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Digitally-produced image comparison of three, 90 diopter-equivalent lenses: Subjective and objective findings

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Abstract

Purpose: To evaluate the image quality of retinal structures as obtained by three high plus lenses manufactured by the Yolk company to determine if any of the lens types provided a better quality of digital image.

Methods: Digital images of two different patients' left and right optic nerve heads (ONH) and left and right maculae (MAC) were obtained with three high plus lenses in conjunction with a biomicroscope. One of each of the following three lenses were used during the study: 90 Diopter Classic (90D), Super Field (SF) and Digital Wide Field (DWF). A total of 10 optometric physicians, who were faculty of an accredited school of optometry at the time of the study, were then asked to view 30 pairs of simultaneously presented photographs and select the image of higher quality. The paired photographs consisted of images of either the same optic nerve head or same macula of the one specific patient, as taken with two different lenses. Three sets of identical images were randomly presented to screen for left- or righthandedness. The digital images were also evaluated by Adobe Photoshop for color and luminosity values within a defined area.

Results: Objective results showed that there was no statistically significant difference between mean color and luminosity of the ONH and MAC images as produced by the 90D, SF and DWF lenses: p = 0.542, p = 0.587, p = 0.232 and p = 0.186. Subjective results were statistically significant for selecting the 90D lens as producing the better ONH image quality 1 (p == 0.041). While not statistically significant (p == 0.165), the subjects followed a similar trend in choosing the 90D lens as having better quality of the MAC images.

Conclusions: The 90D lens appears to produce subjectively better quality in digital images of the posterior pole.

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Digitally-produced Image Comparison of Three, 90 Diopter-Equivalent Lenses: Subjective and Objective Findings

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Erin McCleary received a Bachelor of Science in Interdisciplinary Studies through the Honors Program from the University of North Dakota in 2003. She received the Brim Health Professions Scholarship in the fall of 2003 and was inducted into the Beta Sigma Kappa International Optometric Honor Society in fall 2004. She is currently in her final year at the Pacific University College of Optometry where she is pursuing an OD degree. In her spare time Erin plays the oboe and piano, and also enjoys painting, writing poetry, and tennis.

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Philip received a Bachelor of Science in Zoology and Physiology from the University of Wyoming in 2003. He is currently enjoying his final year at Pacific University were he is pursing a Doctor of Optometry degree and Masters of Education degree. In his spare time he enjoys spending time with his wonderful wife and beautiful children. Philip looks forward to settling in the Mountain West and raising his family.

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Key Words: High plus lenses, 90 Diopter lens, Super Field lens, Digital Wide Field lens, quality, images, optic nerve head, macula,

INTRODUCTION

Since the invention of the ophthalmoscope by Helmoholtz in 1851[1] the modalities used to view the living retina have continually progressed. In the middle of the 20th century, the use of high plus lenses for viewing the retina stereoscopically was introduced by individuals such as George El Bayadi, Emanuel Rosen and David Volk.[2] Comparisons of the various fundoscopic systems and techniques were published as early as 1982,[3, 4] and by 1988 high-plus lens utilization by eye care professionals for diagnosing, monitoring, and documenting conditions of the eye became commonplace.[5] Advances continue to be made in viewing the human retina by incorporating digital imagery in medical records, and this practice is increasingly common in medical offices.[6]

Several techniques exist to photographically record the fundus: mydriatic and non-mydriatic fundus cameras, biomicroscopes that utilize incorporated digital cameras, as well as obtaining images by simply holding a camera to one ocular of a slit lamp.[4] Fundus cameras can be cost-prohibitive because of their initial price and the need for additional office space in which the camera may be placed.[7, 8, 9] While it is a much less-expensive method, obtaining images of the eye by holding a digital camera to the eyepiece of a slit lamp may be of lesser quality. Biomicroscopes with adjunct cameras have been in use for over thirty years[10] and are capable of producing high quality images that are extremely useful in providing documentation and a means for monitoring various conditions of the eye. Currently, using this method to produce images of the fundus requires the additional use of a high plus fundus lens. Such lenses include a myriad of high plus (contact as well as non-contact) lenses ranging in power from 60 dioptors to 130 dioptors.[11, 12]

The intent of this study was to evaluate the quality of digital images produced by several dioptrically-equivalent lenses. The hypothesis surmised that the most recently developed high plus lenses which are designed with special coatings, designated as "digital" and described as "ideal for... documentation of slit lamp images," [2] would produce superior digital images of the fundus.

METHODS

Lens Selection

At the time of this study, three companies [2, 12, 13] are commercially manufacturing high plus fundus lenses: Volk, Ocular Instruments, and iOn Vision. We chose to evaluate three lenses from one manufacturer: Volk. The lenses selected, as described by a Volk sales representative, demonstrate three generations of lens technology. The lenses selected for comparison were the 90D Classic (90D), SuperField® (SF), and Digital Wide Field ™ (DWF). The 90D Classic lens is the "1st generation," the Superfield is the "2nd generation," and the Digital Wide Field is the most recent "3rd generation" lens. [2] When asked what was meant by "digital" (referencing the DWF lens), the Volk sales representative explained that "digital" refers to the combination of the lens and its coating which are ideal for digital photography. Describing the differences in design, appearance, and overall function of these lenses is beyond the scope of this paper and is irrelevant to our stated hypothesis. However, Table 1 provides a brief synopsis of the lenses and their respective properties.

Table 1. Lenses and Their Properties. All Product information and images obtained at Volk's Website.[2] (Images are not scaled equally.)

Lens	Image Magnification	Working Distance	Field of View	Suggested Retail	Ring Color Tested	Lens Appearance
90D Classic	.76x	7mm	74°/89°	$235.00	Black	
"The original Volk 90D lens started the slit lamp examination revolution! It features a small 26mm diameter ring design which is outstanding for dynamic fundoscopy. Volk's exclusive Double Aspheric optical design expands the usable viewing field beyond that of competitive designs. The Volk 90D has good small pupil capabilities, making it ideal for a quick look at the posterior pole."						
SuperField	.76x	7mm	95°/116°	$290.00	Black	
"Doctors call it the "Super 90". Volk's SuperField® has become the standard of slit lamp fundus diagnosis for today's discriminating practitioner. Its ideal .76x magnification and wide field of view make it perfect as the primary high resolution slit lamp fundus diagnosis lens. The SuperField has been specifically designed for increased working distance from the cornea (7mm), making it more practical than competitive pan fundus lenses. Its small 30.2mm diameter housing also proves highly useful for dynamic fundoscopy, allowing the lens to be more easily manipulated in the orbital area of the eye, increasing its dynamic field of view to 116°."						
Digital Wide Field	.72x	4-5mm	103°/124°	$340.00	Blue	
"The Digital Wide Field Lens combines exceptional wide field views and high magnification. The enhanced double aspheric design and multi-layer coating provide high resolutin stereo views of the retina with minimal reflections. These unique features make it ideal for general diagnosis and documentation of slit lamp images."						

Volk kindly loaned the authors the lenses used during this study. While in our care the lenses were cleaned as recommend by Volk, and stored in their appropriate containers when not in use.

Study Design

Many optometric clinicians have a favorite high plus lens that they use on a frequent basis. This frequent use allows the clinician to become comfortable with the feel, handling and idiosyncrasies of that specific lens. If subjects were allowed to manually obtain their own images with the varying lenses, this bias would have contaminated the findings. In addition, not all doctors of optometry are equally familiar with digital-imaging. As a result, this study required subjects to evaluate the quality of digital images, produced by three different high plus lenses, based solely on color photographs which were printed on premium photograph paper.

Image Acquisition

To ensure that all digital images obtained were as standardized as possible, all photographs taken utilized the same instruments, equipment, software, and lab location. This information is summarized in Table 2. All images were taken, electronically stored, and printed in the imaging lab at Pacific University's College of Optometry.

Table 2. Instruments and equipment used in acquisition and printing of fundus images.

