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Anterior segment photography - An evaluation of the various techniques and films

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Abstract

This paper investigates some of the various methods of photographing the anterior segment of the eye. It deals with slit lamp photography, macrophotography, and hand-held photography and points out the advantages and disadvantages of each. Various films including color negative, color slide, and infra-red film were also employed in order to determine the benefits of each. The Hentor slit lamp is dealt with in particular in order to develop photographic attachments for it. This paper also explains why ocular photography is important and how to do it.

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ANTERIOR SEGMENT PHOTOGRAPHY

AN EVALUATION OF THE VARIOUS TECHNIQUES AND FILMS

by

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Of the Requirements of the Degree of Doctor of Optometry

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Abstract:

This paper investigates some of the various methods of photographing the anterior segment of the eye. It deals with slit lamp photography, macrophotography, and hand-held photography and points out the advantages and disadvantages of each. Various films including color negative, color slide, and infra-red film were also employed in order to determine the benefits of each. The Mentor slit lamp is dealt with in particular in order to develop photographic attachments for it. This paper also explains why ocular photography is important and how to do it.

Introduction

Photography is a very practical and precise method of data recording. In the health care professions the eye has been the subject of much photographic research. Ocular photography was first attempted in the middle of the 19th century[1]. Since that time the sophistication of anterior segment photography has progressed along with the state-of-the-art of general photography.

In the 1930's and 1940's there was increasing interest reflected in the ophthalmic literature regarding photographic documentation of ocular pathology. Knighton[2], Irvine and Stimson[3], Bogart[4], Ketzin[5], and Landers[6] developed methods of anterior segment photography utilizing the general close-up photography techniques of plus lenses and extension tubes. Abrahamson[7,8,9] reported on a simple technique for taking anterior segment photographs with extension tubes between the camera and lens and ordinary light bulbs for illumination. He later refined the method by incorporating a macro lens for higher magnification and strobe lighting for more efficient illumination.

Since the introduction of the single lens reflex (SLR) camera, the SLR has become the most popular camera used in ocular photography. Numerous investigators such as Dine[10], Bailey[11], and Sussman[12] have delineated the advantages of the

SLR over other types of cameras. Some of these advantages include a view finder which shows exactly what will appear on the film, focusing screens which allow quick precise focus, high quality interchangeable lenses, and numerous available accessories. Other cameras which have been used include Instamatic, Poloroid, and range finders which have the inherent problem of view finder paralax. Koetting[13] and Crosby[14] have employed these cameras in blacklight photography where high magnification and resolution are not extremely important.

Most monocular macrophotography of the eye has been done using magnifications of 1:2 or 1:1; however, in 1970 Brown[15] reported using up to 10:1 magnification successfully. He also states some of the disadvantages incurred by the use of high magnification; the field of view is reduced, the depth of focus is reduced, and the effective f-stop is increased thus reducing the amount of light reaching the film. These all create problems with subject movement during the necessarily long exposure.

The most recent work in macrophotography of the eye has been done by Bailey[11,16], Ciuffreda[17], and Gutner[18]. Bailey[11,16] reviewed the various macro techniques and utilized an electronic flash for illumination. Ciuffreda[17] reviewed all the available macrophotography equipment and commented on the advantages of each. Gutner[18] described a convenient hand-held macro set-up.

The simplest form of close-up photography is the use of plus lenses over the camera lens. Either commercial close-up lenses or ophthalmic lenses may be utilized as suggested by Cyr[19]. For low power lenses the results are satisfactory but high power lenses result in distortions.

A second method of macrophotography employs extension tubes or bellows, both of which allow an increased lens to film distance and a decreased object to lens distance which results in magnification from the Image/Object ratio. The lens may also be reversed which will allow better abberration control since the lens is designed for an object distance at least ten times greater than the image distance. Photography employing a bellows or extension tubes results in high quality photographs but the effective f-stop is increased by the factor:

$$\text{Effective f-stop} = \frac{(\text{marked f-stop}) \times (\text{extension} + \text{focal length})}{(\text{focal length})}$$

This necessitates a longer exposure time.

Another means of increasing the magnification is to use a tele-converter which effectively doubles or triples the focal length of the lens while retaining its original close focusing distance which telephoto lenses do not normally have. The result is greater magnification with a long comfortable patient to lens working distance. The disadvantages of this are that the resolution is degraded somewhat and the effective f-stop is doubled or tripled.

The last method of using a special macro lens will probably produce the best results since it is specially made for this type of photography. However, it is also one of the most expensive methods. The bellows and extension tubes allow the most magnification of any of these methods. Several of the methods may be incorporated together at the same time for even greater magnification.

The first successful use of photography through the optics of a slit lamp was by Goldmann[1] in 1940. Early slit lamp photographs were difficult due to the need of coincident focusing of the optics and light beam and the low light levels present. Brent[20] and deGuillebon & Lee[21] included electronic flash in the slit lamp illumination system. DeGuillebon and Lee[21] cited the advantages of the use of flash as: 1) short exposure time due to the higher light level, 2) elimination of the disturbing effects of the patient's voluntary and involuntary eye movements, and 3) satisfactory depth of field and illumination for photographic documentation of corneal, lenticular, and fundus pathology. Zeiss and Nikon now manufacture photographic slit lamps with electronic flash capability.

Recent literature focuses on the use of the Nikon and Zeiss slit lamps in photography. Kaps[22] published a review of slit lamp photography with emphasis on the use of the Nikon and Zeiss slit lamps. Rengstorff and Krause[23] developed very complete exposure tables that apply to the Nikon slit lamp. These tables are for corneal photography but the exposure and flash settings can be modified slightly for general slit lamp photography. Rengstorff and Krause[23] found that light requirements increase as magnification increases and recommended 16X as a maximum magnification for most photographs.

Skolnik and Baumann[24] developed a technique for use with the Nikon slit lamp which does not use the flash attachment. Pictures are taken using only the normal slit lamp illumination system. Shutter speeds of up to one second are needed which requires instructing the patient to remain as still as possible during the exposure. Skolnik and Baumann[24] devised the non-flash techniques after having two failures of the flash unit. They concluded that clinically useful pictures can be taken without the added cost of the flash unit and without the necessity of adjusting an auxiliary piece of equipment.

There is some published literature involving the use of the Haag-Streit slit lamp in photography. DeGuillebon and Lee[21] developed an electronic flash for the model 900 Haag-Streit slit lamp. No details are given on the exposure settings used.

No literature was found on the use of photography in conjunction with the Mentor, Marco, or Topcon slit lamps. Mentor and Topcon have recently marketed 35mm photographic adaptors, although no auxiliary flash unit is available.

Also we could not obtain any literature about the adaptation of cameras to slit lamps that do not have commercially available adaptors.

