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A STUDY OF OBJECTIVE REFRACTION DEVICES IN ABNORMAL EYES

by

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A THESIS SUBMITTED FOR THE DEGREE
OF DOCTOR OF PHILOSPHY

THE CITY UNIVERSITY, LONDON

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VISUAL SCIENCE

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ABSTRACT

Automatic infra red optometers provide now an alternative to conventional objective refracting methods for the human eye. The relative merits of streak retinoscopy, the Ophthalmetron and the Dioptron were quantitatively assessed on various clinical groups.

For a normal young population retinoscopy gives a more accurate estimate of the subjective than the Ophthalmetron. Use of a cycloplegic agent showed that the bias linked to the Ophthalmetron was due to instrumental accommodation and this was shown to be psychological in nature.

For a highly myopic and/or highly astigmatic population, retinoscopy is marginally more accurate than the Ophthalmetron, but the clinical usefulness of the latter is certain for this particular population.

For corneal graft patients the correlation between objective methods and subjective refraction is worse than for any of the other groups considered. This is thought to be due to the irregular nature of the dioptric systems encountered. The accuracy of retinoscopy and Ophthalmetron are of the same order, retinoscopy being slightly better.

For aphakic patients the accuracy of retinoscopy was established (standard deviation = 0.6 DS) for the mid equivalent sphere. It was shown that the Ophthalmetron,

which only gave results in 79.03% of cases, was in these cases a more accurate estimate of subjective values than retinoscopy. On the contrary the Dioptron had no failures with a small population but gave results which were poorer than retinoscopy. The precision (repeatability) of refraction in aphakia when comparing three measurements with the Ophthalmetron to retinoscopy and subjective undertaken by three experienced optometrists was best in the former (standard deviation for Ophthalmetron ≃ 0.1D, for subjective ≃ 0.6D and for retinoscopy from 0.6D to 0.9D). The use of positive or negative cylinders and of streak or spot retinoscopy did not influence the accuracy obtained.

Finally the clinical usefulness of the Ophthalmetron as a means of post-operative refractive follow up in aphakia and corneal grafting was demonstrated.

In the laboratory the tolerances for the Ophthalmetron were established: $\pm 2\frac{1}{2}^{o}$ for angular movements and $\pm$ 0.25 mm. for transverse movements and greater than 4 mm. for longitudinal movements. The incident infra-red beam on the patient's eye was shown to be slightly divergent.

CHAPTER 1

INTRODUCTION

The seventies could be said to witness the advent of automation and computerization in everyday life and in science due to the introduction of miniaturized "silicone chip" based electronic circuitory. Visual Science and Clinical Optometry and Ophthalmology are no exceptions.

Electronic arrangments have been used for research purposes in optometry, for example to amplifiy and record ocular electrophysiological responses (ie. ERG, EOG), but more recently because of the manpower and economical situation, part of the clinical duties have been automated to permit delegation to non qualified assistants.

The "objective" part of eye examination which required a bias free operator evaluation of the refractive error was ideally suited for automation and three electronic Infra-Red optometers have been introduced to that effect since 1972 and have gained a certain popularity, mainly in the USA. Despite this success, only limited clinical studies, mainly on normal populations, and at times without real control have been reported, therefore the present study was carried out in the Contact Lens Department at Moorfields Eye Hospital, London.

The aim of the present work was to investigate the usefulness of the instrument with various pathological populations, but also to establish a base line for normal and the detailed protocol proposes.

(i) For the model eye to establish the 'absolute' instrumental accuracy with the Ophthalmetron.

(ii) For normal patients to repeat part of the clinical work already published to show that instrumental accommodation (increased artificial myopia), contrary to some opinions, is still a problem when dealing with a young population and suggested causes and solutions for it are presented.

(iii) For aphakic patients (patients whose crystalline lens is absent (usually following surgical removal) and demonstrating high positive refractive errors).

To establish

a. The accurracy of retinoscopic measurement, by an experienced practitioner, which has never been done with such a population. Further to determine the accuracy of the two automatic Optometers, available in this country, (The Ophthalmetron and the Dioptron) with the same population and discuss the various parameters involved.

b. The precision (repeatability) of aphakia refraction by several experienced practitioners and precision of the two previous automatic instruments and discuss and reach conclusions on the theoretical and clinical tolerances to expect.

(iv) To establish, for high myopia and corneal graft patients, the clinical usefulness of an automatic optometer. (The Ophthalmetron) as a substitute to retinoscopy.

(v) To demonstrate the use of an automatic instrument, as a means of post surgical follow up in aphakia and corneal grafting.

CHAPTER 2

REVIEW OF THE DEVELOPMENT OF OPTOMETERS

2.1. Introduction

The name objective refraction covers a wide field and a few initial differentiations must be considered before embarking on a detailed survey of the literature available on the topic.

For most practitioners, objective refraction is a means of finding the distance correction with minimal participation of the patient (i.e. looking at a distant light) and it involves retinoscopes and optometers. These instruments are objective as far as the patient is concerned but highly subjective for the practitioner whose skill is required. Commercial instruments also exist which are objective for both the patient and the practitioner. They are the electronic optometers; three are commercially available at the moment, all of American origin: the 6600 Auto-Refractor from Acuity Systems, the Dioptron from Coherent Radiation and the Ophthalmetron from Bausch and Lomb.

Other objective methods are available in the laboratory based on different features of the eye but these will not be reviewed here. Before a description of modern electronic optometers for distance refraction it is suitable to look at the whole series of visible light optometers to measure distance refractive error and also at infra-red (IR) optometers designed to measure changes in accommodation upon which the newer ones are based.

2.2. Optometers Using Visible Light

This review concerns objective optometers, and must include a brief resumé of the earlier subjective optometers as they constitute the first part of the objective ones which are composed of:

- a projection system, similar to that of a subjective optometer, which forms an image of the target on the patient's retina.

and

- an observation system, which permits the observer to view the retinal image, and is effectively a modified ophthalmoscopic system.

2.2.1. Subjective Optometers

Subjective optometers, also the projection system of the objective optometers, form two groups of instruments, (Arnulf, 1975[1]; Duke-Elder, 1970[2]; Emsley, 1972[3]; Graves[4]; Le Grand, 1965[5]).

i) Optometers based on the image sharpness principle

The Badal Optometer is the earliest and best known example (fig 1). It is formed by two tubes a few centimetres in diameter, the first holding a convex lens L_o of power D and a second fixed and supporting a photographic reproduction of a test chart (in the newer models). From Newton's principle $xx' = -f'^2$, one derives the relationship:

$$X' = \frac{-x}{f^2_o} = -xDo^2$$

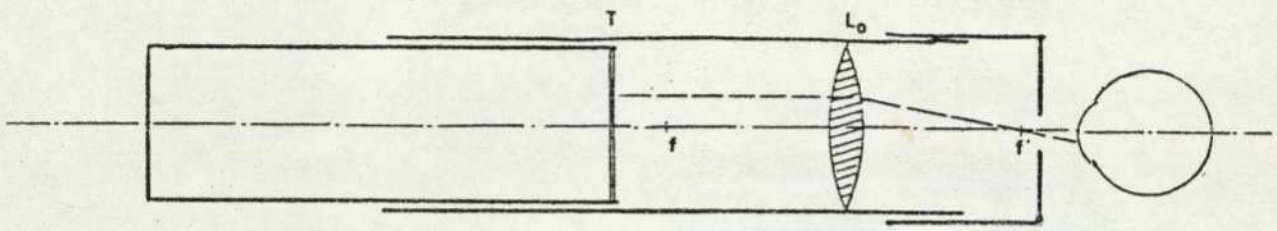


Fig. 1: BADAL OPTOMETER (after Le Grand, 1965)

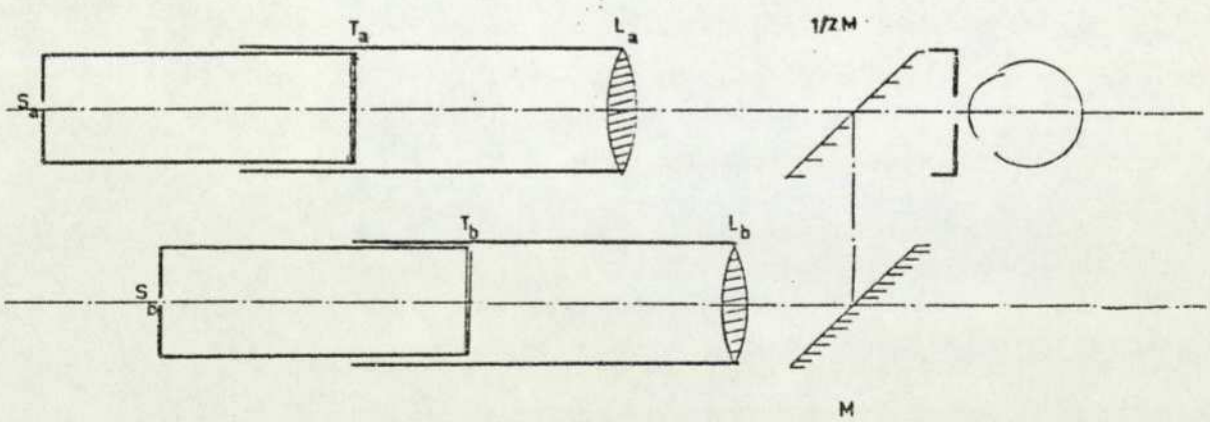


Fig. 2: OPTOMETER BY DE GRAMMONT (after Le Grand, 1965)

Where $X' = \frac{1}{x'}$ The proximity of the image from F'

x = the distance of test from F

f = focal length of the optometer lens

D = power of optometer lens

This gives a linear relationship between the refractive error and the displacement of the test target, (i.e. $Do^2 = 250$; $Do = \sqrt{250}$ → each mm = 0.25D). Depending on the position of F' in relation to the subject's eye the instrument can measure the spectacle refraction (F' in the spectacle plane) or the ocular refraction (F' at the corneal apex).

Among the numerous versions of the Badal optometer, two are particularly worth noting (Le Grand, 1965[6]). Firstly, the Differential Optometer due to De Grammont (fig 2) is formed by two Badal optometers and a system of mirrors, so that a set of parallel lines orientated along the subject's principal meridians can be superimposed and the astigmatism measured directly. And secondly the 'Variator" by Thorner in 1899 (fig 3) which on the same principle gives an image of a distant target on the suject's retina. The two mirrors are movable along yy' and can measure ametropia from -20 to +20 dioptres. In the clinical device a similar system is present in front of the other eye.

ii) Optometers based on <u>doubling principle</u>

The principle is derived from Scheiner's experiment. He placed in front of his eye a blank disc with two small apertures which split the incident beam into two distinctive paths and gave only a single image when conjugate with the retina.

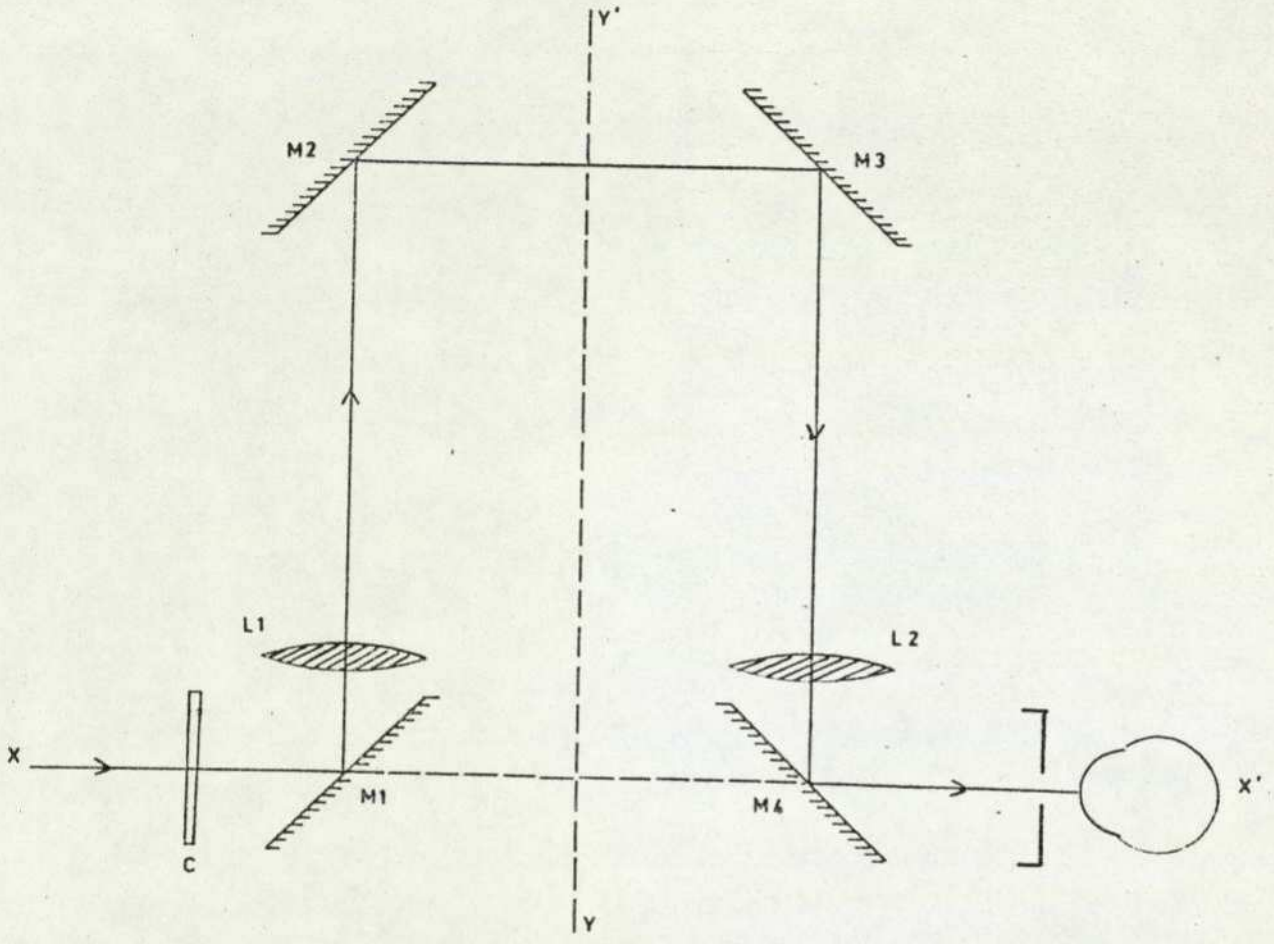


Fig. 3. Variator by Thorner (1899) (after Le Grand, 1965)

Porterfield (1759)[7] was the first to describe an optometer based on Scheiner's principle; he used two narrow parallel slits, cut in a piece of white iron and the separation of which was inferior to the pupil diameter while viewing a vertical line. However, the first optometer suitable for clinical use was only produced by Th. Young: he managed to measure his own astigmatism and spherical aberrations using it. The main improvement was to include a +10 diopters lens rendering the instrument usable with hypermetropia. He also designed triangular apertures making it easier for the patient, and made the system revolutionary around the optical axis. Both Thompson and Trantas (cited by Le Grand, 1965)[8] later developed more sophisticated subjective instruments from that principle.

2.2.2. Objective Optometers

Objective optometers must provide the means by which it is possible to measure the vergence of light originating from details on the patient's fundus. Two alternative methods can be used.

In the first group, the image of the test object is projected onto the patient's retina, and the sharpness of the retinal image is observed using a modified direct ophthalmoscopic system, (Appendix 1). Schmidt-Rimpler in 1877 (cited by Duke-Elder, 1970)[9] probably built the first optometer of this kind, made of a source S, a concave mirror M and a movable lens L (fig 4). At the same time Hardy (cited by Le Grand, 1965)[10] built his "Stigmatomètre" on a similar principle but with a moveable target (fig 5).

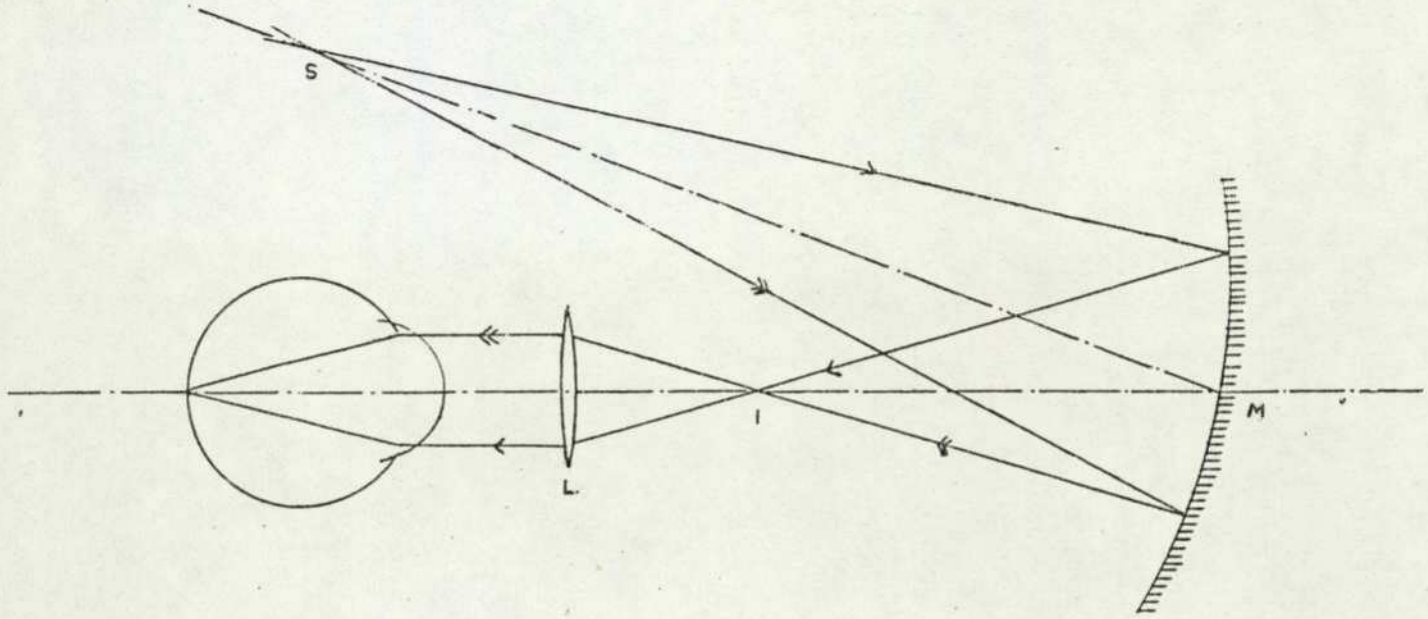


Fig 4. Schmidt-Rimpler Optometer (1877) (after Duke Elder, 1970)

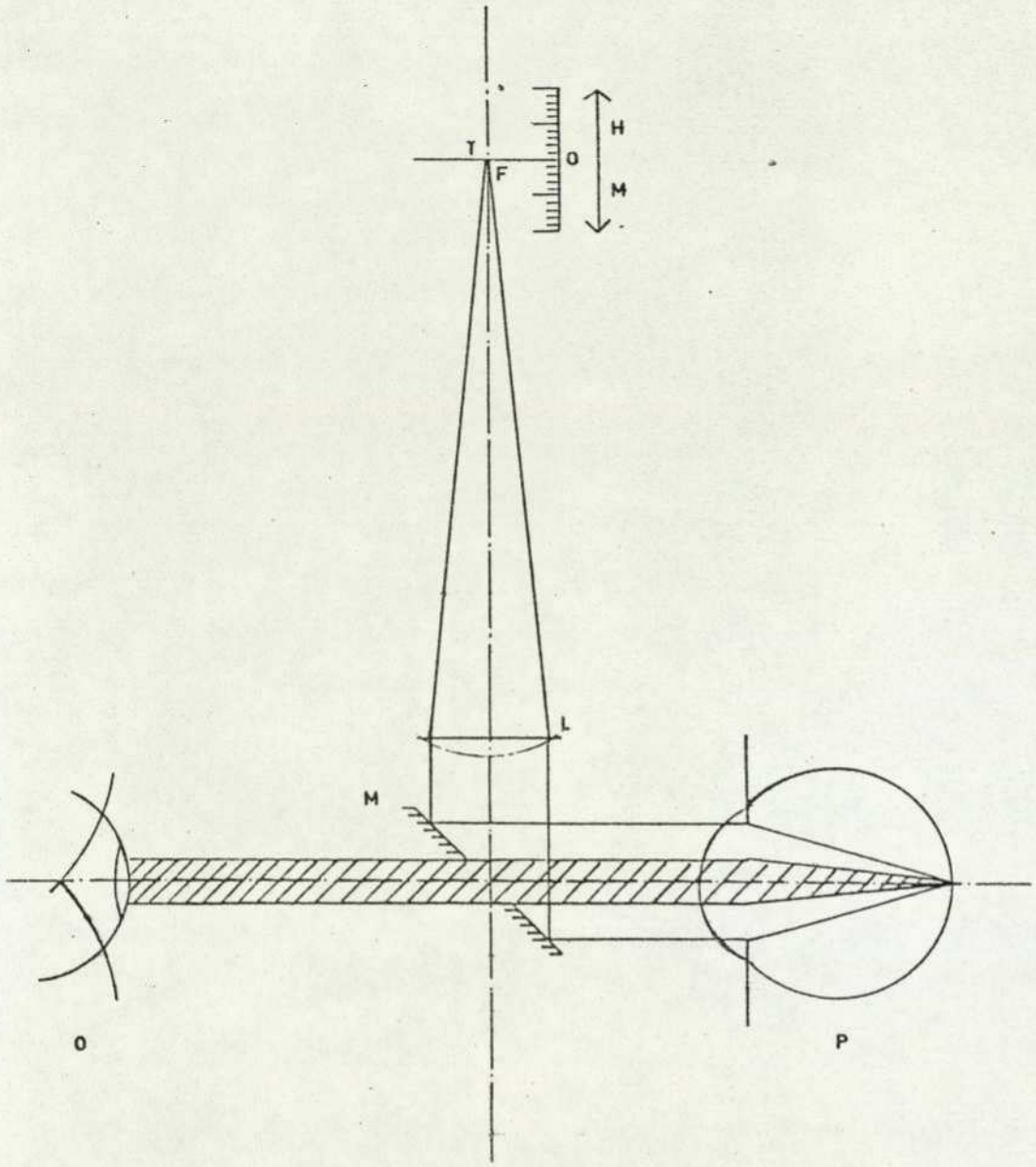


Fig 5: Stigmatometre by Hardy (after Le Grand, 1965)

In 1922, the first Rodenstock Eye Refractionometer appeared as an improved version of these optometers, tending to utilize a larger part of the pupil and to suppress unwanted reflections: the incident light onto the patient's eye forms a peripheral annulus, while the light reflected from the retina is observed via the central pupillary portion of the system (Volk, 1975)[11]. Thorner (cited by Le Grand, 1965)[10] included in his own instrument (fig 6) two semi-circular stops, each covering half the patient's pupil, so that the light entered the patient's eye via the upper part of the pupil and left via the lower part, eliminating unwanted corneal reflections. In all the above optometers the test object was a rotatory set of lines and points only seen correctly aligned when parallel to a principal meridian.

The last instrument of this group is the Retino-focometre by Arnulf (cited by Graves)[12] (Fig 7); as in the system designed by Thorner there is complete symmetry between the projection and observation systems with regard to a line yy' with simultaneous focusing. The main originality of the instrument isthat Arnulf observed the image sharpness of the bright object light source focused on the retina. Under these conditions, corneal reflection does not disturb the observer, and the whole pupillary area can be used by the projection and observation systems, this being closer to the normal conditions.

