A comprehensive look at scotopic pupilometry

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DOCTOR OF OPTOMETRY
THESIS

A COMPREHENSIVE LOOK AT SCOTOPIC
PUPILOMETRY

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SCOTOPIC PUPILOMETRY

Research in medical technology has recently aided in the production of many new and exciting instruments with phenomenal treatment capabilities. As a part of this technology, laser in-situ keratomileusis (LASIK) has made an overwhelming impact on the visual health of millions of people around the world. The explosion of such incredible medical procedures also carries the risk of increasing mal-practice lawsuits. \(^{(1)}\)

Greater attention to important procedural details amongst practitioners could often help avoid these serious medical-legal issues. LASIK success rates often fall in patient satisfaction due to the secondary effects of the ablation zone to scotopic pupil diameter ratio.\(^{(2)}\) Many companies have devoted a lot of time, money, and research to relieve this situation but have failed to produce an instrument that offers all the necessary components needed for accurate, repeatable, and affordable scotopic pupillometry.

The necessity of scotopic pupil diameter measurements in LASIK, Orthokeratology, health-related diagnostic procedures, and the importance of horizontal visible iris diameter (HVID) in special contact lens fits will be addressed in this document. An evaluation of the most common instruments used today for such measurements will also be reviewed. I will conclude this review by introducing a new and innovative approach to successfully acquire the previously mentioned measurements.

LASIK COMPLICATIONS:

Lasik is performed on nearly two million people each year.\(^{(3)}\) As a part of the screening process, one of the most important components for an acceptable LASIK patient is an accurate scotopic pupillometry. There has been much research regarding the importance of scotopic pupil diameter. In fact, it has been stated, "any delinquency of proper measurement can place insurmountable visual effects on many post-op patients". \(^{(4)}\)

Though there are a few within the medical community that will say the effects are negligible, the vast majority agree that when making the final decision, scotopic pupil
diameter is "arguably the most important predictor of vision disturbances" and essential in every pre-LASIK evaluation.\(^{(5)}\)

The visual side effects of performing LASIK on improperly screened patients with larger scotopic pupils may include but are not limited to halos, glare, starbursts, and monocular diplopia. Halos are caused by uncorrected refractive error such as a myopic blur circle which can result after myopic LASIK if the pupil dilates beyond the optical zone, thereby allowing light to pass into the eye through a myopic ring of untreated cornea.\(^{(6)}\) These visual disturbances have been reported in up to 35\% of pt when using a 6.0mm ablation zone.\(^{(7-8)}\) Studies have also shown that when potential LASIK patients are studied with IR light instruments, approximately 50\% have scotopic pupils larger than 6.0mm.\(^{(9)}\) Disturbances are even more severe when the ablation zone is smaller and the pupil diameter is larger than 6.0mm. Visual effects include the disruption of being able to function in society and complete previously simple tasks. The following photos are examples of a few of the previous side affects as viewed through the eyes of a post-LASIK disaster secondary to inadequate scotopic pupillometry.
Unfortunately, for many patients the best treatment for such outcomes would have been from preventing it in the first place. There are few options available to return a patient's vision to pre-LASIK conditions once implications have occurred. Of the methods used, the least invasive often include the use of spectacles and soft contact lens wear. Spectacle lenses offer anti-reflective coatings, which are highly effective in decreasing the amount of image blur. Optometrists often have no other option than to over-minus a patient to stimulate the accommodative system and thereby cause a secondary pupillary constriction to within the ablation zone.\(^{10-11}\) For night-time problems, drivers have been asked to drive with dome lights on to increase the ambient light levels in the car with the hopes that light will cause enough pupillary constriction to eliminate the problems. Miotic eye drops such as Dapiprazole HCL 0.5% (an alpha-adrenergic blocking agent) are also being used as a full time medication for pupillary constriction, which may induce adverse systemic effects.\(^{12}\) Some surgeons have also elected to perform optical zone enlargement re-treatments, which is the most invasive option when compared to those previously mentioned.\(^{13-14}\)

Articles regarding patient satisfaction of LASIK outcomes often overlook the trials patients face while trying to overcome post-op problems.
LAWSUITS:

Many million-dollar lawsuits have entered the courts due to dissatisfied patients secondary to halos and glare alone. As previously mentioned, medical-legal issues regarding LASIK have steadily been on the rise over the past five years. I have chosen the case of an Arizona airline pilot who in 2001 was awarded 4 million dollars to serve as an example of how devastating poor LASIK outcomes can be to both the individual and to the physician. Attorneys argued during the trial that, “though the surgery itself was not botched, the surgical team failed to accurately measure the size of his pupils in dim light”. The ophthalmologist also stated “the problem was that they should never have done the operation in the first place, this man was not a good candidate”. The Arizona Daily Star summary included statistics of LASIK awards years prior to the four million dollar award. Previously in 2000, the largest LASIK award was 1.7 million and the year before that (1999) was 1.2 million dollars. Ophthalmic Mutual Insurance Company (OMIC), which represents surgeons, announced that in 1999, ten percent of all claims were from post LASIK patients. In 2001, the number of claims related to LASIK rose to nineteen percent. It was then estimated that nearly thirty percent of all claims received in 2002 would be due to LASIK. A landmark study by OMIC insurance demonstrated that claims due to LASIK mistakes cost an average of $50,000.00 each. The study also showed that among the most frequently cited reasons for LASIK malpractice lawsuits were complaints of postoperative halos and glare. OMIC then predicted that the trend would probably continue in a similar fashion in the years to come. The article also noted that many of the costlier settlements usually take longer to process and may not have even been a part of the initial assessment.

Various Internet sights have been established to educate perspective LASIK patients regarding the potential risks of the operation. Other sights list articles from well-known and respected journal reviews, news networks, and newspapers about people who have suffered poor effects from LASIK. The vast majority of these articles speak of effects such as halos, glare, double vision, starburst, and nighttime problems, which are all, related to the effects of inaccurate scotopic pupil diameter measurements. Refractive surgery litigation offices are begging to set up all over the nation. Proper screening techniques and documentation by the physician are often the deciding factors to whether
or not the claims are awarded. Many physicians have been lulled into believing that by having the patients sign a consent form they are safe from any possible litigation action against them. Such assumptions are not true. Litigation officers look for all possible loopholes from proper patient education to errors in screening techniques and improper documentation of all procedures. One such web site catches the attention of patients by saying, “DO NOT BELIEVE THAT BECAUSE YOU HAVE SIGNED AN INFORMED CONSENT DOCUMENT THAT YOU CANNOT SUE”. The bottom line of these litigation wars is that even though some physicians may disregard the correlation between scotopic pupil diameter and poor LASIK results, many patients are receiving compensation for it.

It is unfortunate that no surgical correction can guarantee 20/20 vision. For legal reasons, it is essential that any and all parameters that pose a potential risk need to be properly screened to prevent non-reversible complications.

LASIK complications have produced information leading the surgical community to a better understanding of pre and post treatment ablation zones versus actual optical zones. Research shows that effective optical zones appear to shrink a few months after the process. Studies also demonstrate that the functional optical zone after LASIK is smaller than the lasered zone because it shrinks as the cornea heals. In addition, “higher amounts of pre-op myopia generally result in greater amounts of optical zone regression”. One study demonstrated functional optical zone regression to an average of 1.2 +/- 0.68 mm after LASIK. This important research has helped determine how previously unexplained night vision problems have had a tendency to worsen months following LASIK.

ORTHOKERATOLOGY:

Many practitioners and patients believe a corneal reshaping technique known as Orthokeratology to be much safer than surgical intervention. The original form of Orthokeratology, also known as corneal molding, has been available since the 1940’s. This procedure provides patients with independence from glasses or contacts during the waking hours, as does LASIK, but its effects are completely reversible or adjustable for optimal treatment success. Orthokeratology patients enjoy freedom from contact lens
induced symptoms such as dry and scratchy eyes. Many also get more pleasure in outdoor sports and recreation when independent from spectacle lenses. Some patients with lower prescriptions undergoing Orthokeratology may even be successful with only two or three treatments per week. The ease of use and non-invasive aspects of the procedure are the primary factors motivating many to seek out optometric physicians capable of fitting these lenses. Patient satisfaction continues to rise and will likely be the driving factor of successful treatments of Orthokeratology.

The presence of myopia is increasing steadily in epidemic proportions especially amongst younger populations. Most refractive errors are unstable and likely to increase throughout the adolescent and teen years. Orthokeratology is the ideal treatment for the young myopic population because, “not only does it have the advantages mentioned previously, but the procedure also appears to stabilize or retard the progression of the myopia”.