The majority of anterior segment photography to date has been done with black and white and color film which is sensitive only to the visible spectrum of light. However, there has been considerable investigation into the use of infra-red (IR) sensitive film as well. Infra-red photography was discovered by Vogel in 1873[25]. Mann[26], Feldman[25], and Clark[27] have reported on some of the clinical uses of IR photography. The main use of IR film in anterior segment photography seems to be to penetrate dense corneal opacities which scatter visible light. Opaque areas on the cornea have little or no effect on the transmission of IR light. This allows ocular structures behind the opacity to be photographed. Infra-red photography has also been used to photograph and monitor pupil size in the dark.

The most recent literature on IR photography uses color IR film. This film gives a color picture but some colors are altered depending on the IR reflectivity of objects in the picture. Shigekawa, et.al.[28] reported that a melanoma of the iris appeared larger and more defined when photographed with color IR film rather than normal color film. In fundus photography, Dallow[29] reported that pigmented tumors are more defined when photographed with IR film.

Most authors favor the use of Kodak High-Speed Ektachrome film for color anterior segment photography. Bailey[11], Goodlaw[30], Rengstorff and Krause[23], and Ciuffreda[17] reported their preference for High-Speed Ektachrome (ASA 160) in macrophotography and slit lamp photography. Skolnik and Baumann[24] used ASA 125 tungsten color balance film but developed it at ASA 320. Goodlaw[30] also notes that ASA 160 film may be developed at an ASA rating of 400. This method of processing will enable lower light levels and shorter shutter speeds to be used. This would be of use in high magnification and non-flash slit lamp photographic applications. No data has been presented on the use of other high speed color films in ocular photography.

With black and white photography, Ciuffreda[17] recommends Kodak Plus-X (ASA 125) film in macrophotography techniques. In their work with the Nikon slit lamp, Rengstorff and Krause[23] used Kodak Tri-X (ASA 400) film.

After searching the literature it is obvious that photography has become an important documentary tool which should be utilized by the vision care specialist. This is becoming increasingly important today for medical-legal reasons. DiChiara[31] has a comprehensive list of the reasons for having photographs as part of a patient's record. Goodlaw[30] states:

> "The differentiation of tissue changes due to active pathology from benign changes, scarring, or congenital abnormalities which do not further threaten visual well-being may not always be made on first observation. Often repeated observations over a

period of time can be the only means to determine that tissue is changing abnormally. Therefore, a technique which permits comparison of the tissue as it was to what it is now can be a valuable aid in differential diagnosis. Furthermore, a technique which permits quantifing the changes will add precision to the quality of observations and accuracy to decisions. Photography provides just such a technique."

There have been articles published about slit lamp and non-slit lamp photography but none really suggest which method is best for the optometrist to use. Since there has not been literature published about the use of the Mentor and other slit lamps, we directed our research at developing photographic systems for these slit lamps and comparing them to other slit lamps and out of slit lamp techniques.

Methodology

This project investigated the following questions and the answers were provided by the methods following each question.

1. What method of photography yields the best information in a given situation and provides convenient and economical use? What are the advantages and disadvantages unique to each of the various techniques of macrophotography and slit lamp photography?

Single lens reflex camera systems were chosen for use because of their versatility and ease of use in both slit lamp and macrophotography. Other types of cameras did not offer these advantages and were not used.

We examined four methods of macrophotography. The first is a close-up lens system where a plus lens is added to the front of the normal camera lens so that close focusing can be attained. The second type of macrophotography we investigated was the use of an adjustable bellows. This increases the lens-camera distance to create magnification and closer focusing. The third method also increases the lens-camera distance by the use of extension tubes. The fourth method is the use of a macro lens which is specially designed for close-up photography. A 2X tele-converter was also incorporated into the macrophotography methods to see what advantages could be obtained.

Through use of each of these systems we gained information on their practicality and effectiveness in a clinical setting. Patients were photographed with each macrophotographic method and the resulting photographs compared with respect to clarity, depth of field, evenness of illumination, and ability to record the desired information. Slit lamp photographs of patients were also compared. There was an evaluation of the ability of each method to record the desired details.

An electronic flash was used for illumination in macrophotography. During blacklight photography of fluorescein patterns, filters were employed to enhance the visibility of the fluorescein pattern. Additional comparisons of the utility of macrophotography and slit lamp photography were made in the recording of contact lens fitting.

We determined which slit lamps could be modified for photography with a simple adaptor which we developed. At present there are several slit lamps that have no commercially available photographic adaptors or that have photographic attachments that are quite expensive and complex. We perfected photographic techniques through several slit lamps in an effort to determine the utility of our adaptor.

2. What information is gained by the use of different types of film including black and white, color slide and print film, and infra-red film?

Normal and pathological eyes were photographed with each type of film. We could then see if one film type had an advantage in revealing details of the object of interest. The films were also evaluated as to their relative cost per picture.

Most slit lamps do not have auxiliary flash attachments for photography. We used the new high speed color slide and print films to help eliminate the long exposures usually necessary without a flash.

We also used infra-red film to see if this specialization is of use to the optometrist. There are reports of the use of IR film in cases of corneal opacities and iris melanomas.

3. Is the additional data gained by the use of these photographic techniques and films of clinical importance such as an aid in early detection of pathology or monitoring changes in pathology?

These techniques and films were assessed as to whether they provided the desired results. These photographic methods were employed in Pacific University's Electrodiagnostic Clinic where accurate recording and follow up care is important. Patient's pictures taken during the project were incorporated into their clinical records at Pacific University.

Results

Macrophotography:

Our investigation of the various macrophotography methods available was influenced by the factors of economy and ease of use. These two factors will be of highest priority in an optometrist's decision of whether or not to incorporate photography into his practice, and therefore we gave them high priority in our study. There are four common methods of macrophotography as outlined in the introduction. These methods involve the use of close-up lenses, macro lenses, extension tubes, and bellows.

Close-up lenses were not investigated in depth because the advantages present were not sufficient to make this method desirable over other available methods. Close-up lenses are inexpensive ($20) and are easily used. The disadvantages are significant, though. A 1:1 magnification ratio is the maximum practically available with close-up lenses. A 1:1 ratio corresponds to a picture that covers an eye from canthus to canthus. This requires a total of 20 diopters of plus lens in combination with the normal 50mm lens, resulting in a working distance of 5cm between the eye and lens. Other methods gave increased magnification with a longer working distance. We also felt that the optical quality of pictures taken with close-up lenses would deteriorate rapidly as the magnification approached 1:1.

A second method of macrophotography that was not investigated fully was the use of a macro lens. We believe that a macro lens would not prove to be any more useful than other methods that we developed in detail. A macro lens has the disadvantages of costing $150-$200 and has limited versatility in areas other than close-up photography. Although the optics are designed specifically for macrophotography, resulting in better image quality, we did not have any problems with picture quality with less expensive methods. A macro lens is designed to give a better flat field image than can be obtained with the other close-up photography methods. When a picture is taken of a flat object, a macro lens will give reduced aberrations and curvature of field at the edges of the picture. The anterior eye is not a flat field, so a macro lens could be questioned as to whether it would have a significant optical advantage in the case of anterior segment photography. Macro lenses can give 1:1 to 2:1 magnification.