The second group of instruments is based on Fick's (1893)[13] idea ofparallax displacement. A test on a transparent

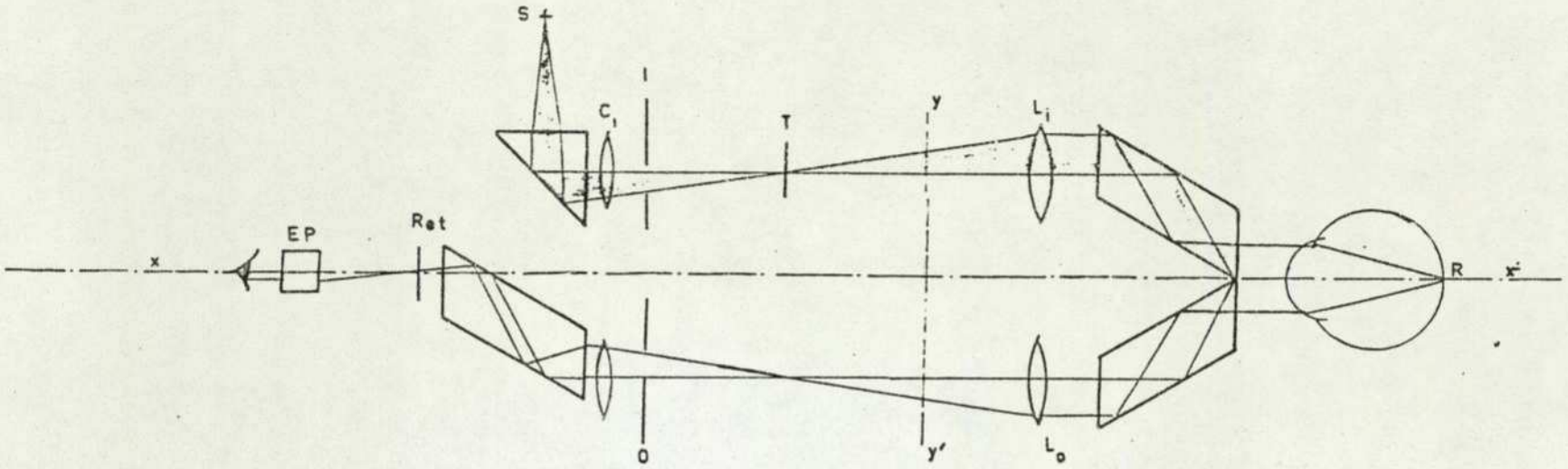


Fig 6. Refractometer by Thorner (1922) (after Le Grand, 1965)

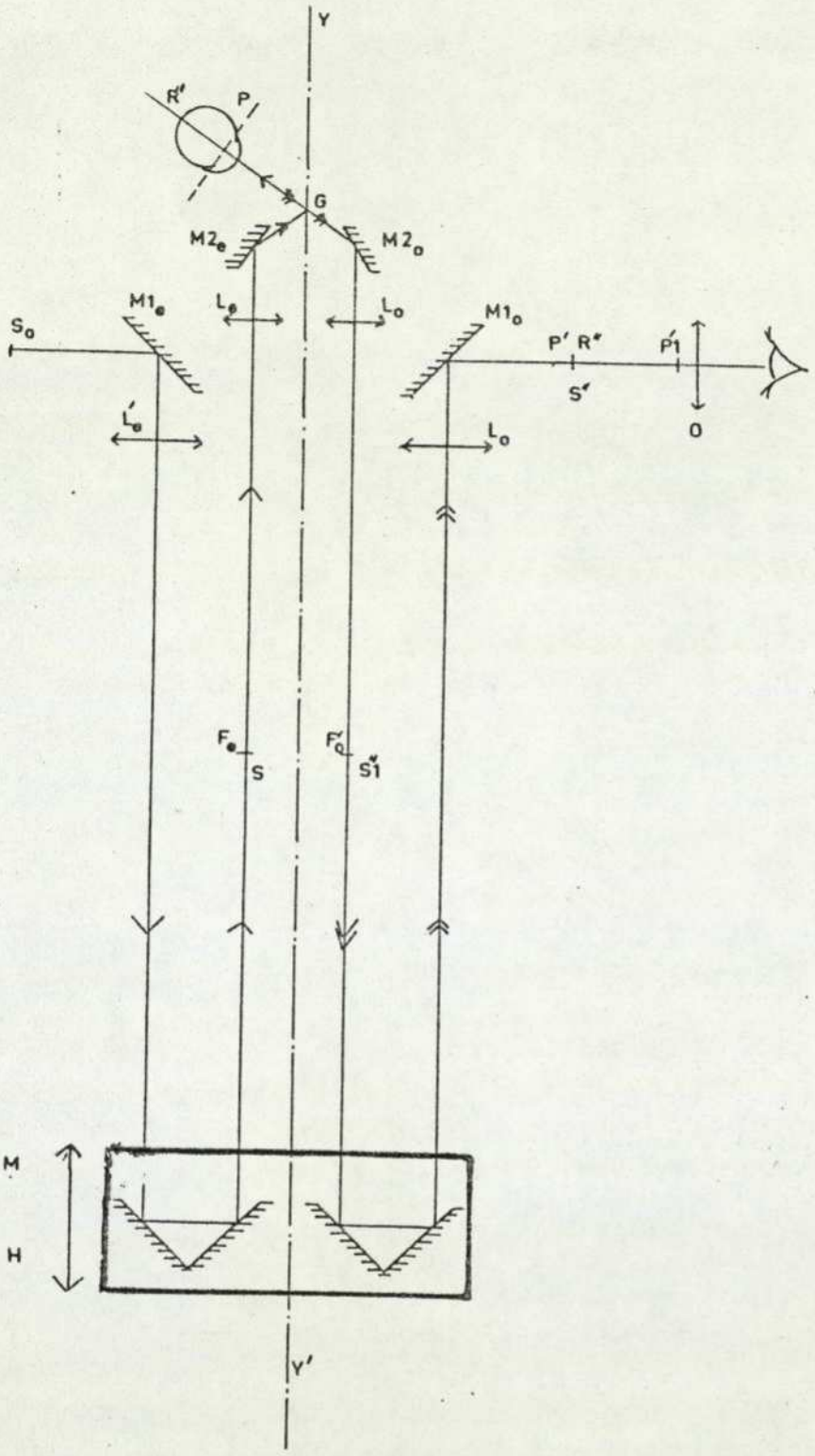


Fig 7. "Retinofocometre" by Arnulf (after Graves)

reticule was translated with regard to an ophthalmoscopic lens, until the observer ceased to notice any lateral displacement between the object and the image. The other feature of these otpometers is the utilisation of an indirect ophthalmoscopic arrangement for the observation system, the modern one being reflex free (appendix 2).

The first instrument of this kind was built by Cluzet (1899) (cited by Le Grand, 1965)[14], but only in 1923 did Zeiss introduce an eleborated version designed by Henker (cited by Emsley, 1972)[15] (fig 8). This system was based on Gullstrand's simplified ophthalmoscope. The illumination system used a peripheral part of the lens O, the eccentric aperture E conjugate with the patient's pupil. It also included a test target T at the focal point F' of the lens O. When the patient was emmetropic there was superimposition between object and image. In all cases of ametropia, parallax was present and the test object was then displaced to remove parallax, the new position giving the value of the ametropia. Astigmatism could be detected by rotating the test through 180^{o}.

The Fincham Coin cidence Optometer, (Fincham, 1937)[16] (fig 9), incorporated the use of vernier acuity to improve the accuracy of measurements. The general principle used was similar to that described for Henker's model (fig 8) but here the observer did not see the test T itself and a prism inserted in the lower half of the observation pathway in front of the eyepiece, split the image in two; these two half images being aligned only when the test T was conjugate with the patient's retina. Other original features included an independent fixation target.

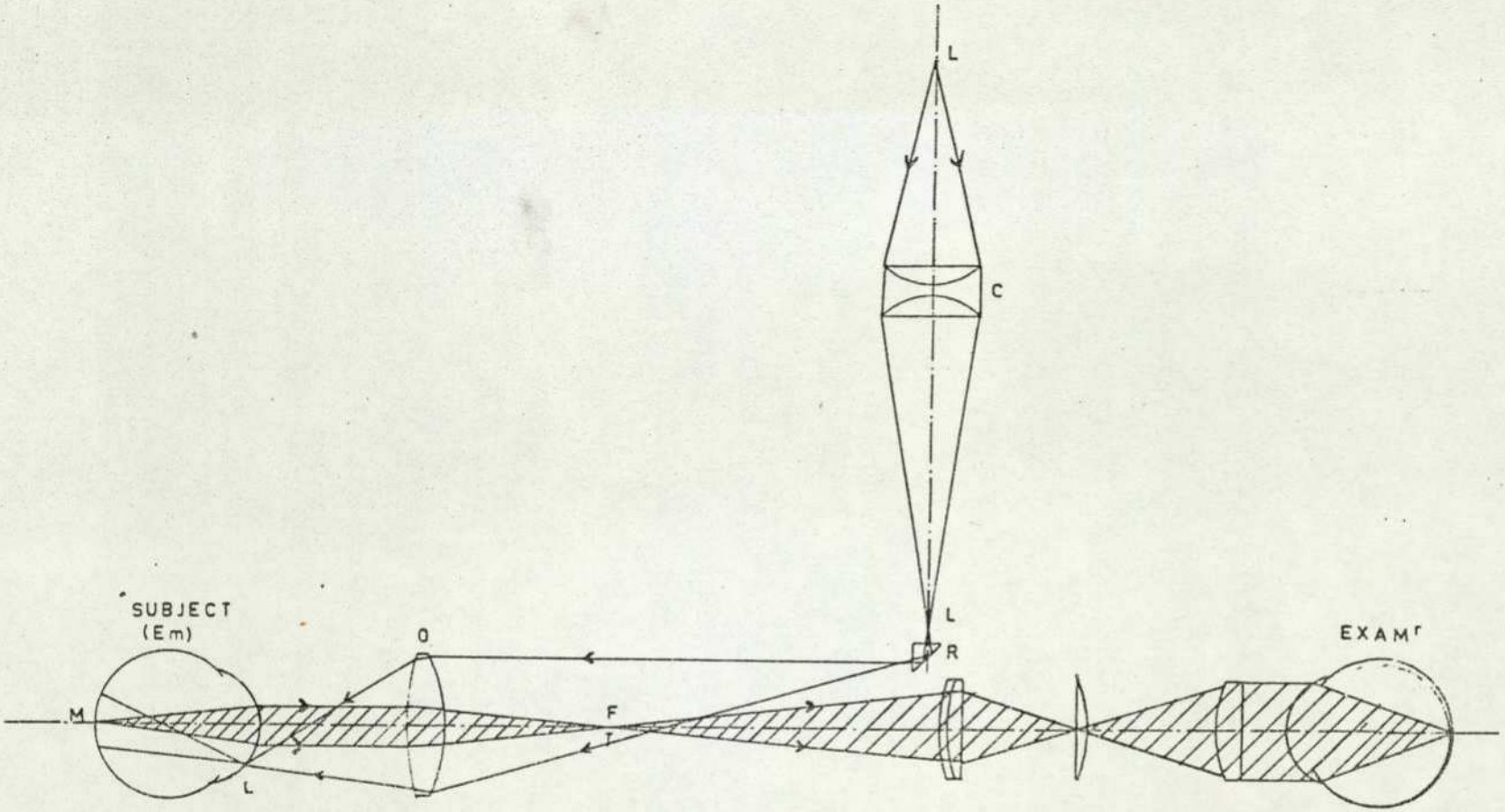


Fig. 8: Zeiss-Henker Parallax Refractionometer (1923) (after Emsley, 1972)

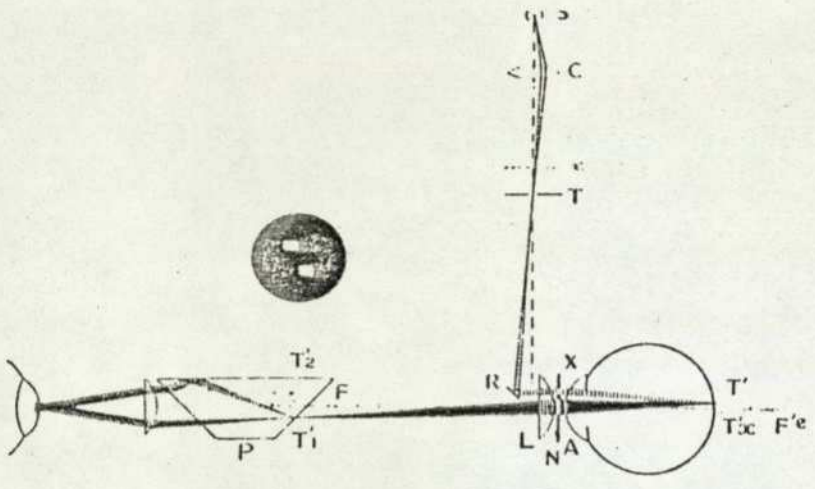


Fig. 9: Fincham Coincidence Optometer (1933)(after Fletcher, 1969)

Finally, Hartinger in 1955 (cited by Le Grand, 1965)[17] presented the most improved version, mechanically (fig 10). The test image is split by means of two identical prisms opposed by their apices and interposed in the projection system. Only when the test is in focus on the patient's retina are the two parts of the image aligned. When the projection system is displaced to focus the target on the retina, the observation system is positioned to focus the image in the focal plane of the eye-piece.

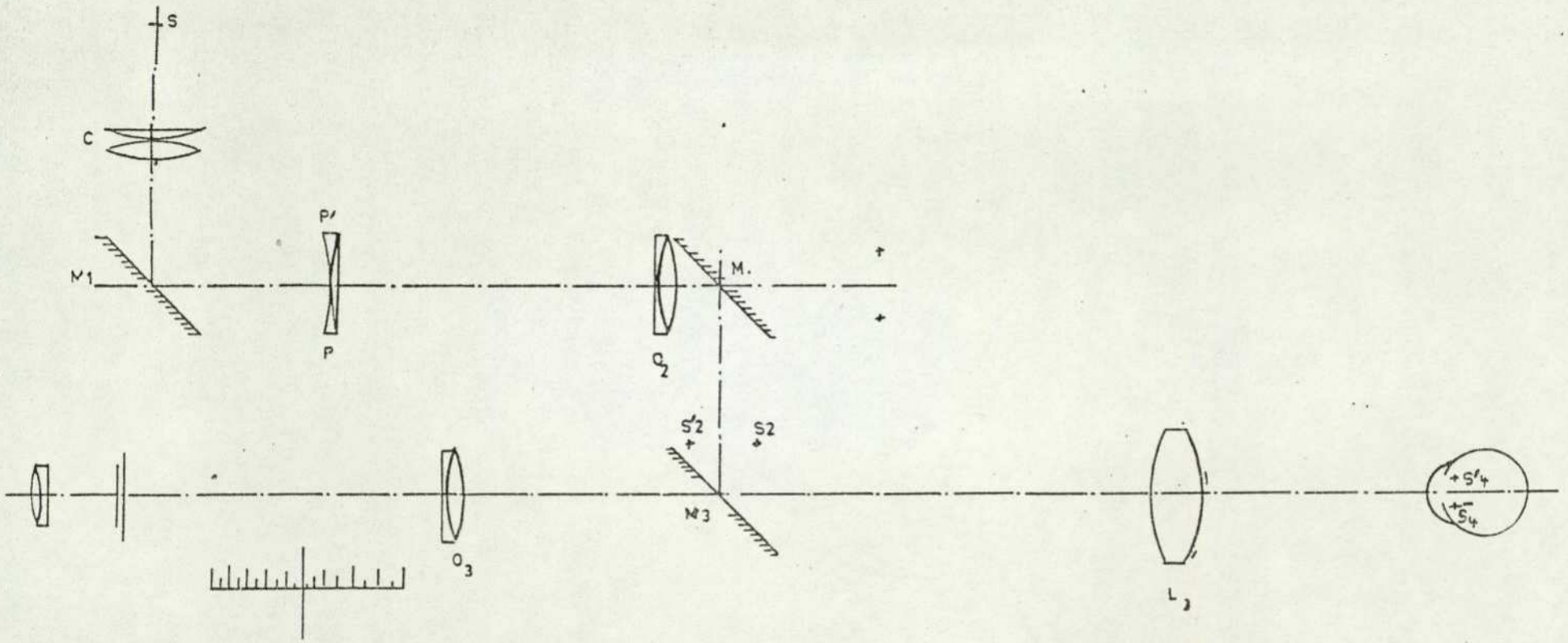


Fig. 10: Refractometer by Hartinger 1955 (after Le Grand, 1965)

2.3. Infra-Red Optometers

2.3.1. Instruments to measure distance refraction

Collins (1937)[18] was the first to produce an optometer utilising IR radiation. This instrument, the Electronic Refractionometer, was desinged to measure the patient's distance refractive error. However, it was forgotten until the seventies when two instruments, the Dipptron and the Ophthalmetron (Charman, 1976[19]; Bennett, 1978)[20], were developed on a similar principle.

In fact Collins can be considered as a pioneer of both use of IR radiation and automation in Optometry. Unfortunately he demonstrated too much foresight for his contemporaries who did not seem to appreciate the advantages of his instrument. Prior to describing the instrument he listed the desirable features for optometers, the most pertinent being that the instrument should be free from both patient and observer's judgements and should permit measurement of distance and near refraction monocularly or binocularly as required, without affecting the psychological environment (thus he used IR radiation to suppress instrumental accommodation).

The instrument consists of a filament source S(fig 11) (36 Watts Automobile headlamp bulb) at the focal point of the condensing lens L1, in the plane of the IR filter F. A semi-reflecting mirror M1 vibrating at 100 cycles per second reflects the beam to be focused on to the patient's retina through lenses L2 (focusing lens of variable position)

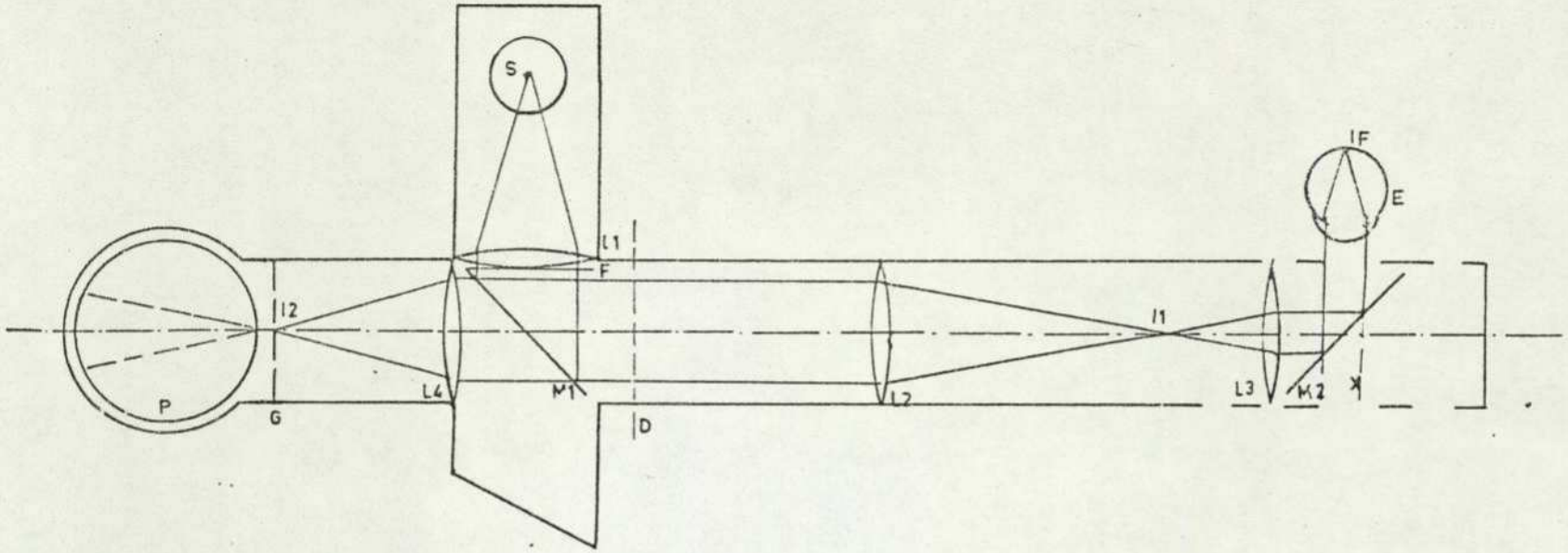


Fig. 11: Collins Electronic Refractionometer (1939) (after Collins, 1939)

and L3 (refractionometer lens). The radiation reflected by the retina, returns along its own pathway and the part not reflected by mirror M1 is focussed by the condensing lens L4 on to a graticule G, positioned in front of the photo-electric cell.

The main features of Collins' instrument are as follows:-

- The optical system utilises IR radiation and the patient can view any fixation object at any distance, through mirror M2, without instrumental restriction. Also the filament S and graticule G can be rotated to measure refractive error in any meridian. Finally the lens L2 is moved without the patient being aware of it so that no psychological bias is introduced.
- The electronic system described is the first to incorporate a null balance principle. The vibrating mirror displaces the image of the filament source, reflected by the retina, axially across the face of the graticule: this graticule G consists of a masking bar of the same size and direction as the image of the source. Hence when the focused image of S is moved across the face of the graticule the amount of light reaching the photo-electric cell is alternately maximal and minimal. This generates an alternating current, which will be maximal when the image of the source is focused onto the graticule plane, as in any other case the masking bar will neither completely obliterate nor be out of the path forming the image of the light source. Since the system is not linked to a continuous

current it avoids the problem of corneal reflection and does not necessitate accurate positioning of the patient's eye ($\pm$ 1.5 mm). The current is finally amplified, rectified and rendered visible through a cathodic tube.

The only limitation of this instrument when compared to modern ones lies in the focusing system: focusing is carried out manually (moving lens L2) after viewing the cathodic image. In fact to automate this system is simple today, by attaching a servo-motor to guide the lens and a pen recorder and/or digital read out for a permanent record. Further the instrument described here can be modified to both measure refractive error under different conditions or accommodative changes with time.

2.3.2. Infra-red Optometers to measure accommodation changes

Between 1950 and 1970 physiologists became aware of the advantages of IR optometers to study the accommodation function without affecting experimental conditions. Several instruments were developed over these two decades all based on three principles already employed with light optometers: retinoscopy, retinal image sharpness detection and Scheiner's disc.

(i) The retinoscopic arrangement was first used in that context by Fry (1939)[21] when measuring relative accommodation using IR radiation.[22] Later Knoll (1953) developed a similar system (fig 12) to measure the refractive status of the eye under low illumination. The illuminiation system is formed by a source L and a condensing lens C which focuses

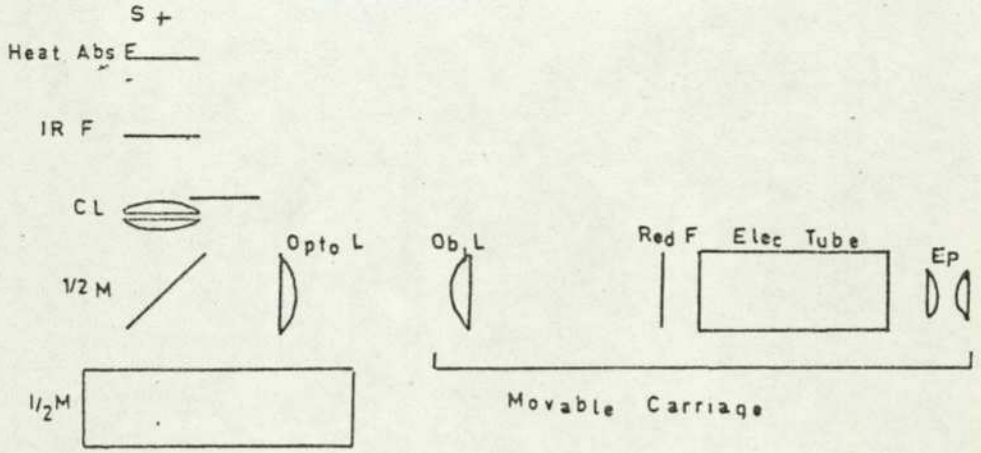
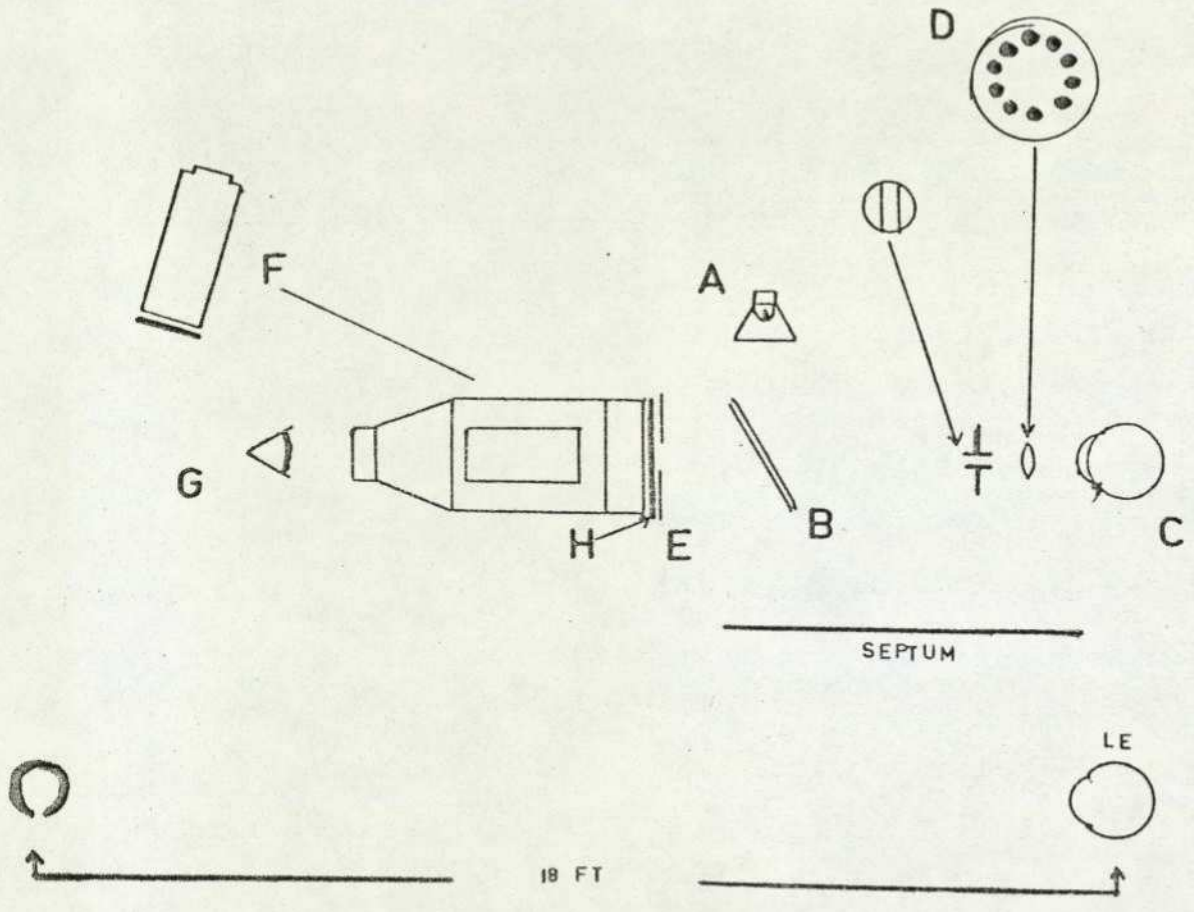


Fig. 12: Infra Red Skiascope by Knoll (1953) (after Knoll, 1953)

the source into the subject's entrance pupil. It also includes a rotating knife edge which can be brought into the beam of light and creates a shadow on the retina. The radiation reflected by the retina is passed into the observation system formed by an optometer lens in Maxwellian view and a movable carriage. This carriage is moved until neutrality is obtained (i.e. when the retina is conjugate with the optometer lens or when the knife edge movement has an "all or none" effect), the image being rendered visible again by means of an electron tube.

