneal perforating injuries. The densitometry measurement of the crystalline lens provided by the Pentacam may become relevant in the future to cataract surgeons practicing in countries where third party payers may begin to require documentation of a need for surgery independent of reduced visual acuity. However, it has proven valuable in routine clinical care as illustrated by a case presented by Dr. Neuhann involving a 21-year-old with 20/15 vision who was anxious after being diagnosed with a cataract by another ophthalmologist.

“The Pentacam quantifies lens density and can differentiate various forms of cataract, and in this case it documented the presence of a small peripheral cataract, which we assured the patient is a relatively common and visually inconsequential finding in young adults.”

The Pentacam also provides a rapid and effective method for documenting IOL subluxation. While that complication can be identified with ultrasound, the ultrasound examination causes much more discomfort for the patient. By providing a clear picture of the IOL, the ophthalmologist might also be able to determine IOL style and based on that information and knowledge of where the surgery was performed, the exact type of IOL present.

“‘In performing cataract surgery in a patient with coexisting keratoconus and dense nuclear cataracts, we were able to achieve a near emmetropic outcome using information from the Pentacam.’

The Pentacam is also particularly useful for guiding decisions about suture removal post-penetrating keratoplasty because it generates a 12.0-mm diameter topography map. In contrast, the out put from Placido-based systems shows only a 9.0 to 10.0-mm zone.
SHEHZAD NAROO, MD

Use of the Pentacam in Research Studies and Clinical Work

The Pentacam offers many unique functions, including the ability to provide an accurate topography map of the posterior surface of the cornea. According to Shehzad Naroo PhD, that feature has tremendous implications for the evaluation of eyes that have undergone excimer laser refractive surgery and those with conditions associated with corneal deformation, such as keratoconus. The development and evaluation of instrumentation for characterising the posterior surface of the cornea has been a primary focus of Dr. Naroo’s research interests. He discussed studies that support the need for technology providing more accurate information on the posterior cornea and an investigation comparing topography and pachymetry measurements obtained with the Pentacam and other instruments.

Analyses of eyes that had undergone myopic LASIK showed a good correlation between the anterior best fit for the anterior corneal elevation and the amount of treatment (R² = 0.81). However, the analyses of the best-fit sphere for the posterior cornea showed much more scatter (R² = 0.36). Pachymetry data from the Orbscan seemed to greatly overestimate the amount of tissue removed by the ablation compared with ultrasound pachymetry.

“That finding causes us to further question the validity of the posterior corneal data from the Orbscan and also highlights that pachymetry data from the Orbscan becomes less reliable after anterior corneal changes. Taken together, these data indicate that while there has been talk about cases of post-refractive surgery ectasia documented using the Orbscan, the ability of the Orbscan to diagnose that complication is questionable.”

However, before new technology is adopted into clinical practice and research, it is critical to validate its performance and know how the measurements it provides correlate with those generated by standard instruments. To that end, Dr. Naroo and colleagues conducted a study comparing pachymetry and topography data obtained with the Pentacam against results measured with existing technologies.

The investigation included 80 normal eyes of 80 young adult patients (47 female, 33 male; mean age 22.6±2.9 years). All eyes underwent evaluation with the OPD (Nidek), Pentacam, and Orbscan in randomised order followed by ultrasound pachymetry (Nidek). The ultrasound pachymetry was performed last in order to avoid causing corneal deformation that might confound the results of the other studies.

In comparing results for central pachymetry the data from the Pentacam correlated slightly better to the ultrasound results than did the Orbscan measures (R² = 0.80 vs. R² = 0.76). However, there was even better correlation between the data generated by the Pentacam and Orbscan (R² = 0.90). Further analyses showed there were no statistically significant differences between the central pachymetry data provided by the Pentacam and Orbscan studies, although correlations were weaker in the superior (R² = 0.50), inferior (R² = 0.20), nasal (R² = 0.62), and temporal (R² = 0.76) regions.

“It should be noted that while there was excellent agreement between the ultrasound and Pentacam data, the two instruments use different technology for data acquisition - ultrasound vs. an optical method. They make different assumptions and provide different information and neither can be said to be more accurate than the other.”

The topographic analyses took into account that the Pentacam provides height data relative to the centre of the map whereas the Orbscan elevation is relative to “best fit sphere”. Therefore, comparisons were made between the axial keratometric data from the Orbscan, the Pentacam total power map, and the OPD axial data. The results showed that Placido topography with the Orbscan was somewhat similar to the Orbscan, which was not surprising to the researchers considering that the Orbscan has a Placido system built in.

There was good correlation between the curvature data provided by the Orbscan and the Pentacam in these normal eyes. The comparisons showed the best correlation was between the OPD axial keratometry data and the Orbscan keratometric map (R² = 0.7771), while the correlation between the Pentacam total power map and the Orbscan keratometric map was only slightly lower (R² = 0.6955), and the Pentacam total power map correlated more poorly with the OPD axial data (R² = 0.4932).

Comparisons were also made for anterior and posterior surface K values measured with the Pentacam and Orbscan using the Orbscan axial data and the sagittal data of the Pentacam. For the anterior data, there was good correlation between the Pentacam and Orbscan (R² = 0.6955), which was even slightly higher than the correlation for the total power maps. However, there was poorer agreement between the two instruments when comparing the data from the posterior surface maps (R² = 0.4737).