The mechanism of this procedure is very similar to LASIK in that it attempts to flatten a zone in the central cornea, therefore focusing images at the fovea. Just as scotopic pupil diameter is an essential screening measurement for LASIK, it is also beneficial in determining Orthokeratology candidates. Treatment zone sizes highly correlate with the power of correction needed. While under scotopic conditions, the treatment zone should not be smaller than the dilated pupil. If such circumstances were violated, differing powers of the cornea would create aberrations and focus unequal images through the pupil causing halos, glare, and monocular diplopia. Some Orthokeratology distributors have listed large pupils of >6mm in dim illumination as one of the contra-indications for the procedure. A factor that may help minimize the effects of optical zone diameter when compared to LASIK is that the Orthokeratology lenses gradually decrease in power over an area known as the blending zone that is larger than the “treatment zone”. By smoothing out the transition zone, aberrations are less likely to occur which decreases the magnitude of halos, glare, and monocular diplopia. Blending zones are improving the success of Orthokeratology fits, but physicians should not overlook the importance of scotopic pupillometry while choosing proper candidates for the treatment.
CONTACT LENSES: SOFT.

Many applications exist for the use of accurate pupillometry while fitting contact lenses. Traditionally, soft and rigid gas permeable (RGP) lenses of known parameters have been placed on the eye to begin the evaluation process. This trial and error method was often repeated multiple times to find an appropriate diagnostic lens. Practitioners have been forced to maintain a level of patience with this method primarily due to the unavailability of proper instrumentation. Keratometric readings and horizontal visible iris diameters (HVID), also known as "effective K readings", provide the needed information to accurately calculate a base curve of an appropriate diagnostic lens.\(^{(21)}\) The ability to determine an appropriate diagnostic lens helps the practitioner save time with the fit and improves patient satisfaction by eliminating excessive patient discomfort from the insertion and removal of multiple trial lenses. Sagittal height of the cornea is another very important parameter affected by the horizontal visible iris diameter. The HVID helps insure that lens edge will adequately drape the corneal limbus.\(^{(21)}\)

Clinical soft lens fitting guides can be successfully consulted when the HVID is between 11.60mm and 12.00mm. When HVID values fall outside of this range, research has found that certain fitting factors need to be used to adjust the base curve selection. Proper selection of a trial base curve can be determined by following three essential steps. First, obtain central K values. Second, measure the HVID. Third, for every 0.2mm larger than the average 11.8 corneal diameter, add one diopter to the horizontal K value, and for every 0.2mm smaller than the average 11.8 corneal diameter, subtract one diopter from the horizontal K value.\(^{(22)}\) When this factor is applied to patients with corneal diameters that are larger or smaller than normal the chance of selecting the appropriate base curve significantly improves. HVID measurements play an obvious and critical role in the design and fitting process of soft contact lenses.\(^{(21,22)}\)

CONTACT LENSES: RIGID.

The ABBA optical fitting guide for RGP lenses states, "the parameter most frequently overlooked by practitioners is the appropriate selection of the overall lens diameter which should be based on the corneal diameter or HVID.\(^{(23)}\) From the corneal diameter, a simple rule of thumb states that the lens diameter should be 2.5mm smaller..."
than the HVID. \(^{(24)}\) As with soft lenses, RGP fitting often requires a trial and error approach which requires the use of anesthetics for patient comfort. With the proper information, one can accurately choose a diagnostic lens that will more easily be tolerated by the patient.

TRANSLATING RGP'S:

A recent article out of the Review of Optometry optimistically discussed the increasing trend of a large emerging presbyopic population and their desires for vision care. \(^{(25)}\) As a result of this trend and growth of the presbyopic population, many are researching diverse treatment methods. Various degrees of skepticism regarding surgical procedures, monovision, and spectacles, have created a desire for new and improved translating contact lenses within the presbyopic community. Fitting instructions of translating bifocal contact lenses advise corneal and pupil diameter measurements to be evaluated in both mesopic and scotopic conditions. \(^{(24, 26, 27)}\) In summary, HVID measurements can assist practitioners in accurately choosing the proper diagnostic lens when fitting any type of lens to improve patient care and satisfaction.