Chin and Horn (1956)[23] described an IR skiascope (fig 13) which is a basic retinoscopic system with an IR converter tube added to measure accommodation behaviour under low illumination.

Allen and Carter (1960)[24] described an other IR optometer based on the knife edge principle (fig 14). The light source S is conjugate with the patient's pupil (through the incident path), which is in turn conjugate with photomultiplier (through the reflected path). The arrangement is such that the incident beam uses the upper part of the pupil and the reflected beam the lower part. A target T is imaged on the retina of an emmetropic patient and in the plane of the knife edge K. Any change in refractive power will create a vertical displacement of the image so that only part of the beam will reach the photo-multiplier. A rotating disc will create a pulsating dc through the photomultiplier linked to a r-c amplifier



A I-R SOURCE B 1/2 REFLEC. MIRROR C SUBJ. D RET. LENSES
E SIGHT HOLE F I/R RECEPTOR G EXAMINER H I-R FILTER

Fig. 13: Infra-Red Skiascope by Chin and Horn (1956) (after Chin and Horn, 1956)

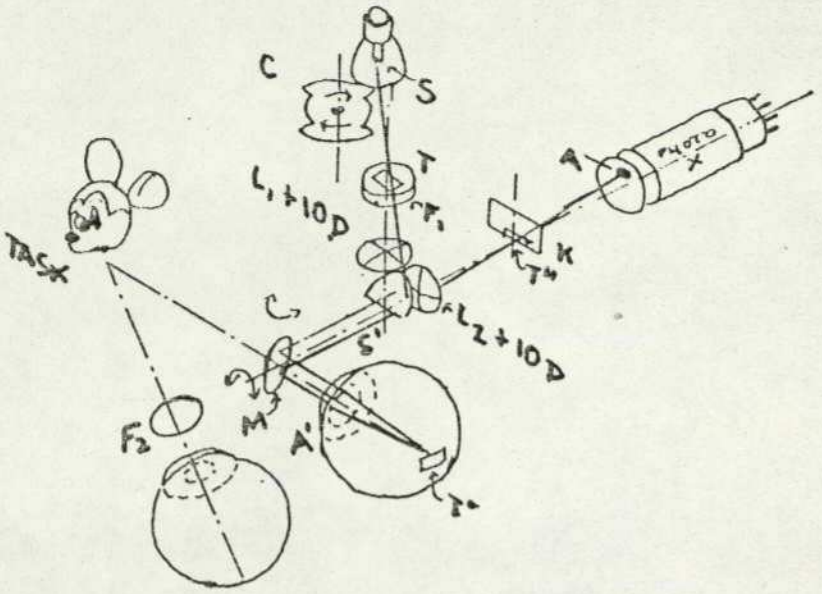


Fig. 14: Allen and Carter Optometer (1960) - Optical Arrangement. (after Allen and Carter, 1960)

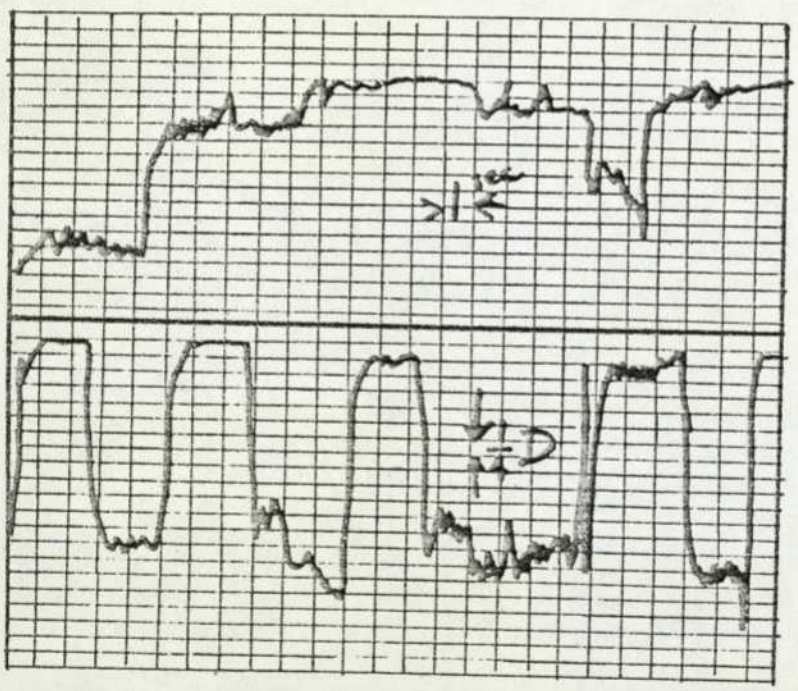


Fig. 15: Allen and Carter Optometer (1960) - Recording of accommodation changes.

feeding a pen writer (fig 15) linking directly radiation output to refractive changes. A modified version on the same principle is described by Allen (1961).[25]

(ii) Knoll (1953)[26] also described the first IR optometer based on retinal image sharpness detection (fig16). The IR part of the radiation from the source L is focused onto the optometer slit S which is in turn brought into focus on the patient's retina via the optometer lens A. The energy reflected from the eye is focused on the curved photo-cathode after passing through a negative field correcting lens K. The slit S and the photocathode being conjugated it is only necessary to move the lens A axially until maximal intensity is reached, when observing through the x 9 eye-piece the image produced by a fluorescent tube.

Harada, Ozawa an Kubota (1965)[27] built an optometer measuring image intensity changes with a photodetector cell similar to Knoll's (1953).[28] The only real difference resides in a more complicated optical system based on Thorner's optometer, but without any real advantage.

Denieul and Simon (1977)[29] also described an optometer based on the study of image sharpness (fig 17), one of the original features of the instrument is that the input beam covers the whole pupil so that accommodation changes are measured as produced by the ocular system.

All the previous instruments had the advantage of simplicity but their main drawback was in being directly

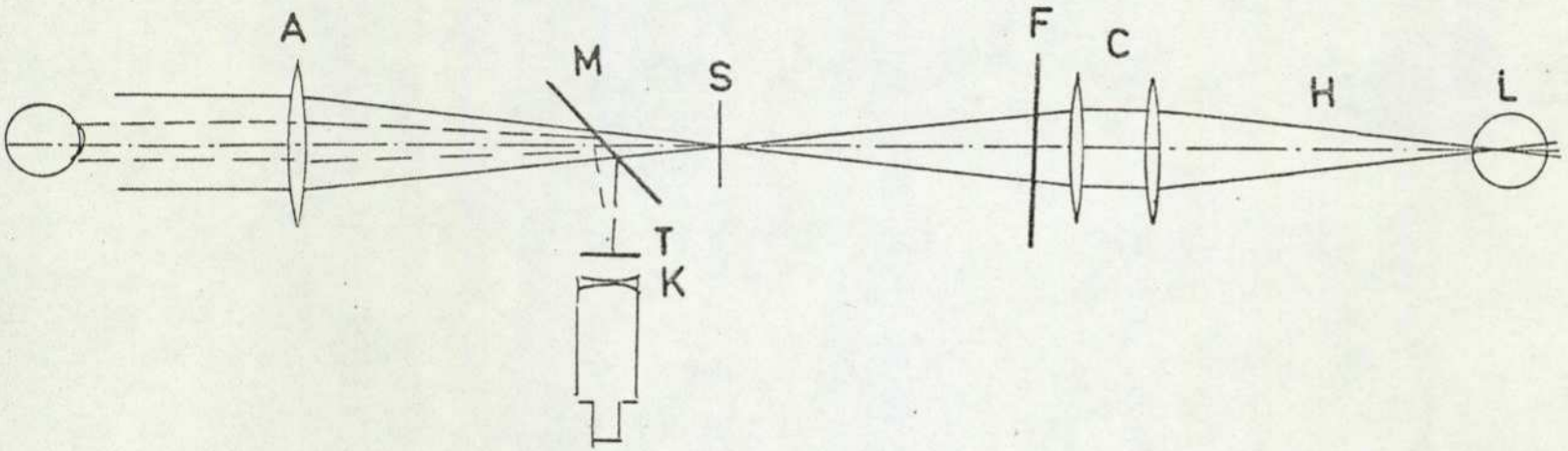


Fig 16: Infra Red Optometer by Knoll (1953), (after Knoll, 1953).

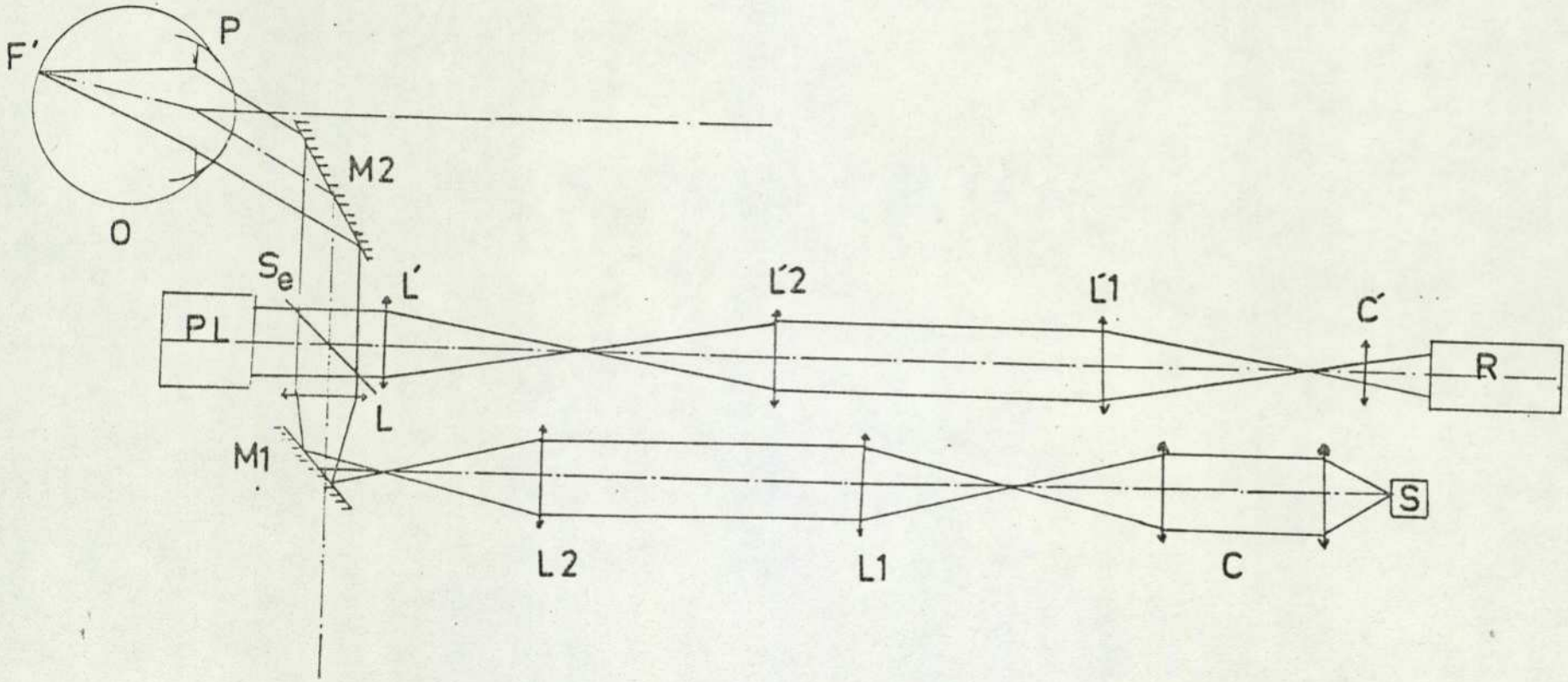


Fig. 17: Infra Red Optometer to record accommodation changes by Denieul and Simon (1977) (after Denieul and Simon, 1977).

linked to light intensity without a null balance zero-point as those of the third group, therefore they were affected by eye movements and pupil changes.

(iii) The third group of instruments using the basic principle of Thomas Young's optometer based on Scheiner's experiment consists of various versions all based on the original instrument described by Campbell (1956)[30] and Campbell and Robson (1959)[31] (fig18). The instrument was capable of recording 0.1D changes. Two narrow beams of light, 4 mm apart, were focussed in the patient's pupil plane through the lens system. An horizontal aperture was placed at the object focal point of the optometer lens, giving a single clear image of it on the retina of an emmetropic patient. Any accommodation produced two over lapping, slightly out of focus, images of the slit. The optometer was rendered objective by introducing an ophthalmoscopic observation system, which brought the image onto a lead sulphide photoconductive cell. This cell consisted of twin photosensitive surfaces lying side by side, and parallel to the slit images. Any movement of the slit parallel to its length would create a differential effect upon the two sensitive surfaces initiating an out of balance voltage. By introducing a sector wheel cutting off each beam alternately an alternating current was produced, which after amplification reproduced accommodation changes on a graph via the electronic system. Finally a target presentation system was included in the instrument.

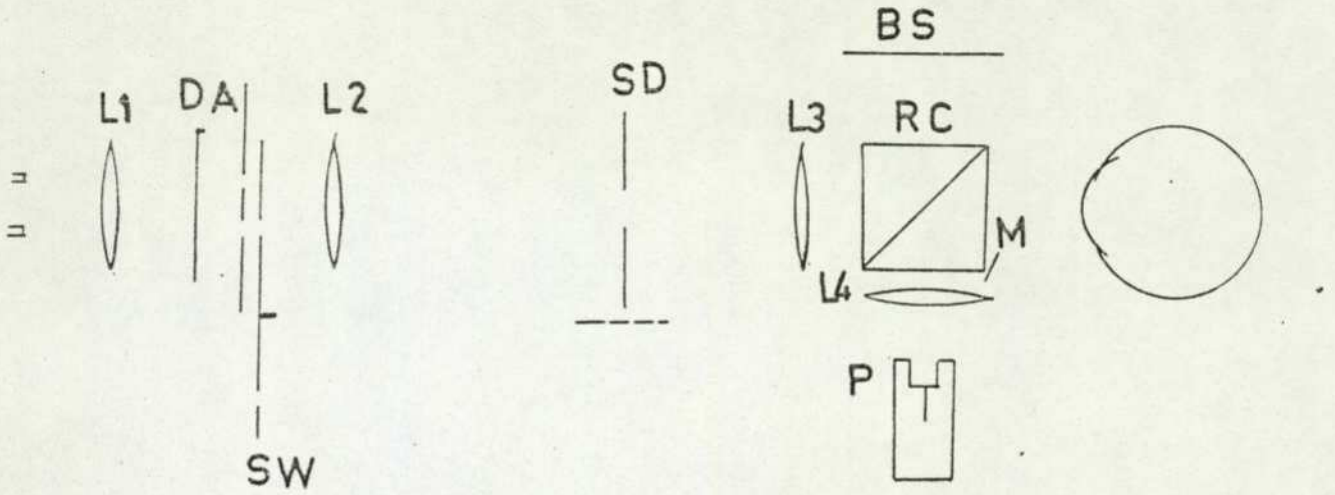


Fig. 18: Campbell and Robson Optometer (1959) (after Campbell, 1956)

Campbell and Weistheimer (1960) improved the previous optometer in various ways. In the detecting system, they replaced the initial lead sulphide photocells by photodiodes which gave greater amplification and output and a spectral distribution better matched to the source. In the optical system, the reflection cube was replaced by a reflection plate to reduce stray light and the two sources were focused onto the retina rather than the slit diaphragm, this system reducing the number of lenses necessary and increasing the light reaching the retina.

Tucker (1969)[33] commenting on the various Campbell's systems, argued that the electronic circuitory cannot differentiate between divergence and convergence around the zero point and offered a possible solution to it.

Roth (1962)[34] described an IR optometer based again on the Campbell-Robson's instrument insofar as it incorporates a Scheiner disc arrangement, but greatly modified to produce a co incidence optometer (fig 19). The source filament was imaged at infinity via the lens L1 and a double slit on either side and above and below the optical axis, is interposed between the lens and the patients eye. Also a prism base down is in the pathway of the upper part of the beam so that, for an emmetropic eye the two slit images were focused side by side on the retina and without vertical imbalance. The reflected radiation was then imaged on the photodetector formed by two pairs of solar cells, each pair being activated by one image only when the lens L2 was

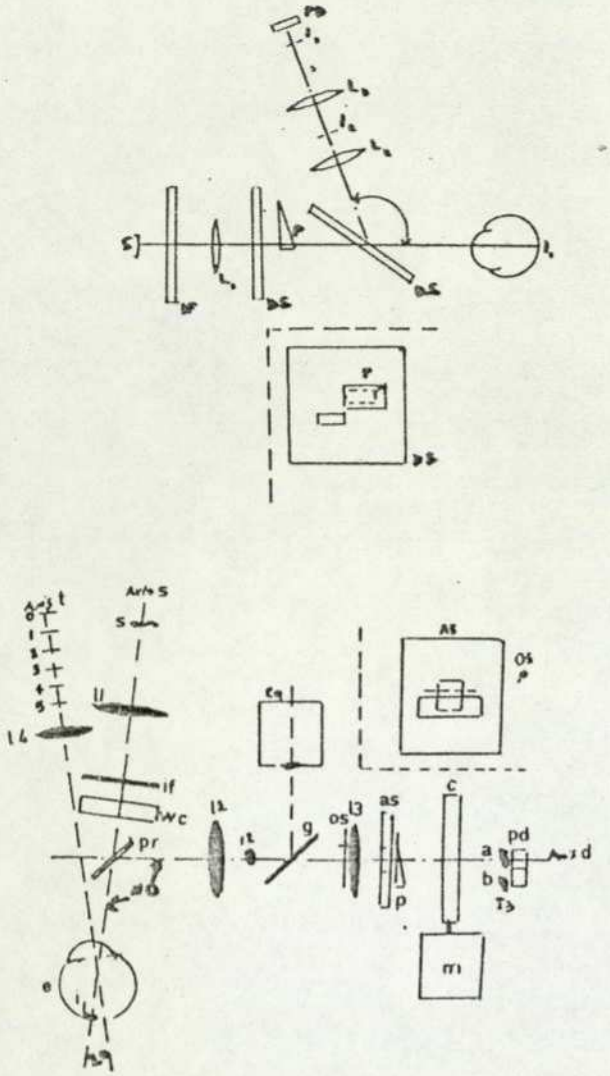


Fig 19 and 20: Roths Optometers

Top: 1962 model

Bottom: 1965 model

rotated at constant velocity. Only when the images were correctly aligned the cell output moved in phase, otherwise they were out of phase, the phase difference being proportional to the misalignment.

Roth (1965)[35] modified his original system by introducing the Scheiner system and positioning the prism in the reflected path, so that the retinal image was single. But the underlying principle remained the same with an identical photodetector cells arrangement. He also introduced a pen writer system for permanent record, (fig 20).

Warshawsky (1964)[36] positioned the photodetector cells on either side of the exit slit, hence reducing the number of detector cells necessary in the system. When the exit slit was conjugate with the retina only stray light fell on the cells. But any defocusing caused the beam to shift axially, hence more radiation fell on one cell than on the other producing an imbalance proportional to the amount of defocusing. The main inovation however was found in the electronic system which included a servo-motor (fig21) operating in three modes:

- Nulling mode, in which the servo adjusted the slit to reach the conjugate null.
- Conjugate Error mode, for which the target was mounted directly on the servo carriage, the servo being externally controlled.
- Open Accommodation Loop mode, in which the target was carried on the carriage and servo controlled via the detector signal. The target position was then dependent on the instantaneous accommodation level.

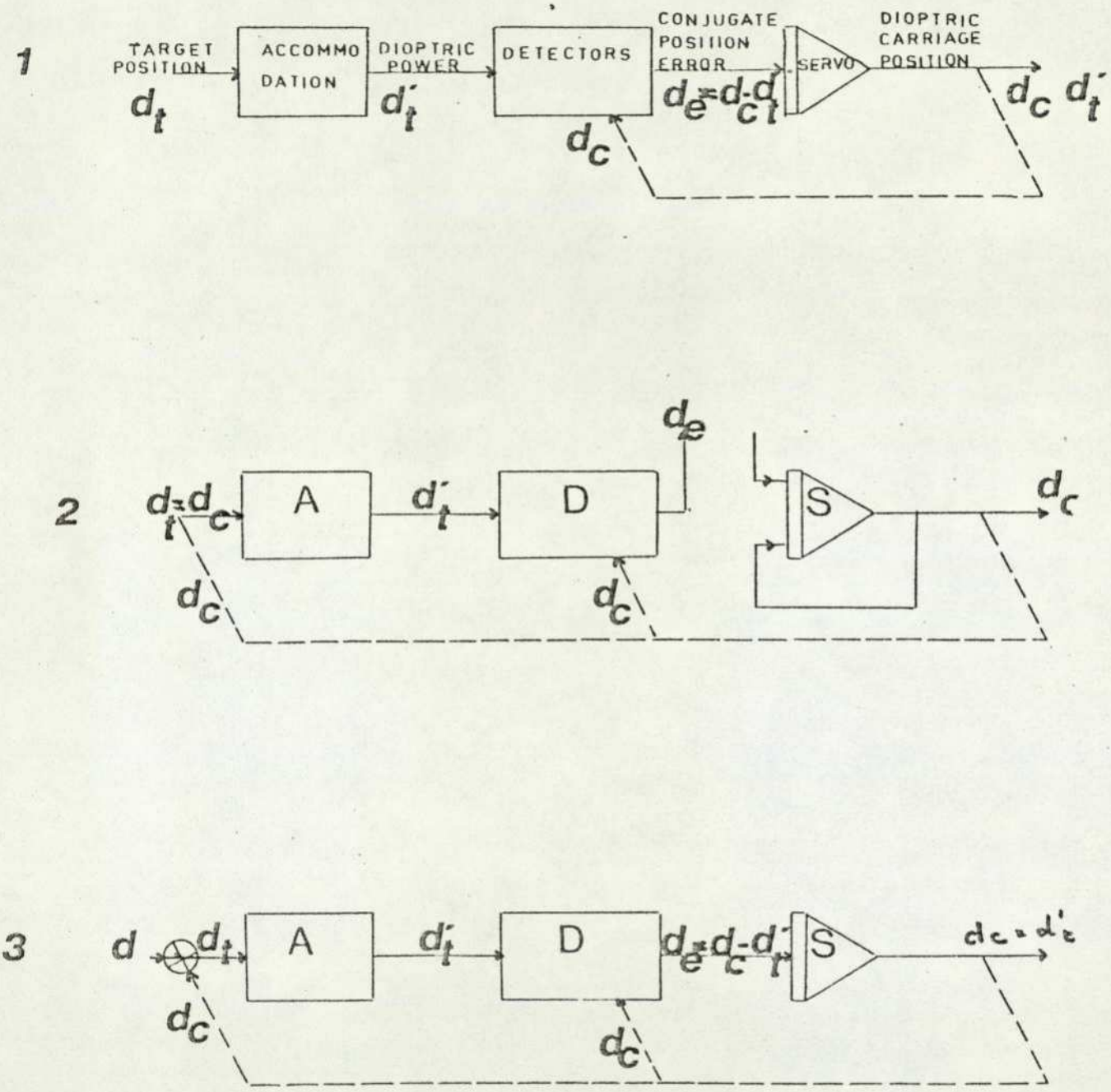


Fig. 21: Optometer by Warshawsky (1964)
Schema of the various electronic modes

1. Nulling mode
2. Conjugate Error Mode
3. Open Accommodation Loop Mode

Elul, Machiafava and Nicotra (1964)[37] commented that the change in the diameter of the blurred retinal image was a first order function of the accommodation and derived the formulae (fig 22).

$$h'' = -bh(A+(1/\ell))$$

where h''= size of 2nd extraocular image

b = distance eye to fixed plane

h = radius of arbitrary limiting stop at principle plane

A = accommodation

ℓ = distance point source to principal plane.

therefore $h'' \propto A$

They subsequently converted this variation in image size into transversal displacement by placing into the path a Scheiner disc allowing only two marginal pencils of radiation to enter the eye (fig 23). The light reflected by the retina, acting as a second source fell on two triangular shaped photodetectors. These cells gave greater or smaller output depending on the position of the pencil of radiation with regard to the optical axis and reflected accommodation changes.

