**Pentacam Interpretation Guideline (Software Version 1.21r33+ or later)**

# Holladay Report -- 2018

### Overview

**The Holladay Report was developed by Jack T. Holladay, MD, MSEE, FACS and Oculus.**
The purpose of the Report is to facilitate the presentation of information for the busy cataract and refractive surgeon to provide the highest quality care.  The bullet points below highlight a number of recent modifications that illustrate the utility of the Report.

- Upper Middle Panel
    - **EKR65 Flat K1, SteepK2, Mean and Astig** provide the corneal power values to be used in IOL Calculations that provide the equivalent K-reading including the front and back power of the cornea.
    - **Total Spherical Aberration** Z(4+6+8,0) is the value that should be used for the selection of aspheric IOLs.  Aspheric IOLs range from 0 to -0.27 μm and can be matched to the patient.
    - **RMS HOA WE (6 mm)** is the RMS higher order aberration wavefront error over the 6 mm zone of the cornea is a measure of corneal irregularity.  As the value increases **above 0.66 μm (highlighted in yellow)** the image degradation from the cornea will become more noticeable and **above 1.00 μm (highlighted in red)** the patient will probably already have complaints about visual quality.  The use of multifocal intraocular lenses (IOLs) should be carefully considered with increasing amounts of corneal irregularity.
- Upper Right Panel
    - **HWTW** (Horizontal White-to-White diameter) is used in IOL Calculation formulas such as the Holladay 2 to size the eye and predict the effective lens position (ELP).
    - **Pachy Min:** Location of Pachy Min is usually temporal, but rarely more inferior than **0.61 mm (highlighted in yellow)** except in keratoconus.
    - **Est. Pre Refr Km** (estimated Pre Refractive Mean Keratometry) provides the estimated mean K-reading before the patient had refractive surgery.  This value is used in the Double K method for sizing the eye to determine the ELP.
    - **ACD external** (external anterior chamber depth) is the distance from the anterior corneal vertex (epithelium) to the anterior vertex of the crystalline lens which includes the corneal thickness.  This value is what is used in IOL power calculations.
    - **Refr Change** (Refractive Change) is the estimated amount of change from refractive surgery.  This value is determine from the back curvature of the cornea and knowing the normal ratio is 82.2%.  This value in non-refractive surgery patients will be near zero.
    - **Chord μ** is the chord distance from vertex normal (assumed to be the visual axis) and the pupil center.  It is **analogous to Angle Kappa**, but due to theoretical concerns is slightly different.  On the Pentacam the **normal value is 0.20 ± 0.11 mm**, so values **above 0.42 mm (highlighted in yellow)** would be highly unusual and have been associated with halos and glare when diffractive multifocal IOLs have been used.

**PROPER Color Bar, Scale and Map Overlay Settings**

**In order for Holladay Report to be consistent, the Color Bar, Scale and Map Overlay ARE FIXED and have been set by Dr. Holladay to provide optimal displays … When an exam is loaded the *HOLLADAY REPORT* WILL ALWAYS BE THE SAME.  After the exam has been loaded, the settings may be changed temporarily in the normal manner by placing the mouse over the scale and right clicking, but when the patient is reloaded all settings will revert to the Holladay Settings.  For REFERENCE, the Settings for the Holladay Report are shown below, but the USER needs to do nothing since these are automatically set.  Settings for OTHER MAPS are unaffected and are set by the USER.  The version of your software may be seen at the bottom of the Miscellaneous Settings Screen (Figure 2).**

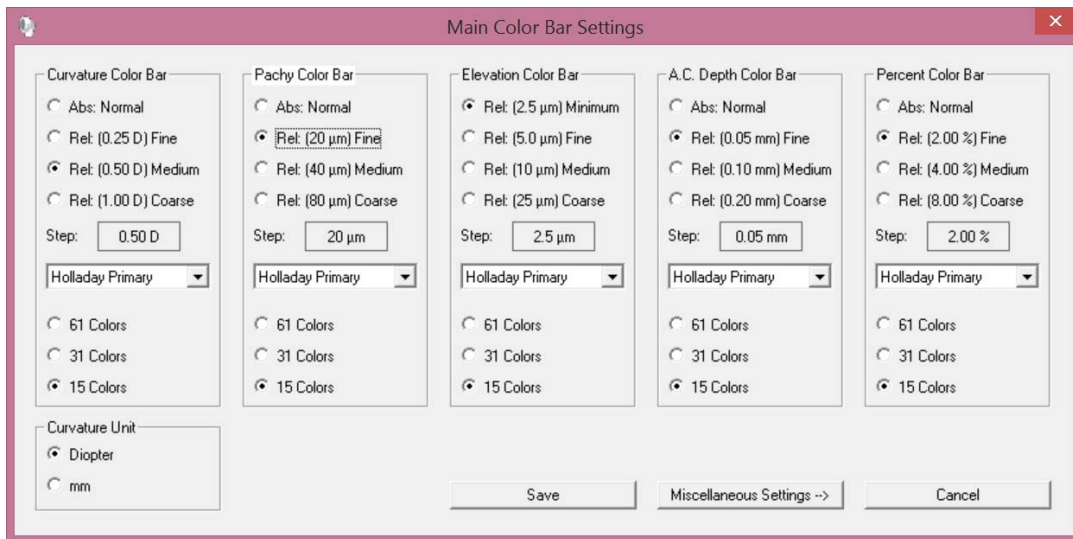The *Color Bar Settings* for the Holladay Report are shown in Figure1 below.
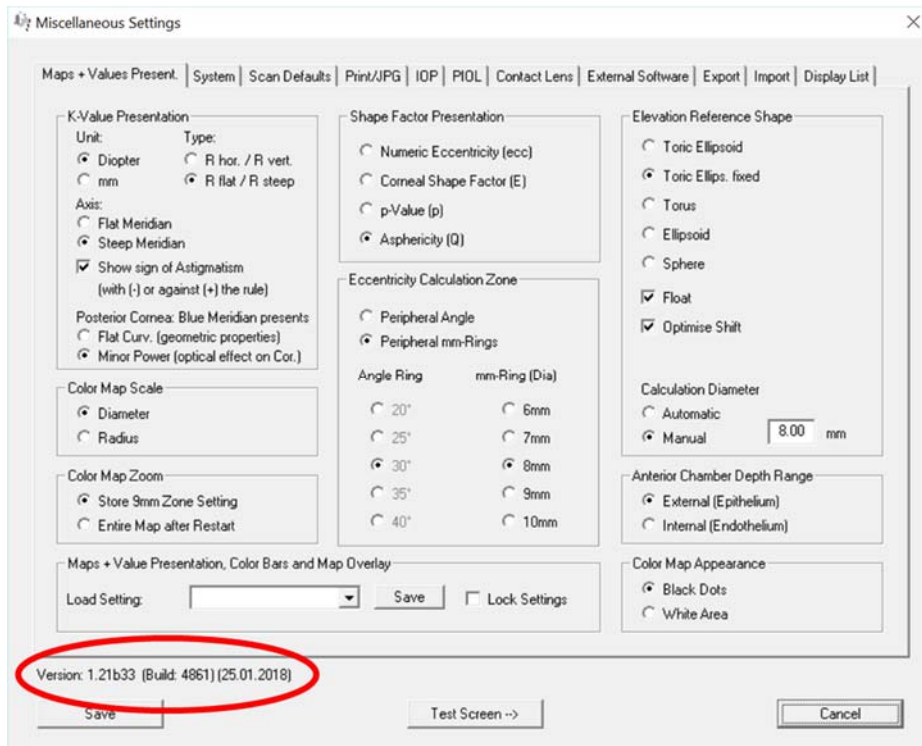