In short, a macro lens does not have any outstanding advantage that would justify its expense over other methods of macrophotography. We had no problem with image quality with other macrophotography methods, so we did not feel the need to look closely at macro lenses.

The macrophotography methods that we worked with extensively were the use of extension tubes and adjustable bellows. Extension tubes and bellows both increase the lens-camera distance to give closer focusing and increased magnification. A bellows gives more range of adjustment and provides more extension and magnification than do extension tubes. A bellows is bulkier than extension tubes and requires a tripod for steady support.

Extension tubes and bellows can be used with the normal 50mm lens supplied with most single lens reflex cameras. There is no need to buy another lens specifically for close-up photography. Extension tubes cost from $40-$60 and a bellows costs from $70-$135. We used the automatic type where the automatic aperature stop-down is carried mechanically through the bellows or extension tubes to the lens. While more expensive than non-automatic types, the automatic extension tubes and bellows are handier to use and are more generally available.

The camera system used was Canon. The accessories used in this study are standard items that can be found in any SLR camera system. A set of three extension tubes; 12mm, 20mm, and 36mm lengths were used in conjunction with the standard 50mm f1.8 Canon lens and the Canon FTb and TX camera backs.

Using all of the extension tubes (to give 68mm of extension) it was possible to obtain 1.4:1 maximum magnification. This gives a complete eye picture that includes both canthi. With the use of the 12mm tube only, bilateral eye photographs are possible. This system worked very well for hand-held anterior eye photos. A flash was used and will be described later. The use of extension tubes and the 50mm lens gave acceptable photographs with no problem of distortion. The range of magnification is adequate for general anterior photography where a full eye picture is desired.

Later the use of a 2X tele-converter was combined with the extension tubes to give greater versatility in magnification and working distance. A tele-converter is an accessory that is placed between the lens and the camera. It costs $20-$40. The purpose of a 2X tele-converter is to double the focal length of the lens (e.g. a 50mm lens becomes a 100mm lens in characteristics by using the tele-converter). This gives a telephoto effect when used with the lens alone. We used the tele-converter in an unconventional manner by combining it with the extension tubes and the lens. The effect of the tele-converter was to increase the working distance and increase magnification. 2:1 magnification can be obtained by using the tele-converter-extension tube combination and still maintain a working distance of 25cm. There are many possible placements of the tele-converter in relation to the extension tubes. By trial and error we found combinations to give 1:1, 2:1, and bilateral pictures. These combinations are outlined in Appendix I. 2:1 magnification includes slightly more than one iris width, or a field of about 17mm. This camera system is easily operated and can be hand-held without problem.

We developed a photographic system utilizing the bellows which was designed to give higher magnifications than could be easily obtained with a hand-held extension tube system. Since the bellows is bulky and the amount of extension is great, the camera system had to be set on a tripod. A simple table-top camera stand was constructed from aluminum flat stock. A small instrument table was used with an attached head rest. Fine focusing is necessary at high magnifications and the head rest helps minimize any problems of patient movement. The flash is mounted on a flexible arm attached to the head rest.

With the use of full bellows extension and extension tubes, a lens-camera distance of 208mm could be gained (the bellows is 140mm long at full extension and total extension tube length is 68mm). This resulted in 4:1 magnification with 9mm of field. Working distance between the lens and eye at this maximum magnification was 4-5cm. This created much difficulty in lighting the eye evenly because of the limited area for placement of the flash between the camera lens and the eye. The pictures taken at this magnification were fair, but it was quite difficult to set up due to the close proximity of the lens, eye, and flash.

We then decided to incorporate the 2X tele-converter into the bellows system. This increased magnification and working distance. The maximum magnification available through use of the tele-converter is nearly 7:1 with a working distance of 6-7cm, making it much easier to use. The increased working distance helped reduce the problem of flash illumination. For tele-converter-extension tube placements in relation to the bellows to give magnifications of 3X to 7X see appendix I. This extends the range of magnification of the macrophotography techniques from bilateral eye pictures up through a magnification where the pupil nearly fills the picture. This has been done with a minimum of accessories and expense.

The picture quality has not been a problem with any of the magnifications used. The use of the tele-converter and the long extensions have no doubt produced unorthodox optical combinations, but the pictures do not seem to have suffered greatly from it. A technique which we did not try is reversing the lens. A normal 50mm lens is designed with the consideration that object distances will be much greater than the image distance. This is the case with normal photography. With the use of lens extension, the image distances become longer than the object distances. The optics in this situation are more favorable if the lens is reversed. There are special adaptors available that allow mounting the reversed lens on the camera. The automatic aperature stop-down can not be used when this is done. Since there was no problem with image quality, we do not feel that the reversing ring is worth the inconvenience.

Another important consideration in high magnification photography is depth of focus. At the lower magnifications (up to 2X), the depth of focus is very adequate. Hand-held pictures are easy at this low magnification since the focus is not extremely critical. At these lower magnifications, all parts of the eye are in focus. As the magnification increases, depth of focus decreases and focusing becomes more critical. The table mounted nature of the bellows system enables more critical focusing. At high magnifications and long extensions, it is difficult to get enough light through the camera system to focus the patient's eye. Room light is not nearly adequate, so an auxiliary light is needed. A small high intensity lamp mounted on a flexible gooseneck is fine for this purpose. This gave enough light to focus without causing undue discomfort for the patient. The hand-held system is easily focused in good room illumination.

Depth of focus in the higher magnifications appears to be adequate as long as the structure of interest is carefully focused. At higher magnifications it is not possible to get the iris and cornea in focus at the same time. This would suggest that the depth of focus is approximately 3mm at 5-7:1 magnification. This could create some difficulty in taking pictures of something with much depth such as lens opacities. Whenever a magnification as high as this is used, the area of interest will usually be quite small and discrete.

Another problem experienced at very high magnifications was the coarseness of the focusing screen in the camera.

Our cameras had standard focusing screens that are used for general purpose photography. A focusing screen is a piece of ground glass in the camera upon which the image produced by the lens is viewed. With the higher magnifications above 2:1, the image became hazy due to the coarseness of the standard focusing screen. This made it difficult to focus on very fine detail such as limbal blood vessels. This problem can very likely be remedied by using a focusing screen designed specifically for macrophotography. It was not possible to replace the focusing screen in our cameras, so we were not able to try a macro focusing screen. A camera that has the feature of interchangeable focusing screens would be of advantage here.

An electronic strobe flash was utilized with the macrophotography techniques to get the proper illumination of the eye. Pictures can be taken with available room light, but this is not practical due to the long exposure times and the large aperatures needed to get enough light to the film through the long extensions. An electronic flash provides an instantaneous, brilliant flash of illumination that freezes movement, allows small aperatures to be used, and causes minimum patient discomfort.