Tucker (1969)[38] built an IR optometer based on Campbell's but with two major differences: there was no sector wheel in the optical system but a bi-prism and in the detecting system the separation between the two retinal images fell on a simple germanium chip positioned at the mid point of the area of overlap of the two images, hence giving maximal out-put when perfect overlap was present.

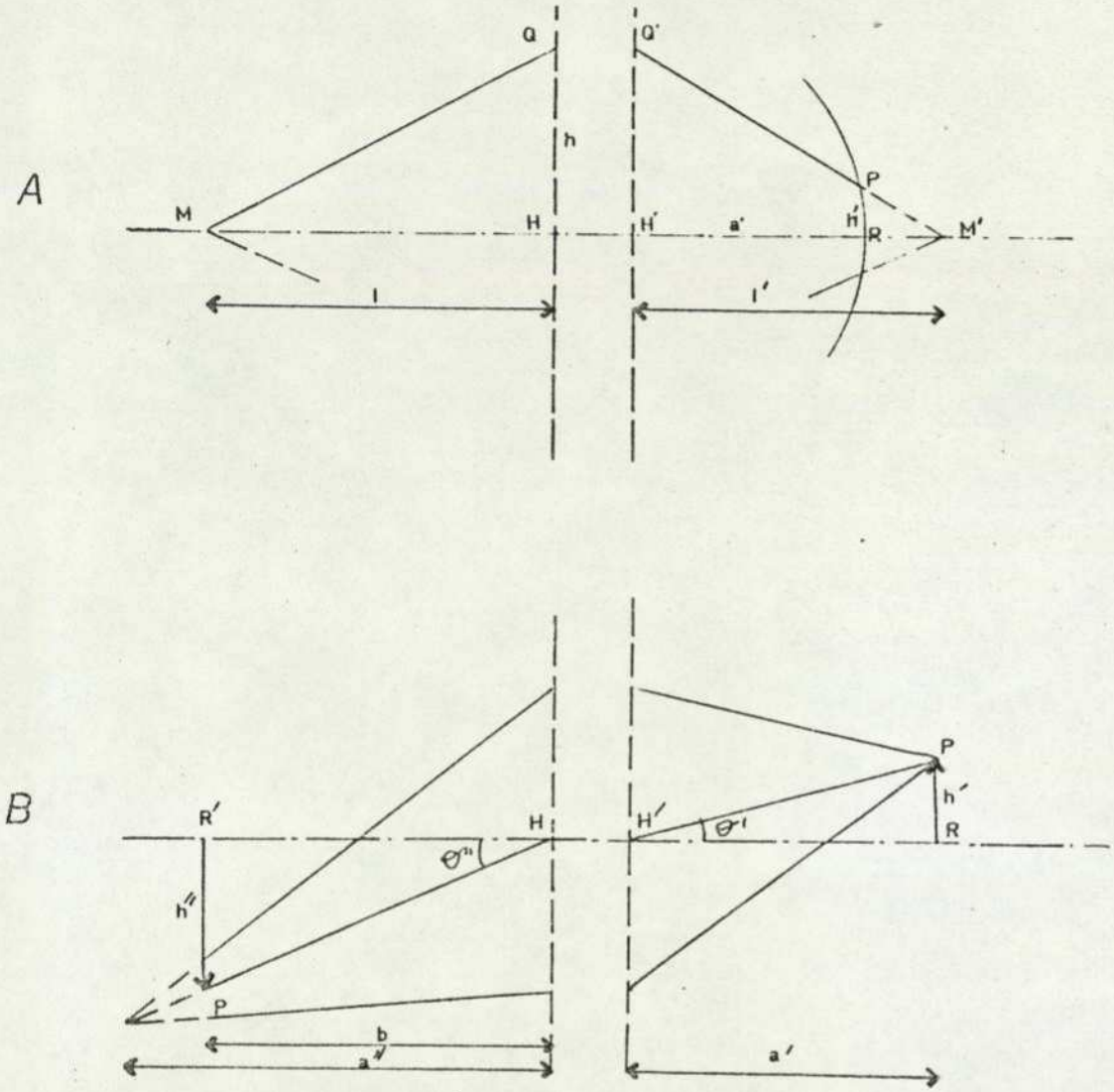


Fig. 22: Optometer by Elul and Machiafara and Nicotra

Top: Incident path Diagram
Bottom: Emergent path Diagram

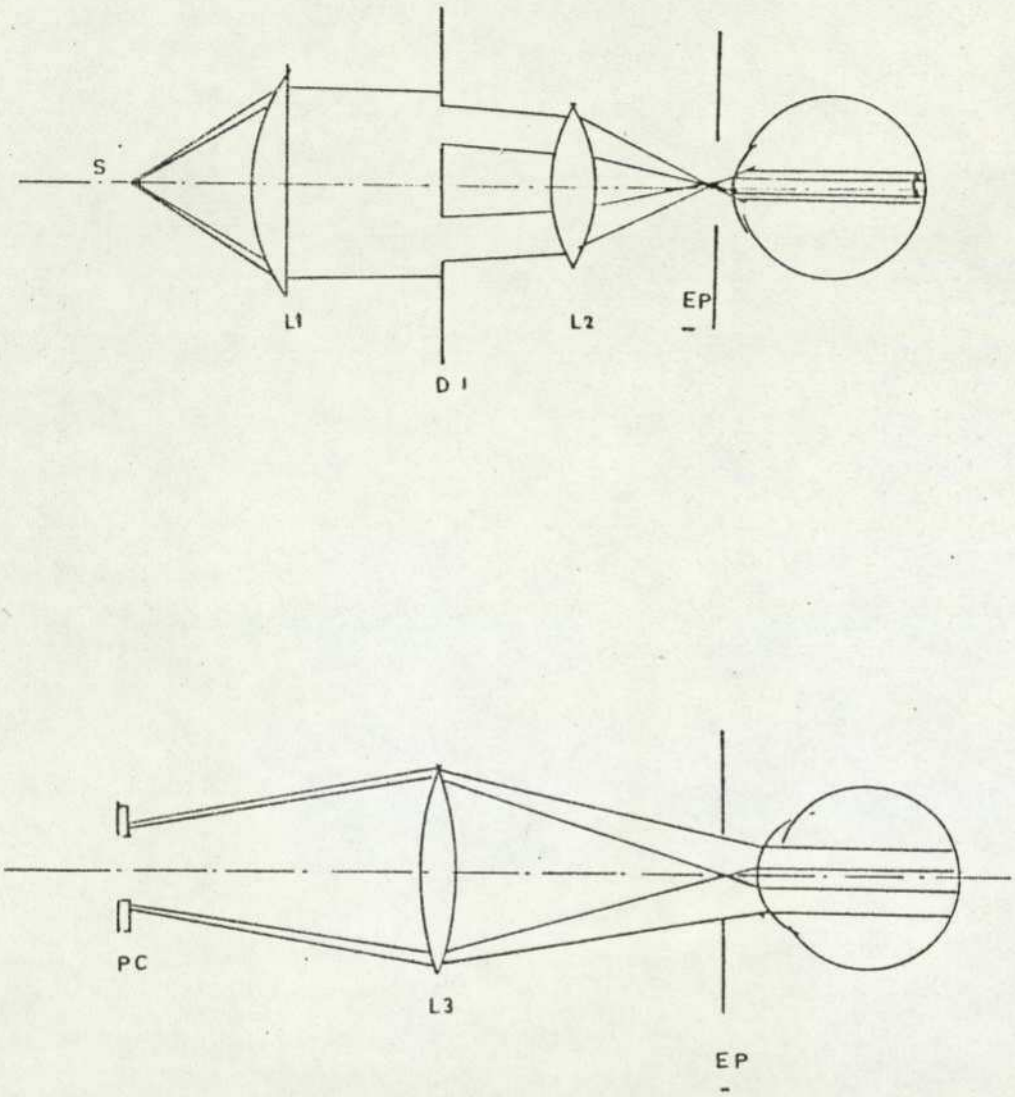


Fig 23: Elul, Machiafara and Nicotra's Optometer
Optical arrangment
Above: Incident path
Below: Emergent path

Cornsweet and Crane's Optometer (1970) included a source formed of two pairs of spots switched on and off in vertical pairs at 450 Hg which formed the Scheiner's arrangement. The image of a slit target was then stationary on the retina if properly focused. The reflected image was then immobile on the photodetector cell. In any other case there was relative movement between the output light and the source of light; the servo-control system moves part of the optical system to cancel the relative movement.

CHAPTER 3

CRITICAL DESCRIPTION AND EVALUATION OF THE NEW ELECTRONIC IR OPTOMETERS

The following is a detailed description of the three IR optometers commercially available. Such a description necessary to the clinical appreciation of the various models is not readily available in a single article in the literature where often only simplist or incomplete descriptions are found.

3.1. The Ophthalmetron

The Ophthalmetron designed by Safir[40] (1964) and manufactured by Bausch and Lomb was the first commercially available IR optometer to measure distance spectacle refraction. The instrument (fig 24) as a whole, weighs approximately 93 pounds, and operating on 175 watts, measures refractive errors from -18.00 DS to +17.00 DS by performing 2,160 retinoscopic measurements in 3 seconds (Mohrman and Hogan, 1977)[41].

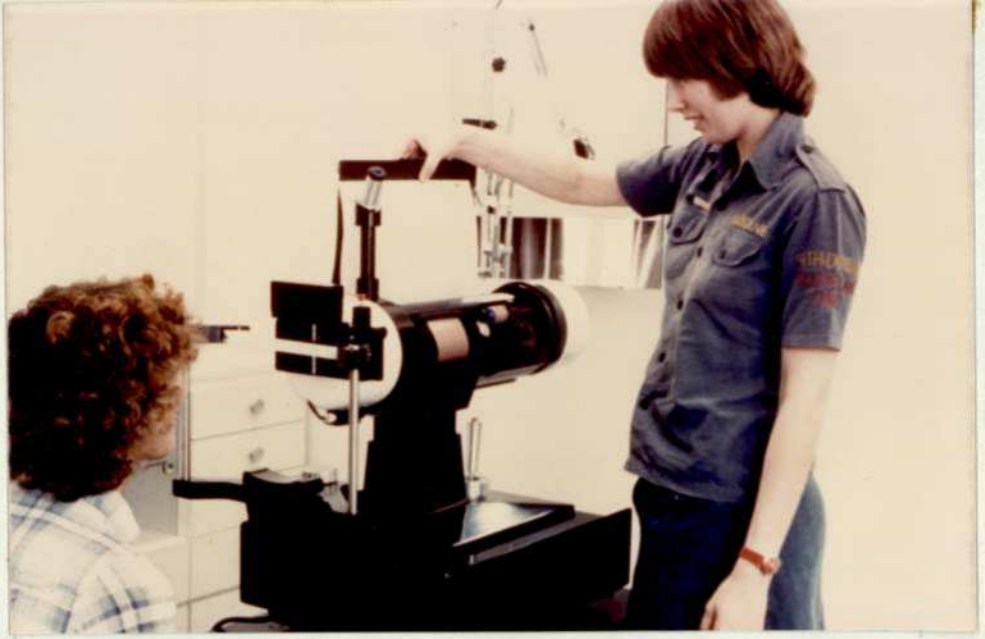
The instrument is divided into four systems: optical, recording, electronic and mechanical to be described separately with emphasis on the optical arrangement.

3.1.1. Optical System

The Optical System (fig 25) includes 4 sub-systems which partially overlap each other.

(i) Patient Fixation System

The purpose of this system is to give the patient a specific point of regard, in order to obtain steady fixation



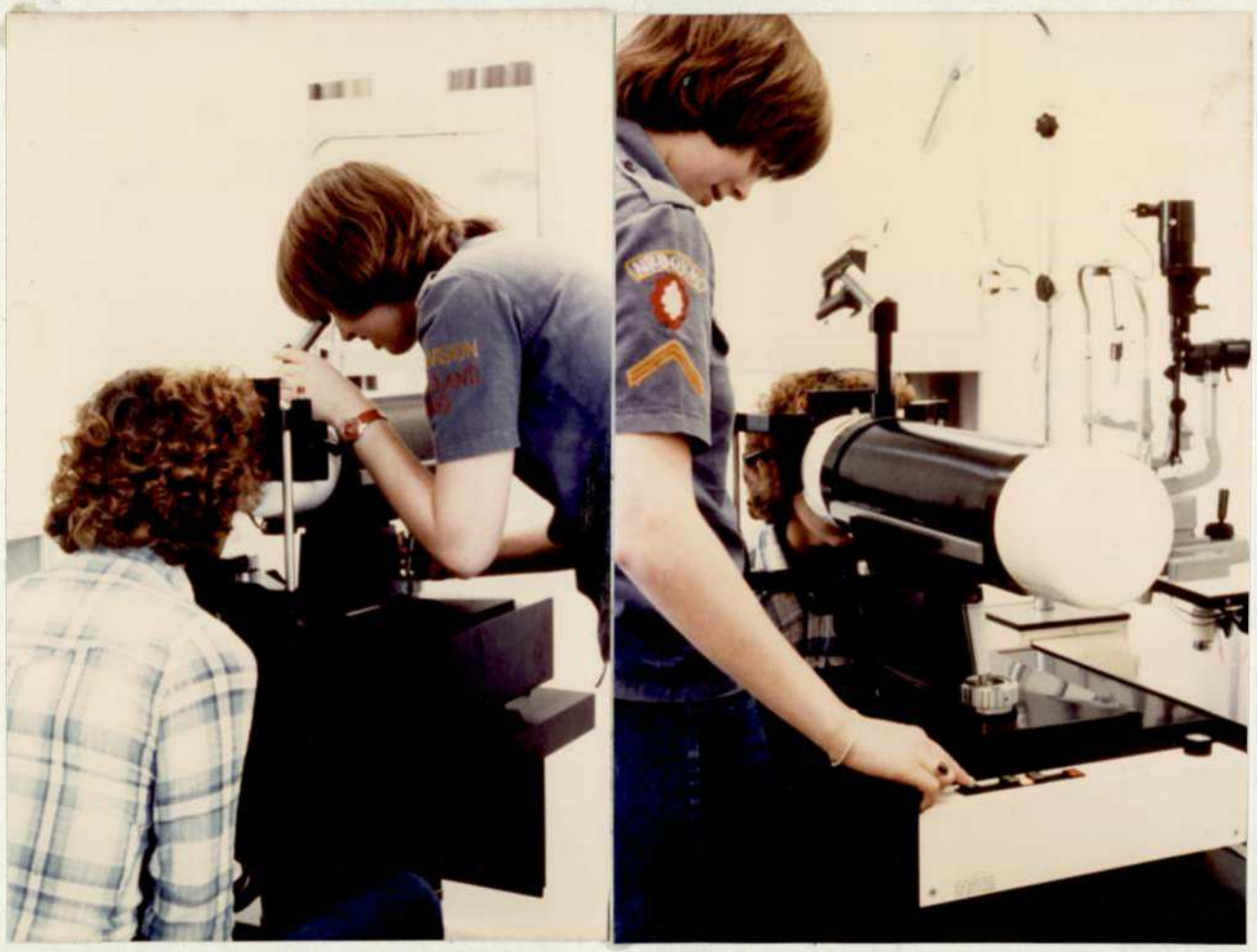


Fig. 24: The Ophthalmetron in Use

a) Insertion of recording chart
b) Alignment of the patient
c) Start of measurement cycle

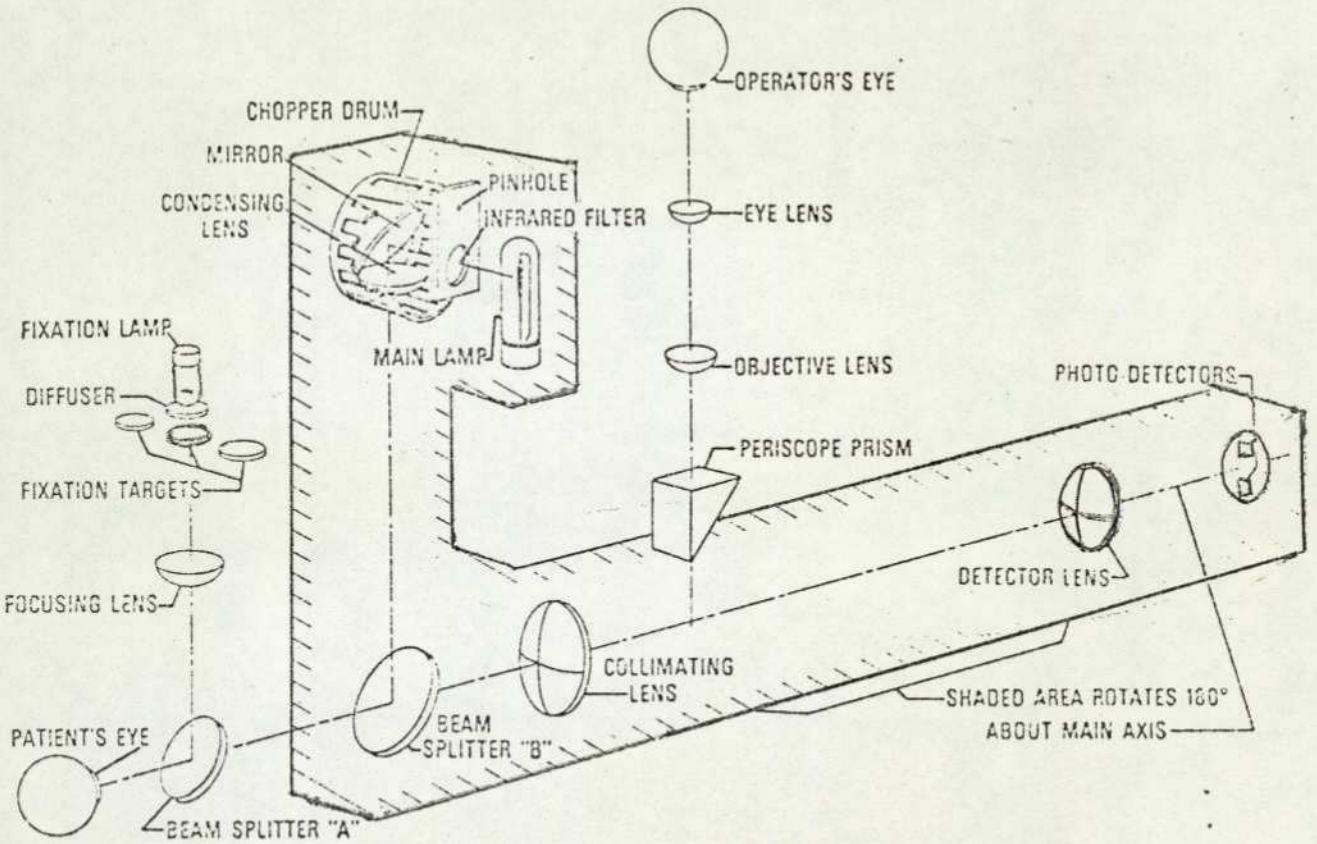


Fig: 25 The Ophthalmetron: Overall Optical Arrangement (after Mohrman and Hogan, 1977)

and to control accommodation during alignment and measurement.

It consists of a fixation lamp (8.5V, 2.75 amp.), a diffuser, a set of 3 targets, a focusing lens, a beam splitter A (working as a reflector) and a Scheiner disc. The fixation targets, mounted on a sliding track are back illuminated through the diffuser by the fixation lamp. The usual "distance" target is a colour photograph of a rocket taking off (fig 26) (Safir, 1972)[42] seen from a distance in an attempt to psychologically relax accommodation (Mohrman and Knoll, 1976;[43] Mohrman and Hogan, 1977).[44] The alternative distance target is a Maltese Cross (fig 26) for patients with low visual acuity. Finally there is a "near" target representing a close up photograph of a thread and needle on a **red** background (fig 26). This can be used to stimulate maximal monocular accommodation and to obtain a measurement of the amplitude of accommodation by comparing with the distance refractive error (Bausch and Lomb, 1973).[45] The focusing lens (+20.00DS) can be displaced in discrete steps along the optical axis of the illumination system in order to focus the fixation target on the patient's retina over a range of +20.00 to -10.00DS (Hogan)[46] (Therefore myopes of more than 10 dioptres cannot see the target clearly). The focusing lens is used in conjunction with the bi-pinhole in an attempt to relax accommodation by the "blur method" following the use of Scheiner's principle (see routine use of the instrument) or stimulate accommodation when trying to measure it.

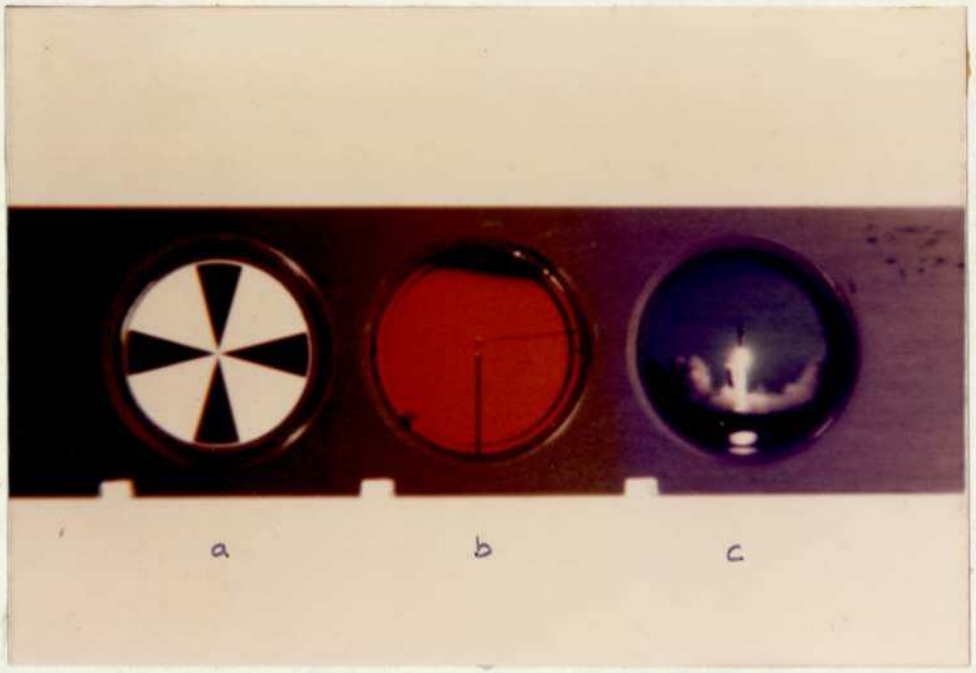


Fig. 26. The Ophthalmetron: Patient's Fixation Targets

a) Maltese Cross
b) Near Target
c) Distant Target

(ii) Illumination System

The main function of the system is to illuminate the retina with a pulsating IR beam, which can be picked up, after reflection, by the detection system.

The Illumination system (fig 27) is composed of an IR filter, a plane mirror, a condensing lens, a "chopper" drum, and beam splitters A (in transmission) and B (in reflection).

During the measurement cycle the light produced by the 20 watt tungsten filament lamp is rendered invisible to the patient by introduction of the Wratten 87 filter. The use of IR has the double advantage of leaving the patient's view of the fixation target unaffected and not causing pupil constriction. This IR beam, invisble to the patient is reflected by the mirror M onto the condensing lens C, which images the filament of the lamp into the plane of the patient's entrance pupil after reflection by beam splitter B (Safir, 1972)[47]. The "chopper" drum is a simple rotating drum with slit apertures through which the light can pass. It surrounds the mirror M and condensor lens C (Mohrman and Hogan, 1977)[48] and forms a pulsating streak of light on the patient's retina (Safir, 1972)[49] at 720 cycles per second. Finally the role of the beam splitter A and B is to render the main illumination system coaxial with the patient fixation system.

(iii) Alignment System

This includes the main illumination system without the IR filter and the optical system occupying the periscope.