Slit Lamp	
	Nikon FS-3 Zoom- Photo Slit Lamp
Digital Camera	
	Nikon D100 6.1 megapixel Digital Camera
Desk Top Computer	
	Apple iMac G5
Software	
	Mac OS X Nikon Capture 4 Version 4.3 Adobe Photoshop CS2
Photo Printer	
	Cannon Pixma iP 8500 Photo Printer
Paper	
	Cannon Photo Paper Plus Glossy premium photopaper 4"x6"

Each author had been properly trained and experienced in digital ocular-imaging and alternately acted as both patient and photographer. Fundus images were obtained of the two patients, E and P, both of which have normal ocular function, health, and appearance. E and P were dilated with 1 drop 1.0% tropicamide and 1 drop 2.5% phenylephrine in each eye five minutes apart. Beginning twenty minutes after instillation of dilating drops, and not exceeding 120 minutes after instillation of dilating drops, the qualified photographer positioned the patient as required and obtained images of both right and left optic nerve heads, and both right and left maculae, with each lens. To ease initial labeling, photographs were designated by patient, eye structure, and lens. For example, a photo labeled 90D E RONH refers to the right optic nerve head of patient E taken with the 90D lens, and DWF P LMAC refers to the left macula of patient P taken with the Digital Wide Field lens. To obtain the requisite images, several non-concurrent sessions for both E and P were required; all sessions consisted of identical procedures for dilation and photography. To eliminate photographer bias, all images of E were taken by the same author/photographer. Likewise, all images of P were obtained by the other author/photographer. All lighting was doused to create a dim, ambient room illumination that was used throughout the image capturing process. This best approximated the standardized 15 footcandles found in most optometric exam lanes with overhead illumination fully dimmed. The method of obtaining high quality images was at the discretion of the photographer; adjustments to angle of illumination, tower tilt, and exposure (i.e. fill flash) were allowed to achieve optimum images. Please refer to Table 3 for a summary of the settings each photographer used. See Appendix C for the images used during this project.

Table 3. Summary of settings and photographer used for image acquisition. N denotes a nasal-ward angle and T, a temporal-ward angle, relative to the patient. The tower angle (Tilt) is described as 0 (0 degree incline), 1 (15 degree incline) or 2 (30 degree incline).

Photo Number	Lens	Exposure	Angle	Tilt	Photographer
E RONH					
212	90D	-1	8° N	1	PR
195	SF	-2	10° N	1	PR
210	DWF	-1	8° N	0	PR
E LONH					
1983	90D	-1	12° N	1	PR
2300	SF	-1	17° N	1	PR
2049	DWF	-1	17° N	0	PR
E LMAC					
1995	90D	-1	12° N	1	PR
2293	SF	-1	17° N	1	PR
2053	DWF	-1	17° N	0	PR
E RMAC					
2330	90D	-1	17° T	1	PR
2280	SF	-1	17° T	1	PR
2060	DWF	-1	17° N	0	PR
Others					
183	SF	Rainbow			PR

Photo Number	Lens	Exposure	Angle	Tilt	Photographer
P RONH					
2104	90D	-1	19° N	0	EM
144	SF	0	18° N	0	EM
2180	DWF	-2	18° N	0	EM
P LONH					
1835	90D	0	15° N	1	EM
2160	SF	-2	17° N	0	EM
109	DWF	-1	14° N	0	EM
P LMAC					
2125	90D	-2	10° N	0	EM
2164	SF	-2	17° N	0	EM
113	DWF	-1	14° N	0	EM
P RMAC					
2117	90D	-2	11° T	0	EM
2145	SF	-2	18° N	0	EM
2195	DWF	-2	12° T	0	EM
Others					
112	DWF	Curved			EM

Images were considered "in focus and usable" if the authors and advisor agreed that the printed image was adequate. This judgment included an assessment of the distinctness of blood vessels, appearance of the optic nerve head and its components, color, foveal light reflex and nerve fiber layer sheen. If the image was not deemed acceptable, additional images were taken, in the same manner as previously described, until an acceptable image was obtained for each required eye structure, with each lens, on each patient. This process resulted in over 100 photographs being taken with each lens to achieve appropriate and comparable images, as agreed upon by the authors and advisor.

This process produced a total of 24 distinct digital images with image number assigned by the imaging software. All optic nerve pictures were printed at the printer's default standards without "scaled-to-media" selected. All macular photos were printed at the photo printer's default standards with "scaled-to-fit" selected. The authors' reasoning for this was to provide a slightly larger optic nerve head photograph, and a broader, more generalized view for the macula images. This also minimized visible, and therefore detectable, differences in the beam shape, as produced by the different lenses. Once printed, each photograph was immediately labeled with permanent ink on the reverse side with the image number assigned by the Nikon Capture program. These were later assigned, as described in the following section, an alpha-numeric designation to aid in their presentation to study participants. All photographs were categorized and stored in a black, water-resistant container to maintain their image quality while not in use.

Assignment and Randomization of Images

Once good quality photos were obtained for each of the selected structures, they were assigned by an alpha-numeric system. Alternating between patients E and P, the right optic nerve head (RONH), left optic nerve head (LONH), right macula (RMAC) and left macula (LMAC) photo-categories were given a number 1 through 8 respectively. These were then further specified with a letter A, B, or C depending which lens (90D, Super Field or Digital Wide Field) was used to produce the image. For example, the photo of E's RONH taken with the 90D lens was labeled 1A and the image of P's LONH taken with the Super Field lens was similarly labeled 4B. See Table 4 for full assignment of images.

Table 4. Alpha-numeric assignment of photos

	RONH		**LONH**		**RMAC**		**LMAC**	
	E	**P**	**E**	**P**	**E**	**P**	**E**	**P**
90D	1A	2A	3A	4A	5A	6A	7A	8A
SF	1B	2B	3B	4B	5B	6B	7B	8B
DWF	1C	2C	3C	4C	5C	6C	7C	8C

To obtain a comparison between the images, a side-by-side presentation technique was designed. All photos were paired and the subject was required to select one photo, out of two simultaneously seen images of the same structure. For example, the two pictures presented might each contain P's RMAC. In addition to making the subjects evaluate the images produced by the various lens types a method was devised to rule out a subject consistently choosing photos on one side over the other (right- or left-preference). This was done by duplicating all images of the LONH, of both E and P, and presenting them with their identical image, once for each LONH image, during testing. This forced the subject to select either the right or left photo, regardless of the fact that they were identical. In theory, this method of comparison should have resulted in choosing either side 50% of the time.

A random number generator was used to form 240 pairs of randomly paired and sequenced presentations of AB, BC, CA combinations. This allowed each lens type, and its respective images within each structural category, to be evaluated against each of its contenders. The generator was also used to form 60 pairs of randomly sequenced presentations of AA, BB, and CC combinations within the LONH category, to monitor right- or left-preference. The presentation of the categories themselves, numbered 1 through 8, for each subject's testing, were also randomized using the generator. Finally, the right and left orientations of the image presentations were randomized by flipping a coin.

The randomized presentations were pre-printed to allow documentation of the subjects' preferences to be as efficient as possible. The test administrator merely had to circle or highlight the corresponding letter of the photo selected. See appendix A for a sample of the pre-printed form used during testing.

Testing Conditions

All testing was conducted in an 8' x 10' room which had a non-flickering, fluorescent light fixture and no windows. A large office desk was covered in a white, fabric table cloth which was secured to the desk, providing a non-distracting, non-moveable testing surface. A MacBeth Easel lamp was used to provide artificial-daylight illumination (color temperature of 6500° K) directly above the photographs. A piece of masking tape one inch in width was used to denote the constant spacing distance between the presented pairs of photos. Tape was also placed on the floor to provide a consistent chair placement for each subject when viewing the images. See Appendix D for images of testing conditions.

A standardized instruction checklist was made for the administrators, and was verbally presented to each subject. The subject was to sit facing forward in the provided chair without moving it. They were informed that they would be shown 30 pairs of photos, that each pair would contain an image of either an optic nerve head or macula as taken with an undisclosed type of high plus lens, and that each pair would be images of the exact same structure. Each subject was told to select, either verbally or manually, the image they felt was of better quality. The subjects were allowed to view the images at a distance no closer than 33 cm. Twenty seconds of viewing time was allotted for each pair of images. The subjects received a five-second warning and were forced to choose an image at the end of the time allowed. If the subject chose a photo in less than 20 seconds, the testing would continue onto the next pair of photos without delay. The subjects were notified that results would be available upon completion of the study. If a subject asked if the presented pair of photos was identical, a standard reply of "I am not at liberty to say" was given. See Appendix B for the standardized instruction checklist used during testing.