“Image capture with the Orbscan scanning slit technology is adversely affected by any degradation in anterior surface quality even to the extent that such changes may be present in normal corneas. That is just one reason why the Pentacam is thought to provide more accurate data on the posterior surface of the cornea, and explains the relatively poor correlation in surface K values measured with these two instruments.”

Dr. Naroo and colleagues are also investigating the Pentacam in a number of other research studies that are underway. The corneal topography function is being evaluated to see if the Pentacam offers a better method for characterising ectasia post LASIK. In addition, its densitometry function is being investigated for quantitative grading of posterior capsule opacification, and the data on anterior chamber angles from the 3-D anterior chamber analyser will be compared with values obtained through gonioscopy to determine their correlation.

JACK T. HOLLADAY, MD, MSEE, FACS

Corneal Power Measurements Before and After Refractive Surgery Using the Pentacam

Accurate calculation of pseudophakic IOL power in eyes that are post-corneal refractive surgery presents a challenge and one that ophthalmologists will find themselves facing increasingly in the future as the numbers of patients undergoing excimer laser ablation procedures continues to grow.

Jack Holladay MD, MSEE, FACS believes the Pentacam may have real potential for use in obtaining a direct and accurate measurement of corneal power in post-corneal-refractive surgery eyes. He discussed the limitations of current methods for obtaining that information, why the Pentacam may provide a solution, and findings from an ongoing study being conducted to validate its use in this important application.
Current methods for determining central corneal power include standard keratometry and topography. However, those techniques overestimate central corneal power after myopic treatments for two reasons: first, the flattening of the anterior surface of the cornea is greater in the centre after PRK and LASIK, and these instruments take their readings from a paracentral area, which is steeper than the centre.

Second standard keratometry and corneal topography also yield incorrect data in post-refractive surgery eyes because they measure only the front surface of the cornea and assume there is a constant ratio between the anterior and posterior surfaces. However, because LASIK, PRK, and RK alter only the front surface of the cornea, they also alter the normal relationship between the ratio of the anterior and posterior surfaces, making the assumption of the posterior corneal power incorrect. Studies have shown that the over-estimate of power by these instruments is between 15 % & 25% of the refractive change induced by the surgery. For example, if you have a –8 D PRK or LASIK and your cornea now measures 38D, it is actually 38D (38D – 0.25 X 8).

Cataract surgeons can choose from among a number of methods to circumvent the limitations of standard instruments for providing data on central corneal power in post-refractive surgery eyes. If the patient’s preoperative manifest refraction and K values are known, the history method can be applied in which the post refractive surgery K value can be calculated by subtracting the change in refractive error caused by the refractive surgery from the preoperative K value. If the preoperative data are not available, the contact lens over-refraction method can be used. However, it provides the best results in patients who have adequate visual acuity to obtain a good manifest refraction. The problem with the historical method is that one never knows if the refractive change is particularly due to the cataract and the contact lens method still assumes there is a proportionate change in the posterior surface of the cornea which is not true in PRK and LASIK.

“As against that background, the Pentacam system appears to be uniquely designed to serve as a direct measurement tool for obtaining accurate information on central corneal power in post-refractive surgery eyes by precisely measuring the curvature of the back and front surfaces of the cornea. Using a rotational imaging process, the Pentacam takes sections through a common vertex point of the cornea, including the centre, and produces a true net power map using the correct refraction index of the cornea.”

A study is now underway investigating the utility of the Pentacam for measuring power changes after refractive surgery. Data are being obtained preoperatively and at three to five months postoperatively, with two scans being performed at each visit to assess reproducibility. The change in refraction is being calculated from the pre- and postoperative Pentacam data. The validity of that value is tested by comparing it with the true refractive change for the patient, which is calculated as the net spheroequivalent change of the refraction vertexed back to the cornea from the pre- and post-operative refractions. To see if correlations found in effective power change are valid across all refractive errors, the study is including myopes, hyperopes, and some patients with mixed astigmatism. Patients eligible for enrollment have refractive errors ranging from +3.0 to -7.0 D.

Initially the Pentacam power data were compared with values obtained using a standard keratometer. Those analyses showed there was good consistency between the two systems when comparing preoperative values. However, there was a marked lack of agreement when comparing the postoperative data. In one case, for example, the keratometry data indicated there was a 2.6 D change in central corneal power after refractive surgery; whereas using the Pentacam, the power change was determined to be 5.7D in the central 1.0-mm region, but only 4.5 D at the 3-mm zone, the actual refractive change at the cornea was 4.0D.

Those data reinforced the concept that when using the Pentacam to calculate refractive change, the value needs to be based on the entire central zone and not at any single ring. For the current analyses, a “4-mm zone value” is being calculated by weighting data from the centre, 1-, 2-, 3-, and 4-mm rings, taking into account the proportion of the total area represented by each ring. However, it is possible that the size of the zone used may be modified slightly as more data are collected and we complete the study.

Results from an initial analysis based on data from about 25 patients show there is excellent correlation between the actual refractive change and the value calculated using the Pentacam measurements (R² = 0.9475). So far, the mean difference between the two values is 0.37 D and the maximum difference is only 0.5 D, which is about fivefold less than the difference that would be achieved using standard keratometry or topography to measure corneal power.

“Based on these encouraging preliminary findings, the Pentacam seems to have real potential for improving the predictability of pseudophakic IOL power calculation in the growing population of cataract patients with a history of refractive surgery.”

As more data are collected, they will be further analysed to determine the correct zone to use for calculating the cornea power value.

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"The Pentacam takes sections through a common vertex point of the cornea, including the centre, and produces a true net power map using the correct refraction index of the cornea."