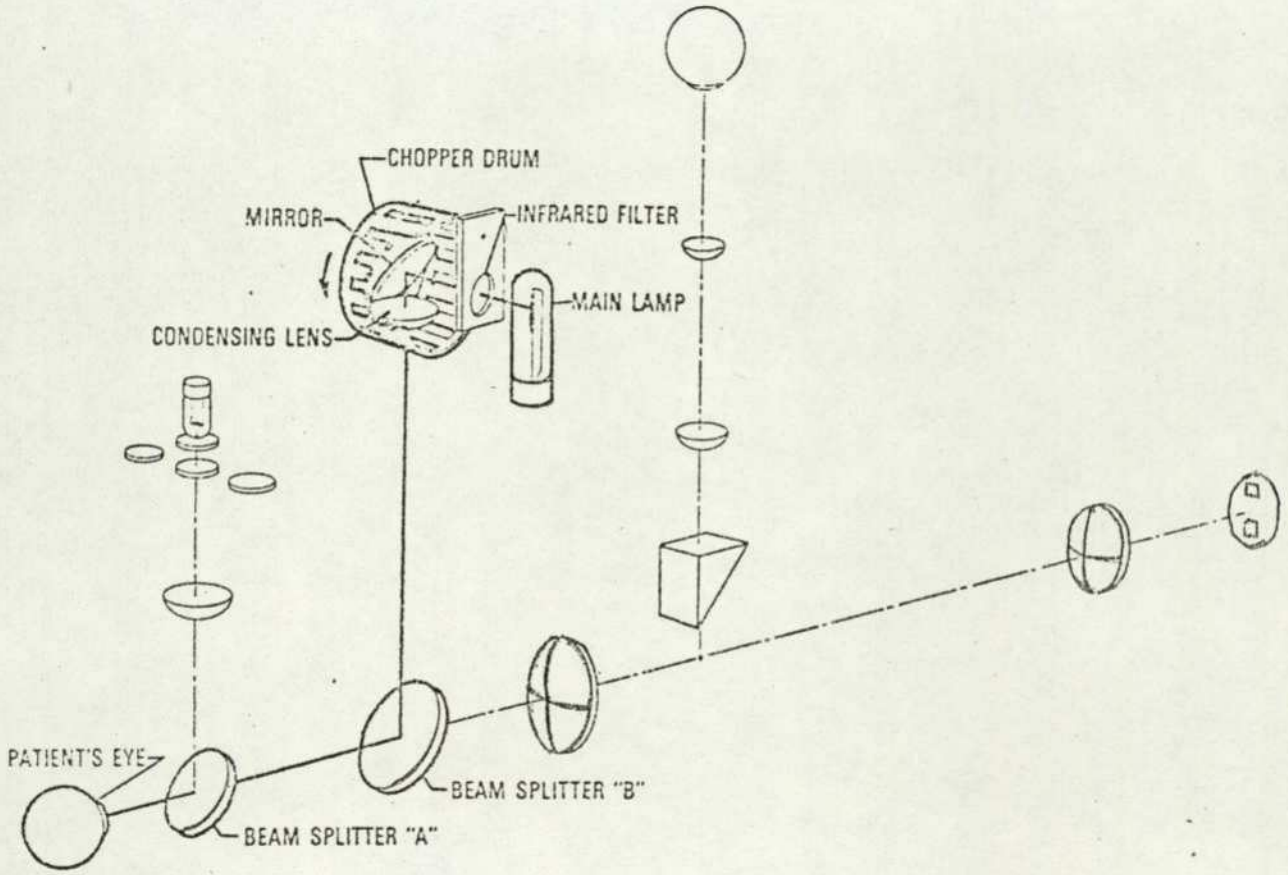


Fig. 27: Ophthalmetron Illumination System

The latter is situated at the superior part of the instrument (fig 24). Lowering of the periscope prevents the instrument from operating in its measurement mode; it also removes the IR filter from the illumination path and replaces it with a pinhole, the illumination light then becomes visible to both patient and operator.

The complete alignment system consists of the illumination system (described in 3.1.1.(ii)) and the periscopic arrangement composed of a prism P reflecting the light through 90^{o} and the x 2 telescope formed by the objective and eye-piece.

The underlying principle for the alignment system is attributable to Mohrman (1971)[50] and utilizes "considerable but controlled spherical aberration" produced primarly by the condensing lens in the illumination system (fig 28). A pinhole positioned at the focal point of the marginal rays, will allow both the marginal and paraxial rays to pass, but blocks the intermediate rays. The operator observes this aberrated image of the pinhole reflected by the cornea (fig 29), this image appears as a bright dot surrounded by a bright annulus. Any vertical or horizontal misalignment of the illumination system, hence of the instrument, with regard to the corneal apex will result in the central bright spot being off centre with regard to the annulus of light. Previous focusing of the alignment target will have insured the correct working distance. In fact the system produced appears to be a highly reliable means of alignment (see 5.1.).

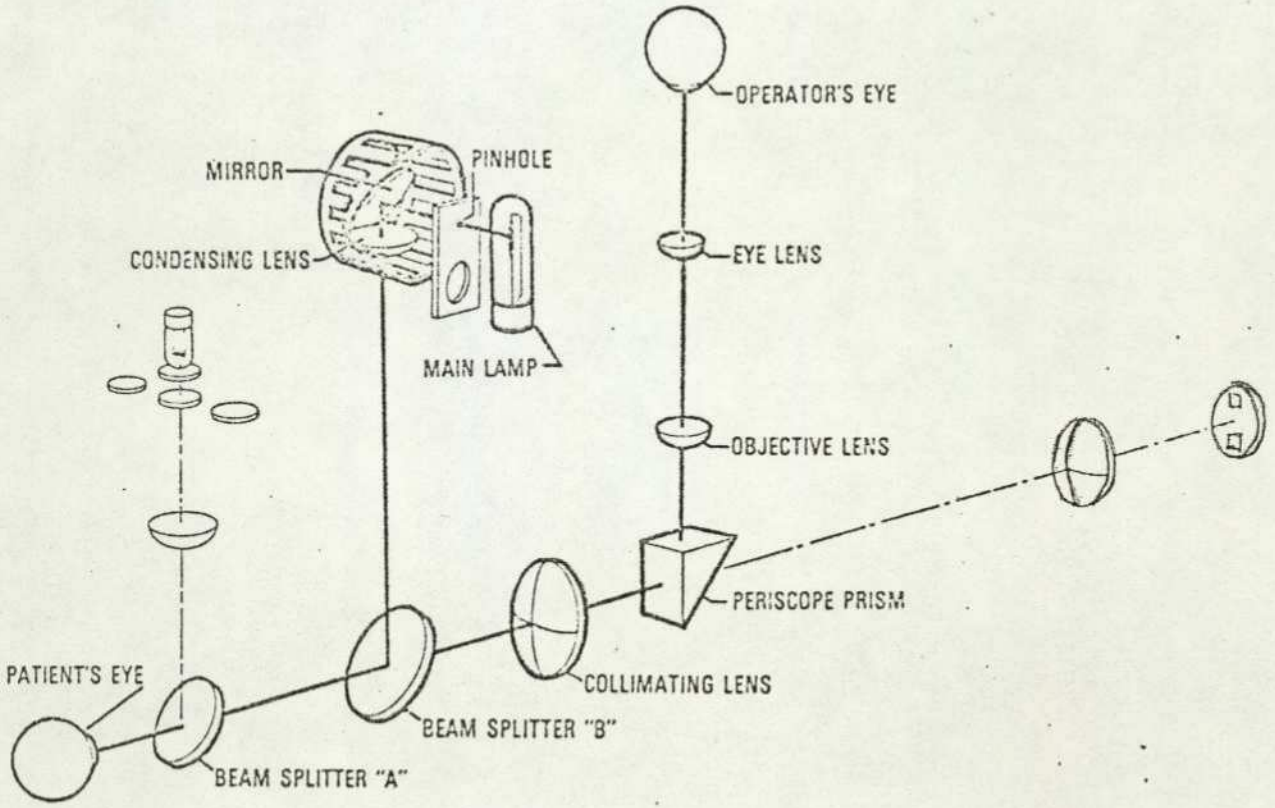
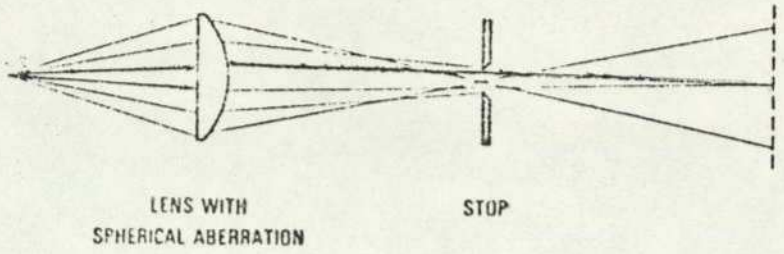


Fig 28: The Ophthalmetron Alignment System



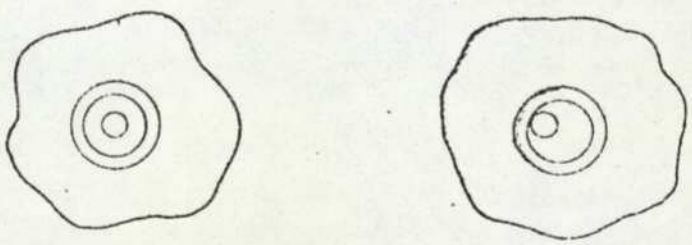


Fig. 29: The Ophthalmetron. Underlying Principle for the Alignment System

(iv) Detection System

The detection system combines the optical and electronic systems of the instrument to study the "refractive" nature of the beam of light reflected by the retina, which acts as the light source for this system. The system (fig 30) consists of the two beam splitters, A and B in transmission, the collimating lens, a pinhole, the detector lens and cells.

The IR radiation reflected by the retina, acting as a secondary source, and emerging through the pupil, converges to the eye's far point. The collimating lens produces an image of the far point within the range of the instrument. The beam then encounters the detection lens, the aperture of which is limited by a slit (Mohrman, 1969).[51] The role of the detector lens is to magnify (Safir, 1964)[52] and image the subject's pupil in the plane of the photo-detector to produce maximal illumination of the cells by the central 3 mm of the pupil (Safir, 1972).[53] The source will be imaged as a vibrating beam on the photodector cells, the characteristics of the vibration being a direct measurement of the refraction of the eye under test. The detection of the nature of the vibrations is the role of the electronic solid state system. In fact the system above detects the refractive error along a single meridian and rotation over 180^{o} of the shaded part of the instrument about the main axis (fig 25) enables measurement of the refraction in all meridians.

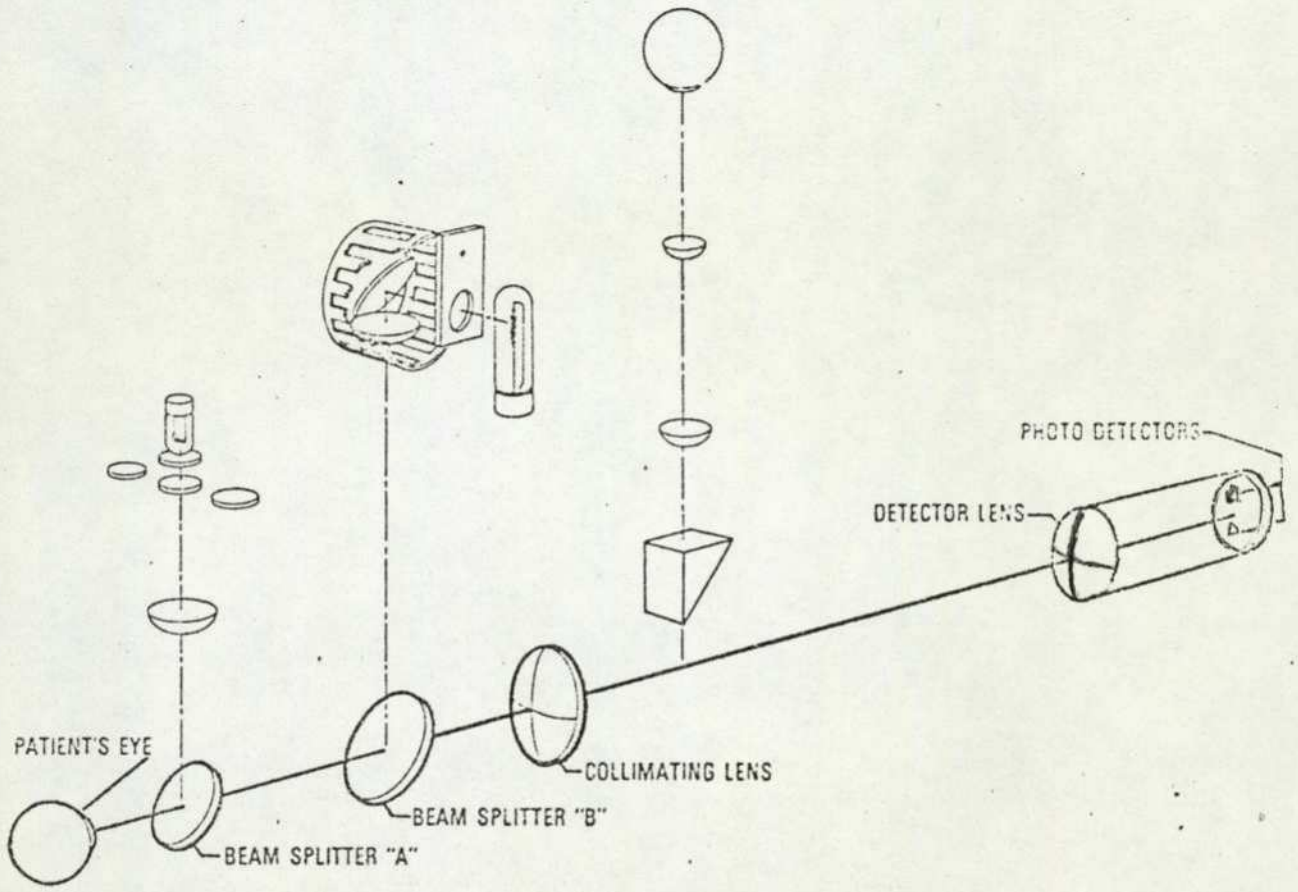


Fig. 30: The Ophthalmetron. Detection System

3.1.2. Electronic System

The role of the electronic system is to detect the amount and type of phase difference between the vibration of the beam incident on the photocells and that of the illumination system and by means of the servo control to neutralise this phase difference.

As illustrated in the schematic diagram (fig 31) if the detector cells are positioned beyond the artificial far point the sequential order of illumination of the photodetector cells will be opposite to the illumination of the eye (i.e. detector B will sense before A). It is the situation known as an "against movement": the amount of phase difference being indicative of the magnitude of refractive error. On the contrary, when the detector cells are positioned within the far point, the order of illumination will be identical to that encountered in a "with movement". In the unique case where the photocells are in the plane of focus the cells will be illuminated simultaneously. At this stage the servo control will cause the recording pen to come into contact with the paper and start recording the refractive error.

The electronic system (fig 31) consists of a pair of photodetectors. a two channel preamplifier, a filter network, a phase discriminator and a servomotor.

The dual photodetector is a pair of sensitive field effect transistors (FET) which emit two electronic signals whose phase relationship represents the error positioning

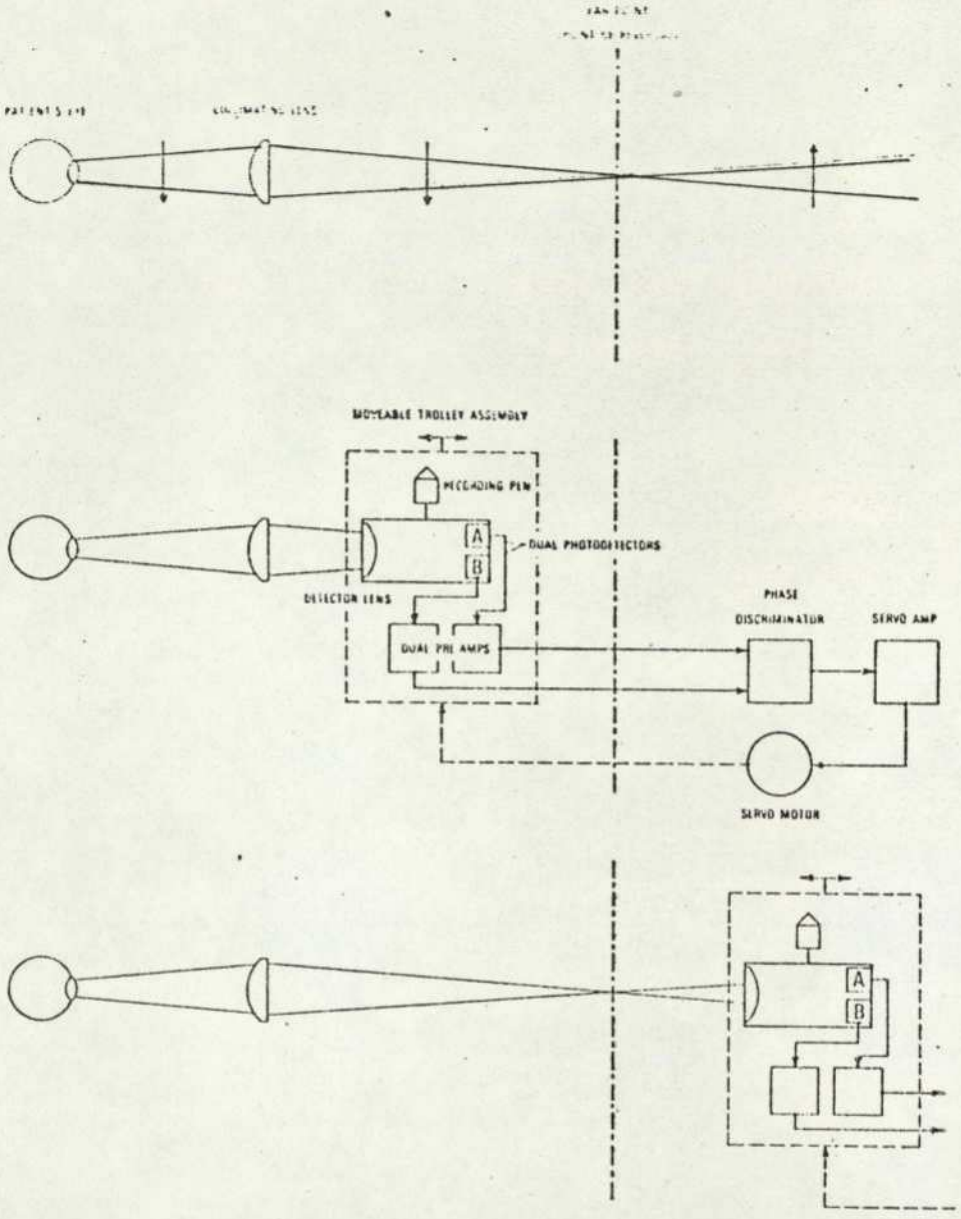


Fig. 31: The Ophthalmetron
Schematic Diagram of the Electronic System

of the detector trolley. The resistance of the FET's is proportional to the amount of radiation falling on them; here the light is either present or absent because of the action of the "chopper" drum, at 720 Hz. The voltage variations between the two FET's will be directly linked to the position of the trolley, in phase when the trolley is situated at the far point, and otherwise out of phase.

Because the two FET's emit a very weak signal, amplification is necessary before phase discrimination, two amplifiers are employed and give 100 times amplification.

A filter network which cuts down extraneous noise is situated in close proximity to the phase discriminator. The phase discriminator which receives a signal from each of the two channels generates a direct current proportional to the phase difference between the two signals.

The servo amplifier amplifies the dc error voltage to a power level sufficient to drive the servo motor. The servo motor will in turn drive the trolley towards the far point. The circuitory will repeat the same process 2,160 times in 3 seconds during the 180^{o} scan.

3.1.3. Recording System

The pen recorder attached to the detection system produces an analog tracing on the record chart mounted on the cylinder around the optical system: the refractive error is plotted along the abscissa and the meridian along the ordinate. The refraction obtained is computed for a back vertex distance of 13 mm.

The analog read out appears as a straight line in the case of spherical ametropia (fig 32) and as a sinusoidal curve when regular astigmatism is present (fig 33). This curve is of the Sin $^2\theta$ form; the two peaks of this curve represent the dioptric value of the two principal meridians (ie. -3.25 al 180/-6.00 al 90) and should be at 90^o to each other. The two values can be translated into a sphero-cylindrical formula (ie. -3.25/-2.75 x 180). A flexible type of ruler is supplied to help to locate the exact position of the peaks of the curve (fig 34).

The idea of a Sin $^2\theta$ to represent the variation of power over 180^o is technically fallacious, as pointed out by Benner (1978).[54] It is known that a cylindrical surface varies continuously in radius of curvature from zero (along the axis meridian) to a maximum rc (in the meridian perpendicular to the axis). If this cylinder is intersected by a plane making an angle θ with the axis of the cylinder it will generate an elliptical section of which the semi-major axis OA is rc Cos Sec θ and semi-minor axis OB is rc. This ellipse will have a curvature at the extremity of its minor axis equal to $\frac{rc}{rc \text{ Cos } Sec^2\theta} = Rc \text{ Sin }^2\theta$ (Bennett, 1968).[55] So by extension if we call c the cylinder power we can calculate the "oblique power" due to the cylinder in any meridian by $F\theta = C \text{ Sin}^2\theta$. In fact this notion of 'bblique power' or "spherical equivalent" in a given meridian is technically erroneous as the rays in an oblique meridian do not come to a point or line of focus but exhibit skew convergence.