The amount of time each subject took to complete the testing was documented immediately thereafter. Ocular and hand preference of each participant was later requested after the completion of all testing.

Participant Selection

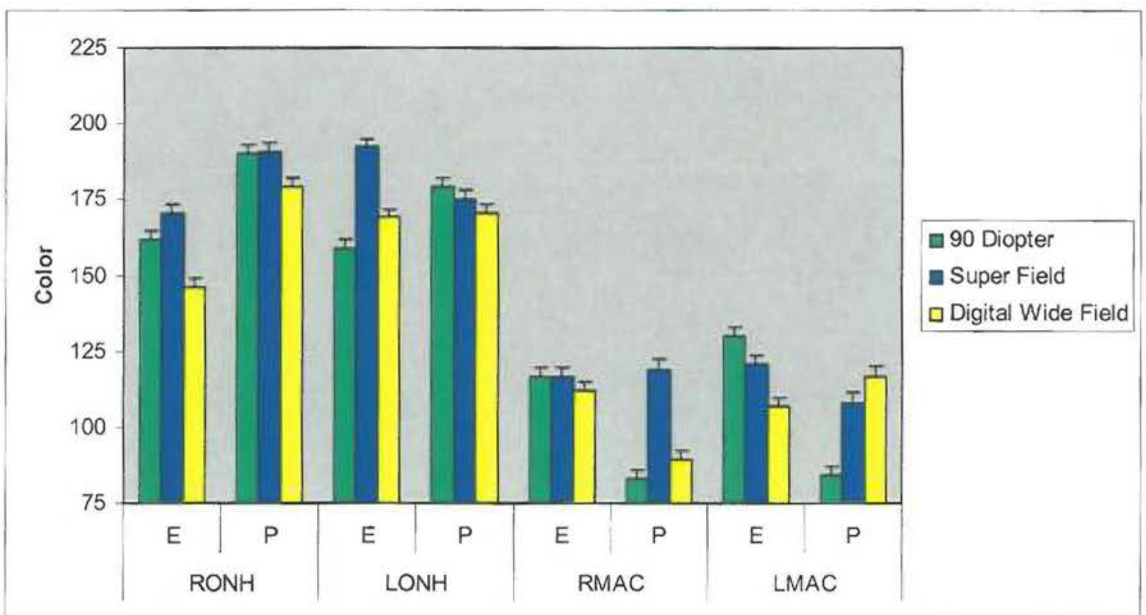
The ten participants of this study were all licensed Doctors of Optometry and faculty members of Pacific University College of Optometry as of May 2006. This sampling was representative of a volunteer-basis only and did not differentiate between areas of specialty. This selection method was based on the fact that all participants had graduated from an accredited school of optometry, were licensed to practice optometry and were therefore held accountable to differentiate between and evaluate the various structures viewed. While two participants were visually-abnormal (one having a moderate red-green color deficiency and the other being a small angle strabismic manifesting monofixation), they were not excluded from the study as they were clinically functioning optometrists who were required to make the same visual discriminations as their visually-normal counterparts. In addition, the images were presented in a two-dimensional fashion where binocularity was not necessary.

RESULTS

Analysis of Images

Color and luminosity were analyzed separately for the optic nerve head (ONH) and macula (MAC) images. Figure 1 shows the average color, and Figure 2 shows the average luminosity, of the images taken with each of the three lenses. Images were imported as JPEG files to Adobe Photoshop. A circular area comprised of 450 pixels, and a distinct border set at 100 percent hardness, was centered on the ONH or MAC, respectively. Mean, standard deviation, and median values for these pixels were calculated directly by Photoshop. Within Photoshop, a 256 point scale is used to define color and luminosity with arbitrary units 0 through 255. Each specific color, or hue, is comprised of varying amounts of red, green and blue; each component has its own individual value ranging from 0 to 255. While an average of the three color values was used to describe the overall color within the detailed area of the photos, this is not to imply that each of the constituents had values equal to, or approximating, the mean, i.e., a hue red-orange in appearance may consist of red, green and blue values correlating to 251, 114 and 68 respectively. While these are quite varied, the mean is approximately 144, which is comparable to the overall means found for the three lenses' images studied here. Similarly, the luminosity values approximate the relative brightness of the defined areas.

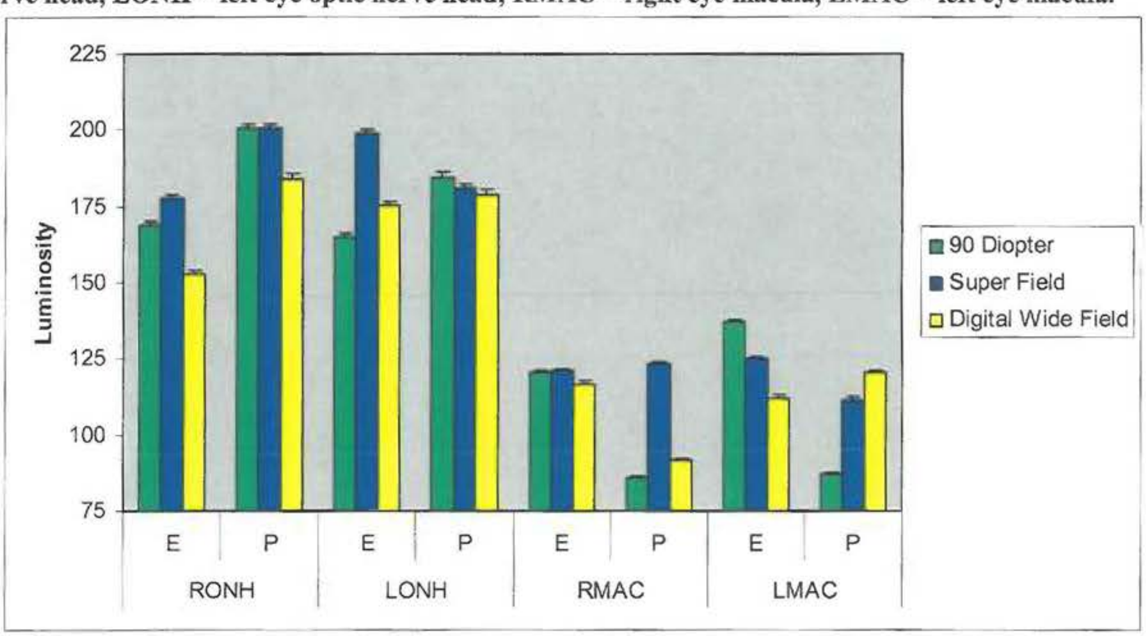
Figure 1. Average color of images for two patients, E and P, taken with each of three lenses, 90 Diopter, Super Field, and Digital Wide Field. Standard error bars indicated. RONH = right eye optic nerve head, LONH = left eye optic nerve head; RMAC = right eye macula, LMAC = left eye macula.



Analysis of variance of the ONH images shows that there are significant differences in color between patients, $F(1,438) = 6.1$, $p = 0.014$, and based on the interaction of patient and eye, F(1,438) = 5.0, p = 0.026. These differences are not relevant, since pairs of images were presented from only one patient and one eye at a time. There are no significant differences based on the main effects of eye, F(1,438) = 0.03, p = 0.869, or lens, F(2,438) = 2.6, p = 0.076, nor on interaction effects of patient and lens, F(2,438) = 1.36, p = 0.259, or eye and lens, F(2,438) = 0.51, p = 0.598, nor on the overall effect of patient, eye, and lens, F(2,438) = 0.61, p = 0.542.

Analysis of variance of the MAC images shows that there are significant differences in color between patients, F(1,438) = 7.4, p = 0.007, and based on the interaction of patient and lens, F(1,438) = 3.3, p = 0.038. These differences are not relevant, since pairs of images were presented from only one patient and one eye at a time. There are no significant differences based on the main effects of eye, F(1,438) = 0.63, p = 0.429, or lens, F(2,438) = 1.50, p = 0.225, nor on interaction effects of patient and eye, F(2,438) = 0.02, p = 0.901, or eye and lens, F(2,438) = 0.49, p = 0.615, nor on the overall effect of patient, eye, and lens, F(2,438) = 1.47, p = 0.232.