Figure 1 – Color Bar Settings



Figure 2 – Miscellaneous Settings

*Map Overlay Settings* for the Holladay Report are shown in Figures 3 (Corneal Thickness Maps) and 4 (All other maps) below.
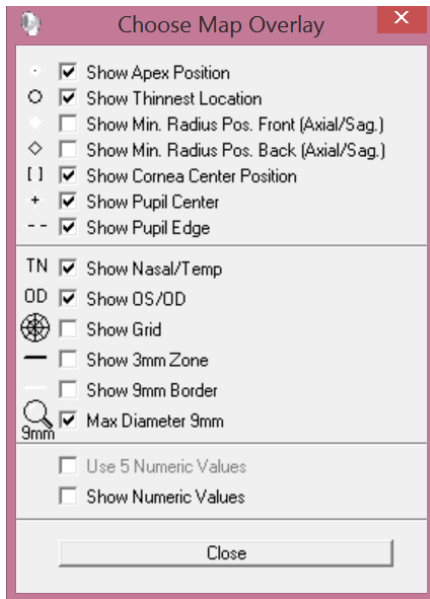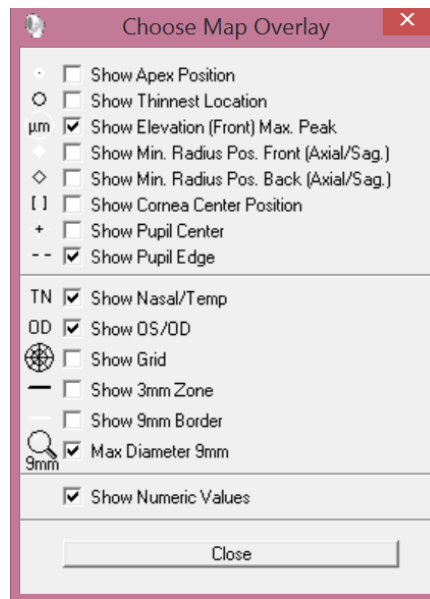
Figure 3 – Corneal
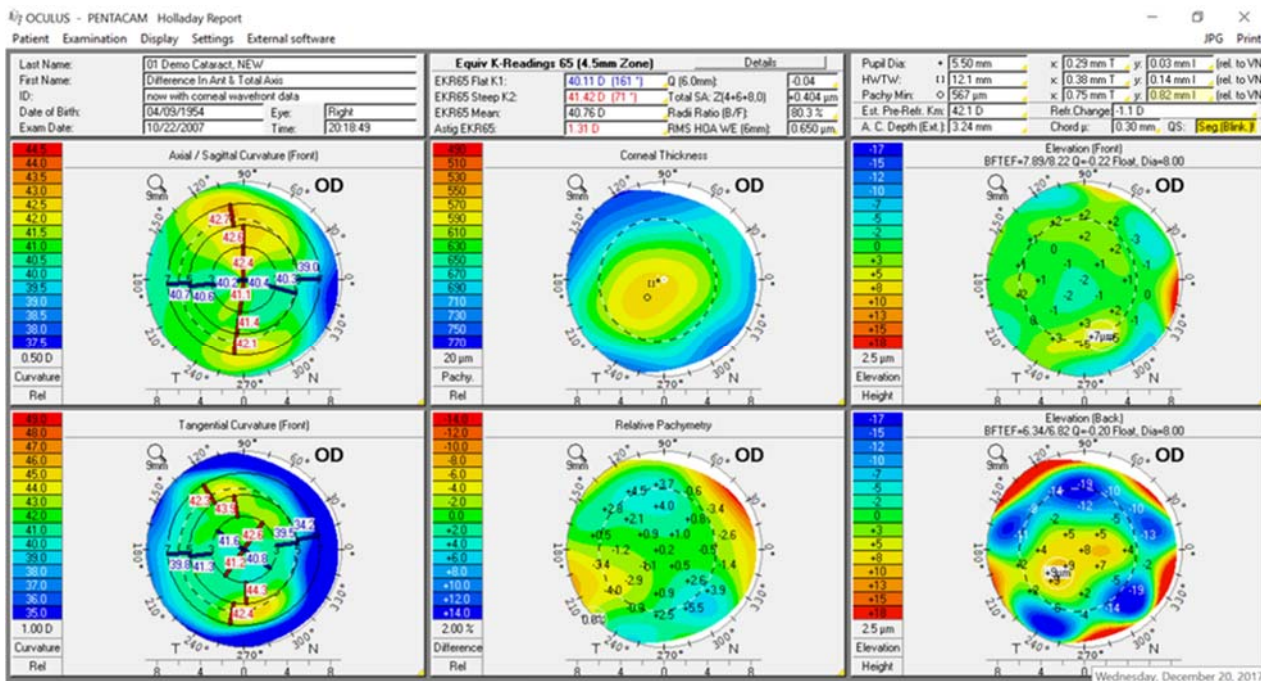Thickness Map Overlay



Figure 4 – Other
Map Overlays



Figure 5 – Page 1 of Normal Exam

**General Description of Page 1 of the Holladay Report for a Normal Patient in Figure 5**

*Upper left box*: Demographics of the patient.

*Center upper box*: Equivalent K-readings[1] (EKR65) for the 4.5 mm zone, along with Mean EKR65, Astigmatism, Q-value (6 mm zone) and *total Spherical Aberration* (SA) [Z(4,0) + Z(6,0) + Z(8,0)] for 6.0 mm zone and the Ratio of Back to Front Radii. The EKR65 values in the Center upper box have been shown to be the optimal values to use in IOL Power Calculations for K-Readings including the amount of corneal astigmatism using the Holladay IOL Consultant software. The values include front and back surface power and astigmatism, so no additional adjustments are necessary for the back surface with Toric IOL Calculations, except for corneal changes due to surgically induced astigmatism (SIA).

