Pentacam opens eyes to new diagnostic possibilities
Scheimpflug based anterior segment tomography
**Introduction**

The innovative technology of the Oculus Pentacam HR is, with increasing clinical experience, fulfilling its promise as an essential tool for diagnosis, biometry and management of cataract and refractive surgery patients. Tobias Neuhann MD served as Moderator of an EuroTimes Satellite Education Programme Symposium on the current state of Scheimpflug based anterior segment tomography during the XXIV Congress of the European Society of Cataract Refractive Surgeons in London.

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**Pentacam HR**

The high resolution Oculus Pentacam is a rotating Scheimpflug camera that generates images from the anterior surface of cornea to the posterior surface of lens. It acquires 50 Scheimpflug images in two seconds. These images show the anterior segment of the eye from the anterior corneal surface to the posterior surface of the crystalline lens.

The Pentacam software extracts 2,760 true elevation points from each of these images, obtaining 138,000 true elevation points for each surface, including the centre of the cornea. The software generates a three-dimensional model of each surface as a basis for corneal topographic and chamber analysis.

The rotating camera supplies anterior segment images in three dimensions, creating a movable three-dimensional presentation of the anterior chamber. The centre of the cornea is measured very precisely because of this rotating imaging process, which takes less than two seconds and corrects the slightest eye movements. By measuring more than 25,000 true elevation points the Scheimpflug system offers precise representation and repeatability.

The high reliability of the rotating Scheimpflug system is a result of the measuring principle in which highly precise measurements are obtained through many repeated, mostly central, corneal measurements. The topographic analysis of both the corneal front and back surfaces is based on the true elevation measurement from limbus to limbus.

The information provided by the Pentacam includes:

- Anterior and posterior corneal topography and elevation maps
- Corneal pachymetry from limbus to limbus
- 3D-chamber analysing (ACD-map, chamber angle, chamber volume etc.)
- Lens density (quantification of the light transmittance of the crystalline lens and IOL’s)
- Tomography
- Improved IOL-calculation for post LASIK, PRK and RK patients.
Iris-fixated phakic IOLs are now considered a useful treatment option for the correction of myopia, hyperopia, and astigmatism. They have become an alternative to laser refractive surgery, particularly in patients needing higher amounts of correction. However, surgeons continue to be concerned about the potential for complications with these lenses, such as progressive endothelial cell loss, pigment dispersion, and cataract.

Dr. Mana Tehrani MD, Department of Ophthalmology, Johannes Gutenberg-University, Mainz, Germany, has extensive clinical experience with the Pentacam in a variety of settings. In her presentation at the symposium she described how valuable the Pentacam could be in pre-operative evaluation of potential iris-fixated phakic IOL candidates.

“The goal is safety. What we need to know is how can we ensure post-operative safe distances to crucial intraocular tissues?”

“Improving phakic IOL patient selection with the Pentacam”

 Mana Tehrani

The pIOL software module

The pIOL simulation software by Mana Tehrani MD, Burkhard Dick MD and colleagues, uses Pentacam data to create a preoperative simulation of phakic IOL fitting. The simulation is based on data obtained on distances between the peripheral implant and the corneal endothelium/ shortest distance from implant to endothelium and distance between implant to crystalline lens. The software can extrapolate the position of the phakic IOL in the eye for several decades into the future. The p-IOL simulation software can be upgraded to any Pentacam HR system in the field.

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“The goal is safety. What we need to know is how can we ensure post-operative safe distances to crucial intraocular tissues? We want to know how to screen patients so we can exclude poor candidates such as those with protruding irides, or inadequate peripheral anterior chamber depth. In other words, how can we ensure postoperative safety preoperatively? The Pentacam can help answer these questions,” said Dr Tehrani.

Dr Tehrani and colleagues conducted studies using the Pentacam and a pIOL software module they developed to create precise preoperative simulations of postoperative iris-fixated IOL location. She described the results of a study of 44 eyes of 23 patients. The average age of the phakic IOL candidates was 41 years, ranging from 26 to 57 years. The mean proposed IOL power was -8.7 D, ranging from -22.0 to +11.0 D. The patients would receive either the rigid Artisan®, (Ophthech); Verisyse™, (AMO) or the foldable Artiflex®/Veriflex™ (AMO).