Figure 2. Average luminosity of images for two patients, E and P, taken with each of three lenses, 90 Diopter, Super Field, and Digital Wide Field. Standard error bars indicated. RONH = right eye optic nerve head, LONH = left eye optic nerve head; RMAC = right eye macula, LMAC = left eye macula.



Analysis of variance of the ONH images shows that there are significant differences in luminosity between patients, $F(1,438) = 7.0$, $p = 0.008$, and based on the interaction of patient and eye, $F(1,438) = 5.3$, $p = 0.021$. These differences are not relevant, since pairs of images were presented from only one patient and one eye at a time. There are no significant differences based on the main effects of eye, $F(1,438) = 0.0003$, $p = 0.986$, or lens, $F(2,438) = 2.8$, $p = 0.065$, nor on interaction effects of patient and lens, $F(2,438) = 1.38$, $p = 0.254$, or eye and lens, $F(2,438) = 0.86$, $p = 0.424$, nor on the overall effect of patient, eye, and lens, $F(2,438) = 0.53$, $p = 0.587$.

Analysis of variance of the MAC images shows that there are significant differences in luminosity between patients, $F(1,438) = 8.9$, $p = 0.003$, and based on the interaction of patient and lens, $F(1,438) = 3.6$, $p = 0.029$. These differences are not relevant, since pairs of images were presented from only one patient and one eye at a time. There are no significant differences based on the main effects of eye, $F(1,438) = 0.80$, $p = 0.372$, or lens, $F(2,438) = 1.48$, $p = 0.228$, nor on interaction effects of patient and eye, $F(2,438) = 0.003$, $p = 0.954$, or eye and lens, $F(2,438) = 0.61$, $p = 0.544$, nor on the overall effect of patient, eye, and lens, $F(2,438) = 1.69$, $p = 0.186$.

Analysis of Subject Responses

Table 5 shows the frequencies at which images of the respective patients' ONH's were chosen by the subjects. Since there are no significant differences in color or luminosity of the respective images for the patients' right eye and left eye ONH's, subject responses are combined for this factor.

Table 5. Response frequencies for images of ONH's presented to subjects. Side = presentation position of image taken with the given lens (Pro); Con = image not chosen, which was taken with either of the two other lenses. 90D = 90 Diopter, SF = Super Field, DWF = Digital Wide Field.

Patient	E ONH						P ONH					
Side	Left			Right			Left			Right		
Lens	90D	SF	DWF	90D	SF	DWF	90D	SF	DWF	90D	SF	DWF
Pro	11	8	11	12	11	7	14	11	5	11	10	9
Con	7	7	16	10	14	6	6	11	13	9	8	13

Chi-squared analysis shows that there is a significant difference in subject responses based on lens type, $\chi^2(2) = 6.4$, $p = 0.041$. Images taken with the 90 Diopter lens were chosen more often (48 of 80 times) than those taken with the other two lenses (32 times); images taken with the Super Field lens were chosen equally often (40 times) as those taken with the other two lenses; and images taken with the Digital Wide Field lens were chosen less often (32 times) than those taken with the other two lenses (48 times). There are no significant differences in image choices based on the interaction effects of patient and lens, $\chi^2(5) = 7.6$, $p = 0.180$, or presentation side and lens, $\chi^2(5) = 8.2$, $p = 0.144$.

There was no obvious bias to the responses, as images presented on the subjects' right were chosen as often as those presented on the left (60 times each). To check for potential subject bias, the three images of the patients' left ONH's were duplicated and presented simultaneously on the subjects' left and right sides. Each image from the respective pairs should have been chosen fifty percent of the time. For patient E's images, the right image was chosen 17 of 30 times (56.7%); this is not significantly different from the expected frequency, $z = 0.73$, $p = 0.465$. For patient P's images, the right image was chosen 19 of 30 times (63.3%); this is not significantly different from the expected frequency, $z = 1.46$, $p = 0.144$.

One of the ten subjects had moderate color deficiency. An additional subject had normal color vision but has a small-angle strabismus with monofixation. Both subjects were right-handed and left-eye dominant. Based on their overall responses, they responded differently than the remaining eight visual-normal subjects, $\chi^2(11) = 123.5$, $p = 0$. The visually-abnormal subjects overwhelmingly chose the images presented on the right side, 20 of 24 times (83.3%), $\chi^2(1) = 21.3$, $p = 0$. Interaction effects based on presentation side also show significant differences, with respect to patient, $\chi^2(3) = 22.7$, $p = 0$, and with respect to lens, $\chi^2(5) = 22.6$, $p = 0$. There are no significant differences in image choices based on lens, $\chi^2(2) = 0.50$, $p = 0.779$, or interaction effect of patient and lens, $\chi^2(5) = 1.00$, $p = 0.963$. For the simultaneously-presented duplicate images, the visually-abnormal subjects chose the right image 10 of 12 times. This is significantly different from the expected frequency of fifty percent, $z = 2.31$, $p = 0.021$.

Analysis of the data for the eight visually-normal subjects alone shows a similar significant result with respect to all subjects based on lens type, $\chi^2(2) = 6.1$, $p = 0.047$. The preference of lens for these subjects is the same as reported above. However, a preference for images presented on the subjects' left was now revealed, where they chose those images 56 of 96 times (58.3%), $\chi^2(1) = 5.3$, $p = 0.021$. While this difference is statistically significant, it may not be of practical significance.

Table 6 shows the frequencies at which images of the respective patients' MAC's were chosen by the subjects. Since there are no significant differences in color or luminosity of the respective images for the patients' right eye and left eye MAC's, subject responses are combined for this factor.

Table 6. Response frequencies for images of MAC's presented to subjects. Side = presentation position of image taken with the given lens (Pro); Con = image not chosen, which was taken with either of the two other lenses. 90D = 90 Diopter, SF = Super Field, DWF = Digital Wide Field.

Patient	E MAC						P MAC					
Side	Left			Right			Left			Right		
Lens	90D	SF	DWF	90D	SF	DWF	90D	SF	DWF	90D	SF	DWF
Pro	17	5	8	16	4	10	3	18	7	10	13	9
Con	3	17	10	4	14	12	14	5	13	13	4	11

Chi-squared analysis shows that there is no significant difference in subject responses based on lens type, $\chi^2(2) = 3.6$, $p = 0.165$. Nonetheless, the trend is similar to that of the ONH results: images taken with the 90 Diopter lens were chosen more often (46 of 80 times) than those taken with the other two lenses (34 times); images taken with the Super Field lens were chosen equally often (40 times) as those taken with the other two lenses, and images taken with the Digital Wide Field lens were chosen less often (34 times) than those taken with the other two lenses (46 times). There is no significant difference in image choices based on the interaction effect of presentation side and lens, $\chi^2(5) = 4.2$, $p = 0.515$. However, there is a significant difference in image choice based on the interaction effects of patient and lens, $\chi^2(5) = 48.0$, $p = 0$. Subjects overwhelmingly preferred the images of patient E's maculae with the 90 Diopter lens (33 of 40 times), but of patient P's maculae with the Super Field lens (31 of 40 times). There was no obvious bias to the responses, as images presented on the subjects' right were chosen almost as often as those presented on the left (62 and 58 times, respectively).

Based on their overall responses, the two visually-abnormal subjects again responded differently than the remaining eight visually-normal subjects, $\chi^2(11) = 115.4$, $p = 0$.

The visually-abnormal subjects overwhelmingly chose the images presented on the right side, 17 of 24 times (70.8%), $\chi^2(1) = 8.3$, $p = 0.004$. Interaction effects based on presentation side also show significant differences, with respect to patient, $\chi^2(3) = 8.7$, $p = 0.034$, and with respect to lens, $\chi^2(5) = 13.7$, $p = 0.018$. There are no significant differences in image choices based on lens, $\chi^2(2) = 1.50$, $p = 0.472$, or interaction effect of patient and lens, $\chi^2(5) = 11.0$, $p = 0.051$.