The Q-value is shown and is determined over a 6 mm zone.  The Total SA is the sum of the 4th, 6th & 8th order Zernike spherical aberration terms and is the best value to use in the selection of aspheric IOLs.[2]  Example aspheric IOLs are the Tecnis (Advanced Medical Optics, Santa Ana, Calif.) which is -0.27 µ, the Acrysof SN60WF (Alcon Inc., Fort Worth, Texas) which is nominally -0.18 µ and varies with IOL power and the SofPort AO (Bausch & Lomb, Rochester, New York) which is 0.00 µ.[3]  An ocular (cornea + IOL) SA of zero will result in the best visual performance at the Target Refraction (usually emmetropia).  A small amount of residual ocular SA causes the same amount of blur whether positive or negative.  However, since the pupil constricts with a near (accommodative) stimuli, residual ocular negative SA results in better near vision, so if there must be a residual SA, slightly negative is preferable.  The Ratio of Back to Front Corneal Radii average is 82.2% ± 2.1%.
The RMS HOA WE (6 mm) is the RMS value for the Higher Order Aberration of the Wavefront Error over the 6 mm zone of the cornea.  This value is a good measure of the optical quality of the cornea, especially after refractive surgery.[4]  Above > 0.66 µm the corneal optical quality begins to degrade the retinal image degradation and above 1.00 µm patients will already have complaints about visual quality.  Use of multifocal intraocular lenses (IOL) should be carefully considered with corneal irregularity where the retinal image quality is already reduced.

If the amount of spherical aberrations is not displayed, the Pentacam must be sent to OCULUS USA in WA or to the authorized distributor to get the test tool measurement. Usually a loaner unit is provided for the 2 to 4 week turnaround. **You must contact Oculus before shipping the unit**.  Contact information for OCULUS Service USA is as follows:

> Oculus, Inc.
> 17721 59th Avenue Northeast
> Arlington, WA, 98223
> **(425) 670-9977**
> **service@oculususa.com**

***Upper right box***: **Pupil diameter**, Corneal Diameter (**HWTW**), **Pachymetry minimum** with x and y coordinates relative to Vertex Normal (Vertex Normal is the center of the exam and near the visual axis) with "T" for temporal, "N" for nasal, "S" for superior and "I" for inferior.  The normal location of Pachy Min is slightly temporal and **0.19 ± 0.21 mm inferior** with **more than 0.61 mm inferior abnormal**. The **normal pupil center is Temporal to Vertex Normal (0.15 ± 0.11 mm)** and may be **superior or inferior (0.11 ± 0.08 mm)**.  The **Estimated Pre-Refractive Surgery Mean K** and the **Refractive Change** are determined from the normal ratio of the Back to Front Radii compared to the current ratio.  These values are useful for the Double-K method used for IOL calculations after refractive surgery.  The **External anterior chamber depth** (ACD from anterior corneal vertex to anterior lens vertex) and **Chord µ** (formerly known as chord length of angle kappa) in polar coordinates relative to the pupil center (**average is 0.20 ± 0.11 mm**).[5]  **Chord µ magnitudes above 0.42 mm (mean + 2 SD)** may be associated with poor performance of diffractive multifocal and high toric IOLs.[6,7]  This upper limit of **Chord µ** is slightly less than Purkinje based systems. If HWTW values are missing the new Iris Camera is not installed.  The **average HWTW (horizontal limbal diameter from white-to-white)** is **11.77 ± 0.22 mm.  The Center of Limbus is always Temporal and Inferior to Vertex Normal (average is 0.38 ± 0.22 mm Temporal and 0.01 ± 0.14 mm Inferior)** x and y coordinates are also the respective **chord lengths of Angle α** (visual axis to optical axis of eye, ~ 5.2°) and Examination **Q**uality **S**pecification (**QS**) of the 3D scan.

***Upper Left Map [Axial/Sagittal Curvature (Front)]:*** The Axial curvature or Power Map uses a sphere as the reference and the Keratometric Formula for Power (337.5/axial radius in mm).  A steel ball with a 7.5 mm radius of curvature (ROC) would have a uniform power of 45.0 D (337.5/7.5 mm = 45.0 D) at all points.  It therefore does not show the Refractive Power (using Snell's Law) of the cornea except in the central 3 mm, where the difference is negligible.  Since the normal shape of the front surface of the cornea is a prolate ellipsoid with the ROC steepest in the center and flattening as we move peripherally, the colors become cooler (toward blue) by 1 to 2 D, but are less than the actual refractive power using Snell's Law.
Assuming a Normal distribution, 1 SD would result in 68% between the lower and upper limit, 16% would be above 45.33 D and 16% below 42.31 D.  Similarly, for 2 SD 2.3% would be below 40.80 D and 2.3% would be

above 46.8 D (1 in 44 cases) and for 3 SD 0.1% would be below 39.29 D and 0.1% would be above 48.35 (1 in 769 cases).  In general, beyond 2 SD is suspicious of pathology and beyond 3 SD is considered abnormal statistically. The Steep (Red) and Flat (Blue) Semi-meridians (Principal) are shown in the 3 mm, the 3 – 5 mm and 5 – 7 mm diameter zones.  If these semi-meridians do not form single meridians (one line) and are not orthogonal then irregular astigmatism is present and the axis and magnitude are less accurate

***Lower Left Map [(Tangential Curvature (Front)]:*** The Front Tangential Curvature (or Instantaneous Curvature) Map does not depend on reference axis (axis through vertex normal) and the radius is not the distance from the surface to the axis as with axial radius.  It is the radius of curvature (reciprocal is the curvature) relative to the surface at that point.  For example, if the earth has an average radius of 4000 miles and if there was a semicircular mountain of 6 miles, the axial radius would be 4006 miles from the center of the earth to the top of the mountain but the tangential radius would be only 6 miles … a significant difference.  **The tangential curvature or power is much more sensitive** and **shows geometrical changes much more sensitively.**  Because of this increased sensitivity the default scale is in 1 D steps, whereas the axial map is in 0.50 D steps.[8]