Since macrophotography utilizes close working distances for the flash, only a small flash is needed. We used a Honeywell Strobonar 109 with a guide number of 28 for ASA 25 film. This is about the smallest size flash available. A more powerful flash than guide number 28 is not required from an illumination standpoint. Due to the very small subject to flash distance, the output of the electronic flash must be reduced by aperatures and/or neutral density filters. The flash output can be reduced by masking part of the flash with tape or by using a cardboard cover with the desired area cut out. An alternative is to use a series of neutral density filters to cover the flash to allow only a certain percentage of light to escape from the flash window. An aperature has the advantage of reducing the amount of corneal light reflex caused by the area of the flash window. Neutral density filters have the advantage of easier regulation of the light output. The flash output can be varied simply by changing the number of filters in front of the flash.

We combined the advantages of aperature reduction and neutral density filters by incorporating both systems on the flash. An aperature was constructed of cardboard to cover the flash. The aperature was of a size to allow the maximum amount of light from the flash that is needed for any of the magnifications used. Then a small holder was constructed for neutral density filters to cover the aperature. This enabled the flash output to be reduced further in situations where less light was needed. The aperature reduces the amount of corneal reflex area and the slip-in filters allow easy regulation of flash intensity.

The flash was mounted just underneath the front part of the camera lens in the hand-held system. A bracket was made from flat aluminum that positioned the flash horizontally at the front plane of the lens. The flash could be angled up or down depending on the subject distance. The bracket was attached to the tripod socket on the camera and the flash was attached to the bracket with a hot-shoe adaptor available at camera stores. The flash is electrically connected to the camera by means of a PC cord.

Mounting the flash underneath the lens has several advantages. The flash reflex will occur on the lower portion of the cornea where it will not usually affect the picture. Nose reflections imaged on the cornea are minimized when the light comes to the eye from directly straight ahead. With the flash mounted underneath the lens, no adjustment need be made for photographing right or left eyes.

The bellows camera system requires much shorter working distances due to the high magnification, so the flash was mounted so as to project from the lateral side of the eye being photographed. The flash was mounted on a section of flexible tubing which was attached to the head rest. The flash could then be moved to any desired position much like a gooseneck lamp. The flash was connected to the camera by means of a PC cord. A 10cm distance was maintained between the eye and the flash to keep the amount of illumination standard. This short flash-eye distance was necessary because of the close proximity of the camera lens to the eye.

The greatest problem with the illumination in the bellows system was reflections. Since the flash came in from the side, the nose would often be reflected in the cornea. With high magnifications, the cornea can occupy all of the picture. This makes any corneal reflections more of a problem due to their large size. We reduced the nose reflections to some extent by using a black ring of paper around the eye which covered the nose. Eyelash reflections are usually present, but cause little problem. Projecting the flash from underneath the lens would help these problems, but there is some difficulty with having enough room to position it there.

There are four variables to be considered when calculating the amount of flash illumination needed for proper exposure of the film. They are: 1) output of the electronic flash, 2) distance of the flash from the eye, 3) effective f-stop of the camera system, and 4) the ASA of the film used. We calculated what fraction of the flash output was needed for a picture, then used aperatures and neutral density filters to limit the output to that fraction. The output of an electronic flash is commonly specified as a guide number. The guide number is equal to (flash-to-subject distance in feet) multiplied by (f-stop setting needed for proper exposure). This is usually specified for ASA 25 film. The distance of the flash from the subject is a variable that is accounted for in the guide number formula. In macrophotography the flash is very close to the subject and cannot be considered a point source. This introduces error into the calculations. The effective f-stop of the camera system must be calculated. As the amount of lens extension is increased, the f-stop markings on the lens are no longer correct because of the light loss resulting from increasing the lens-camera distance. The following formula determines what f-stop is in effect in the modified system:

$$\text{Effective f-stop} = \frac{(\text{marked f-stop}) \times (\text{lens extension} + \text{focal length})}{(\text{focal length})}$$

Once the amount of flash reduction is calculated, the flash can be blocked off or filtered to give the desired result. If different ASA film speeds are used, this must be compensated. Doubling the film speed is equal to opening the camera lens by one f-stop. As a faster film is used, the flash output must be reduced or the lens aperature must be closed down one stop.

The amount of light needed when the camera lens was at its smallest marked aperature (f-16) was calculated. This was done to give the largest depth of focus possible. The flash output was adjusted until the proper exposure could be obtained with the lens aperature at f-16.

The procedure for calculating flash illumination is outlined in Appendix II. It must be remembered that this only gives a rough approximation of the flash intensity required. Final calibration of the flash must be done by trial and error.

We used 0.6 neutral density filters which have a transmission of 25%. This gave a two f-stop change with each change of one filter.

The hand-held extension tube system requires a minimum of time and effort to operate once the flash has been calibrated. The shutter speed is a constant 1/60 second when the camera is used with a flash strobe. The f-stop and flash output are set as required for the magnification used. The flash is rotated until it points directly at the eye. The subject is seated in a chair or asked to stand quietly. Normal room illumination is needed for focusing. The examiner moves the camera in and out until the eye is focused in the viewfinder and the picture is taken. Slight movements are of no consequence since the flash lasts only 1/3000 second and any movement is frozen as the picture is taken.

The bellows system is mounted on a table-top tripod. once the subject is seated at the head rest, the tripod can be moved until the camera is centered in front of the eye to be photographed. The tripod can be moved back and forth until a gross focus is found. The focusing rail on the bellows is then used for fine focus. The aperature of the lens is opened completely and the high intensity light is directed at the subject to allow focusing. The flash is positioned on its flexible arm until it is directed at the patient's eye at the desired distance, usually 10cm. After final focusing, the high intensity light is turned off to reduce corneal reflections and the picture is taken.

Fluorescein pictures can be taken with a macrophotography system by using a blue filter on the flash. A Wratten filter No. 47A was used over the flash aperature. This filter transmits only the blue and ultraviolet region of the spectrum. There was some difficulty getting enough fluorescein excitation to show up on the picture. There were two probable reasons for this. One was a tendency to underexpose the picture. We found that a slight overexposure was needed to bring out the fluorescein, resulting in a hazing of the details of the eye. Another reason may be the fact that the cardboard aperature cut the flash window area in one-half. There is a limited amount of UV light available from the flash and this aperature would reduce it significantly. It may be better to use a full flash window and use filters rather than aperatures. This could allow more UV light to be transmitted and thereby increase fluorescein excitation. We did not try using a yellow filter over the camera lens as has been suggested in the literature. This could help increase the fluorescein contrast.

Slit Lamp Photography:

Because of limited financial backing we were unable to acquire the commercially available camera attachment for the Mentor slit lamp. We did, however, design and produce an adaptor which would allow us to take pictures through the Mentor slit lamp. We also found that this design could be adapted for use on the Bausch and Lomb Thorpe, American Optical Campbell, Gambs, Marco, Topcon, and Neitz slit lamps.

Adaptors were made and used on all but the Marco and Topcon slit lamps. See Appendix IV for a diagram of the Mentor adaptor.