Analysis of the data for the eight visually-normal subjects alone shows a similar non-significant result with respect to all subjects based on lens type, $\chi^2(2) = 2.6$, $p = 0.269$. However, the trend of lens preference for these subjects is the same as reported above. As before, a trend for preference for images presented on the subjects' left was evident, where they chose those images 51 of 96 times (53.1%), but this difference is not statistically significant, $\chi^2(1) = 0.75$, $p = 0.386$.

While not statistically analyzed due to the small range of results, the amount of time taken to complete each testing session was documented. Subjects finished testing in as little as 10 minutes 18 seconds and as long as 14 minutes. The mean and mode were both 11 minutes 42 seconds. Administration duties took approximately 10 seconds between each successive presentation of image pairs, so the administrative time for all 30 presentations equaled roughly 5 minutes. When administrative time is factored out, actual testing and image comparison time was estimated to be 6 minutes 42 seconds, equaling an average 13.4 seconds per paired-image assessment. This correlated well with the allotted 20 second viewing time.

DISCUSSION

Objective Findings

As seen in the statistical analysis, there was a significant difference in perceived image quality of the ONH's between the three high plus lenses, with the 90D lens surpassing both the SF and DWF lenses. While not statistically significant, a similar trend was evident for the MAC images as well. From this we are able to conclude that the 90D lens does appear to produce superior quality images of the optic nerve head and macula. In contrast to these findings, the values describing the mean luminosity and mean red, green and blue contributions show no significant difference among the three lenses tested. This leads us to believe that there were other subtleties beyond color and brightness that led the subjects to perceive a higher quality of image.

Throughout the testing, it was noted that several participants felt it difficult to choose between certain pairs of images, whether or not they were identical photos. Verbalized comments indicated subjects sometimes felt they had to pick one photo because of time constraints rather than being able to identify a subjective difference or that they were unsure of which specific component of a picture to compare to its fellow. In addition, some subjects commented that the photos seemed identical, and some noted that they felt like they always picked the photo on a certain side.

Subjective Findings

Prior to this study, the authors themselves had previous experience with all three lenses and had their own "favorite" lens. One author primarily used a 90D lens and the other had used all three, with an emphasis towards use of the SF lens. Nonetheless, several distinct characteristics of each lens became apparent as the authors acted as both photographer and patient. Each of the authors noted that the 90D lens produced the least amount of reflections and allowed the photographer to achieve a clear, focused image with minimal adjustment to the capturing system between photographs. (See Appendix D for an image produced with the SF lens, labeled "Rainbow;" this is a representative of the various reflections created by the SF and DWF lenses.) Where as a minimum of 100 images were taken with the SF and DWF lenses merely to obtain usable images for the study, the same 100 photos taken with the 90D lens were achieved in the shortest amount of time, and needed close discrimination to determine the best photo out of two equally high-quality images. Also, it should be noted that the images obtained from the 90D lens were often used as the quality control images, against which all other photos were compared in the attempt to construct equal comparisons between all three lenses' photos.

Each author's familiarity with the three lenses tested was evident as impressions on ease of use were compared. The DWF proved most challenging to use which may be attributed in part to its shape, and increased size and weight compared to more familiar lenses. This merely proves that had the participants handled the lenses, a bias towards a familiar lens would have most likely played a part in their assessment of each lens' image.

Adjunct to the differences between the lenses in image acquisition, there was also an interesting finding noted by the authors when serving as the patient. Each author observed, a typical straight, white beam when being examined with the 90D and SF lenses. Conversely, when the DWF lens was used to capture images of the optic nerve heads and maculae, the beam subjectively appeared bent or curved to the patient. More interesting is the fact that this curve, or bend, is actually visible in the final images obtained with the DWF. For this very reason, we chose *not to* "scale to fit media" on the ONH pictures. The beam width used to photograph this structure accentuated the curve created by the DWF lens. The beam width used to photograph the maculae did not provide the same pronounced, curved appearance. Therefore we *did* choose to "scale to fit media" on the MAC photos. We have included a photo that accentuates the curved beam formed by the DWF lens. See the photo labeled "Curved" in Appendix D.

Study Limitations

One of the difficulties in this study was the inability to define an "in-focus" photo. Each person has their own method in evaluating whether or not they are viewing a clear image. To determine if something is in focus, one must be able to compare the produced image to the structure being photographed. As a result, the photographer must make a subjective decision based on several things including color constancy, distinct edges or borders and accurate reproduction of the structures viewed. We were unable to find an objective way to evaluate these details that a subject would detect. This is reflected in the fact that while the mean color and luminosity of the various photos was not significantly different, subjects were still able to perceive a divergence in image quality.

Another complexity entailed producing a focused, two-dimensional image of a three-dimensional, non-flat retina. Each structure photographed had its own obstacles. The ONH has several different depths of focus: the cup, lamina cribrosa, rim tissue, blood vessels as they both leave the ONH and traverse through the retina, not to mention the nerve fiber layer (NFL). Where ONH has many distinct points which may be focused, the MAC has very few. Ultimately, a picture of the MAC was deemed "in-focus" if the blood vessels were distinct, a foveal light reflex was visible and the NFL sheen was manifest.

While both authors were properly trained and equally experienced in obtaining digital images of the fundus, there were two different photographers. A single photographer would be necessary to completely remove any discrepancy between the quality of captured images .

The scope of this study was limited to using three high plus lenses to view, and photograph, structures which are located exclusively in the posterior pole of the eye. Based on the literature provided by Volk, we did not test each lens to its full capacity, i.e. field of view. One author of this study offered anecdotal support that the DWF lens can be used to easily view vortex veins in the peripheral retina, and that peripheral views are more easily attained through an undilated pupil as compared to a 90D lens. However, this does emphasize that using specialty lenses for viewing the posterior pole, may not in fact provide any additional benefit to the optometric physician. Moreover, these lenses may be best utilized in addition to the traditionally used 90D lens in possible cases where very peripheral views are wanted with minimal lens and patient manipulation.

Indications for Further Study

This study included images of healthy optic nerve heads and maculae with no signs of pathology. Future research may include images of fundi with various conditions or diseases, as well as various locations within the retina. As previously mentioned, we did not test the field of view for the selected lenses. It is possible that another lens may produce higher quality images in a different, more peripheral location in the retina. Also, the presence of pathology may alter subject perception of image quality.

In the analysis of the individual responses, an intriguing disparity between visually-normal and visually-abnormal subjects was found. Not only were these two subjects respectively deficient in color and binocularity, they also manifested a crossed dominance of eye and hand. They accounted for two of the three subjects with the described cross-dominance. Further study should be done to conclude whether or not this discrepancy is representative of all visually-abnormal individuals and/or those presenting with an eye-hand cross dominant pattern. It may be inferred that those with specific visual deficiencies compensate in some manner consisting of either dependence on their dominant hand or some other means of differentiation.

A small study may be conducted to observe the effects of verbal versus manual selection. In this study, subjects were allowed to respond in either manner. It may be useful to know if a person's eye or hand dominance affects their decision if they are limited to a verbal or manual response.

Finally, this study could be expanded to include optometric physicians, optometry students as well as lay people. As the intent was stated to the subjects of this study, they were merely to choose the image of higher quality. The methods that these subjects used to differentiate between poorer and higher quality images may very well be identical to a person not familiar with images of a fundus. However, some subjects did note that they were attempting to identify details that they would use in making a diagnosis, had the structure been abnormal. This may imply that optometric knowledge of the retinal structures, both normal and abnormal, would be needed to make an accurate distinction. A study such as one described here would likely assess whether or not any optometric knowledge is indeed necessary to select a higher quality image of the retina, as produced by a high plus lens.

CONCLUSION

Of the three lenses tested, the 90D lens appears to produce subjectively better quality in digital images of the posterior pole. Objectively, there was no discernable difference between the three lenses evaluated.