SYSTEMIC DISEASE RESEARCH:

In addition to LASIK, Orthokeratology, and contact lenses, corneal and pupil diameters are being used to assess the function of many systemic disease processes. Observation of ocular responses to autonomic stimuli is being studied to assess many elements of physical health. Systemic and physiological functions can be adversely affected by many of the most common disease processes.

Scientists are currently involved in research regarding the assessment of autonomic nerve function by way of pupillometry in adolescents with type 1 Diabetes Mellitus. Diabetic medical research has found many interesting correlations with slow pupillary constriction and the degree of the disease process. For example, adolescents with abnormally low pupillary constriction have shown to have higher levels of glycolated hemoglobin in their blood. \(^{(28)}\) In fact, the summary of one such article states that "pupillometry appears to be a more sensitive test of autonomic nerve dysfunction in adolescents with diabetes than the most commonly used test or assessment of"
cardiovascular reflexes" (I.E. treadmill evaluations). Additional studies are evaluating the amount or abnormality of pupillary dilation in low illumination situations of diabetic children. The degree of rubeosis in conjunction with central retinal vein occlusion (CRVO) has also been associated with abnormal pupillary reactions in many patients with CRVO. The degree of these abnormalities has a relationship to the development of rubeosis and might prove useful in planning the follow up of these patients or in deciding whether to apply pan retinal photocoagulation. In short, pupillometry is a method that can provide valuable data collection concerning the functioning of the autonomic nervous system.

Many reports are beginning to surface regarding the usefulness of pupillometry in the research of various conditions including depression and Alzheimer’s disease. Scotopic pupillometry is expected to continue to be a useful research tool in the study of many diseases that have the potential to affect the autonomic nervous system functions such as, alcoholism, myasthenia gravis, cancer, and multiple sclerosis. Although the previous disease processes could be evaluated through scotopic pupillometry, HVID can assist medical professionals in diagnosing disease processes in infants such as infantile glaucoma and megalocornea.

INSTRUMENTATION:

Valuable uses for accurate pupillometry in the eye care profession continue to drive a search for an accurate measuring. Jack T. Holladay MD wrote an article entitled “The High cost of inaccurate pupillometry”, which provides evidence for the need of better pupillometry instrumentation at a more affordable price. Many physicians obviously feel that even with improvements of technology, they are not yet satisfied with the available instruments or the costs. Dr. Holladay also shows a comparison of various products on the market that will be discussed here. With greater public awareness, Dr. Holladay states, “good refractive surgery outcomes demand and patients have come to expect precise measurement of pupil size”.

A comparison and evaluation of current scotopic measurements is needed to clarify the problems that practitioners face in correctly assessing the scotopic pupil.
Surgeons involved with the earliest LASIK procedures often trusted dim illumination pupillometry during pre-op evaluations. This historic method allows for multiple sources of variability and error including: patient and room set-up differences, physician technique variability, and variations in the amount of illumination needed for differing iris pigmentation. Unfortunately, iris pigmentation is often overlooked, but an increased level of illumination creates an additional pupillary constriction, which can cause a gross underestimation of the actual pupil diameter. The historic approach suggested that the physician trusted values obtained by averaging ten different measurements. Valuable clinic time of both the physician and technician was utilized on such measurements. Studies show that obtaining scotopic pupil dimensions under dim illumination methods have a variability of $+1.3$ mm, which in the case of LASIK could create devastating outcomes for many patients. \(^{(41)}\)

Accommodation is another factor that can cause pupillary constriction via the accommodation/convergence near triad. Most practitioners attempt to relax unwanted accommodation by having the patient fixate on a distant target. Darkened rooms often need an additional source of illumination to display such a target, which can potentially elicit a consensual pupillary constriction. As LASIK continues to gain momentum, the quest to produce instruments capable of accurate scotopic pupillometry measurements continues to be developed. Plastic key shaped millimeter rulers were first invented in hopes of getting closer to the eye making it easier to accurately approximate the pupil diameter. Many versions of millimeter rulers have since been produced, but the need for proper illumination continues to present the same uncontrollable variables that previous methods faced.

The most common simplified methods used today include the standard mm ruler, key whole, Rosenbaum, Novelty cards, and Holladay pupil gauges.\(^{(35-41)}\) Below are examples of only a few of these millimeter ruler methods.
Attempts to design pupillometers have produced a wide range in instrument complication. Many products have been over-simplified which requires perfect accuracy on the part of the physician or technician, while others have become so complicated and expensive that physicians cannot afford to use them. Current literature and surveys seem to support the idea that physicians would prefer a product that would provide both affordability and accuracy. 