The Pentacam pIOL software module takes into consideration the patients refraction and selects a phakic IOL from the database to simulate the lens in the anterior chamber. The simulated IOL is automatically aligned on the iris surface and centred on the pupil.

The programme calculates the distances to adjacent eye structures three dimensionally from each point of the phakic IOL. The distances are presented as colour maps that show every point of the phakic IOL in top view and as minimum space values for critical areas of the lens. The colour maps demonstrate the actual simulated position in the x–y plane relative to the apex and the pupil. The system also allows the surgeon to make final corrections in height and tilt to compensate for incorrect positioning caused by irregular iris spots.

After the simulations are completed the surgeons implanted the phakic IOLs, and then evaluated the outcomes, comparing the mean difference between preoperative simulation and postoperative results.

Seventeen eyes received the foldable phakic IOL while the remainder received rigid phakic lenses. The Pentacam proved to be an excellent way to screen the patients and to select the appropriate lenses. The actual post-operative images were very close to those visualised with the preoperative simulations.
Dr Tehrani described a case that illustrated the use of the Pentacam in this clinical situation. A 25-year-old female presented with a subjective refraction in the right eye of $-11.0 \rightarrow -2.0 \times 40$, with an uncorrected visual acuity of counting fingers and a best spectacle-corrected visual acuity of 20/40. Her anterior chamber depth was 3.60 mm, with an endothelial cell count of 3244 cells/mm², and an intraocular pressure of 11.0 mm Hg.

Based on preoperative Scheimpflug imaging with the HR Pentacam, the patient received an Artiflex phakic IOL with a power of $-12.5$ D in the right eye. A comparison of the preoperative simulation image and the actual post-operative position of the IOL showed that the phakic IOL was 50 mm higher with the simulation. Dr Tehrani attributed this to the fact that following surgery the phakic lens was actually enclavated in the iris and therefore was closer to the iris than in the simulation.

“The new features in the Pentacam will be especially beneficial in patients with irregular iris formation and poor central and peripheral anterior chamber dimensions”

She reported that the high-resolution Scheimpflug imaging device and software module could also be used to extrapolate the postoperative position of an iris-fixated phakic IOL over subsequent decades. In the example, a simulation of the phakic IOL position in the patient 30 years after surgery revealed a safe phakic IOL position with no contact with the crystalline lens or corneal endothelium.

Taken together the Pentacam imaging and software driven simulations could help identify not only those patients who would initially be considered poor candidates for phakic IOL implantation, but also those who might benefit in the short term but develop complications some years later.

“The new features in the Pentacam will be especially beneficial in patients with irregular iris formation and poor central and peripheral anterior chamber dimensions. The image can be used to show the patient why he or she is not a good candidate for iris-fixated IOL implantation,” Dr Tehrani commented.

Dr Tehrani hopes that future research will build on the current findings. She noted that future features now in development include a module that simulates the phakic IOL position up to 50 years after surgery. Oculus engineers are also expanding the simulation module to include toric models of phakic IOLs, which will help surgeons to decide which model would best fit in a patient’s anterior chamber anatomy.

“The phakic IOL simulation software for the Scheimpflug imaging device represents a useful tool for preoperative detection of postoperative phakic IOL positioning and anterior chamber analysis. This tool improves preoperative selection or exclusion of patients, and the aging simulation tool may help ensure a safe phakic IOL position, not only after surgery, but also for the next 30 to 50 years,” said Dr Tehrani.
Accurate calculation of biometry values in cataract surgery candidates who have previously undergone refractive surgery is an issue of increasing importance to eye surgeons. Dr Edmondo Borasio MD, Refractive Surgery Fellow to Mr Julian D Stevens at Moorfields Eye Hospital, London, UK described an interesting approach to the problem, using the Pentacam and a new formula for biometry calculation.