***Central Upper Map (Corneal Thickness):*** The shape of the normal cornea is a negative meniscus lens (back surface radius of curvature is steeper than the front) in which it is thinnest at its optical center and thickens by the square of the distance from the center.  The positive total power is a result of air in front and aqueous behind.  The shape of the central colors should be circular if no significant astigmatism is present and elliptical if there is astigmatism.  In either case the ***Small Black Circle*** (***thinnest point***) should be at the center of the ellipse (or circle).  It will be temporal and either inferior or superior to the ***apex*** (**vertex normal of Purkinje-Sanson Reflex I, *white circle with central black dot*) which is the normal center of all maps**.  This point is also very near the visual axis and is usually considered to be this point.  The ***dashed black circle*** is the border of the pupil and the ***black cross*** is the ***centroid of the pupil***.  The ***pupil centroid*** is also temporal to the **apex** and may also be inferior or superior.  The **Center of the Limbus (center of HWTW) is shown with Brackets [ ]** is considered the optical center of the cornea.  The angle between the Apex (visual axis) and Optical Center (center of the Limbus) is referred to as **Angle Alpha** and has both a horizontal and vertical component.  The angle between the Apex (visual axis) and the Pupil Center is known as **Angle Kappa** (now **Chord Length μ**) and also has a horizontal and vertical component

***Central Lower Map (Relative Pachymetry):***  Because a negative meniscus lens has a predictable thickness from its center to periphery, the **percentage thicker or thinner than normal at each point** may be calculated.  The Relative Pachymetry Map shows these values at all points.

***Upper Right Map [Elevation (Front)]:***  The elevation in microns above the Best Fit Toric Ellipsoid with a Fixed Asperity (BFTEF) is determined over an 8 mm zone.  The Q-value of the ellipsoid for the FRONT SURFACE is fixed at -0.22 (eccentricity = +0.47) and the principal radii are varied for the best least square fit of the surface.  The Q-value of the ellipsoid for the BACK SURFACE is fixed at -0.20 (eccentricity = +0.45) and the principal radii are varied for the best least square fit of the surface.  Plus (+) values for elevation are above the reference surface and negative values (-) are below and are all given in microns.  The Q-values for the BFTEF are slightly less (-0.22 versus -0.26 for the FRONT and -0.20 versus -0.24 for the BACK) for both elevation maps because it is the average value for the population when "fit" over an 8 mm zone rather than the normal 6 mm zone.

***Lower Left Map [Elevation (Back)]:***   The elevation in microns above the Best Fit Toric Ellipsoid with a Fixed Asperity (BFTEF) is determined over an 8 mm zone.  The eccentricity of the ellipsoid is fixed at 0.45 (Q-value = -0.20) and the principal radii are varied for the best least square fit of the surface.  Plus (+) values are above the reference surface and negative values (-) are below and are all given in microns.
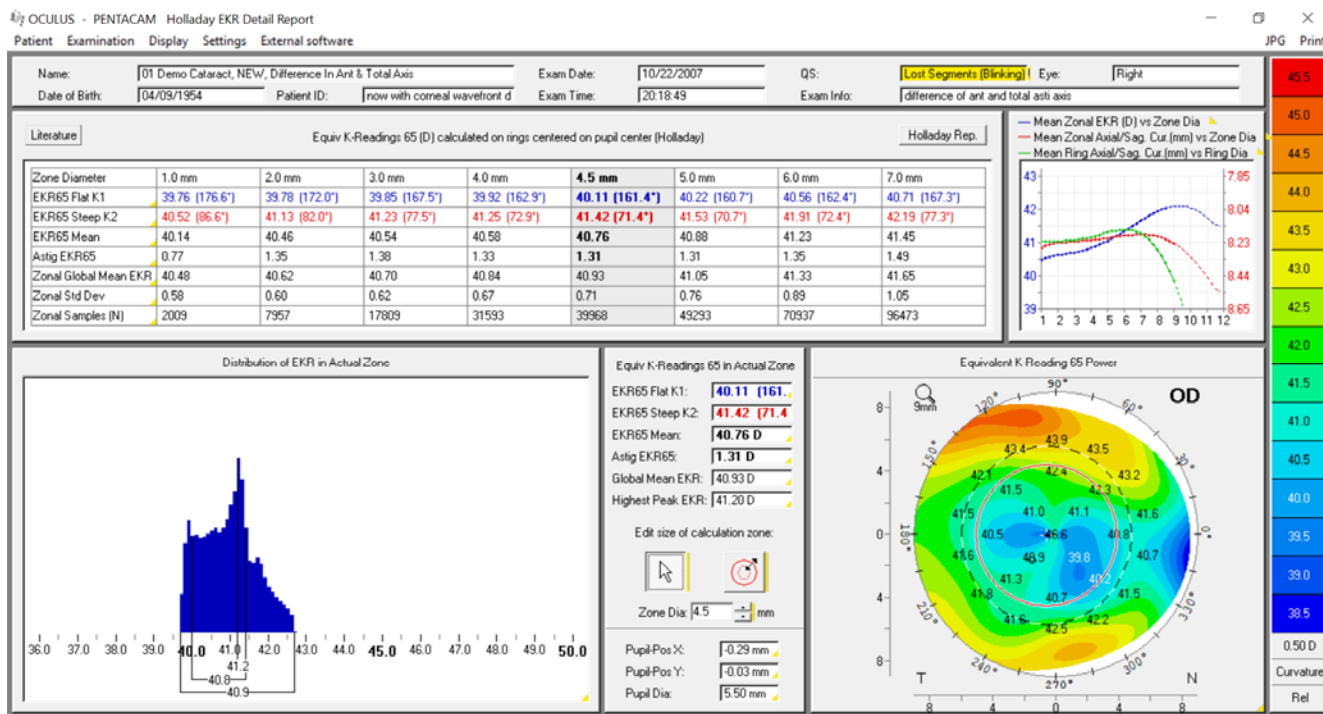
OCULUS - PENTACAM   Holladay EKR Detail Report

Patient  Examination  Display  Settings  External software                                    JPG  Print

| Name: | 01 Demo Cataract, NEW, Difference in Ant & Total Axis | | Exam Date: | 10/22/2007 | QS: | Lost Segments (Blinking) | Eye: | Right |
| Date of Birth: | 04/09/1954 | Patient ID: | now with corneal wavefront d | Exam Time: | 20:18:49 | Exam Info: | difference of ant and total asti axis |

Equiv K-Readings 65 (D) calculated on rings centered on pupil center (Holladay)        Holladay Rep.