Appendix A

L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
#1							Time:								
5		8		2		3		1		6		4		7	
A	B	B	C	A	B	B	A	C	A	C	A	B	C	A	B
C	A	C	A	A	C	A	A	C	B	B	C	A	A	C	A
B	C	A	B	B	C	C	A	A	B	A	B	A	C	B	C
						C	B					B	B		
						B	B					B	A		
						C	C					C	C		
#2							Time:								
3		6		1		2		7		4		5		8	
A	A	A	C	B	A	A	B	B	A	B	A	C	A	C	A
C	A	B	C	C	B	A	C	A	C	C	B	B	C	C	B
C	B	B	A	C	A	B	C	B	C	A	A	A	B	B	A
C	C									C	C				
B	B									B	B				
B	A									A	C				
#3							Time:								
1		6		5		8		7		3		2		4	
C	B	B	C	A	C	B	C	C	A	C	C	C	B	C	C
C	A	B	A	C	B	C	A	A	B	C	B	B	A	B	B
A	B	A	C	A	B	B	A	B	C	A	B	A	C	C	A
										B	B			B	A
										C	A			A	A
										A	A			B	C
#4							Time:								
8		5		4		2		1		7		3		6	
A	C	C	A	B	A	A	B	B	A	B	A	B	B	B	C
B	A	B	C	A	A	A	C	C	A	A	C	A	A	C	A
B	C	B	A	C	C	C	B	B	C	B	C	A	C	B	A
				B	C							C	C		
				C	A							B	C		
				B	B							A	B		
#5							Time:								
7		1		3		8		6		4		5		2	
B	A	A	C	C	C	A	B	B	C	C	C	A	C	B	C
B	C	C	B	A	B	C	B	A	B	B	B	B	C	A	C
C	A	A	B	A	A	A	C	C	A	A	B	B	A	B	A
				C	B					C	B				
				B	B					C	A				
				C	A					A	A				

Appendix A con't.

#6 Time:

L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
6		2		7		1		5		8		4		3	
C	B	C	A	C	B	B	C	A	C	B	C	B	B	A	A
A	B	B	A	A	B	A	C	C	B	A	B	B	A	C	A
C	A	B	C	A	C	A	B	A	B	C	A	C	C	C	C
												A	A	B	C
												A	C	B	B
												C	B	A	B

#7 Time:

L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
7		8		3		6		2		5		4		1	
A	B	C	A	C	C	C	A	B	C	C	A	A	C	A	C
C	B	B	C	B	A	A	B	B	A	B	A	C	C	B	A
A	C	A	B	B	B	B	C	A	C	B	C	A	B	C	B
				C	A							A	A		
				A	A							B	B		
				B	C							C	B		

#8 Time:

L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
5		1		7		6		2		4		8		3	
A	C	B	A	B	A	A	B	A	B	B	A	C	A	C	B
C	B	A	C	C	A	B	C	B	C	C	C	B	A	C	A
B	A	B	C	C	B	C	A	C	A	A	A	B	C	C	C
										B	B			A	B
										C	B			A	A
										C	A			B	B

#9 Time:

L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
6		1		8		2		4		3		7		5	
C	B	C	B	B	A	C	B	A	A	C	C	B	A	C	A
A	B	B	A	B	C	A	B	C	A	A	C	A	C	B	C
C	A	C	A	C	A	A	C	C	C	C	B	B	C	B	A
								C	B	A	B				
								B	B	A	A				
								B	A	B	B				

#10 Time:

L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
3		5		7		6		1		2		8		4	
C	A	A	B	A	B	A	B	A	B	A	C	A	C	C	C
A	A	C	A	A	C	C	A	C	A	A	B	A	B	B	B
C	C	C	B	C	B	B	C	B	C	C	B	C	B	C	A
B	B													B	A
C	B													B	C
A	B													A	A

Appendix B

L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	Results

#1 Denise Goodwin Time: 11:42 min

5		8		2		3		1		6		4		7		
A	B	B	C	A	B	B	A	C	A	C	A	B	C	A	B	A=14
C	A	C	A	A	C	A	A	C	B	B	C	A	A	C	A	B=6
B	C	A	B	B	C	C	A	A	B	A	B	A	C	B	C	C=10
						C	B					B	B			
						B	B					B	A			R=4
						C	C					C	C			L=2

#2 Peter Bergenske Time: 11:42

3		6		1		2		7		4		5		8		
A	A	A	C	B	A	A	B	B	A	B	A	C	A	C	A	A=11
C	A	B	C	C	B	A	C	A	C	C	B	B	C	C	B	B=11
C	B	B	A	C	A	B	C	B	C	A	A	A	B	B	A	C=8
C	C									C	C					
B	B									B	B					R=2
B	A									A	C					L=4

#3 Scott Cooper Time: 13:49 min

1		6		5		8		7		3		2		4		
C	B	B	C	A	C	B	C	C	A	C	C	C	B	C	C	A=12
C	A	B	A	C	B	C	A	A	B	C	B	B	A	B	B	B=11
A	B	A	C	A	B	B	A	B	C	A	B	A	C	C	A	C=7
										B	B			B	A	
										C	A			A	A	R=3
										A	A			B	C	L=3

#4 Jennifer Smythe Time: 10:56 min

8		5		4		2		1		7		3		6		
A	C	C	A	B	A	A	B	B	A	B	A	B	B	B	C	A=10
B	A	B	C	A	A	A	C	C	A	A	C	A	A	C	A	B= 11
B	C	B	A	C	C	C	B	B	C	B	C	A	C	B	A	C=9
				B	C							C	C			
				C	A							B	C			R=4
				B	B							A	B			L=2

#5 James kundart Time: 14:00 min *Color Vision Deficiency

7		1		3		8		6		4		5		2		
B	A	A	C	C	C	A	B	B	C	C	C	A	C	B	C	A=12
B	C	C	B	A	B	C	B	A	B	B	B	B	C	A	C	B=11
C	A	A	B	A	A	A	C	C	A	A	B	B	A	B	A	C=7
				C	B					C	B					
				B	B					C	A					R=4
				C	A					A	A					L=2
L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	

L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R

#6 Salissa Williams Time: 12:00 min

6		2		7		1		5		8		4		3		
C	B	C	A	C	B	B	C	A	C	B	C	B	B	A	A	A=12
A	B	B	A	A	B	A	C	C	B	A	B	B	A	C	A	B=10
C	A	B	C	A	C	A	B	A	B	C	A	C	C	C	C	C=8
												A	A	B	C	
												A	C	B	B	R=3
												C	B	A	B	L=3

#7 Dennis Smith Time: 11:09 min *Color vision Deficiency

7		8		3		6		2		5		4		1		
A	B	C	A	C	C	C	A	B	C	C	A	A	C	A	C	A=10
C	B	B	C	B	A	A	B	B	A	B	A	C	C	B	A	B=10
A	C	A	B	B	B	B	C	A	C	B	C	A	B	C	B	C=10
				C	A							A	A			
				A	A							B	B			R=6
				B	C							C	B			L=0

#8 Graham Erickson Time: 10:06 min

5		1		7		6		2		4		8		3		
A	C	B	A	B	A	A	B	A	B	B	A	C	A	C	B	A=10
C	B	A	C	C	A	B	C	B	C	C	C	B	A	C	A	B=11
B	A	B	C	C	B	C	A	C	A	A	A	B	C	C	C	C=9
										B	B			A	B	
										C	B			A	A	R=3
										C	A			B	B	L=3

#9 John Smith Time: 11:15 min

6		1		8		2		4		3		7		5		
C	B	C	B	B	A	C	B	A	A	C	C	B	A	C	A	A=10
A	B	B	A	B	C	A	B	C	A	A	C	A	C	B	C	B=11
C	A	C	A	C	A	A	C	C	C	C	B	B	C	B	A	C=9
								C	B	A	B					
								B	B	A	A					R=5
								B	A	B	B					L=1

#10 Karl Citek Time: 10:18

3		5		7		6		1		2		8		4		
C	A	A	B	A	B	A	B	A	B	A	C	A	C	C	C	A=13
A	A	C	A	A	C	C	A	C	A	A	B	A	B	B	B	B=8
C	C	C	B	C	B	B	C	B	C	C	B	C	B	C	A	C=9
B	B													B	A	
C	B													B	C	R=2
A	B													A	A	L=4

Total: A=114
B=100
C=86

Right: 36
Left: 24

Appendix C

Sample of patient instruction check-list

Participant Name: ______________________________

Date: ______________ Time: ________________

Subject # _______

I will show you two photos at a time.
There will be a total of thirty pairs.
I would like you to choose which photo has the better image quality.
Please make your decision within 20 seconds.
Please maintain a viewing distance of 33 cm or more. This will be demonstrated.
Please do no touch or move the photos.
Please do not move the chair while seated.
Please remain facing forward the entire time.