The BESSt formula was developed to estimate true corneal power in eyes that have previously undergone keratorefractive surgery. It is a modified version of the Gaussian optics formula for paraxial imagery. The calculations are based on information from the anterior and posterior corneal curvatures rather than keratometry. The formula takes into account anterior and posterior corneal radii and pachymetry obtained with the Pentacam and does not require any information on the pre-keratorefractive surgery state. The BESSt formula was then developed into a software program, the BESSt Corneal Power Calculator, to simplify the process.

“Prior to this, many techniques have been proposed to improve IOL power calculation accuracy and predictability in eyes that have undergone refractive surgery, but none has proven to be fully reliable. In our experience, using the Pentacam and the BESSt formula for biometry after refractive surgery has led to a significant improvement in accuracy,” he told the symposium.

He described his clinical experience in a study of 25 eyes. All patients had previously undergone refractive surgery and were now in need of cataract surgery. The study included patients with myopia ranging from –2.9 D to –8.6 D and patients with hyperopia ranging from +1.7 to D +8.5 D.

The refractive results obtained using the BESSt formula were significantly closer to the target refractions compared to those estimated with the Holladay 2 formula using K values obtained with corneal topography (Zeiss Atlas). The Holladay 2 formula would have induced 0.5 D of myopia, and the standard Gaussian optics formula (without any adjustment) would have induced an even greater amount, 0.9 D, Dr Borasio reported.

The use of the BESSt formula produced 77% of eyes within 0.75 D of the target refraction. By contrast, the historical technique was within 0.75 D of the intended correction in 23% of cases. The double-K adjustment and the contact lens over-refraction technique were only slightly better, with 38% of eyes within 0.75 D. With the Holladay 2 formula 61% of eyes would be within 0.75 D of the target refraction.

“All eyes were within one dioptre of the target refraction, compared to 69% with the Holladay 2 formula. If we look at the mean absolute differences between the target and the achieved refraction after phacoemulsification following refractive surgery, we can see that the BESSt formula had a standard deviation of 0.25 D, which was nearly half of that of the best of the other methods, the Holladay 2 Formula using the K values from the Zeiss Atlas topographer. The standard deviations of the other techniques were significantly larger,” he emphasised.

Dr Borasio’s study also highlighted some of the known problems with using the SRK/T formula to calculate IOL power. The published SRK/T formula is known to be affected by two phenomena that could result in inaccurate IOL power calculation in eyes with particular combinations of axial length and keratometric values. These phenomena are known as the zero argument problem and the cusp phenomenon. They are known to occur most frequently in eyes with very steep corneas.

“When they occur, these phenomena may give rise to markedly inaccurate IOL power calculations. In this situation, alternative formulae (such as the Hoffer Q) can be used, either alone or in conjunction with the BESSt formula. In our software, we implemented an algorithm to automatically detect when either
phenomenon occurred and opted for alternative formulas in those situations. No eye in our study was affected by these phenomena,” he said.

“In our experience, the BESSt formula allows significantly more accurate estimation of corneal power following refractive surgery. Its major advantages are that it does not require any pre-refractive surgery information, and it provides automatic detection of the zero argument and cusp phenomena. In our practice, it has significantly reduced the standard deviations of IOL power calculations after refractive surgery. We believe the BESSt formula represents a significant leap forward in IOL power calculation accuracy after keratorefractive surgery, and we think it should reduce the risk for refractive surprises in these eyes,” Dr Borasio said.

A trial version of the BESSt Corneal Power Calculator can be downloaded from the website, www.besstformula.com
As the overall population continues to increase in age, cataract surgeons can expect to see more candidates who have previously undergone refractive surgical procedures. These cases are particularly challenging to evaluate biometrically. Carlos Verges MD, PhD Professor of Ophthalmology, Institut Universitari Dexeus, Universitat Autonoma de Barcelona, Spain, reviewed these challenges and described the utility of the Pentacam in obtaining accurate biometry in such cases.

Dr Verges said that when standard biometric methods have been used in the past in patients with a history of keratorefractive surgery, significant refractive ‘surprises’ often resulted. Myopes tended to have residual hyperopia, while the hyperopes had myopic overcorrection.

He said that the reasons for this were now much better understood. Early attempts at biometry in post-LASIK patients failed to take adequately into account changes of the anterior surface of the cornea, reduction in cornea thickness, and the stability of posterior surface of the cornea.