| Zone Diameter | 1.0 mm | 2.0 mm | 3.0 mm | 4.0 mm | 4.5 mm | 5.0 mm | 6.0 mm | 7.0 mm |
|---|---|---|---|---|---|---|---|---|
| EKR65 Flat K1 | 39.76 (176.6°) | 39.78 (172.0°) | 39.85 (167.5°) | 39.92 (162.9°) | 40.11 (161.4°) | 40.22 (160.7°) | 40.56 (162.4°) | 40.71 (167.3°) |
| EKR65 Steep K2 | 40.52 (86.6°) | 41.13 (82.0°) | 41.23 (77.5°) | 41.25 (72.9°) | 41.42 (71.4°) | 41.53 (70.7°) | 41.91 (72.4°) | 42.19 (77.3°) |
| EKR65 Mean | 40.14 | 40.46 | 40.54 | 40.58 | 40.76 | 40.88 | 41.23 | 41.45 |
| Astig EKR65 | 0.77 | 1.35 | 1.38 | 1.33 | 1.31 | 1.31 | 1.35 | 1.49 |
| Zonal Global Mean EKR | 40.48 | 40.62 | 40.70 | 40.84 | 40.93 | 41.05 | 41.33 | 41.65 |
| Zonal Std Dev | 0.58 | 0.60 | 0.62 | 0.67 | 0.71 | 0.76 | 0.89 | 1.05 |
| Zonal Samples (N) | 2009 | 7957 | 17809 | 31593 | 39968 | 49293 | 70937 | 96473 |

— Mean Zonal EKR (D) vs Zone Dia
— Mean Zonal Axial/Sag. Cur (mm) vs Zone Dia
— Mean Ring Axial/Sag. Cur (mm) vs Ring Dia

Distribution of EKR in Actual Zone

Equiv K-Readings 65 in Actual Zone

| EKR65 Flat K1: | 40.11 (161.. |
| EKR65 Steep K2: | 41.42 (71.4 |
| EKR65 Mean: | 40.76 D |
| Astig EKR65: | 1.31 D |
| Global Mean EKR: | 40.93 D |
| Highest Peak EKR: | 41.20 D |

Edit size of calculation zone:

Zone Dia: 4.5     mm

| Pupil-Pos X: | -0.29 mm |
| Pupil-Pos Y: | -0.03 mm |
| Pupil Dia: | 5.50 mm |

Equivalent K Reading 65 Power

OD

Figure 6 – Page 2 of Normal Exam

**General Description of Page 2 of the Holladay Report for a Normal Patient in Figure 6**

*Upper Box:* The demographic information regarding the patient is in the box at the top of the Page 2.

*Upper Left Box:* The Table at the Top Left of the Page is for the Equivalent K-Readings 65 (D) for various parameters from 1.0 to 7.0 mm pupil diameters.[9,10,11] All values are calculated from the pupil center, so that only actual rays contributing to the retinal image are used.

*Upper Right Graph:* **The Graph shows the Mean Zonal EKR (D) versus Zone Diameter (blue)**, the Mean Zonal Axial Radius of Curvature (mm) versus Zone Diameter (red) and Mean Ring Axial Radius of Curvature (mm) versus zone diameter (Green). The Blue values illustrate the Refractive Power (D) of a zone as one moves from the center of the pupil. The normal increase in power reflects the normal presence of positive spherical aberration in the human cornea (~2 D from center to 8 mm diameter periphery).

*Lower Left Graph:* The graph is a histogram showing the relative frequency of EKR Power over the selected zone (default is 4.5 mm zone). The graph is rarely symmetrical and often has multiple peaks with a nominal 2 to 3 D range.

*Lower Central Table:* The EKR65 mean, is the weighted mean where 65% of the values are represented using the smallest range of points. In the above graph this value is 40.76 D (40.8 D) with the range indicated. Notice this value is less than the 40.93 D Global Mean of EKR when all points are used. The highest peak is at 41.20 D. For a normal cornea, these three values vary less than 0.50 D. The actual size of the pupil during the exam is shown with a dashed circle and the Zone diameter may be changed by using the up or down arrow button or by clicking the red graphic and dragging the red circle larger or smaller. The new values are calculated instantaneously.

*Lower Right Map:* The Equivalent K-reading Power Map uses both front and back power, Snell's law and represents the values that are appropriate for IOL Power Calculations. The EKR65 Flat K1 (40.11 @ 161° and 41.42 @71°) are the appropriate values to enter for K-readings. No additional adjustment needs to be made for back surface power, since they are included. The 4.5 mm zone has been shown to be the best value for a large data set, but for a specific patient the value may be customized to the individual patient (values from 3.0 to 4.5 mm zonal diameter may be used). For example, if a patient has an unusually small pupil (3.0 mm) in mesopic light levels and the EKR65 mean is significantly less at 3.0 mm than at 4.5 mm, one may choose to use the 3.0 mm zonal EKR65.

**Normal Exam Details – Page 1 (Figure 5)**

The EKR65 values at the Top Center are ~ 3.0 D flatter than average with 1.31 D of astigmatism. In the *Axial Power* Map it is steeper above than below by ~ 1.0 D, which is not unusual. The broken semi-meridian lines show mild irregular astigmatism which have been orthogonalized to the best least squares fit of 161° for the flat meridian and 71° for the steep meridian axes for both the front and back surface. Since the irregular astigmatism is mild and the magnitude of 1.31 D relatively low, this orientation is desired for a toric IOL. It should be noted, however, that repeated measures and using the average magnitude and axis would improve results even more. The *Tangential Curvature* Map also illustrates the irregular astigmatism component due to the broken semi meridian lines.

The *Q-value* over the 6.0 mm zone is -0.04, which is more positive than normal (-0.23), so more spherical aberration is expected. *Table 13* shows the Longitudinal Marginal Spherical Aberration (LMSA) in diopters for typical Apical K-values and Asphericity Quotients (Q-values) of anterior cornea assuming surface is an aspheric conic.[12]. The *Total SA* confirms the increased SA with a value of +0.404 microns, which is much higher than the average of 0.27 microns. The Total SA is the value that should be used for the selection of an aspheric IOL for a specific patient.[2] The *Radii Ratio (Back/Front)* is 80.3%, which is lower than the normal ratio. Although this cornea has not had myopic refractive surgery (LASIK or PRK), the percentage gets lower the greater the amount of the myopic treatment. The *RMS HOA WE over a 6 mm* zone is 0.650 microns, which worse than a virgin cornea, but normal for post refractive. It also confirms the mild breaks in the semi meridians. The *Pupil Diameter is 5.50 mm* and taken with low light levels, but depending on the location of the device (illuminated room), the value is usually smaller than the scotopic pupil size measured with infrared pupilometers that are in complete darkness. In this case, the value is larger than 4.5 mm, so this zone would be appropriate for the EKR65 values for this patient. When the patient's pupil is 3.0 or 4.0 mm, going to the appropriate columns for the EKR65 value is recommended. The *Horizontal White-to-White (HWTW)* is 12.1 mm and normal. The *Pachymetry Min* is 567 microns which is thicker than average (543 microns). **The Estimated Pre Refractive Corneal Power** is 42.1 D and the **Refractive Change** is -1.1 D. The 42.1 D would be used in the Double K method to estimate the Effective Lens Position (ELP). **Chord µ** is 0.30 mm and **External ACD** is 3.24 mm used in IOL Calculation Formulas. Note the *QS* (Exam Quality) shows "blinking" and should be repeated. The Scheimpflug Image Overview may be reviewed by selecting the *"Overview"* under *Display* to see how many eye images were corrupted by the blink.