The analog read out needs to be interpreted by the

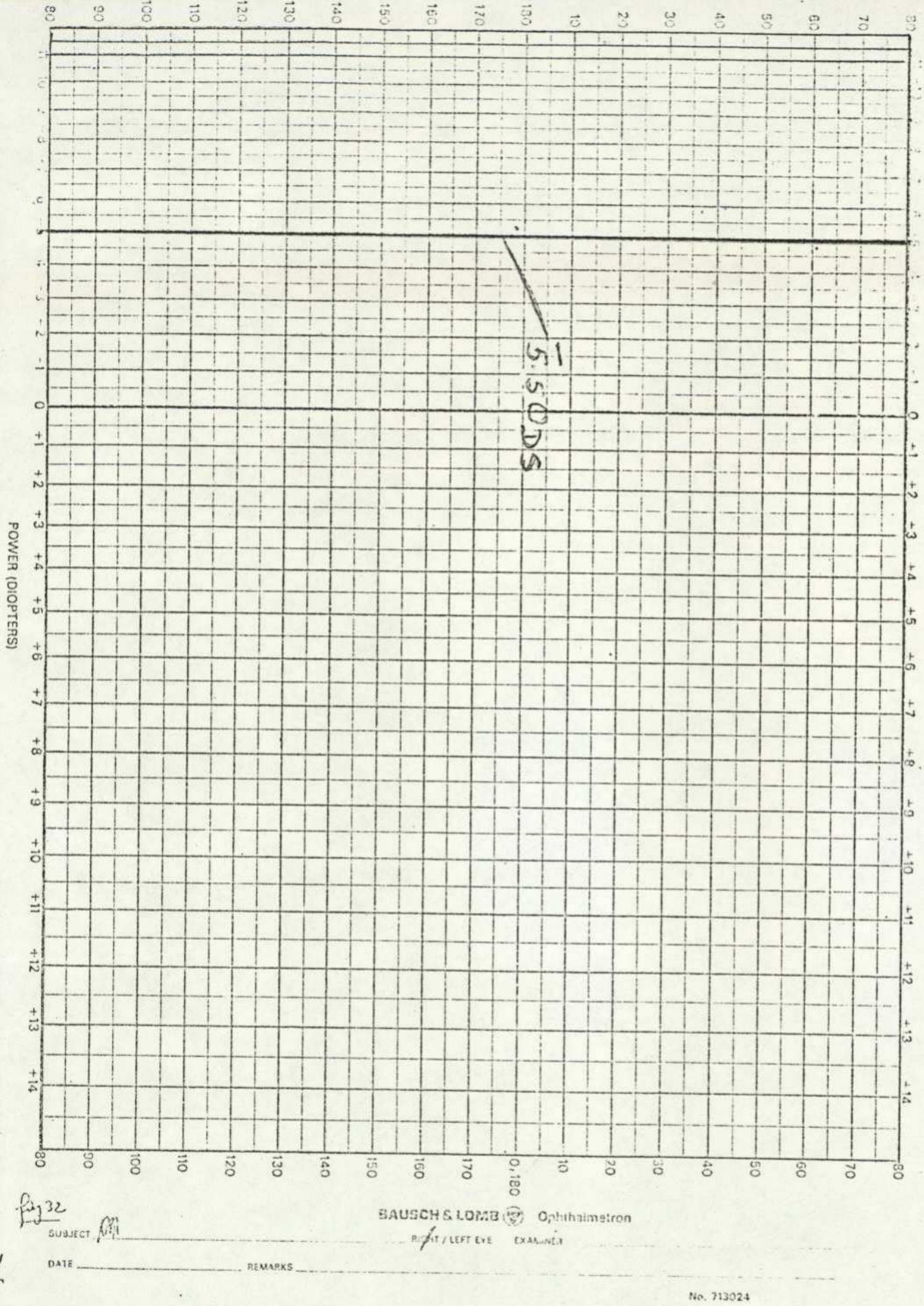


Fig. 32: The Ophthalmetron. Spherical Ametropia Recording

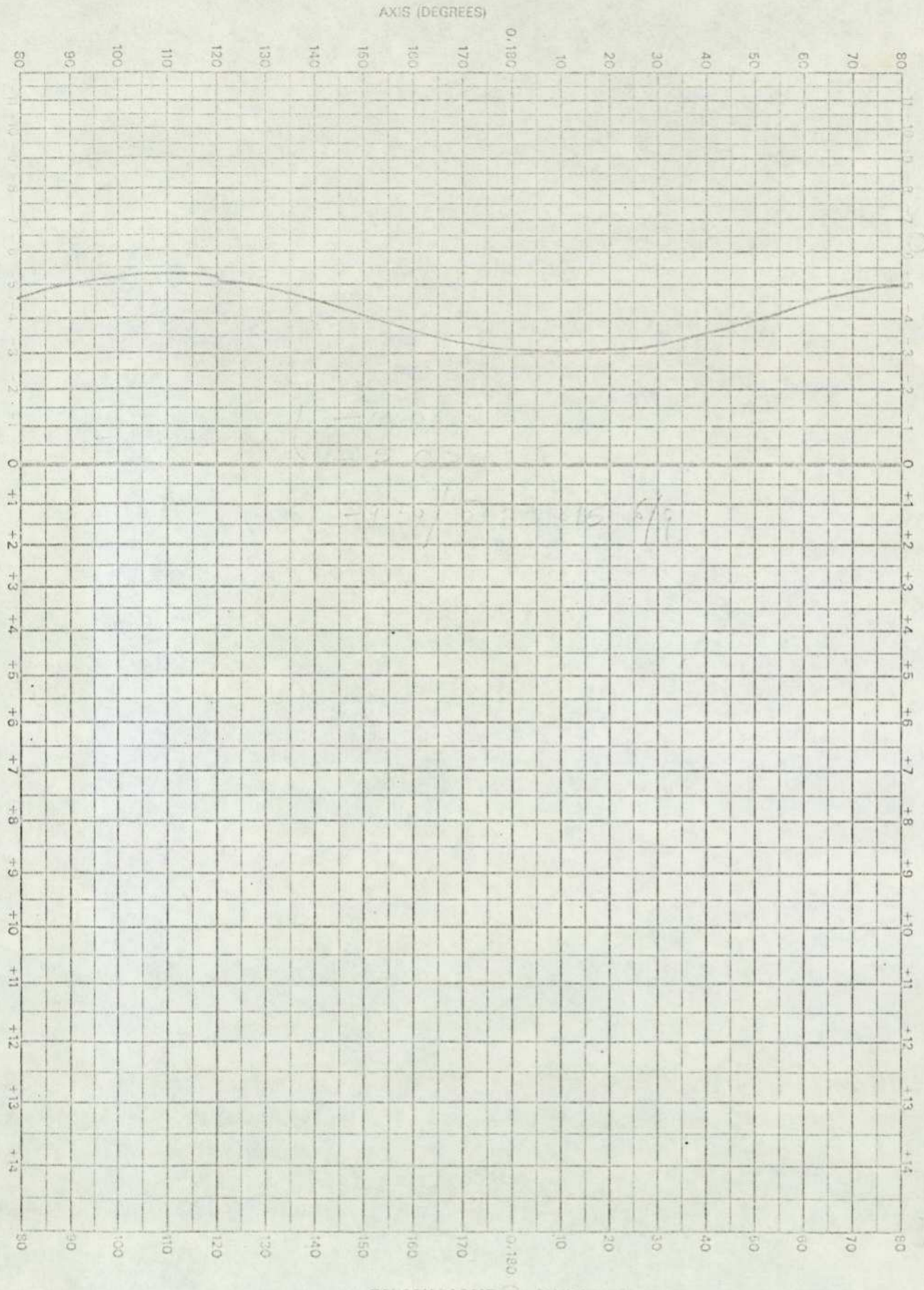


Fig. 33. The Ophthalmetron. Spherocylindrical Recording
– use of negative range

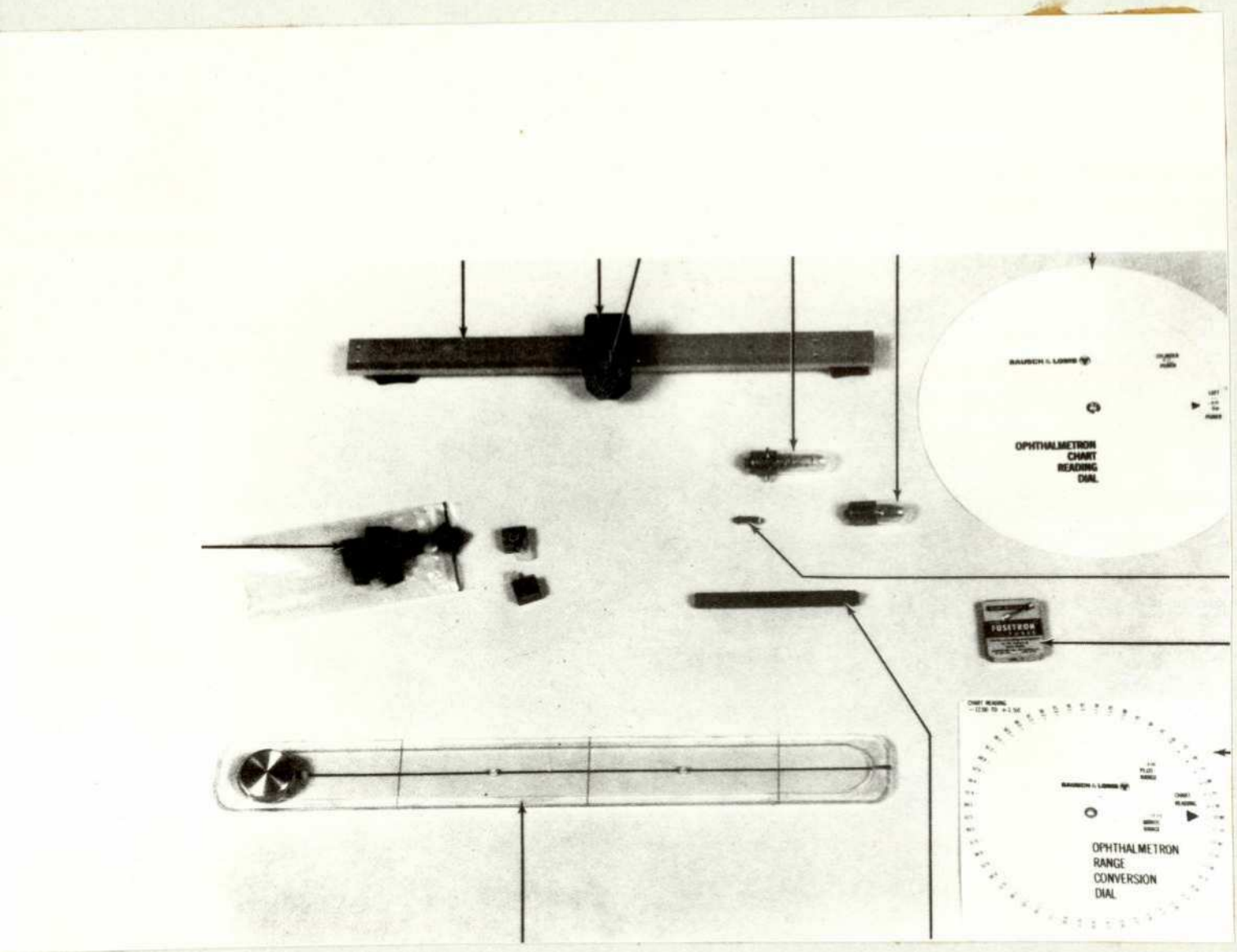


Fig. 34. The Ophthalmetron: Flexible ruler and conversion chart

operator, hence is not as readily available as would be a digital print out. However, more information is conveyed by the analog system, particularly with patients difficult to manage or having non-regular anomalies.

The recording starts and finishes along the 80° meridian (fig 35), hence the same refractive value should be obtained and any difference is indicative of fluctuating accommodation during the measurement, such a fluctuation indicates that a new reading should be taken.

Artifacts are also easily detected; the commonest are blinks (fig 36) and loss of fixation (fig 37). Sometimes for patients with unsteady fixation (ie nystagmus) the refractive error measurement can be obtained by building up a curve from several tracings (fig 38). In fact half the graph is sufficient to assess refractive error when using the Ophthalmetron ruler.

Finally the main advantage of an analog print out is appreciated in cases of irregular astigmatism, often present with hospital patients (ie corneal grafts,....) (fig 39). Here the analog print out gives an accurate picture of reality, while a digital system programmed for regular sinusoidal curves may fail to give a result or give an erroneous reading without the operator being aware of it.

Three modes of recording are available. The "normal range" which corresponds to the printed values on the record charts from -11.00D to +14.00D. The extended ranges are, "plus range" for which the zero is automatically shifted to -5.00D increasing the range to +17.00D and the "minus range" shifting the zero to +5.00D, hence extending the negative range to -18.00D. The positive and negative