Another source of error was the calculation of the effective lens position (ELP). Most of the formulas assume the ELP calculation by means of the radius of the cornea curvature. If it is flat, the ELP value decreases and lens positioning is nearer to the cornea.

In the past, one biometry method surgeons have had to rely on was the clinical history method. This depends on having detailed patient history including pre-refractive surgery manifest refraction data. Many years may have passed since a patient had radial keratotomy or LASIK and often the data are simply not available.

Another method, contact lens over refraction, does not require pre-refractive surgery data, but requires at least 20/60 visual acuity. Computerized videokeratography needs the average of central corneal power and the K value must be modified in LASIK and PRK by the percentage of refractive change. He described other biometry options, and the limitations with each.

Dr Verges emphasised that of the seven options for post-LASIK IOL calculation now available, he believes the Pentacam is the most practical and the most accurate, with the least standard deviation. He reviewed his own clinical studies and those of others to support this belief.

“The new era in IOL power calculation should utilise ray tracing formulas because they provide information that is more accurate. The problem used to be obtaining the needed data to perform the calculations. With Pentacam, we have the data, the anterior and posterior curvature of the cornea and the natural lens, the anterior chamber depth and natural lens thickness. Only the axial length measurement is needed from other instruments.”

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Recent clinical studies with the Pentacam in refractive surgery patients call into question some of the conventional wisdom regarding post-operative ectasia, and also suggest that some patients may be inappropriately denied access to refractive procedures because of false positive keratoconus readings. Professor Michael Belin MD, Albany Medical College, New York, discussed these issues during a presentation at the symposium.

The main tools now in use for measuring corneal topography include Placido disk and scanning slit topography systems. While these are undoubtedly valuable tools, both of them have limitations. Unlike current keratometers and topographers, the Pentacam accurately measures the anterior cornea and the posterior corneal surfaces, Dr Belin noted.

“While I know this is not generally agreed upon, I believe Placido-based topography alone is no longer standard of care. Modern topography analysis based solely on Placido derived anterior curvature is incomplete and outdated. It is like relying on an X-ray when a MRI is available,” he commented.

In the past the scanning slit Orbscan II device has been used to assess both the anterior and posterior corneal surfaces. Recent studies with the Pentacam call into question some of the earlier observations reported in Orbscan II studies.

For example, some investigators using the Orbscan system have reported that subclinical post-LASIK ectasia is common. However, those studies, are somewhat limited by their dependence on Orbscan-generated post-LASIK data measuring the posterior corneal surface, and the validity of those data has not been independently confirmed. Dr Belin noted that his own published research calls into question some of the Orbscan pachymetry data on which the ectasia findings were based, with the likely source of error being the posterior measurements obtained with the Orbscan.

“Post-LASIK ectasia is a serious LASIK complication. It is characterised by poor visual performance and corneal thinning, which may progress to require corneal transplantation. Because investigators suggest that changes in the posterior corneal shape are key to early recognition of corneal ectasia, it is important for clinicians to have an accurate method of studying posterior corneal elevation in post-LASIK patients,” he said.
In a prospective study, Dr Belin used the Pentacam to evaluate 121 corneas of 62 refractive surgery patients. He studied only myopic eyes, since most reports of posterior corneal surface changes after refractive corneal procedures involve myopic eyes.

He obtained images of the eyes of 52 LASIK patients and 10 photorefractive keratectomy (PRK) patients before and one and two months following surgery. The PRK patients served as controls because ectasia is exceedingly rare in those patients.

The imaging studies did not find any statistically significant difference in the forward displacement of the posterior corneal surface between post-LASIK eyes and post-PRK eyes. In contrast to previous reports, the post-LASIK corneas in Dr Belin’s study displayed no significant change in the mean elevation of the posterior surface. Moreover, no cornea in the LASIK group had significant forward displacement, an early indication of post-LASIK ectasia.

According to Dr Belin, this study calls into question earlier conclusions about the rate of post-LASIK ectasia obtained with the Orbscan system. He said that while his study does not suggest that post-LASIK does not occur, it does raise the possibility that the incidence of subclinical post-LASIK ectasia may be lower than previously reported.