The adaptor is mounted on the slit lamp by first removing one eyepiece and setting the instruments P. D. at its widest. The eyepiece is inserted into the camera side of the adaptor. The eyepiece with the adaptor is inserted back into the eyepiece tube of the slit lamp and the three thumb screws are tightened. The camera back is then attached to the adaptor in either a horizontal or vertical position. The camera is put into parfocus by using the normal eyepiece focusing ring and a narrow slit on the focusing rod.

Focusing for a picture is best done by viewing through the camera viewfinder. The focus could be lost if the clinician viewed through the other eyepiece and changed his accommodation.

Exposure setting is accomplished by utilizing the built-in exposure meter of the SLR camera and adjusting the shutter speed. This worked well for pictures using full diffuse illumination. When the illumination was a narrow slit, the light meter became very difficult to read since it was superimposed on a black background in the viewfinder. Through trial and error it was found that shutter speeds of between 1/4 and 1/30 second worked well in narrow slit situations where the light meter could not be read. Optical sections of the cornea were obtained with exposure times of

1/2 to 1 second. Needless to say the patient must be cooperative and hold extremely still. Even at these long exposures good pictures were obtained. In very low light situations a flash system would be a distinct advantage. When the camera's light meter is used, the exposure times vary from 1/4 to 1/500 second depending on the illumination level and the amount of light reflected by the subject matter (e.g. sclera compared to a dark iris). For most pictures and especially narrow slits the illumination should be turned as high as possible to permit faster shutter speeds. A cable shutter release is also helpful on the longer exposures.

The advantages of this system are as follows: 1) inexpensive, 2) simple and fast to mount on slit lamp, 3) easy to use, 4) excellent photographs result, 5) adaptors can be made for slit lamps which have no factory photographic system, and 6) almost any brand of camera that the optometrist may have can be used, such as Canon, Nikon, Minolta, Olympus, and Pentax. The cost of producing one of these adaptors is about $45 and a camera back can be purchased for roughly $150-$200. Thus the system only costs $200-$250 compared to the Mentor factory system which is $885.

The disadvantages of this system are: 1) the low light levels inherent in any non-flash illumination system necessitates long exposure times; 2) difficulty in seeing the light meter in the viewfinder with certain illumination modes such as narrow slits. This may be solved to some extent by using one of the new cameras that have an LED (light emitting diode) readout for the light meter; 3) since the light source is a tungsten bulb, the photographs will have a reddish tint unless a tungsten color balance film is used; 4) the depth of focus is quite shallow at high magnifications; 5) the focusing screen of the camera is somewhat coarse and grainy which makes it difficult to focus on very small details. A different focusing screen may help solve this problem.

The Mentor slit lamp seemed to lend itself better for photographic application than any of the other slit lamps. The Marco and Topcon were not tried but should work identically to the Mentor. The illumination system of the Mentor seemed to be the best of the group of slit lamps tried. The Mentor adaptor allows use of either the 10X or 16X eyepiece as well as both magnifications of the microscope head. This gives four different magnifications which have fields of view of 16, 11, 7, and 5 millimeters. There was one problem with the illumination system in that the largest spot of light is 8mm in diameter. The field of view on the lower magnification is greater than this so the resulting photograph has a small lighted area surrounded by a black void. To circumvent this problem a plastic diffuser was inserted between the light source and the slit lamp mirror. This diffuses the light over a larger area and illuminates the entire picture. The diffuser worked much better than our first idea of using a minus lens to spread the light out. The diffuser can be easily flipped out of the way for slit illumination or higher magnification where it is not needed.

The Bausch and Lomb Thorpe slit lamp was probably the poorest candidate for photographic applications. Its main problem is the illumination system. The slit does not open up to a full spot of light.

The American Optical Campbell slit lamp produced acceptable photographs using this type of adaptor. However, it was not as easy to use as the Mentor.

The Gambs slit lamp had the largest illuminated spot of all the instruments. The main disadvantage of this slit lamp was distortion produced in the periphery of the pictures.

The Neitz slit lamp did not have the sharpness that the other instruments had. With the Neitz you also have to disassemble the adaptor and insert the other eyepiece when you want to change magnification.

Film results:

The ideal film for ocular photography would be a general purpose film which could be used in both slit lamp and macrophotography. One film is desired so that the photographer can get used to its qualities and does not have to change back and forth from one film to another. The film should produce a true color rendition, sharp detail, and have fast, inexpensive processing available. The film should also be a relatively fast film since the illumination level in the slit lamp is limited.

A fast film is one which is very sensitive and does not require a great deal of light to produce the picture. The ASA rating tells how "fast" it is. A larger number ASA is a faster film. When the ASA is doubled, as from 200 to 400, the film is twice as fast and requires only 1/2 as much light to expose it. This means that for a given f-stop the ASA 400 film may be exposed at one shutter speed faster than the ASA 200 film. There are three variables concerned with film exposure; f-stop, shutter speed, and film speed. In the slit lamp the f-stop is a fixed, non-variable factor. The shutter speed is still a variable but can not be too slow or subject movement becomes a problem. Film speed is the other variable that can be used to allow reasonable shutter speeds. We found that an ASA 400 worked well with the slit lamp. This is the fastest ASA that can be practically used and still maintain good resolution of detail. The faster a film is, the grainier it tends to be.

Slides seem to be the format of choice for the pictures. Slide film is capable of producing high quality pictures and is considerably less expensive than color prints. Slides are also easy to store. The disadvantage here is that either a projector or a slide viewer must be set up in order to view them. If a color print is desired it may be obtained from the slide, but image quality is not as good as a print directly from a negative.

Color negatives produce excellent photographs. Some people prefer to look at a print instead of going to the trouble to set up a projector or slide viewer. The disadvantage of color prints is their relatively high cost which is at least twice the cost of slides. There are several new high speed color negative films now available including Kodacolor 400 and Fujicolor 400. We found that Kodacolor 400 produced excellent results and is more available than other brands.

Black and white film has limited use in the modern optometric office. Color is vital to the recording of information in most of the situations that should be recorded for future reference. Black and white film has no cost advantage since it is about the same cost as color slides. We also found that most photographic film processors do so little business in black and white that it takes longer to receive the results.

We investigated several color slide films including Kodak High-Speed Ektachrome, Fujichrome R100, and GAF 500. High-Speed Ektachrome 200 is a very good film that is commonly available and gives excellent results. This film can also be push processed to allow exposure at ASA 400 instead of the normal ASA 200. Push processing is more expensive, but the cost is still less than that of color prints.

Fujichrome R100 is rated at ASA 100 and we pushed it to ASA 400. This resulted in a very grainy picture which also had an extreme reddish tint. For these reasons we found it unacceptable for our purposes.

GAF 500 is rated at ASA 500 which is fast enough to not require pushing. The pictures were quite grainy and unacceptable in comparison to the results from other films.