In the *Corneal Thickness* Map the thinnest point of the cornea (small black circle) is usually temporal and inferior to the apex (small white spot with black dot). The pupillary center (black and white cross hair) is usually less temporal and less inferior to the apex. Angle Alpha is the angle or distance (chord) between optical center (shown as brackets **[ ]** for center of limbus) and apex (considered visual axis, a white circle with black dot) which has both a significant vertical and horizontal component. Diffractive and Refractive Multifocal and high Toric IOLs perform best when located at the pupillary center and visual axis, which is **extremely rare and only occurs when Chord µ is zero**. If these IOLs are to be used the surgeon should note these locations because the IOL will normally center in the bag at the optical center, rather than the pupil center and visual axis. The IOL haptics will need to be "nudged" to achieve the optimal lens performance halfway between the vertex normal (visual axis) and the pupillary center. **If Chord µ is > 0.42 mm, then performance of these premium IOLs is compromised**.

The *Relative Pachymetry Map* is normal with a distribution that parallels the steep and flat meridians. The flatter meridian usually has negative values (thinner) that are similar to the positive values (thicker) in the steeper meridian. The *Elevation Maps* are normal, even with the lobulated pattern on the *ELEVATION (BACK)* since these values would result in thicker corneal pachymetry in these areas. Positive Elevations on the Back Surface are the most important values indicating the possibility of a thinning disorder.

**Normal Exam Details – Page 2 (Figure 6)**

With a normal pupil of 5.50 mm, the 4.5 mm gray column with EKR65 Flat K1 = 40.11 @ 161 and Steep K2 = 41.42 @ 71, would be the correct keratometric values to enter in to an IOL calculator for the proper spherical equivalent power (SEQ) and toricity of the IOL.   An EXACT TORIC CALCULATOR like the one provided in the Holladay IOL Consultant Program (www.hicsoap.com) which does not use a constant ratio of the corneal astigmatism to the ideal toricity of the IOL.[13]  **When the EKR65 K-values are used and an Exact Toric Calculator, the back surface power and astigmatism have already been implemented and there is no need for additional adjustments!  Only the Surgically Induced Astigmatism (SIA) from the corneal incisions must be added.**

The ***Blue Line*** in the ***Upper Right Graph*** demonstrates that this is approximately a 0.62 D increase in power from the 1 to 4.5 mm zone.  This was also confirmed by the Q-value and Total SA values on page 1.  Note the EKR65 uses Snell's Law, whereas the ***Axial Power*** lines (Green and Red) do not and therefore do not reflect actual refractive power changes due to the cornea.

The distribution of EKR65 in the 4.5 mm zone shows that the ***EKR65 Mean*** (40.76), ***Global Mean*** (40.93) and the ***Highest Peak*** (41.20) are all within 0.50 D of each other.  The difference in these values is a measure of the irregular astigmatism and is a measure of the precision of the EKR65, which is the best value to use.  **The greater the differences, the broader the range of the distribution and greater number of individual peaks, the lower the reliability of the EKR65 which results in a lower predictability of the IOL power outcome.**

Multiple examinations are helpful for repeatability, but when the range is large the patient should be prepared for the possibility of a "fine tune" to achieve the exact refractive SEQ target and elimination of astigmatism. The ***EKR Map*** in the lower right allows the clinician to see the EKR distribution graphically.
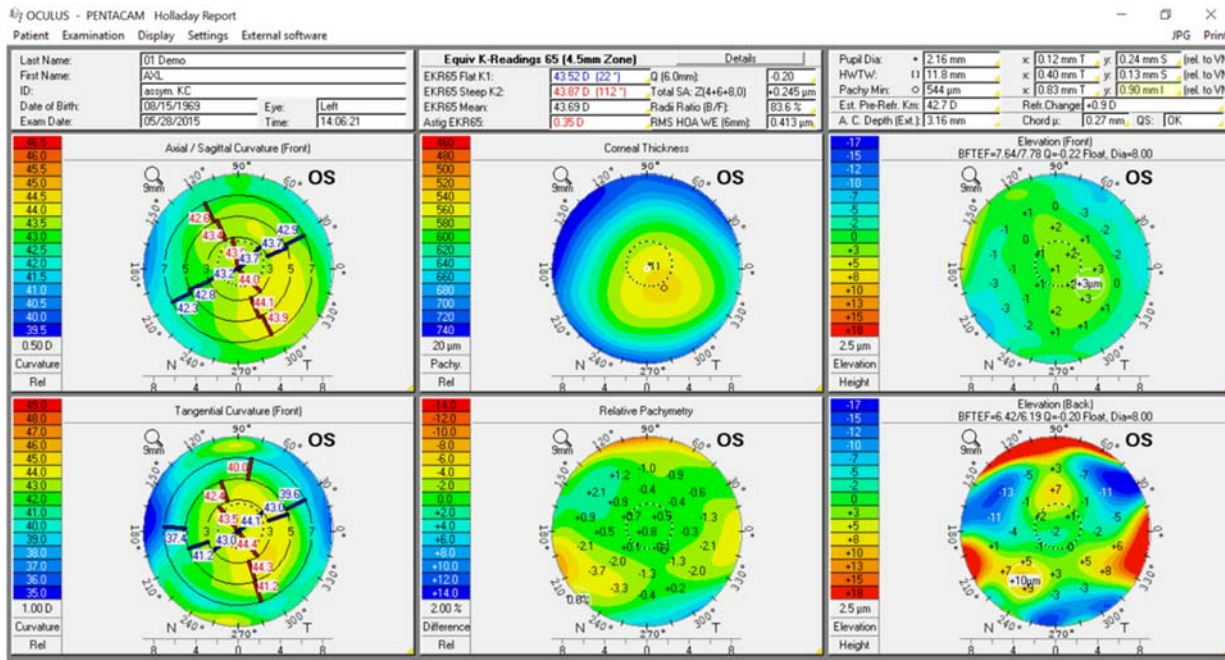