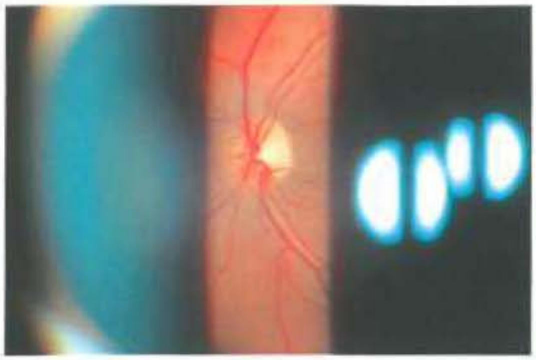
If you have any questions about this study, we will be happy to supply the outcomes after its completion.

Appendix D

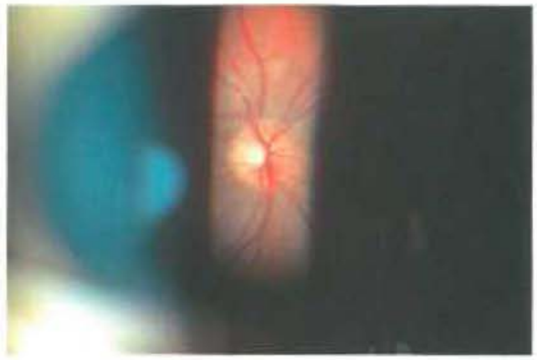
E Optic Nerve Head

Right Eye | **Left Eye**

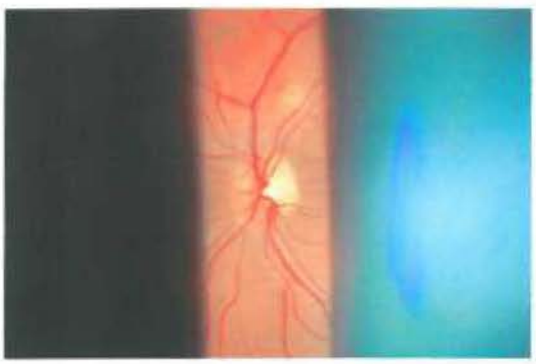
90 D Photo 212 1A



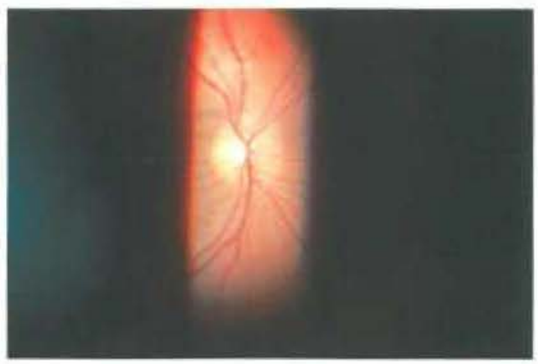
90 D Photo 1983 3A



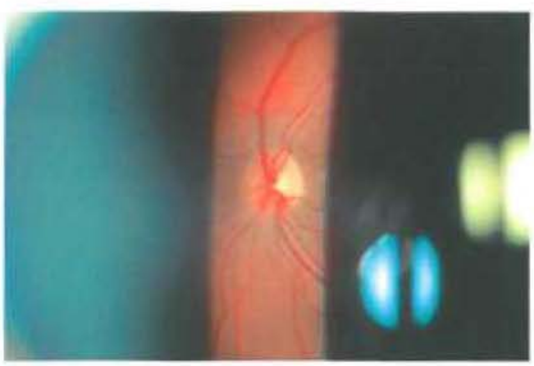
SF Photo 195 1B



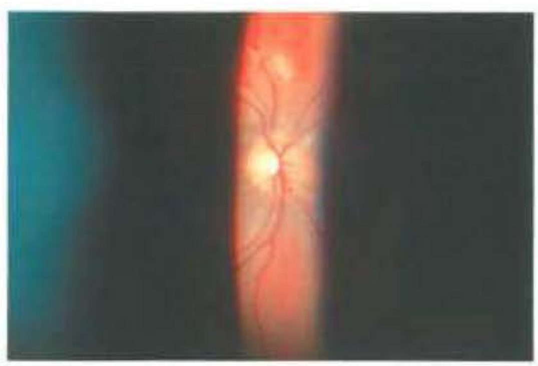
SF Photo 2300 3B



DWF Photo 210 1C



DWF Photo 2049 3C

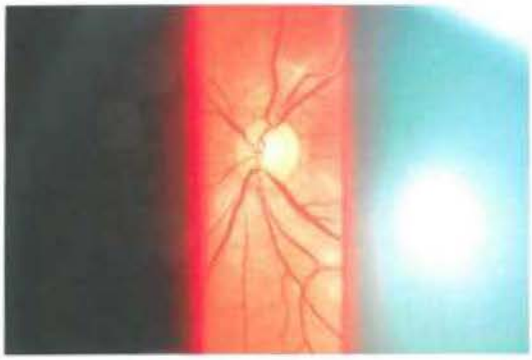


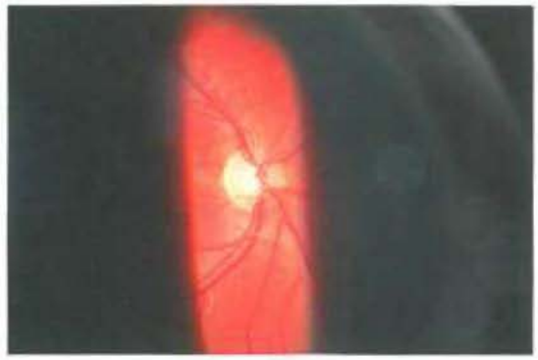
Appendix D con't.