We found one film which comes very close to meeting our ideal requirements. It is Eastmancolor negative 5247. This is a color negative film and not a slide film; however, the processing lab can make slides from it as well as prints. This allows the doctor to have either prints or slides or both made from it. The 5247 film may be exposed at ASA's of 100, 200, or 400 with no extra processing charge. The color balance can be regulated in the processing depending on whether it is exposed with daylight flash or tungsten light. The processing cost was only $6.00 for a 36 exposure roll and includes negatives, mounted slides, and a replacement roll of film. The processing time from mailing to delivery of slides was about one week. Slides from this film appear to be very sharp and clear even when exposed at a high ASA rating.

We were unable to fully investigate the practical uses of infra-red film in anterior segment photography as intended. Kodak Ektachrome Infra-Red Color film was tried using a

Wratten No. 12 filter over the slit lamp lenses. This film did not permit seeing through corneal opacities as has been reported in the situations where it was tried. It did cause pigmentary deposits on the iris to stand out much better than regular color slide film. Infra-red film may be of value in photographing pigmented growths of the eyes. Overall, we did not find that infra-red film produced a significant amount of information over that provided by regular color film.

Discussion

It is important for the optometrist to photo-document certain ocular abnormalities seen in his patient population. The areas that can be photographed using our methods include: eyelids, conjunctiva, cornea, anterior chamber, iris, pupil, lens, and contact lenses. The optometrist who has decided that he wants to incorporate photography into his patient care routine must decide which type of photgraphy will serve his purposes best. Expense is also a factor because of the high cost of available factory systems. The optometrist who would like to do photography but can not afford these systems can do as we did and build his own system for a considerable savings.

The first and possibly the least expensive method of photography is slit lamp photography. In our method the only necessary equipment is a camera back and the adaptor to mount the camera on the slit lamp. With such a system the practitioner is able to photograph anything that can be seen through the slit lamp. Subtle corneal details can be quite difficult to photograph and a flash photographic slit lamp system would be of advantage here. For general slit lamp photography our adaptor works quite well.

The lighting system of the slit lamp is unique in the various ways that the eye can be illuminated. A slit has the advantage of enabling the optometrist to create an optic section of the cornea or lens to study opacities. This is not possible with a macrophotography system. The problem here with a non-flash lighting system is that long exposures of up to one second are sometimes needed when using a very narrow slit.

The focusing of the slit lamp camera is very simple by use of the joy stick. The camera is easily mounted and removed as needed. The slit lamp camera such as our Mentor system gives magnifications from 2:1 to 7:1. This corresponds to fields of view from 16 to 5mm respectively. These magnifications cover most photographic situations.

There are situations where a slit lamp is not the ideal photographic tool. Less magnification is needed for some larger subjects such as the whole eye including the lids or a bilateral picture showing eye position as in strabismus. In these situations a macrophotography system is the instrument of choice. A handheld apparatus consisting of a camera, lens, extention tubes, tele-converter, and flash will provide bilateral photographs and up to 2:1 magnification. Such a system is extremely handy for taking pictures of children because they do not have to be constrained to sit behind a slit lamp. If high magnification is necessary a bellows can be incorporated to give up to 7:1 magnification. The bellows necessitates the use of a tripod and chin rest in order to allow fine focusing. All of the macrophotography systems produce excellent pictures and are only limited by not being able to produce slit illumination.

Slit lamp photography is better than macrophotography in cases where high magnification is used to observe small fine details. The utility of high magnification in macrophotography has not been fully explored so it is hard to compare them as to picture quality. The bellows system will produce as much magnification as most slit lamps, but it is much more cumbersome to photograph an area of interest with it.

We feel that in order to photograph any anterior pathology that is seen in the clinic the optometrist should have a slit lamp camera and a hand-held camera. The same camera back can be used for both of these systems. The cost of the equipment needed is only about $400 and would be considerably less if the practitioner already has a suitable SLR camera for personal use. If the optometrist does not wish to make his own system, he can purchase commercial slit lamp cameras and macrophotography outfits. These are considerably more expensive. The Mentor 35mm camera attachment is $885 and one commercially available anterior segment macrophotography outfit is $1700.

We recommend using either Eastmancolor negative 5247, Kodak High-Speed Ektachrome 200, or Kodacolor 400 film when doing slit lamp photography. They should all be exposed at ASA 400. For macrophotography we recommend using a slower film such as 5247 or Kodacolor II (ASA 125). Here the fast film is not as necessary because of the flash illumination. Again the Eastman color negative 5247 is the most versatile film since it can be exposed at ASA 100, 200, or 400 and can be color balanced for either daylight or tungsten light.

Fluorescein photographs can be taken with either slit lamp or macrophotography techniques. With the cobalt filter in place on the slit lamp, the illumination is very low, requiring long exposures. Exposures of 1/4 second or more were required. A hand-held close-up system has the advantage of a flash that produces more illumination. The disadvantage of the hand-held set-up is that the fluorescein pattern cannot be viewed without a slit lamp or Burton lamp. The pattern must be checked and then the hand-held system can be used to take the picture. Picture quality appears to be adequate with either method. The lower magnification of the hand-held system allows a better view of the overall contact lens-lid relationship.

Anterior photography has been used more extensively in the electrodiadnostic clinic at Pacific University in an effort to have a more complete record of any external eye problems. Photographs have been taken of patients with pterygiums, iris atrophy, corneal dystrophy, corneal staining, cataracts, and limbal neovascularization to monitor the possible progression of these problems. This is of special importance in a clinic like that at Pacific University where several clinicians will be caring for the patient over a given time period. A picture enables a new clinician to quickly and easily assess any changes in the condition of the eye. Pictures have been taken of congenital anomalies and various traumatic conditions that are not commonly seen so that students will be able to view these things.

If the optometrist incorporates these photographic methods into his practice he should be able to better serve his patients. He will be able to keep more accurate and vivid records on his patients. In this manner slow subtle changes can be observed in the patient and corrective measures taken. The photographic methods described do an excellent job at a reasonable expense and are simple to operate.

Appendix I

Anterior Segment Macrophotography System

1/4:1	(bilateral)	Camera, 20mm tube, 2X tele-converter, lens. Working Distance: 50cm Field: 150mm
1:1		Camera, 36mm tube, 2X tele-converter, 12mm tube, lens. Working Distance: 15cm Field: 35mm
2:1		Camera, 36mm tube, 2X tele-converter, 12mm tube, 20mm tube, lens. Working Distance: 7cm Field: 18mm

These magnifications are used with the hand-held system. The components are listed in the order that they should be placed on the camera. The flash (guide number 28 for ASA 25) is used with 1/2 aperture and no neutral density filters. f-16 is used. The change in working distance compensates for the increased light needed at higher magnifications. This flash calibration is based on ASA 200 film. The f-stop can be changed to compensate for slower films. Example: with ASA 100 film, use f-11.

2.3:1	Camera, bellows (collapsed), 2X tele-converter, 36mm tube, lens. Working Distance: 8cm Field: 16mm
5:1	Camera, bellows (fully extended), 2X tele-converter, 36mm tube, lens. Working Distance: 7cm Field: 7mm

Magnifications between 2.3-5:1 can be obtained by adjusting the bellows length.