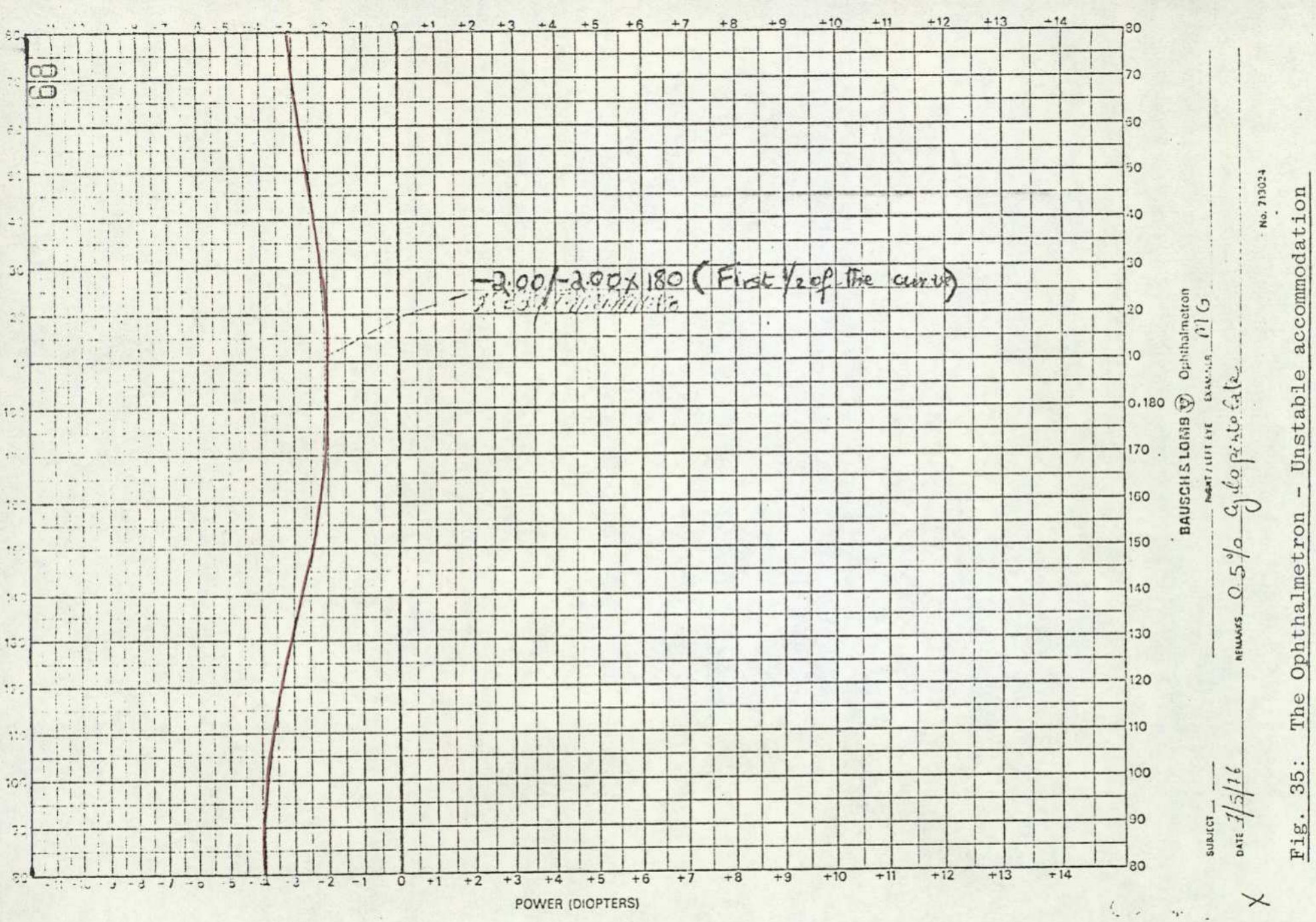


Fig. 35: The Ophthalmetron - Unstable accommodation

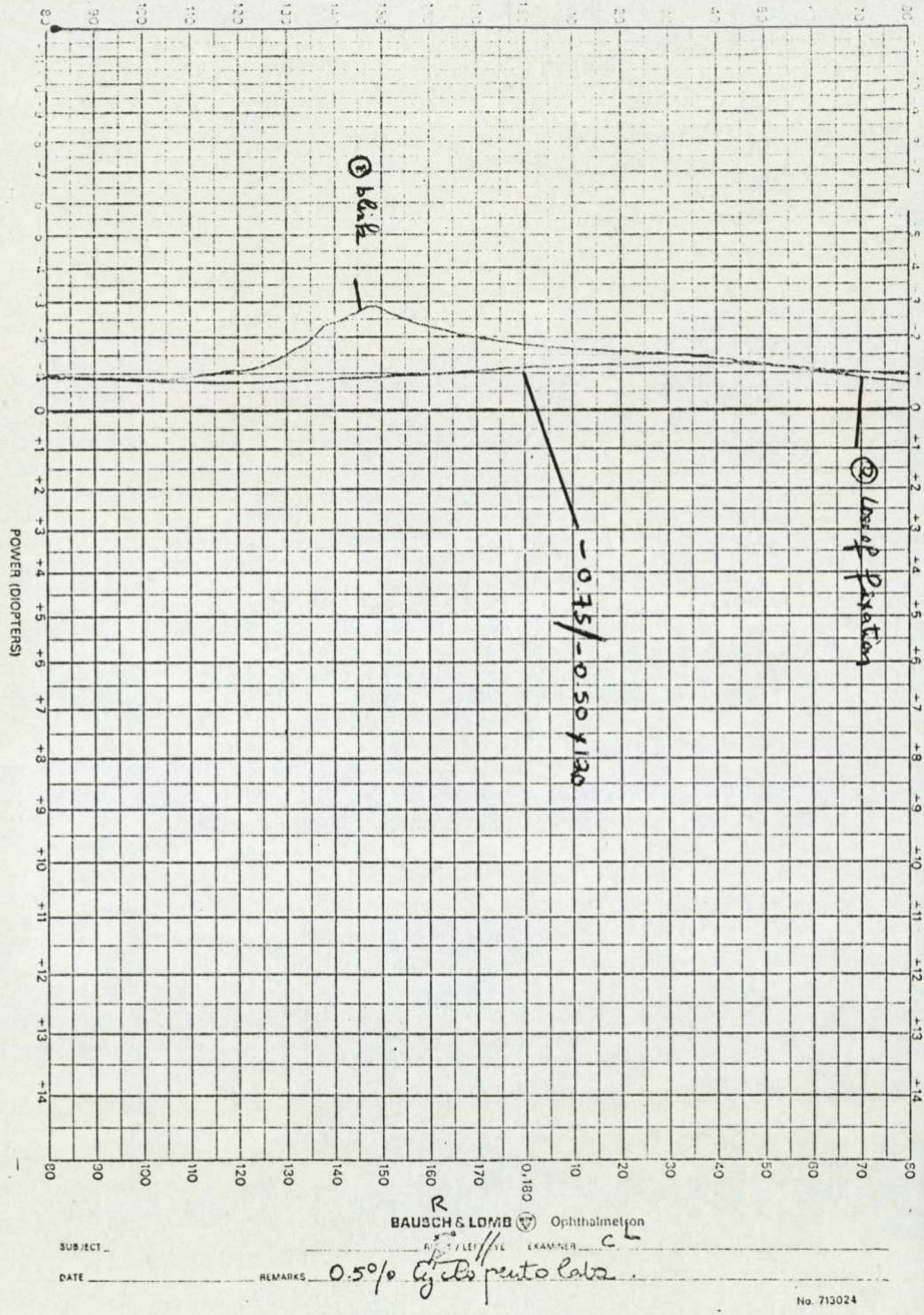


Fig. 36: The Ophthalmetron - Blink Artifact

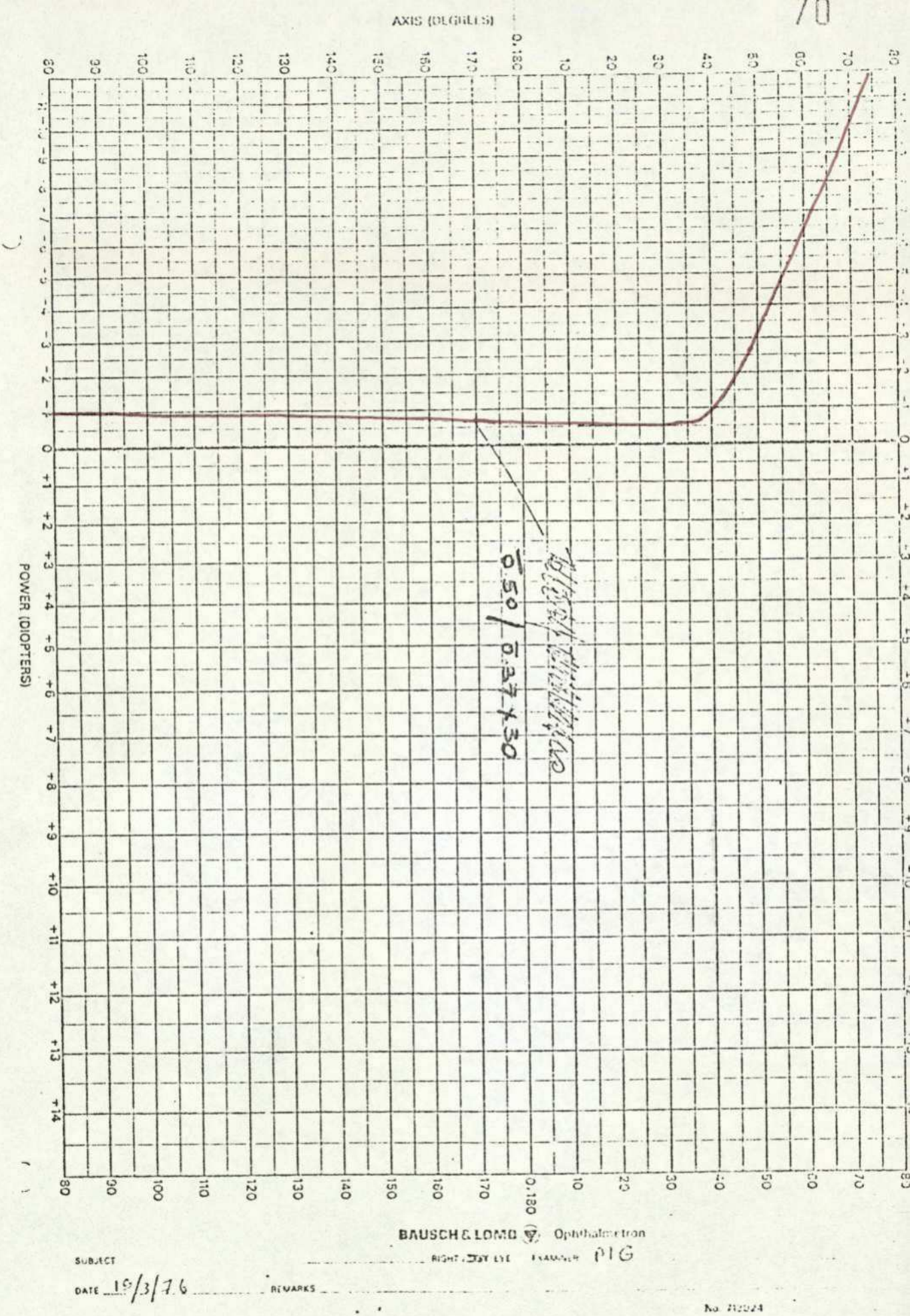


Fig. 37: The Ophthalmetron: Loss of Fixation

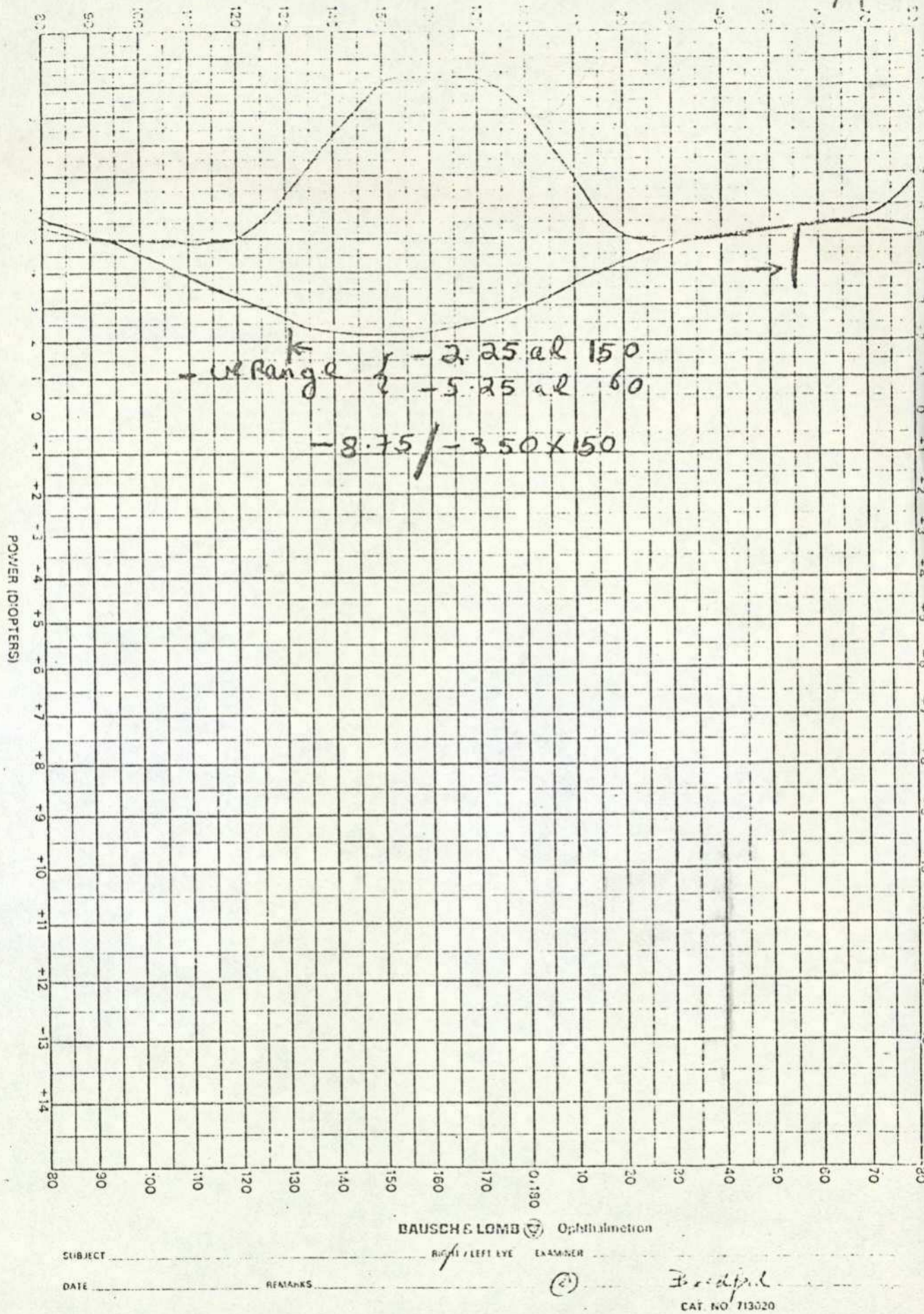


Fig. 38a. The Ophthalmetron "Build up" of tracing

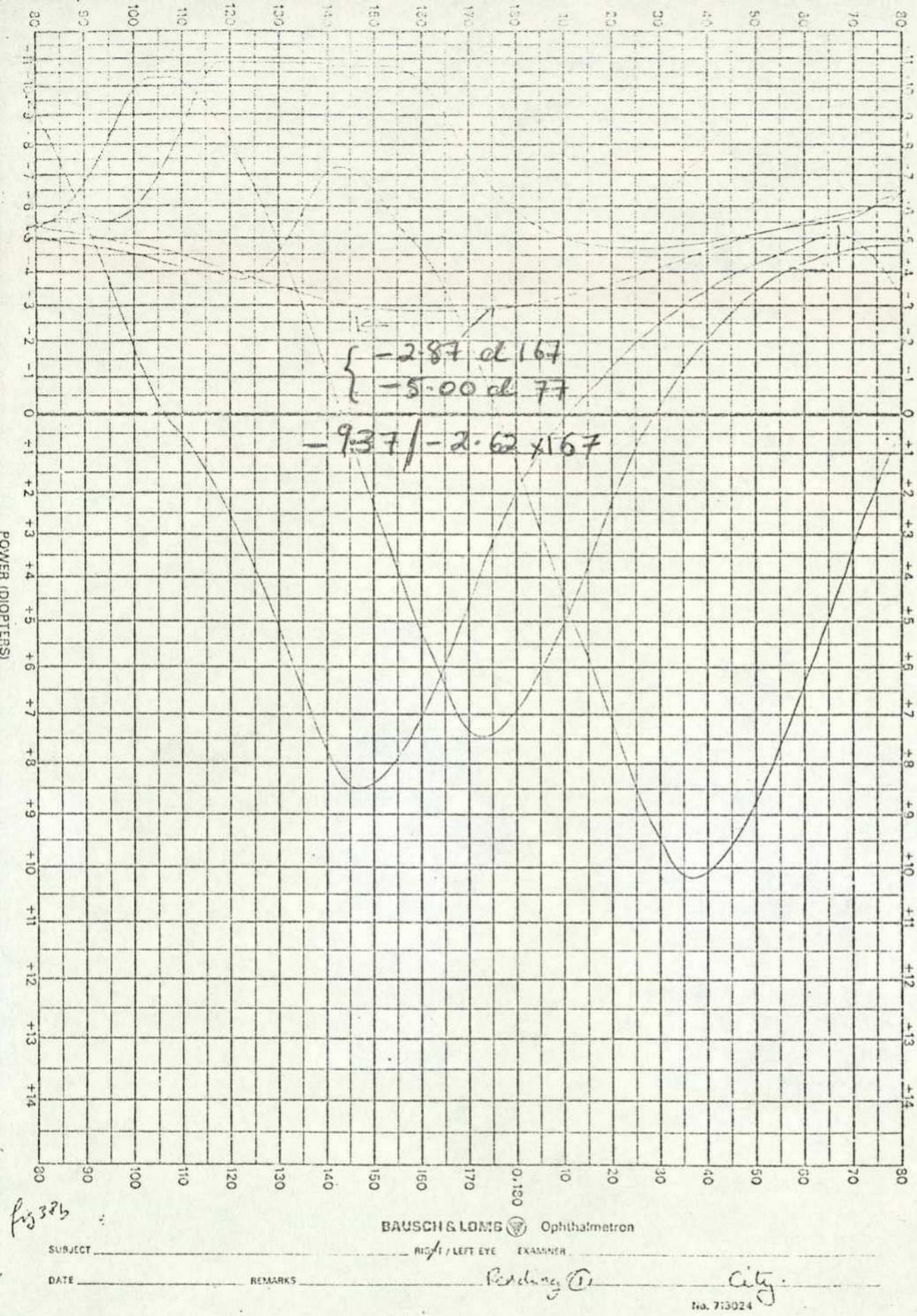


Fig 38b

Fig. 38b. The Ophthalmetron "Build up" of tracing

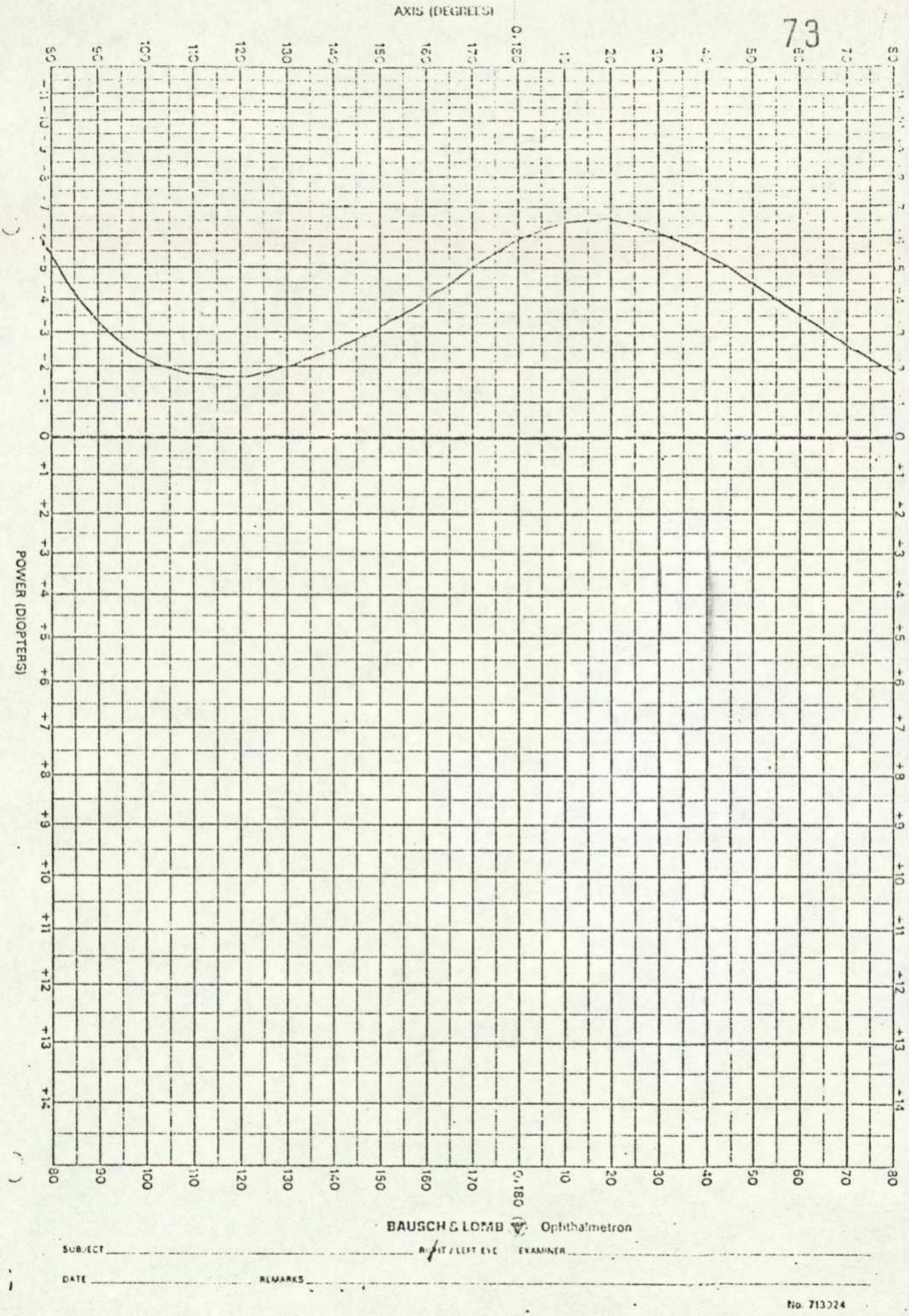


Fig. 39. The Ophthalmetron - Irregular Astigmatism (Aphakic with implant)

"ranges" shifts are accomplished by off setting the zero-point in the electronic system (Mohrman, 1978)[56]. However because of the analog nature of the print out, with the extended ranges the refractive values cannot be read directly, but are obtained from the actual reading by using a converter nomogram supplied with the instrument (fig 34).

3.1.4. Mechanical System

This includes a head rest for patient positioning, a motor system to rotate the illumination and detector system over 180^{o} during the measurement and the joystick arrangement to align the instrument. Two of these systems are of particular interest because of their originality. The head rest, which has been constructed on a designed patented by Blood et al (1971)[57], consists of "a semiflexible abutment for the forehead to prevent forward and sideway movement of the head" (Blood et al, 1971)[57] and practically achieves this claim. The joystick system with a special brake mechanism patented by Blood (1970)[58] enables braking without creating unwanted movement by using a special solenoid arrangement.

3.1.5. Routine use of the instrument

The patient is seated comfortably looking straight into the instrument while chin and forehead are positioned on the chin/forehead arrangement. The patient is asked to look at the centre of the reddish orange light (present when the periscope is in a down positon) or at the base of the rocket (when the periscope is up) as it applies.

The operator then aligns the patients corneal apex with the optical axis of the instrument as described previously. The double pinhole is introduced and the patient is asked to report as soon as he/she sees a single image of the rocket while the operator decreases the dioptric value of the optical system between the patient and the target from maximum positive. After removal of the double pinhole the target is blurred by one or two "clicks" ($\hat{=}$ 1 to 2 D). The patient is instructed to keep looking at the base of this distant rocket without blinking or moving for three seconds while the start button is depressed.

The above routine is modified at times, when dealing with patients having a low VA the Maltese Cross is used as a fixation target. With aphakic patients the double pinhole is not used and the image of the rocket is not blurred but kept at its optimal sharpness.

3.2. The Dioptron

The Dioptron manufactured by Coherent Radiation was first supplied as a production model in November 1974 (Krepick, 1977)[59]. It consisted at the time of two parts linked by a single cable: the optometer itself on a hydraulic table and the computer printer case (fig 40). This resulted in a cumbersome piece of equipment with a very noisy printer. Since then a second generation version of the instrument, Dioptron II, has been developed. It is based on the same underlying principles, but introduces a certain miniaturisation, (the new instrument is a single unit) (fig 41) and has a far less noisy printer. The description that follows refers to Dioptron II with special annotations when necessary to explain differences between the two models.

Dioptron II weighing 90 kg and operating on 300 watts measures the patient's refractive error by retinal imagery sharpness detection. Its range is -10.00 to +16.00 DS and ±5.00 DC, all values obtained being referred to 12 mm vertex distance. The time taken for a typical measurement is between 25 and 30 seconds, the manufacturers claiming an accuracy of $\pm\frac{1}{4}$DS in 80% cases, $\pm\frac{1}{4}$DC in 85% of cases and $\pm 10^{o}$ in 76% of cases (Coherent Radiation, 1977)[60].

As for the Ophthalmetron, the instrument will be broken down into four different systems for description.

Fig. 40: The Dioptron I

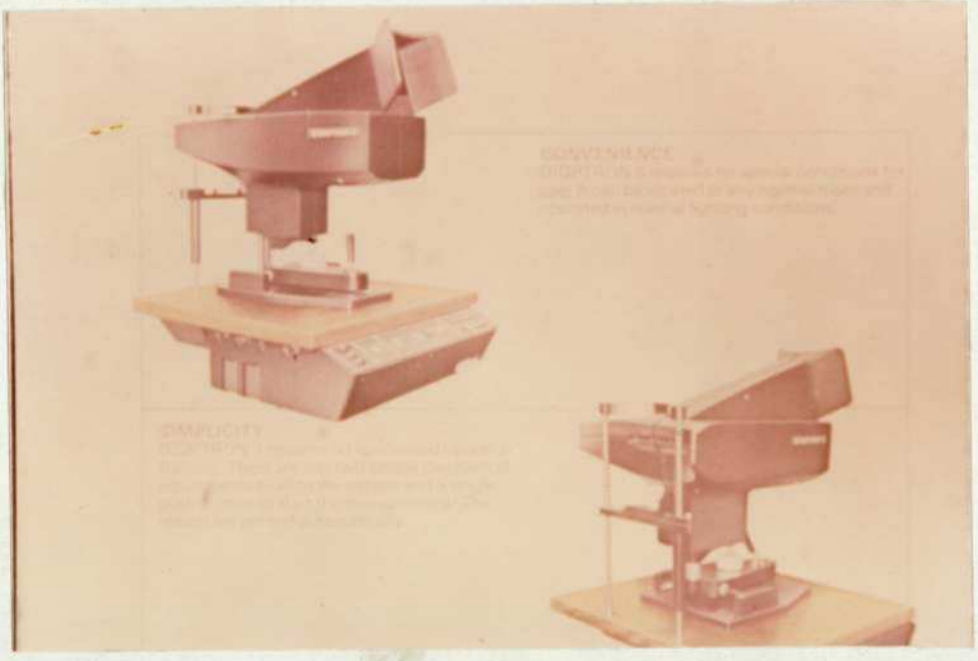


Fig. 41: The Dioptron II

3.2.1. Optical System

The various optical systems overlap to a certain extent in the Dioptron II (fig 42).

(i) Patient Fixation System

The fixation system protected by a patent issued to Munnerlyn et al (1974)[61] uses a binocular fixation and "auto-fogging" to relax accommodation and maintain accurate fixation to render measurement possible.

On the patient's side the instrument has three windows: the central one refers to the eye undertest, and is aligned with the measuring path, and the outer ones to the eye not tested at the time.

The two outside windows, used alternately, image a fixed target on the retina of the fellow eye, by means of back illumination and an eye piece lens (fig 43). In fact the target is imaged at infinity by the eye-piece, but its image never appears clear to the patient. The target used and produced photographically, has been purposely photographed out of focus to stimulate blur due to over-correction. These windows can be occluded if the operator does not wish to use binocular fixation in a particular case.

The target presentation assembly for the eye under test consists of a 6 Volt lamp run on 1.5 volt (Saunders, 1978)[62], a target T, movable lens L (fig 43) and a beam splitter B/S working as a reflector. Therefore the main illumination-detection paths and the target fiaxation system become coaxial. Lamp S will produce a steady and low level of IR illumination

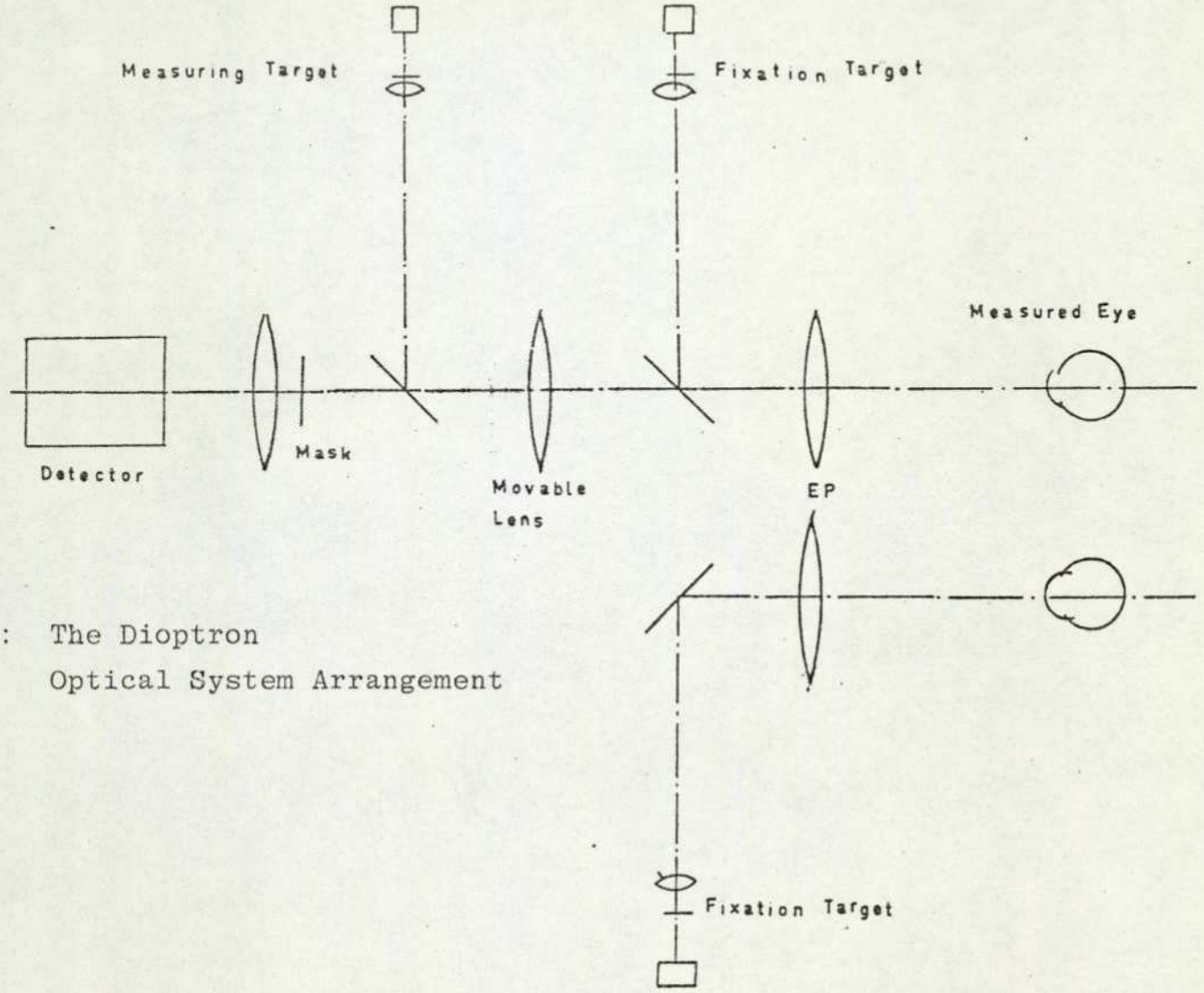


Fig. 42: The Dioptron
Optical System Arrangement

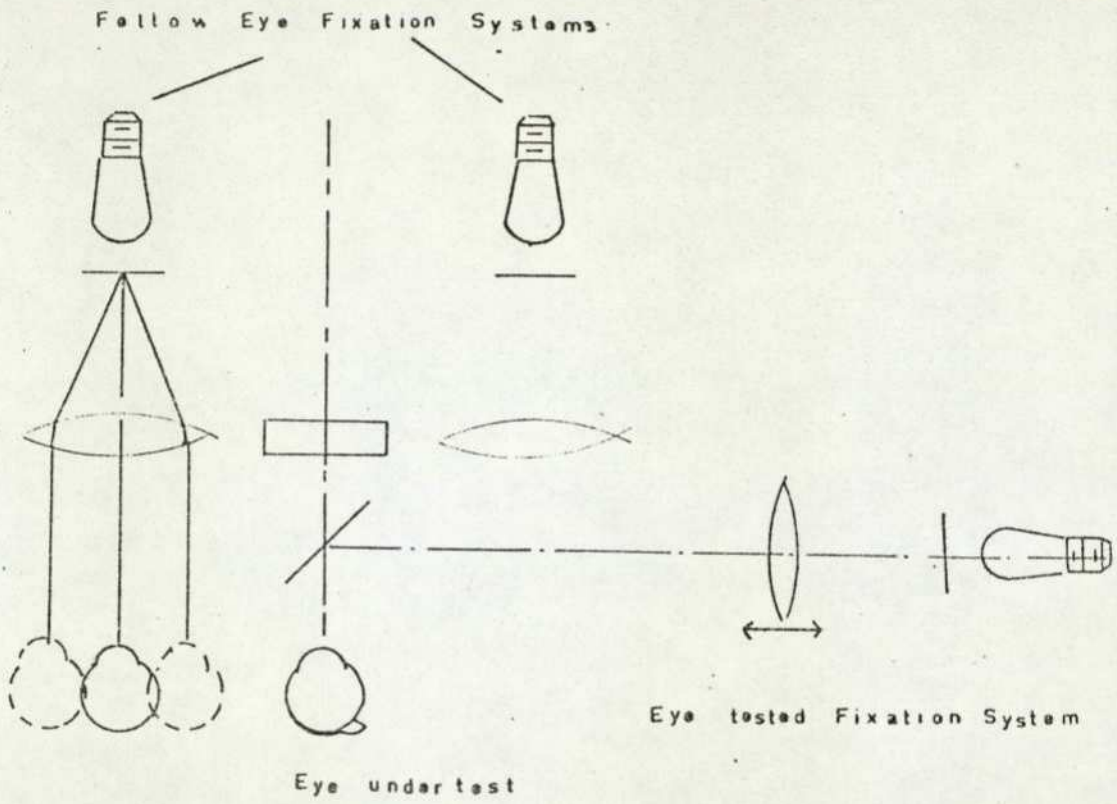


Fig. 43: The Dioptron: Patient's Fixation System

part of which will reach the detector cells producing a continous dc signal which is filtered out in the electronic system (Mannerlynn et al, 1974)[63].

The target is automatically fogged through a feed back control linked to the measuring system. Basically, the instrument quickly scans the patient over 180° and finds the positon of maximal positive or minimal negative correction and automatically displaces the focusing lens to render the target blurred to the patient. If the patient shows further relaxation in accommodation the process is repeated (Krepick, 1977)[64]. The amount of blur seems predetermined at +1.50 Dioptre above the patient's refraction (Coherent Radiation, 1977)[65].

The target itself, identical in both eyes, is a starburst pattern in Dioptron II. Previously the target used was a set of optotypes on a red background (Coherent Radiation, 1973)[66], the choice of colour being open to criticism (Guillon, 1978)[67].

(ii) Illumination System

The illumination system is also based on a design due to Munnelynn who claims an improved system to capture light reflected from the retina with minimal noise (Munnerlynn et al, 1975)[68].

The system diagrammatically represented in fig 44 projects an IR grid image covering approximately 3° of the patient's macular region.

It consists of:-

- A light source S_2 and IR filter F assembly, which emits

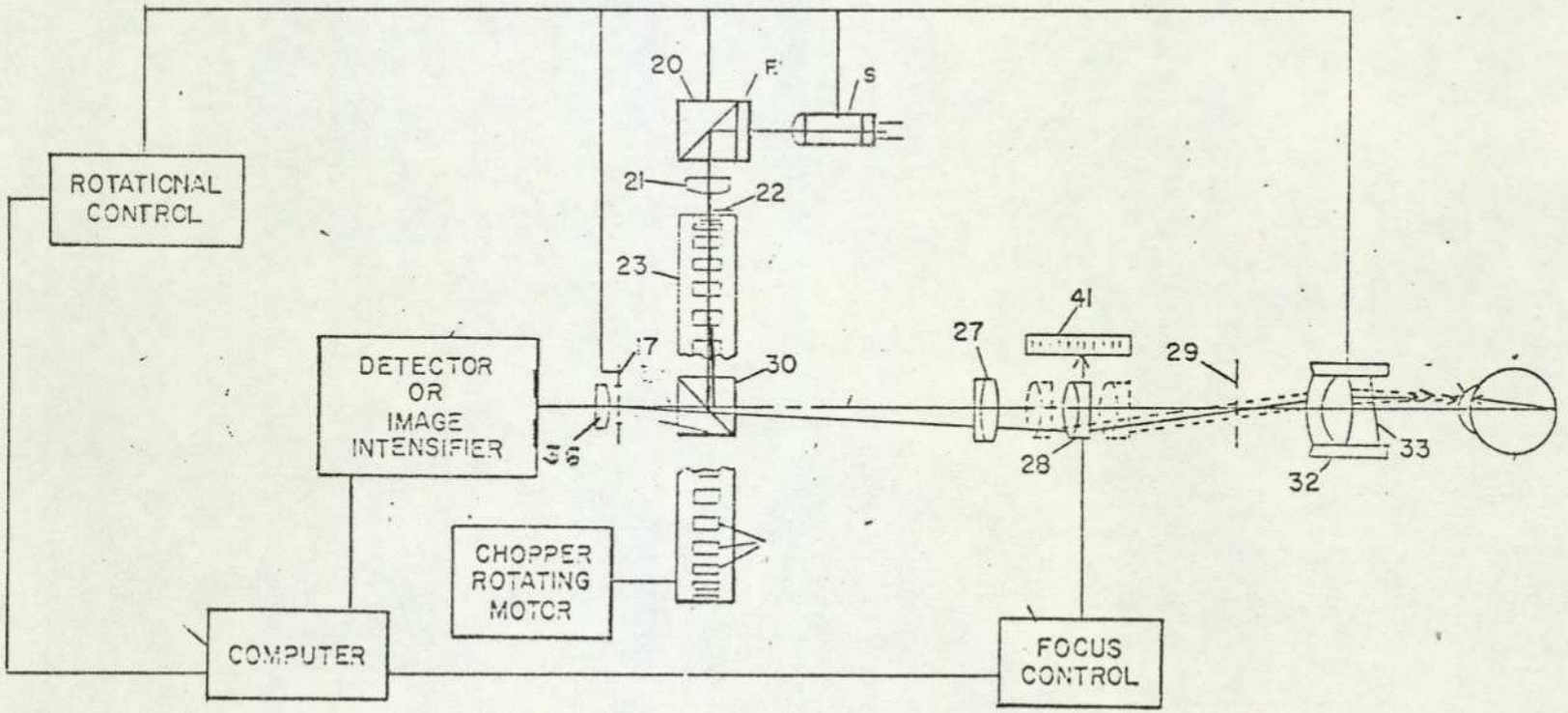


Fig. 44: The Dioptron Illumination and Detection Systems

only IR beyond 850 nm [69] (Krepick, 1977) onto a polarized beam splitter which polarizes and reflects about 50% of the light towards the condenser lens 21 and field stop 22 (Munnerlynn et al, 1975)[70].

- A reticule 23 formed by a rotating drum, coaxial to the light path, has a number of equally spaced slits parallel to the axis of revolution (Bennett, 1978[71]; Munnerlynn et al, 1975)[72]. This drum acts as the target which the rest of the illumination system focuses onto the retina forming an endless succession of line images moving in one direction only on the patient's retina.

The light passing through the reticule is almost entirely reflected in the direction of the patient's eye by the polarizing beam splitter 30. The beam splitter is then collimated by a doublet 27 and refracted through the axially movable collimating lens 28. A field stop 29 is interposed between the focussing lens and eyepiece 32. Finally a quarter wave plate 33 is situated between the eye-piece and the patient.

(iii) Detection System

The light reflected from the retina passes through the quarter wave plate for a second time so that its angle of polarization will have changed by 90^{o}. Therefore if the beam incident on the beam splitter 30 is horizontally polarized all unwanted specular reflections at the various reflecting surfaces will have the same angle of polarization and will be reflected back towards the source S, while the vertically polarized beam reflected by the retina will be refracted at the beam splitter and

directed ...

towards the photo-multiplier along with part of the unpolarized beam originating at the retina. This will produce enough light to obtain a usable signal.

Before reaching the detector the beam passes through a stationary mask 17 which has a bar pattern matching the image of the reticule when in sharp focus on the retina. A focusing lens 36 is positioned before the detection cells.

The light pattern produced by the reticule drum 23 and the source S, the two beam splitters 20 and 30 and eye piece 32 and mask 17 are all able to rotate in concert around the optical axis.

(iv) Alignment System

This system is protected by a patent issued to Munnerlynn and Moore (1975)[73]. It uses IR radiation and an image intensifier to observe the patient's eye and adjust the alignment and spacing of the instrument. It is the part of the IR beam produced by the main illumination beam and reflected off axis by the cornea (fig 45) which is utilised. The system includes an eyepiece 26 for viewing the image intensifier on which the image of the eye is focused by means of the mirror 29 and objective 28. The aperture 30 fixes the field of view of the image intensifier.