Problems with inaccurate pachymetric screening may also be excluding some otherwise suitable refractive surgery candidates from treatment. Dr Belin discussed how Placido-based topography systems can lead to inaccurate diagnosis and characterisation of keratoconus and a high incidence of pseudo “pellucid marginal degeneration”.

He demonstrated the point with a series of case studies. One case was a 27-year-old male referred because of poor vision in the left eye secondary to keratoconus. The patient complained of poor contact lens tolerance and was being considered for Intacs corneal implants. Anterior corneal curvature analysis revealed significant inferior cone displacement, maximum steepness of greater than 50D, with the steepest part of the cone well below the pupillary margin. This led to a presumptive diagnosis of pellucid marginal degeneration. However, a Pentacam analysis revealed errors in the initial diagnosis, highlighting the shortcomings of making a keratoconus classification based solely on anterior curvature, reported Dr Belin.

In a second case, a 47-year-old female who had been told she was not a candidate for refractive surgery because of “Forme Fruste” keratoconus presented for a second opinion.

A Pentacam anterior segment analysis revealed normal pachymetry, with a normal distribution and central thickness of greater than 650 microns. Anterior and posterior elevation studies revealed a slightly decentred apex, which had led to the “False Positive” inferior steepening on a curvature map. That patient went on to have customised LASIK with a good visual result.

Dr Belin re-iterated that current topography systems are limited by an assumption that all corneas share a common conic section. The Pentacam overcomes this limitation by providing maps based on elevation data that is independent of axis, orientation or positioning.

"I have worked with just about every topography system available and the Pentacam is the first system that performs every measurement in an accurate and reliable fashion.”

The Pentacam has become our indispensable topography system."
One of the keys to successful screening of refractive surgery candidates is preoperative identification of forme fruste keratoconus and other forms of ectasia. The current consensus is that no less than one percent, and probably more, of patients undergoing refractive surgery have undiagnosed keratoconus or other forms of corneal ectasia.

The Pentacam can provide fast, accurate and very sensitive screening for sub-clinical ectasia. The exam also provides critical data for determining the “susceptibility of ectasia” that any cornea from refractive candidates should have, so that proper planning is possible. Renato Ambrósio Jr. MD, PhD, Universidade Federal Fluminense (UFF), Rio de Janeiro, Brazil provided a detailed description of the use of two specific Pentacam tomographic parameters for this task, the corneal thickness spatial profile (CTSP) and corneal volume distribution (CVD).

“Corneal topography and pachymetry are indispensable tools in the preoperative screening of refractive surgery patients. Our recent studies confirm the importance of the corneal-thickness spatial profile and corneal-volume distribution in differentiating keratoconic and normal corneas.”

He described a study conducted at his institution in which he and his colleagues used the Pentacam to evaluate 46 eyes diagnosed with mild to moderate keratoconus and 364 normal eyes. They calculated corneal thickness at the thinnest point and the averages of the points on 22 imaginary circles centred on the thinnest point with increased diameters at 0.4 mm steps in order to create a corneal-thickness spatial profile. They calculated corneal volume within diameters from 1.0 to 7.0 mm with 0.5 mm steps centred on the thinnest point to create the corneal-volume distribution. The researchers also calculated the percentage increase in thickness and the percentage increase in volume for each position of the corneal-thickness spatial profile and corneal-volume distribution from their first value.

The analysis revealed statistically significant differences between the groups in all positions of corneal-thickness spatial profile and corneal-volume distribution. They also noted significant differences in the percentage increase in thickness and percentage increase in volume between 3.5 mm and 7.0 mm diameters.

The study confirmed previous reports that keratoconic eyes have thinner corneas than normal eyes. In addition, they confirmed the hypothesis that eyes of keratoconic patients also have less volume and a more abrupt increase from the thinnest point toward the periphery. This is evident when analysing the Scheimpflug images of the cornea of moderate to advanced keratoconus, in comparison to normal thin corneas (Figure 1). However, only the progression graphics generated by the exam enable identification of early sub-clinical forms of the disease.