7:1 Camera, bellows (fully extended), 2X tele-converter, lens.

Working Distance: 5cm Field: 5mm

With bellows photography, the flash is maintained at 10cm from the eye. The flash calibration has not been completely tested, but 1/2 aperture with no neutral density filters works best at 3-4:1 magnification and ASA 200 film at f-16.

Appendix II

Calculation of Needed Flash Output

Example: Calculate the flash output needed for a 2:1 hand-held system.

Assume:
- Flash guide number is 28 for ASA 25
- Lens to eye distance = 7cm
- Flash to eye distance = 10cm or .33 ft.
- Total extension = 72mm
- We want to use f-16 for maximum depth of focus.
- The 2X tele-converter must be compensated for by opening up two f-stops. This is the standard light loss due to the use of a 2X tele-converter.

$$\text{Guide number} = (\text{f-stop}) \times (\text{flash-to-subject distance in feet})$$

$$29 = (\text{f-stop}) \times (.33 \text{ ft.})$$

$$\text{f-stop} = 84$$

This is the effective f-stop we need for proper exposure using ASA 25 film. Now we will calculate what actual f-stop we need for 72mm of lens extension:

$$\text{Effective f-stop} = \frac{(\text{marked f-stop}) \times (\text{lens extension} + \text{focal length of lens})}{\text{focal length of lens}}$$

$$84 = (\text{marked f-stop}) \times \left(\frac{132}{50}\right)$$

$$\text{marked f-stop} = 32$$

This says that for proper exposure we need to set the lens f-stop at 32. We only have f-16 on the lens. f-32 is two f-stops smaller than f-16.

f-stops: 2, 2.8, 4.5, 5.6, 8, 11, 16, 22, 32, 45, 64 ...

We have f-32 and we need f-16, which calls for a reduction in the light we need. The 2X tele-converter cuts out two f-stops of light, exactly compensating for the reduction we need.

Therefore the flash does not need to be changed in any way to get a theoretically correct exposure with ASA 25 film.

ASA 200 film is 3 f-stops more sensitive than ASA 25 film:

ASA's: 25, 50, 100, 200, 400, 800

Each doubling of ASA corresponds to 1 f-stop or a change of 1/2 the light needed.

With ASA 200 film, you need only 1/8 of the light to get a proper exposure as compared to ASA 25 film. The flash output would have to be reduced to 1/8 of its normal value by aperatures or neutral density filters.

Appendix III

A Representative System: Pentax MX camera

This is the lowest-priced SLR system that includes two features that we feel are valuable in slit lamp and macrophotography. These features are interchangeable focusing screens and LED light meter display.

Hand-held system:	Pentax MX, 50mm f1.7 lens	$250
	Extension tubes	70
	2X tele-converter	40
	Flash	25
	Bracket, filters	15
	Total	$400

Bellows system:	Automatic bellows	$135
	Tripod	30
	High intensity lamp	10
	Miscellaneous	10
	Additional cost	$185

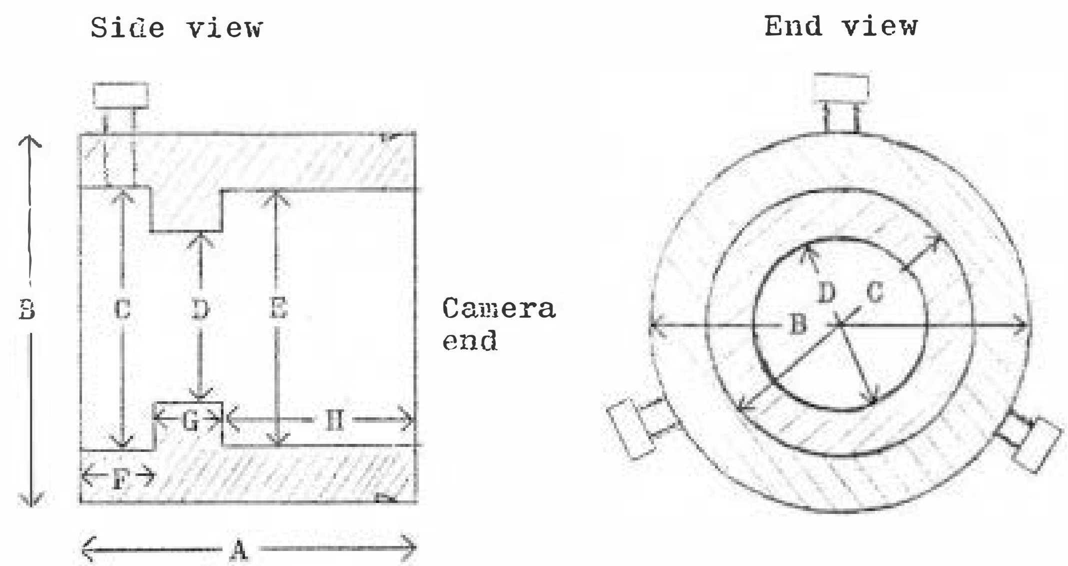
An instrument table and headrest are also needed.

The Canon system we used, with the same accessories, cost as follows:

Hand-held system:	$310
Additional bellows accessories:	$120
Total:	$430

Appendix IV

Mentor slit lamp camera adaptor design:



Dimensions

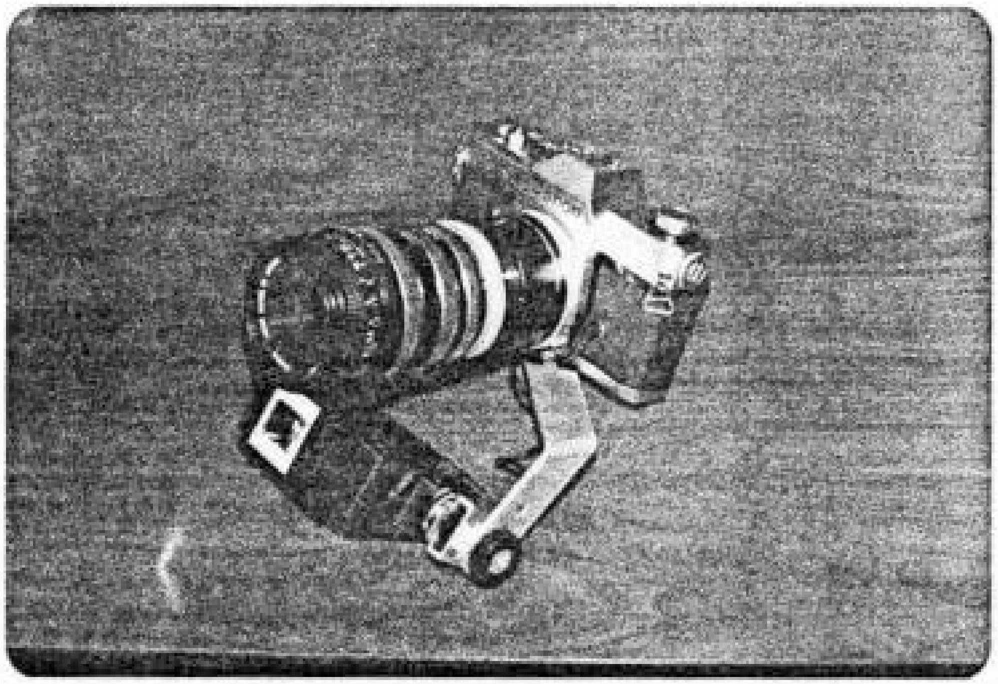
A = 44mm
B = 49mm
C = 35mm
D = 23mm
E = 34mm
F = 9.5mm
G = 9mm
H = 25.5mm

All tolerances were machined to produce a close fit to the eyepiece when inserted into the adaptor.