Figure 7 – Page 1 of Mild Keratoconus

**Keratoconus Exam Details – Page 1 (Figure 7)**

The ***Axial Power Map Scale*** is centered at 43.0 D (Green) which is normal.  The ***Axial Curvature Map shows an Asymmetric Bowtie and Tangential Curvature Maps*** show a "***hot spot***" (orange) with the peak at 4 mm.  The peak is geometrically more accurately located on the Tangential Map.  The Corneal Thickness Map shows the thinnest point is displaced inferiorly by 0.90 mm, which is much more than the 0.61 mm, the upper limit of normal.  A yellow or orange egg-shaped area with the thinnest point inferior by this amount is suggestive of

keratoconus.  The ellipse or egg-shaped area has the small end of the "egg" pointing in the direction of the "**hot spot**" on the **Curvature Maps**.  On the **Relative Pachymetry Map** the minimum -2.0% in the area of the hot spot on the **Tangential Curvature Map**.  The **Elevation (Front)** is +3 μ and located at the "hot spot" and minimum of the **Relative Pachymetry**.  The **Elevation (Back)** is highly elevated at 5-8 μ above the reference BFTEF and also at the same location as the peak on the Front.  It is typical in keratoconus for the **Back Elevation** to be higher than the Front, due to epithelial remodeling on the Front.  The average thickness of the epithelium is 50 μ and 6 – 8 epithelial cells thick.  The 6 μ higher on the back (8 – 3 μ) indicates that the epithelium is ~1 cells thinner than normal due to the protrusion and physiologic smoothing of the anterior surface.  The **RMS HOA WE** is 0.413 μm which is almost normal.
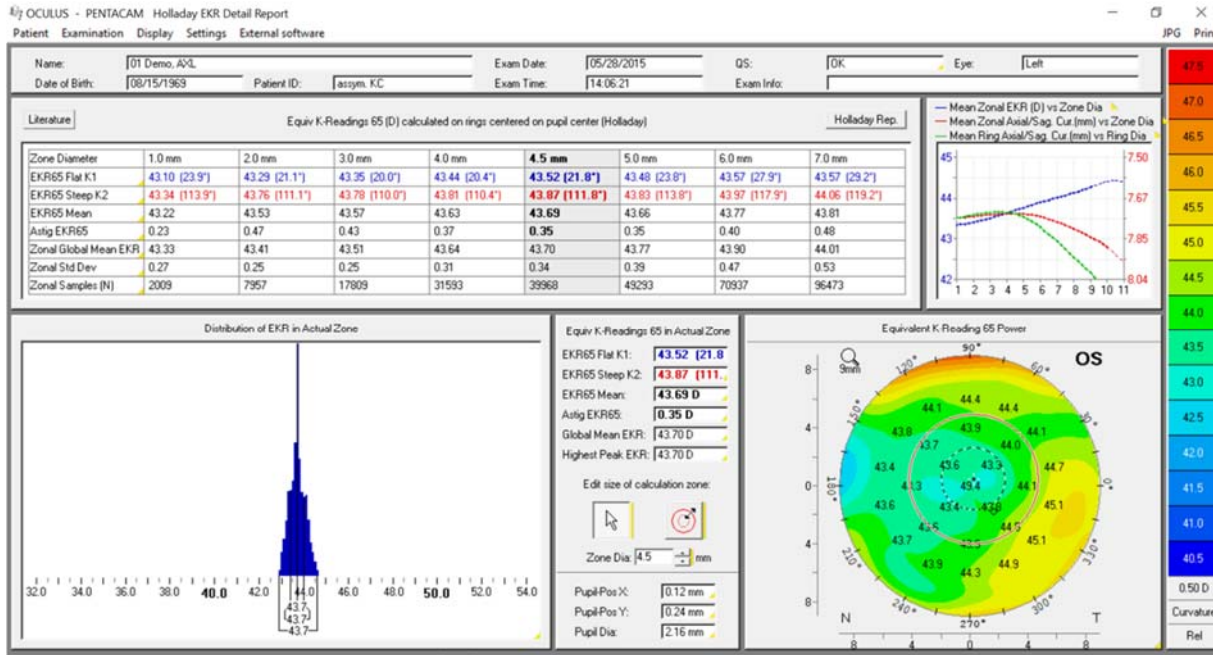


Figure 8 – Page 2 of Keratoconus

**Keratoconus Exam Details – Page 2 (Figure 8)**

The **Distribution of EKR** is a singular distribution and the EKR65 of 44.69 D is nearly the same as the 43.70 D peak.  Standard keratometry usually measures nearer the peak and will over-estimate the power in keratoconus will often leave the patient with a hyperopic surprise.  In severe cases, this difference may be up to 3 or 4 D.  The Ks that should be used for this case are the EKR65 Flat K1 = 43.52 @ 22 and EKR65 Steep K2 = 43.87 @ 112.  In the **EKR65 Table** the EKR65 Mean varies very little from 43.57 to 43.69 (0.11 D) from the 3 to 4.5 mm zone.  The EKR65 power increases (SA) as the pupillary diameter increases (blue curve in upper right).  This visual performance is also affected by KC and the RMS HOA WE is the best indicator which is this case is mild.    Regular Astigmatism is also often present, but determining the ideal toricity is ambiguous at best and stability of the astigmatism is also a problem.  In our experience, determining the optimal toric IOL power almost always involves an intra-operative refraction or post-operative refraction and secondary procedure to achieve the optimal toric IOL with keratoconus.  This specific case of keratoconus is very mild and could only be confirmed by the severe form in the other eye.
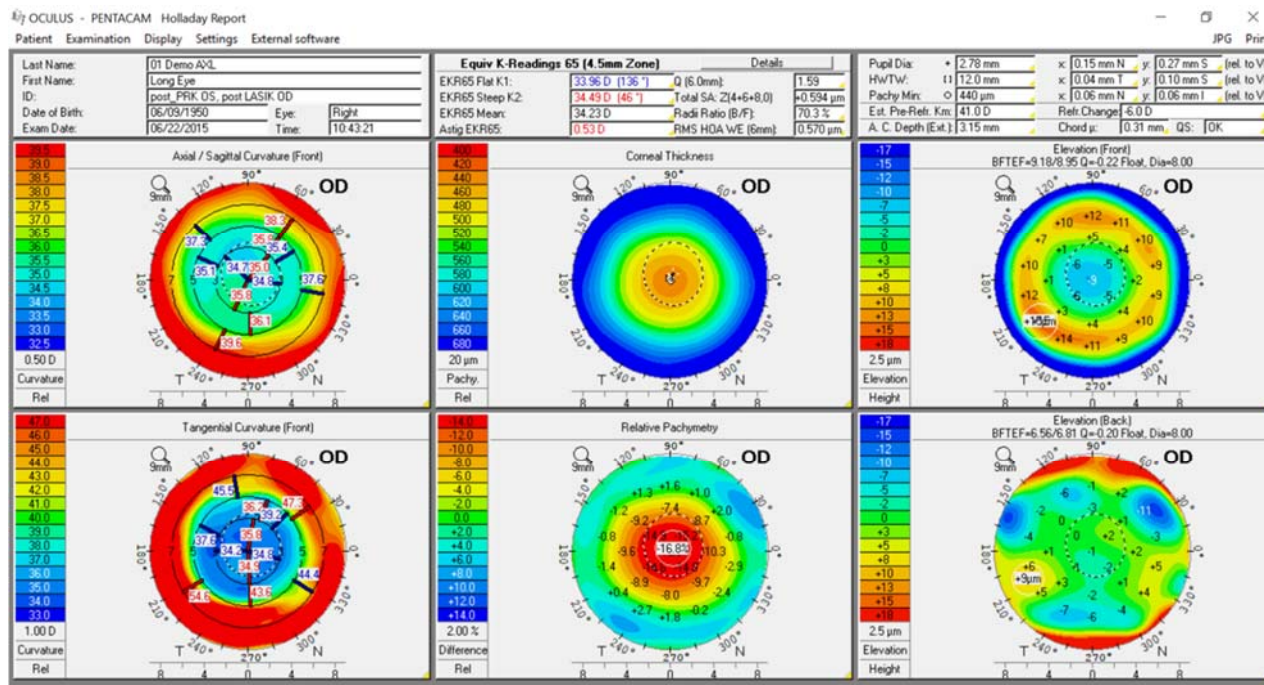
Figure 9 – Page 1 of Post LASIK