“This study shows that indices generated from corneal thickness measurements over the entire cornea and calculations of volume can identify mild to moderate keratoconus. In addition, we also have determined the 95% confidence interval for these variables among normal corneas. These could serve as indices to diagnose very early forms of keratoconus and screen refractive candidates.”

Indeed, Oculus has reviewed these findings so that new summaries and graphics will be added to help clinicians detect ectasia using these parameters.

“The Oculus Pentacam Corneal Tomographer has become a very important tool for my daily clinical practice because the screening process for refractive surgery needs to evolve to improve safety. Progressive ectasia is a very severe complication and could occur even with no identifiable risk factors detected from corneal surface topography (Placido) and single point ultrasound pachymetry. Very early forms of ectasia can be detected by corneal tomography, which also enables the refractive surgeon determine the susceptibility for ectasia for any cornea. This is a new concept which is also related to corneal biomechanical measurements. I believe we need to revise what are the minimal tests necessary for screening candidates for kerato-refractive procedures.”
The symposium moderator Tobias H Neuhann MD, Medical Director, Augenklinik am Marienplatz, Munich, Germany, described his extensive clinical experience with the Pentacam HR in a wide variety of cases.

“We use the Pentacam daily in our practice. It is an invaluable tool for the assessment of refractive surgery candidates and cataract patients. The measurement process lasts less than two seconds and minute eye movements are captured and corrected simultaneously. By measuring 25,000 true elevation points, precise representation, repeatability and analysis are guaranteed. This allows us to see far more than we could with topography. It is really a significant advance in ophthalmology,” said Dr Neuhann.

He noted that the Pentacam was proving useful in monitoring patients implanted with the Staar ICL phakic IOL. He presented several cases showing how the Pentacam had helped him to understand which patient would, or would not benefit from the ICL.

“Phakic IOLs have been available to refractive surgeons now for many years. While a small group of surgeons favours these lenses, there are still many ophthalmologists who remain very sceptical about their use. This is particularly true regarding the implantable contact lens. The Pentacam is now a very helpful tool for an objective follow-up and helps to prove that this phakic lens has its indications,” he emphasised.

He began by showing an image of the first ICL he implanted in early 1995 in a hyperopic patient. This showed that the distance between the lenses was greater than expected, and the anterior chamber was only 1.4mm. However, the patient did well over time.

He displayed a second case, a patient who developed a mild anterior subcapsular cataract after receiving an ICL. Imaging revealed the ICL sitting on the crystalline lens. This did not evolve over the last four years. The patient has uncorrected visual acuity of 0.6. In this case, recalculation helped explain why the ICL was too short, he explained.

Serial Pentacam imaging has helped to explain what happens to ICLs in the eye over time.

It is clear that when a phakic IOL is implanted into the eye, the crystalline lens thickens both anteriorly and posteriorly. The lens can thicken as much as 20 μm per year, mostly anteriorly. The Pentacam provides clear images of the space between the posterior surface of the ICL and the anterior surface of crystalline lens, so sequential imaging will show the growth of the crystalline lens.

“We use the Pentacam as the screening tool for patients asking for refractive surgery. For phakic IOL candidates it tells us what we need to know about anterior chamber depth. Together with the power of their glasses or contacts and the Pentacam printout, we have any information we need to assess a patient’s suitability for LASIK or epi-LASIK,” he noted.

Dr Neuhann explained that he uses the Pentacam in his practice to help solve all manner of clinical puzzles. For example, he has found it valuable for identifying problems with subluxated IOLS as well as decentred anterior chamber IOLs with vitreous behind the IOL.

He showed another case where the Pentacam confirmed a greater than expected influence of soft contact lenses on corneal power. Following that observation, he now requires patients who undergo any corneal or lens refractive surgery to remove soft contact lenses before he calculates the lens or corneal power.

He also uses the Pentacam system for glaucoma screening, troubleshooting under and over correction following refractive surgery, and for pre- and peri-operative assessment of corneal transplantation patients.

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“The Pentacam allows you to see more than with any other topography system. It is the state-of-the-art of non-contact examination. We consider it a “a must have” instrument for any refractive, cornea, cataract or glaucoma department.”