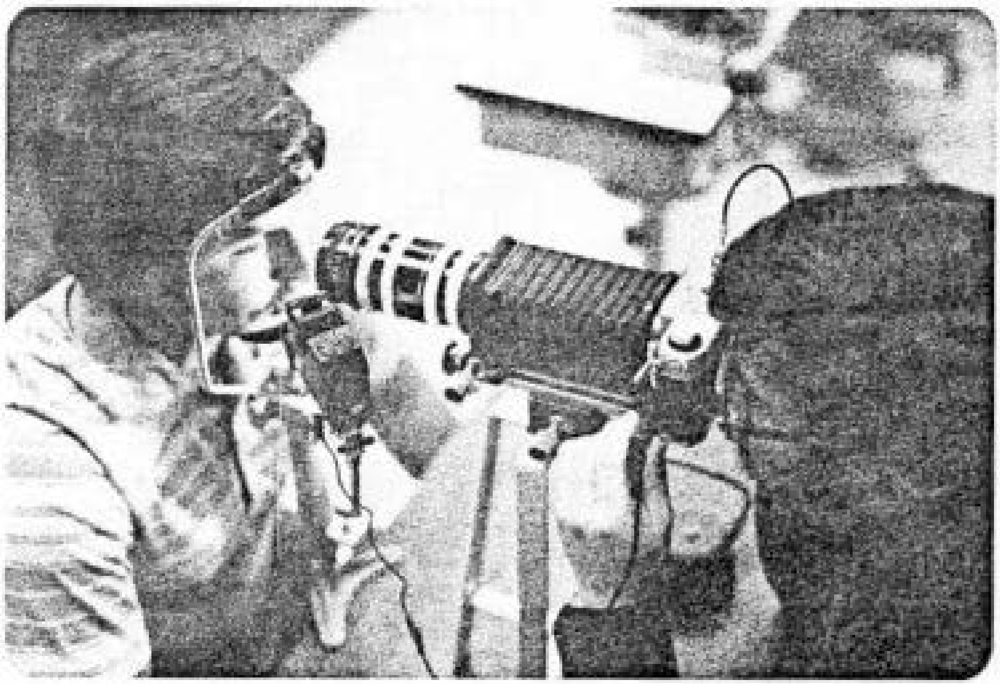
A "T" adaptor is then fitted to the camera end of the machined adaptor to enable attachment to the camera.

Appendix V

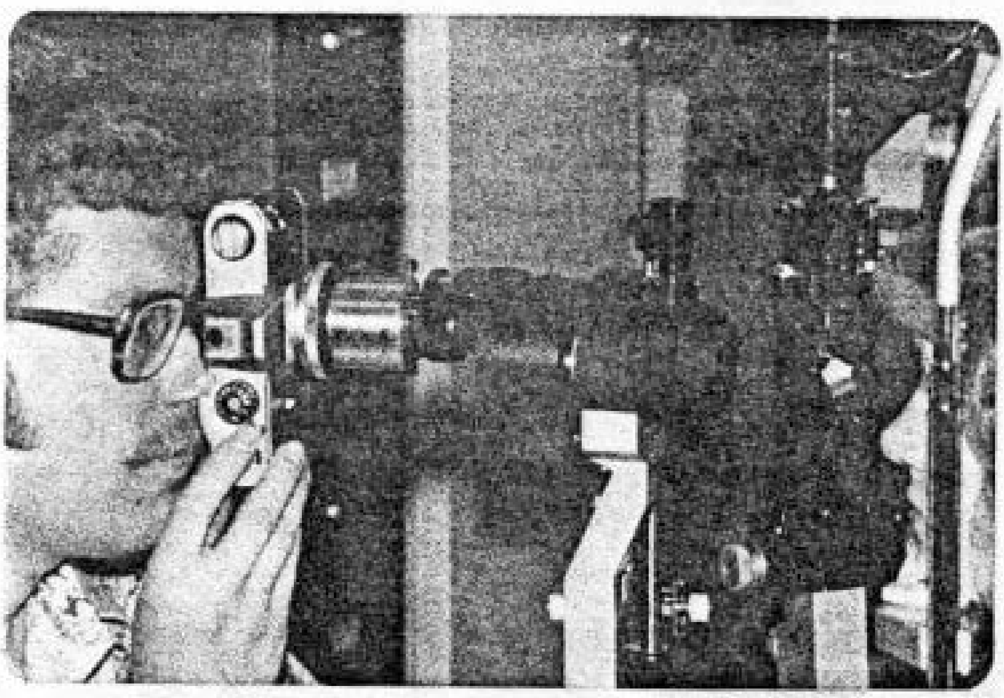
Pictures of the apparatus:



Hand-held apparatus showing the camera, lens extension, and flash bracket.



Macrophotography system showing camera, bellows and lens extension, tripod, and flash.



Mentor slit lamp with camera and adaptor in place.

Appendix VI

Human subject release form:

1. Institution
   A. Title of project: Anterior Segment Photography
   B. Investigators: Stanley Nelson and Frank Puckett
   C. Faculty Advisor: Dr. Robert Yolton
   D. Location: Pacific University College of Optometry
   E. Date: 1977-1978

2. Description of Project
   This project investigates several methods of obtaining anterior photographs of the eye. We will evaluate the quality of results and the ease of use of each of these photographic methods.

3. Description of Risks
   The risks involved in eye photography are minimal and are not greater than those incurred in a normal optometric exam. The flash used in eye photography is comparable in brightness to that in normal indoor flash pictures. Biomicroscopic methods of photography require a high level of illumination which can cause slight discomfort. There may be some afterimages (spots before the eyes) that occur from the illumination. These will last no more than 10-15 minutes and are not harmful in any way.

4. Description of Benefits
   Optometric visual care can be improved by utilizing ocular photography to record abnormalities of the eye and using the photographs to monitor ocular changes over time. Patient records are very important and photography can be of much use in patient documentation. We hope to show optometrists and optometry students that anterior segment photography is very useful and that it can be done with minimum cost and effort.

5. Offer to Answer any Questions
   We will be happy to answer any questions that you may have at any time during the photography session.

6. Freedom to Withdraw
   You are free to withdraw your consent and to discontinue participation in this project at any time without prejudice to you.

I have read and understand the above. I am 18 years of age or over.

Signed__________________________________ Date_______________

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