**Post LASIK Exam Details – Page 1 (Figure 9)**

The Mean Value of the Color Scale (Green) is 36.0 D which is 4.5 D flatter than normal and the semi-meridian lines are extremely segmented demonstrating a large amount of irregular astigmatism. The EKR65 Mean is 33.96 D which is ~ 10 D flatter than normal. The Q-value of +1.59 is extremely oblate, rather than the normal prolate cornea and is also reflected in the +0.594 µm of total spherical aberration. The flattened front curvature from LASIK has resulted in a 70.3% Radii Ratio (B/F). The RMS HOA WE is 0.570 µm is higher than normal, but is average for a post LASIK and is not associated with any visual performance complaints. The Estimated Pre Refractive Mean K is 41.0 D with an Estimated Refractive Change of -6.0 D. The 41.0 D would be used for the Pre Refractive K in the Double K method and the 34.23 D Mean EKR65 would be the current Mean K. The Corneal Thickness Map shows that the thinnest point, pupillary center and vertex normal are almost coincident and at the center of the almost circular color rings. The Relative Pachymetry Map is also circular, 16.8% thinner than normal at the center and gradually returning to normal (green) at the 6 mm diameter. The *Elevation (Front)* is -3 µm at the center and on the *Elevation (Back)* is -1 µm.
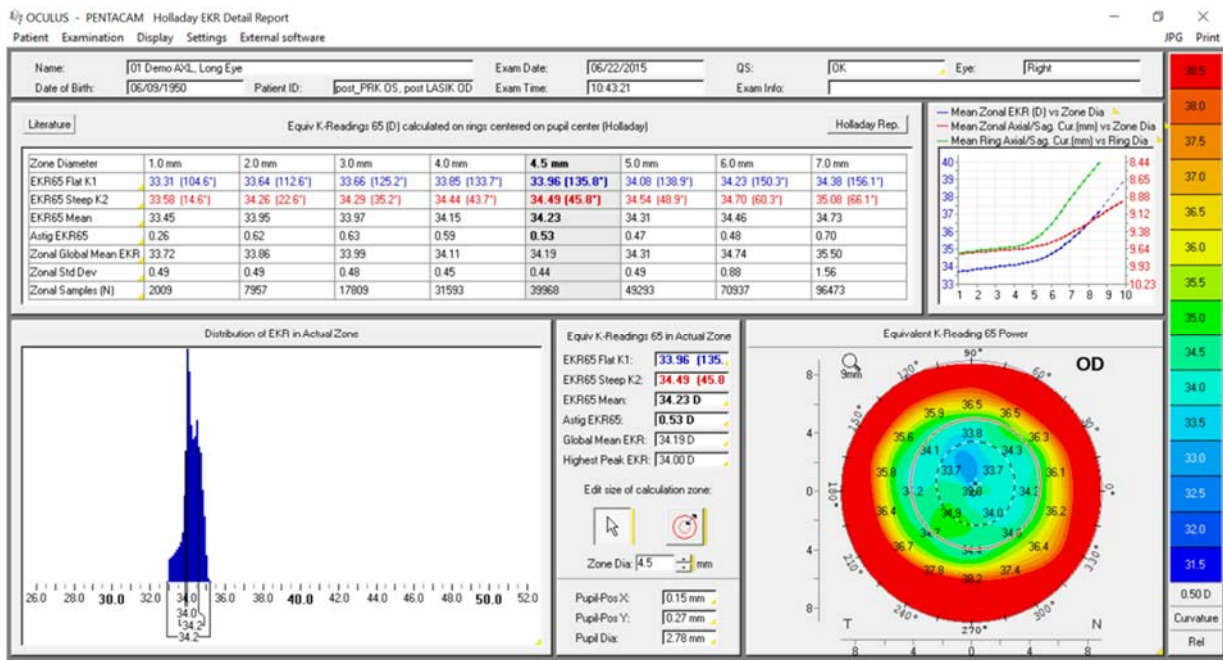
Figure 10 – Page 2 of Post LASIK

**Post LASIK Exam Details – Page 2 (Figure 10)**

The EKR65 Mean is 34.23 D at the 4.5 mm zone and 33.97 D at the 3.0 mm zone.  The pupil diameter was 2.78 mm and confirmed with scotopic pupilometry done with another device.  Due to the small pupil, the appropriate Ks for IOL calculation would be at the 3.0 mm zone and are EKR65 Flat K1 = 33.66 @ 125° and EKR65 Steep K2 = 34.29 @ 35°.  The axes are about 10° different from the 4.5 mm zone, but this is due to the small magnitude of the astigmatism and is seen in the segmented semi-meridian lines in *the Axial and Tangential Maps*.  The Blue Curve (Mean EKR65) shows a gradual increase in power from vertex normal which confirms the +0.594 µm of total spherical aberration.  The 4.5 mm red circle versus the actual 2.78 mm pupil can be seen clearly, and confirm that the 3 mm zone should be used which is flatter.

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