Infrared (IR) light sources have been implemented in the production of scotopic pupil measurement instrumentation, which create effect pupillary constriction minimally when compared to other light sources. Keeler distributes the Pupilscan II model 12A, which has an IR light source and a digital readout of the measurements taken. Keeler claims that the Pupilscan II is accurate within +/- 0.1mm of the actual pupil diameter.

Accommodative pupillary constriction is still a possible cause for error but has been addressed by having the patient fixate on a distant object. The price of this instrument is approximately $1,800.00.

Colvard, another IR instrument produced by Oasis Medical, uses a graduated reticule that overlays the iris. The practitioner must align each pupil margin with the superimposed millimeter ruler to make an accurate measurement.
An eyepiece must be adjusted so that the reticule is in focus at the time of each measurement in order for it to be accurate. Oasis also claims that this battery-operated instrument has an accuracy of reticule to +/- 0.1mm. Instructions require the examiner to turn off all lights and open the door about two inches to approximate nighttime driving levels. The price of this instrument is approximately $1,600.00.

Keeler also distributes a binocular pupillometer known as the Procyon P2000SA in the United States, which comes with price tag of approximately $12,000.00.

This is an infrared video camera system that works by capturing ten pupil image sizes in two seconds and averages those to give a final result. An optical infinity target is also used to control the accommodative constriction response. This instrument has the capability to measure the pupil size at three light levels: the scotopic, low, and high myopic ranges are given upon completion of the measurement. Accuracy of the Procyon P2000SA instrument claims to be within +/- 0.1mm of true pupil size.

Corneal topographical instruments also have the ability to measure scotopic pupil sizes from the placido ring projections. Several studies have concluded that though corneal topographers are able to consistently obtain repeatable pupil diameter values, the
excess luminance of the placido rings causes an underestimation of the largest possible scotopic pupil diameter.\textsuperscript{(30)} The Humphrey Masterview, Alcon Eye Map, and Technomed C-Scan have been compared to one another in pupillometry measurements and the results will be shown later.

The average price for the topographers equipped with this capability is approximately $12,500.00 to $17,500.00.

To solve the issue of proper illumination variables, Cobalt blue light effects have been studied on as a possible standardized light source. Unfortunately, aberrant wavelengths within the cobalt blue light continued to penetrate the eye causing pupillary constriction equal to that of previous incandescent light sources. Others have assessed the function of slit lamp green light in comparison to common IR techniques. Silt lamp green light proved to have reproducible results in the measurement of scotopic pupil diameter. However, for larger pupils, the slit lamp green light also overestimated the diameter by up to .35mm over that of the IR instruments.\textsuperscript{(42)}

RESULTS OF COMPARISON STUDIES:

A COMPARISON OF SCOTOPIC PUPIL MEASUREMENTS USING THE COLVARD PUPILOMETER AND SEKUNDO’S SLITLAMP GREEN LIGHT TEST:
Reproducibility of any technique is a necessary component of equipment evaluations. Sekundo’s method used a Hagg-Streit slit lamp with a vertical green light. The method produced data suggesting that the average of 100 patients had scotopic pupil diameter of 6.4mm (± 0.9mm). The same patients were then examined by the Colvard system, which recorded a scotopic pupil diameter of 5.99mm (± 1.0mm). The summary report of the comparison stated that the 3.5mm difference between each method was probably due to the fact that the slit lamp green method measured the vertical component whereas the Colvard system measured the horizontal dimensions. Statistical analysis demonstrated that the reproducibility of the slit lamp green method was as good as or better than that of the Colvard system. (42)

USE OF A DIGITAL INFRARED PUPILLOMETER TO ASSES PATIENT SUITABILITY FOR REFRACTIVE SURGERY:

This study examined the eyes of 58 patients presenting for refractive surgery assessment. The P2000 SA pupillometer (PROCYON) was used to evaluate the eyes in a binocular infrared dynamic fashion. Though the study did not compare two instruments, the dual function of monocular versus binocular measurements was compared. Hippus and anisocoria proved to be complications while taking measurements. Such complications demonstrated that there was an appreciable amount of pupillary motion during measurements of various illuminations. The pupillary motion proved to demonstrate errors greater than ± 1.0mm overall. Final comments regarding the study emphasized the need of multiple binocular measurements for maximal accuracy. (43)