P Optic Nerve Head

Right Eye | **Left Eye**

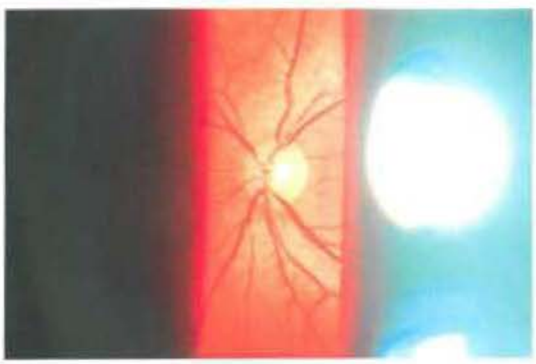
90 D
Photo
2104
2A

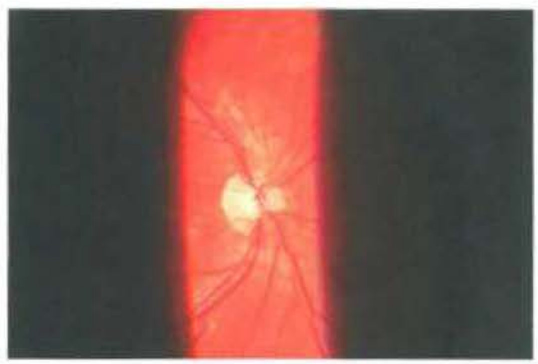




90 D
Photo
1835
4A

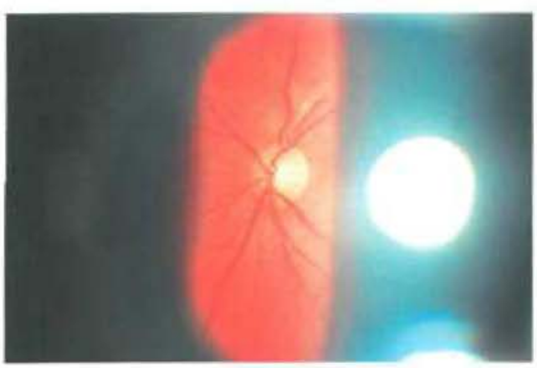
SF
Photo
144
2B

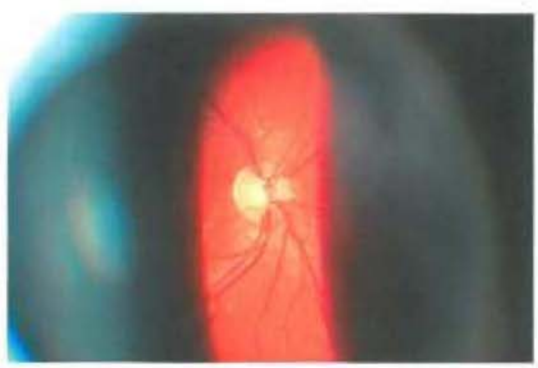




SF
Photo
2160
5A

DWF
Photo
2180
3C



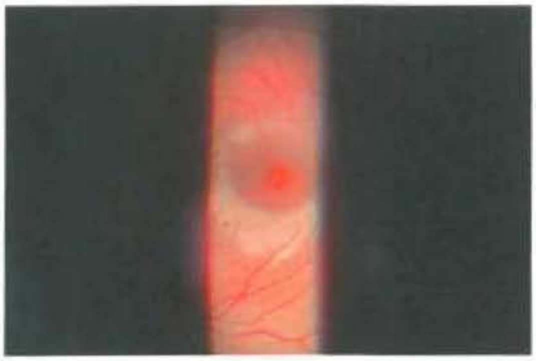


DWF
Photo
109
6A

E Macula

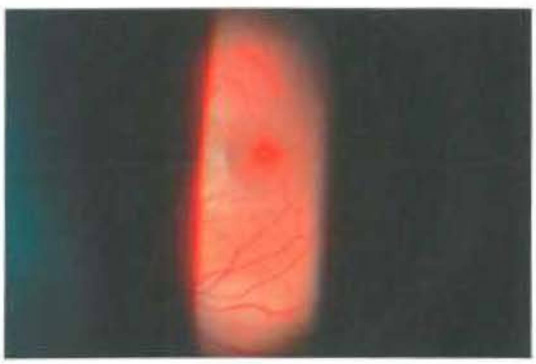
Right Eye	Left Eye

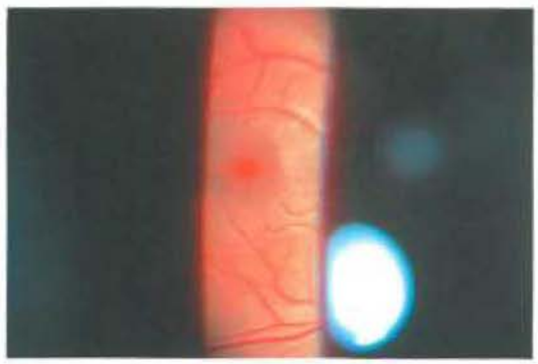
90 D
Photo:
2330
5A



90 D
Photo:
1995
7A

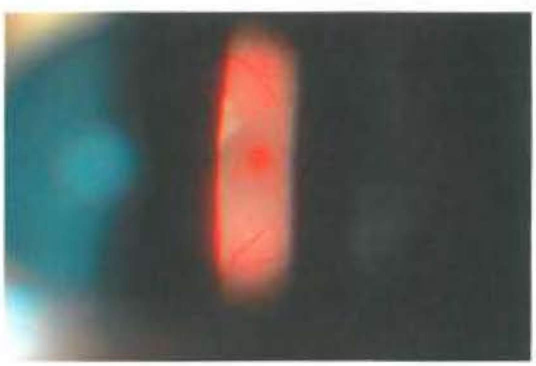
SF
Photo:
2280
5B

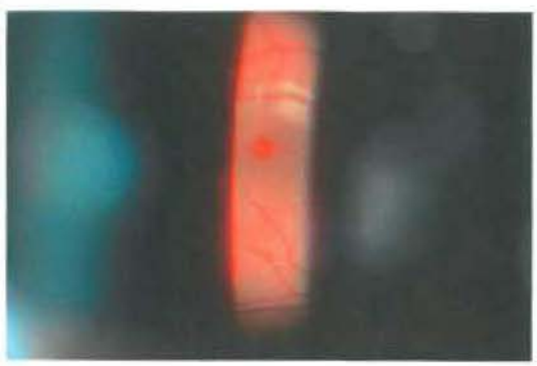




SF
Photo:
2293
7B

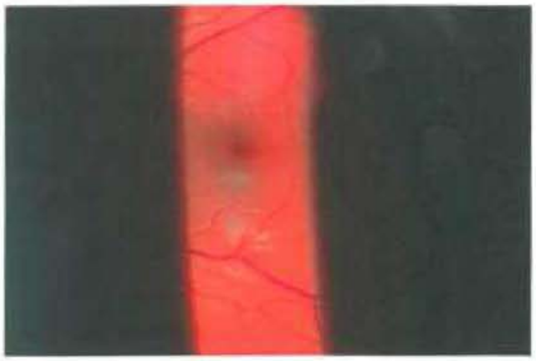
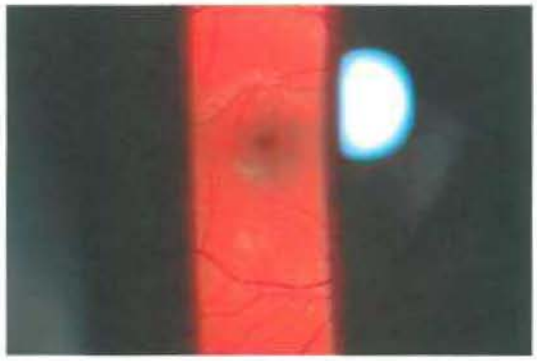
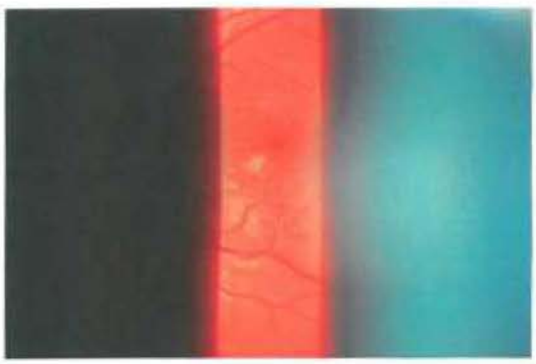
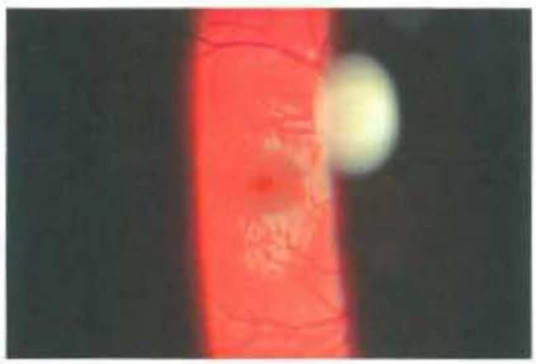
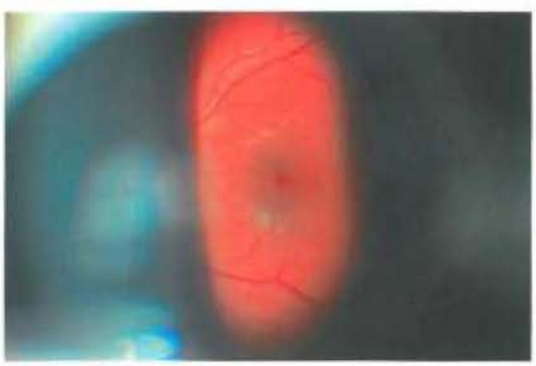
DWF
Photo:
2060
5C





DWF
Photo:
2053
7C

P Macula

Right Eye		Left Eye	
90 D Photo: 2117 6A			90 D Photo: 2125 8A
SF Photo: 2145 6B			SF Photo: 2164 8B
DWF Photo: 2195 6C			DWF Photo: 113 8C

Appendix E

Other Photographs

SF
Colors

DWF
Curve

Set Up

Set Up

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