TO EVALUATE THE ACCURACY AND REPEATABILITY OF PUPIL-MEASURING MODULES OF CORNEAL TOPOGRAPHY DEVICES:

Pupillometry was done with three corneal topography devices and with an infrared pupillometer under luminance-matched conditions. Mean pupil diameter measurements with the Technomed C-scan were found to be 3.35mm, the Humphrey Masterview data revealed a mean of 2.96mm, Alcon’s EyeMap found mean pupils at 2.34mm. Pupillometry was also performed with an infrared device and found that the
mean scotopic pupil was 5.94 mm. Although topography pupillometry was repeatable for each individual instrument, the effect of the luminance from the Placido rings caused a gross underestimation of actual pupil size. Final comments stated, “We do not recommend using pupil diameters measured by topography to preoperatively determine halo-related safety.”

**COMPARISON OF THE PUPIL CARD AND PUPILrometer IN MEASURING SCOTOPIC PUPIL DIAMETERS:**

The Rosenbaum system was used as a comparison to the Colvard pupillometer. Pupillometry was performed with each instrument by two different examiners on 58 patients. Results of the study showed that the repeatability of the Colvard was +/- 0.8 mm, while the Rosenbaum was +/- 1.3 mm. The conclusion of this study stated that “Examiner bias” was the greatest variability for the use of both instruments. Surgeons were advised to assume a pupil size 0.5 to 0.8 mm greater than the measured zone when calculating optical zones for refractive surgery.

**REPEATABILITY OF INFRARED PUPILometry AND THE ROSENBAUM COMPARISON METHOD:**

Although this study was conducted similarly to the previous study listed, the results did not perfectly correlate between the two. The mean repeatability of pupil diameter for the Rosenbaum card varied between +/- 1.0 to 1.2 mm and the infrared measurements varied from +/- 0.6 mm to 1.4 mm suggesting poorer repeatability for the infrared system. Conclusions stated that range of agreement between the Rosenbaum and the infrared system was large. The Rosenbaum method consistently over-estimated the accurate pupil size, but the infrared system had poorer repeatability.

**SUMMARY OF THE STUDIES:**

Previous information regarding each of the systems evaluated in these studies provided data from the manufacturers claiming accuracy within +/- 0.1 mm. Though manufacturers are highly optimistic about their devices, reality demonstrates a wide range of variability when placed in the hands of researchers and physicians. None of the
studies available for review agreed with manufacturer claims of having such high accuracy and repeatability. In many cases the hand held pupil gauges were more repeatable than the IR systems. Repeatability ranges for all systems, regardless of the cost, would probably be best stated as having the ability to accurately assess the scotopic pupil diameter down to +/- 0.8mm. Unfortunately, for many patients, scotopic pupillometry is a critical measurement and +/- 0.8mm allows too much potential for unsuccessful refractive surgery and may cause many complications.

Corneal topographers are very valuable in certain areas; however, topography usage should be limited to the main function of creating a corneal topographical map. Topographers have not proven to have any place in the market to assess scotopic pupillometry.

**PROBABLE CAUSES FOR ERROR AMONGST METHODS:**

Many measurements are static and do not account for ocular fluctuations. Others require the practitioner to align one end of a reticule with the edge of the structure in question while rapidly changing focus back and forth from the other edge to estimate the measurement. Strict operational tactics such as these assume but cannot guarantee that the alignment remained fixed at the initial position while taking the measurement. A slight deviation or minor eye movement could easily be the source of very inaccurate results. The addition of lighted fixation targets still allow for micro eye movements that can cause measurements to be off up to +/- 1.5mm. Significant errors such as these could influence the presence of nighttime visual problems following refractive surgery.

In closing, it is important to understand that physicians commonly gather both subjective and objective information when diagnosing and treating patients. While subjective information is crucial, the ability to acquire and use objective information is essential to the art of medicine. For this reason, wise physicians have remained skeptical to sources currently used in the acquisition of information regarding scotopic pupillometry. There seems to be little on the horizon to improve scotopic pupillometry. I guess we will just have to wait to see what the technological industry produces to eliminate error in this crucial measurement.
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