The operator views the patient's eye and the illumination patch through the alignment system, by moving the instrument horizontally and vertically, in relation to the patient, to centre the alignment patch of light with the patient's corneal reflex. Further, by centering the image of the eye in the filed of view of the image intensifier the distance

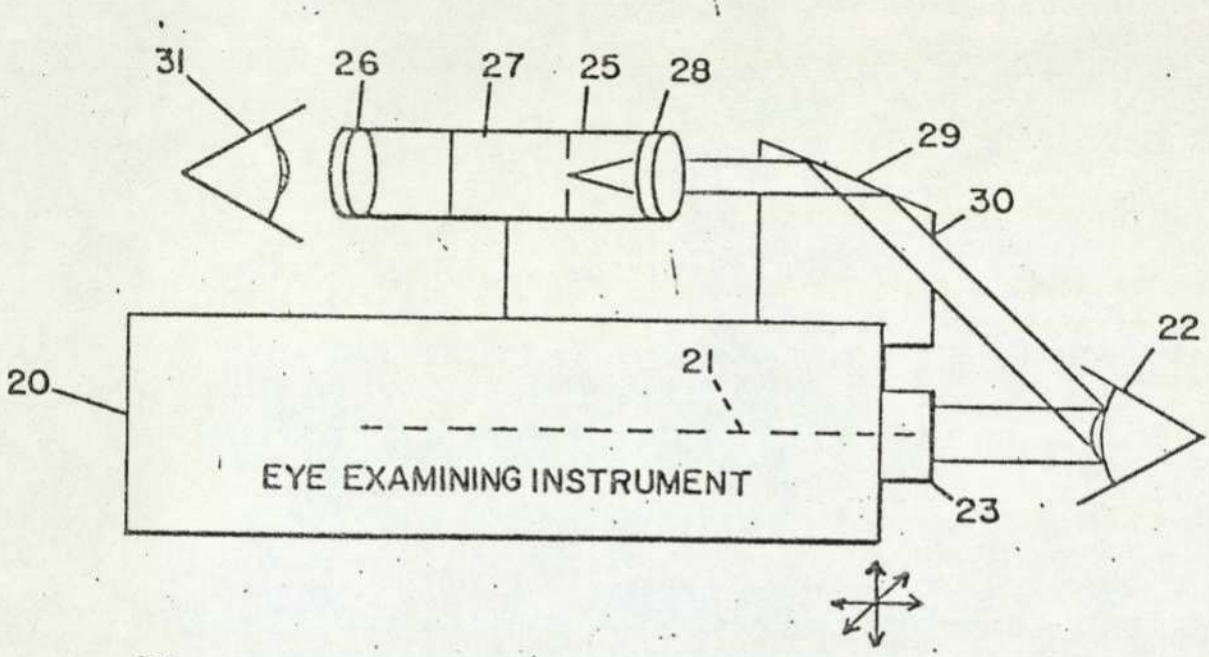


Fig. 45: The Dioptron: Patient's Alignment System

between the eye and eyepiece can be adjusted. To facilitate this an horizontal black line is included in the image intensifier and by moving the instrument axially the image can be centred on the eye.

3.2.2. Electronic System

The pattern of the light reflected from the retina and focused by the variable power refractive system is detected by means of the electronic system which first produces an analog signal and then converts it into a digital signal. The computer stores data obtained in several meridians and fits a sine square wave to the data and compares the experimental values with the theoretical ones from its memory.

As seen above when the incident beam is focused on the retina, the reflected beam bar pattern matches that of the mask 27 so that alternately maximal light or no light at all falls onto the detector, creating maximal modulation.

The analog electronic output (fig 44) of the detector photodiode is fed into the digital computer which drives the lens 20 by means of a stepping focus control motor until maximal out put is obtained. When this is achieved the computer operates the rotational control motor whcih changes the orientation of the bar pattern and the previous cycle starts again.

When sufficient data are gathered, the computer fits a sine square wave to these, checks the accuracy and either rejects the measurement or commands the printer to

print out the refractive error (Munnerlyn et al, 1975). In fact the electronic system measures six values selected in the region of maximal response. The system finally includes a blink detection mechanism which stops measurement for 400 miliseconds when a blink is produced.

The actual instrument cycle is divided into three phases:

Phase 1 lasting 5 seconds. The general order of the refractive error is obtained (Gross sphere and cylinder). During that period the "auto-fogging" system is activated for maximal relaxation of accommodation. At the same time the automatic gain control operates establishing the level of retinal reflection, which varies with the subject's pigmentation and adjusts the gain of the amplifier accordingly.

Phase 2 lasting 5 seconds. The exact orientation of the meridian with the maximal positive refractive error or minimal negative error is determined.

Phase 3 lasting 15 seconds. The refractive value of 6 data points is measured. Those points are as follows: The maximal positive meridian and the two meridians situated at $\pm$ 15° of it, then at 90° from the maximal positive and the values at $\pm$ 15° from that.

The computer then decides if the values obtained are in good agreement with the theorectical sine square wave or if measurements should be repeated (Saunders, 1978).[75]

3.2.3. Mechanical System

It consists of the hydraulic table with the joystick and the two controlled motors.

3.2.4. Print Out

The printed ticket contains seven lines of information: Lines 1 to 4 relate respectively to the sphere power, cylinder power and axis and spherical equivalent. Line 5 refers to the "Confidence Factor", line 6 to engineering information and the number of data scans missed and line 7 to further engineering data.

Refractive values can be printed to the nearest quarter, eighth, or hundredth of diopter as requested. The $\pm$ 0.01D accuracy is not intended to be a gimmick suggesting that this level of accuracy can be obtained when measuring refractive errors, but indicates the resolution power of the system: the stepping system is programmed to 100 steps per dioptre (Saunders 1978)[76].

When the instrument is used on mode $\pm$ 0.01 D the "confidence factor" is printed. A good confidence factor does not seem to have high correlation with the clinical value of the reading: it only indicates how accurately the 6 data obtained match the theoretical sine square curve. "Confidence factor" values between 0.10 and 1.00 are optimal, an exact 0.00 or any value above 20.0 asksfor a repeat of the measurement.

3.3. The 6600 Auto-Refractor

The 6600 Auto-Refractor (fig.46) has been manufactured since 1972 by Acuity Systems in the USA. It is based on a Scheiner disc type arrangement known as "Lumière Dirigée": there are actually two beams of light entering the patient's eye using different parts of the pupil (Bennett, 1978).[77] The other feature of the Auto-Refractor is the inclusion of a Badal Optometer System (Crane and Cornsweet, 1970;[78] Bennett, 1978).[79]

The instrument weighing 175 pounds measures the patient's refractive error in 2 seconds (McDewitt,Jr., 1977)[80] over a range of +15.00 to -8.25 DS and $\pm$ 5.00 DC. The vertex distance is 13.5 mm for the sphere and variable for the cylinder. The manufacturers claim an accuracy of $\pm$ 0.50 DS, $\pm$ 0.25 DC and $\pm$ 5^{o} on cylinders over 0.50 DC according to Decker (1974).[81]

3.3.1. Optical System

(i) Patient Fixation System

The fixation system forming part of the overall optical system (fig 47) is based on a design protected by an American Patent issued to Cornsweet in 1974.[82]

Cornsweet, commenting on the difficulty to relax accommodation by a classic fogging method claims that optimal relaxation of accommodation is obtained by using a set of stimuli interesting to the eye but without spatial details. The visual stimulus chosen is a pulsating green light.

Fig. 46: The 6600 Auto Refractor: Instrument in use

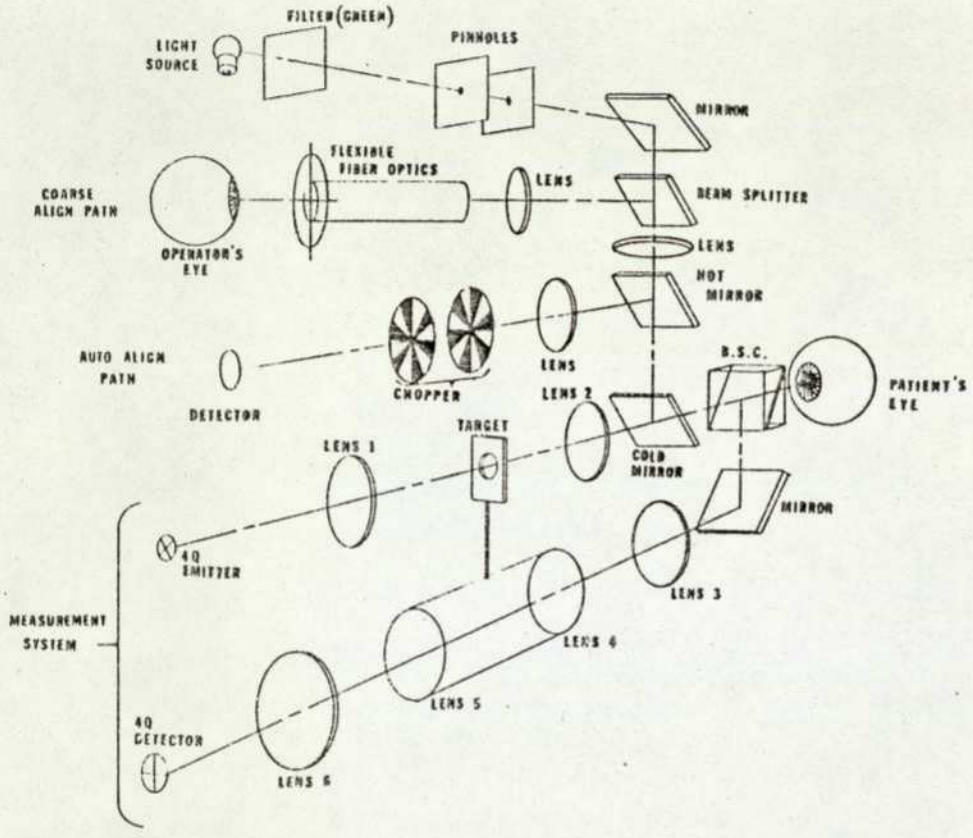


Fig. 47: The 6600 Auto-Refractor: Overall Optical System

The actual system (fig 47) comprises a source of light S pulsating at 12 Hz and seen through a green filter F, a pinhole, a focusing lens L_1, two mirrors and a beam splitter cube to render the system coaxial with the other optical components of the instrument. The frequency chosen enables the patient to notice the pulsation thus giving a certain interest to the target. The green light which is very suitable to relax accommodation was in fact chosen for its increased visibility with colour defectives (Cornsweet, 1974)[83].

The lens L is positioned to render the image of the source very blurred to the patient, it also focuses the pinhole aperture in the patient's pupil plane. (In the patented system two lenses are used but McDewitt,Jr's description refers to a single lens).

The pinholes are used to render the target blur independent of the state of accommodation by increasing the depth of focus of the eye, without increasing the target clarity since the reduction in the apparent size of the blur is compensated by the diffraction effect they generate.

(ii) Illumination System

The illumination system (fig 47) comprises four infra-red emitters E (IR emitter diodes Ga As with peak emission at 935 nm), a collimating lens L_1, a target T, a focussing lens L_2 of power +10.00 DS and a mirror and beam splitter working in transmission.

The four sources, S_1, S_2 and S_3, S_4 mutually perpendicular, are seen in Maxwellian view by the patient (i.e. focussed in the plane of the patient's pupil) (McDewitt, Jr. 1977)[84]. This has the advantage of creating an artificial pupil and maintaining the retinal luminance constant despite changes in accommodation.

The target T is a circular aperture axially movable between L_1 and L_2 and, in operation, it is moved until sharply focussed on the patient's retina. The position of accurate focusing is a direct reading of the refractive error using Newton's formula (see 2.2.1.(i)). The power of the focussing lens L_2 (+10.00DS) limits the range of the instrument on the myopic side to -9.00 DS; in theory -10.00 dioptres of ametropia could be measured using a +10.00 DS focusing lens, but this is not possible here because of the mechanical clearance needed.

(iii) Detection System

The light reflected by the retina and collimated by the patient's eye is reflected by the beam splitter cube BSC and mirror M onto the lens L_3 which focuses it onto lens L_4 (fig 48). The light is then collimated by lens L_5 and focused by lens L_6 in the plane of the photodetector cells (McDewitt, 1977)[85].

The target T and lens system L_4 - L_5 are driven by a servo control motor until T is conjugate with the retina R and lens L_4 (McDewitt, Jr., 1977)[86].

(iv) Alignment System

The instrument incorporates an automatic alignment system which controls the relative position of the optometer

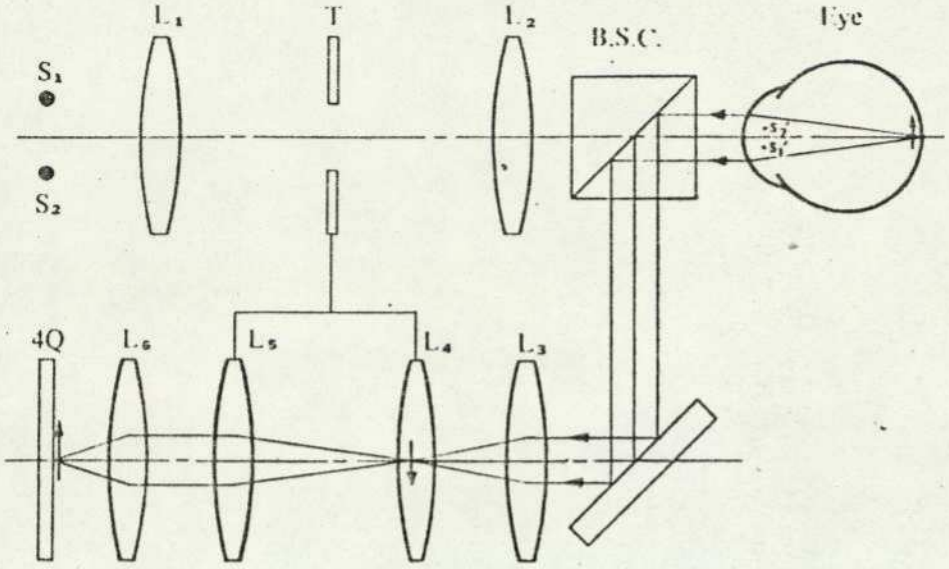


Fig. 48: The 6600 Auto-Refractor: The detection system

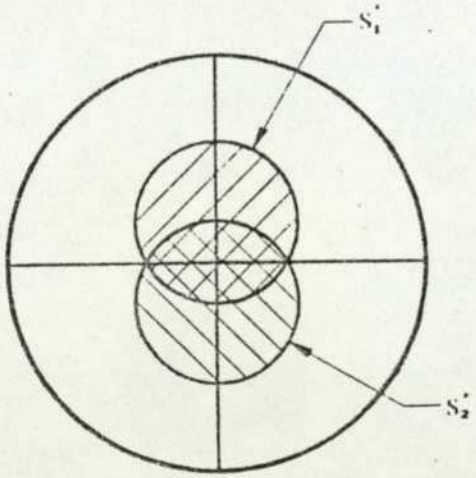


Fig. 49: The 6600 Auto-Refractor: The detection system

and the patient's eye both transversely and axially, (Cornsweet, 1975).[87]

The system uses the part of the IR produced by S_1, S_2, S_3, S_4 and specularly reflected by the cornea. Any misalignment produces a signal fed to the servomotor which bodily brings the instrument into position (see 3.3.2.).

The actual device (fig 47) includes the beam splitter cube BSC in transmission, a cold and a hot mirror in reflection, a focussing lens, a"chopper"and a detector.

3.3.2. Electronic System

(i) Detection System

The detector cells form a quadrantic arrangement (fig 49); each quadrant producing a signal directly proportional to the amount of IR energy striking its surface; such a system is an ideal nulling system.

When the source S_1 shuts off, S_2 is on and this repeats itself in the same sequence throughout the cycle. If the target T is in focus on the retina (hence on the detector cell through the detection system) switching from S_1 to S_2 will not produce an image movement and generate equal output from the four quadrants. If the target is out of focus, its image will move across the detector when S_1 and S_2 are alternating. This creates an error signal whose knowledge of its phase and amplitude will enable the servo-motor to drive the target T and lens system L_4, L_5 in the correct direction to obtain the null condition. This measures the spherical component of the refractive error.

The sources S_3, S_4 situated perpendicular to S_1, S_2 also alternate but at a different frequency. If an astigmatic error is present after neutralising the spherical element of the refractive error, switching from S_3 to S_4 will create a signal error and two posibilities arise. If S_3 and S_4 are situated along the cylinder axis then the only signal produced will be between the inferior and superior halves of the detector and its amplitude will be a direct measurement of the cylinder power. However, if S_3 and S_4 are not situated along the cylinder axis, their alternace will also create a signal difference between the right and left halves of the detector: this will drive a servo controlled motor to rotate the cells until null is obtained between the right and left fields when S_3 and S_4 alternate. The corresponding angular direction to null will be the cylinder axis.

(ii) Alignment System

Alignment along the z axis utilises the two chopping discs with alternating phases. The reflected light from the cornea is focused between the two choppers. When the focus is at the mid point between the two discs, the cornea is seen in focus, and the instrument is in correct position. In such a case the detector cell modulation is 50%. A servo-motor is used to detect, the sign and amplitude of the modulation and move the system until 50% modulation is obtained.

CHAPTER 4

PREVIOUS CLINICAL ASSESSMENT OF OPTOMETERS

4.1. Visible Light Optometers

Optometers using visible light never encountered a great popularity among clinicians. The two most common problems reported were instrumental accommodation and pupil constriction (Bradford and Lawson, 1954[88]; Volk 1955[89], 1975[90]; Fletcher, 1969[91]; Borish, 1970[92]). Instrumental accommodation was caused both by the proximity of the instrument and the brightness of the light entering the patient's eye and necessary to measure the refractive error, while pupil constriction was mainly due to the latter stimulus.

Difficulties encountered with cloudy media, uncooperative patients and poor fixation were also frequently commented on as affecting the optometer measurement to a greater extent than they affect retinoscopy.

Even when the above difficulties are eliminated discrepancies still exist between subjective and optometer findings: the former method involves the whole pupil with its aberrations, diffraction and irregularities, while optometers use only a small part of it.

As a result of the lack of popularity of these optometers, only three controlled studies have been undertaken: Briggs. (1937)[93] surveyed the Fincham Coincidence Optometer; Bradford and Lawson, (1954)[94] studied the Rodenstock Refractionometer as did Volk (1955)[95] comparing it to the Reid Streak Retinoscope. The results obtained are summarised below.

Briggs studying 110 cases ranging from 12 to 74 years of age with refractive error from +12.00 DS to -12.00 DS and

without using cylcopegic found that 88% of the cases were within ± 0.50DS; 91% within ±0.50DC and 91% within ± 10° from the subjective findings.

Bradford and Lawson, studying 140 eyes from a younger population (range 9 to 38 years, with mean 19 years), compared subjective values obtained under cyclopegic (5% Homatropine) with optometer and retinoscopic values obtained without cyclopegia, the mean error was respectively 0.81 DS (Standard Deviation SD = 0.99) and 0.31 DS (SD 0.35) for the sphere, 0.30 DC (SD 0.33) and 0.18 DC (SD 0.21) for the cylinder and 5° (SD 5.1°) and 2° (SD 2.25) on the cyl axis. Therefore better accuracy was obtained by retinoscopy than with the optometer. In both cases the accuracy increased when the same measurements were made under cyclopegic.

Volk studied 37 eyes under cyclopegic and 52 without cyclopegia from a population ranging between 11 and 77 years and found that the mean error on the sphere from the subjective was, without cyclopegic agent, - 0.03 DS for retinoscopy, - 0.81 DS for the optometer and with cyclopegia - 0.19 DS for retinoscopy and - 0.36 DS with the optometer suggesting the presence of an accommodative factor. However firm conclusions cannot be formulated as the use of the cyclopegic agent was arbitrary rather than random or systematic.

A special mention was given to aphakia in all three studies. Briggs had 6 aphakic patients and reported problems with cloudy media and the small gap with the extracapsular technique of extraction used at the time. Bradford and Lawson and Volk, using the same instrument disagreed on its

value in aphakia: Volk commented on the poor results he obtained while Bradford reported on the excellancy of the results obtained in aphakia when clear media is present.

4.2. Infra-Red Electronic Optometers

The literature available is reviewed for each individual instrument, then a general discussion of the present knowledge regarding accuracy, repeatability and time saving is undertaken.

4.2.1. The Ophthalmetron

Six clinical papers are related to this instrument and are reviewed in chronological order.

Knoll, Mohrman and Maier[96] (1970) tested the Ophthalmetron on 100 regularly scheduled patients of an optometrist's practice. They compared the Ophthalmetron refraction, performed by a technician, with the retinoscopy carried out by an optometrist. Subjective refraction was performed by an optometrist and the starting point used was, at random, the Ophthalmetron or the retinoscopic findings unknown to the refractionist. Unfortunately no statistical analysis was performed; Knoll et al plotted scatter diagrams which showed a close correlation between the data obtained by the various methods.

Safir, Knoll and Mohrman[97] (1970) selected 10 patients aged 10 to 40 years, free from pathology and with low refractive errors to assess the instrument clinically. They performed a very careful double blind study; in order

to eliminate bias the 10 patients were refracted twice by five ophthalmologists (using streak retinoscopy and cross cylinder techniques) and then with the Ophthalmetron. Here, again, observation of the scatter plots show slightly better agreement between retinoscopy and subjective than between Ophthalmetron and subjective, however, most values were within $\pm$ 0.50 D for power and $\pm$ 10^{o} for the axis.

Safir et al (1973)[98] as part of a screening programme in a community schoool in Harlem tested 141 children, (63.8% Blacks, 36.2% Puerto Ricans) most of them 9 years of age. They performed an Ophthalmetron refraction with and without cyclopegic (1 drop of 1 or 2% Cyclopentolate Hydrochloride depending on skin pigmentation) and retinoscopy with cyclopegic; 43 of the children were tested a second time to assess repeatability. The accuracy was statistically estimated in terms of mean value of the population obtained with different techniques. The mean sphere was -0.24 DS before cyclopegia and +0.38DS after cyclopegia with the Ophthalmetron and -0.04 DS for retinoscopy after cyclopegia; the difference being only significant when comparing the Ophthalmetron with and without cyclopegic. The mean cylindrical values were 0.77 DC by retinoscopy under cyclopegia, the difference between the two techniques being significant. Clinically the accuracy was judged by means of additive frequencies: 63% of the spherical values obtained with the Ophthalmetron (with and without cyclopegic) were within $\pm$ 0.50 DS of the retinoscopic values and around 70% of the cylinders were

within ± 0.50 DC of the retinoscopy, with slightly better agreement when cyclopegia was used.

Repeatability, measured in terms of standard deviation and additive frequencies, demonstrated that at ± 0.50 DS level the ability of the Ophthalmetron to repeat itself without cyclopegia was similar to retinoscopy with cyclopegia and inferior to the Ophthalmetron with cyclopegia (≃ 80%).

99

Safir et al (1973) directed another screening programmed involving 369 children (70.4% Puerto Ricans, 16.3% Blacks, 13.3% Whites) varying between 6 and 15 years of age (mean 10.1 years) and based on the same protocol as the previous study. They obtained satisfactory Ophthalmetron readings in 94.1% of cases without cyclopegia and 96.1% with.

The mean sphere values of the population were - 0.705D with the Ophthalmetron without cyclopegia and +0.065 with cyclopegia and - 0.075D by retinoscopy with cyclopegia, the t test being significant at 1% level. This showed an hyperopic shift for the whole population of approximately 0.70D when the cyclopegic agent was used. This shift being linked to the childrens age (+0.95DS at 8-9 years; +0.55DS at 13 years).

The data at ± 0.50D level showed that the Ophthalmetron used by different technicians (81% of cases within ± 0.50DS with cyclopegia and 76% without) repeated itself better than retinoscopy with cyclopegic by different practitioners (63% within ± 0.50DS).

100

Bizzell et al (1974), in an independent survey randomly tested 286 patients aged 6 to 82 years. In a manner similar to Safir et al but without using a cyclopegic, they compared retinoscopy, subjective and Ophthalmetron values, but found markedly different results. A larger number of eyes were rejected (26%) by the Ophthalmetron mainly due to poor cooperation in children, it also included 12 aphakes out of 19 present in the survey. Accuracy also was not as good: only 53% of the spherical values and 66% of the cylinders were within $\pm$ 0.50D of the subjective.

101

Floyd and Garcia (1974) selected 100 patients aged 8 to 72 years, free from any ocular pathology and cooperative. In their statistical analysis they considered the mean value of the population and found that in general the Ophthalmetron gave higher negative spheres and larger negative cylinders, the difference being only significant for the cylinder (Δ 0.20DC). Repeatability was good and similar to Bizzell's.

4.2.2. The Dioptron

This instrument has been the subject of the largest number of studies.

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Sloan and Polse (1974) were the first to report clinical data on the Dioptron. They studied its accuracy on 98 patients regularly scheduled in an optometric practice. They found excellent correlation for the sphere values ($r \triangleq 0.98$) and cylinder axis for cylinders $\geq$ 0.50DC; poorer

correlation was obtained for cylinder powers but in all cases these were similar to retinoscopic - subjective correlation values. The slope of the curve through the points in the scatter diagram and its intercept with the axis did not demonstrate any instrumental accommodative bias and standard deviation for all values were not significant.

Repeatability was based on 15 measurements performed on two female patients aged 58 and 25 years and seemed to be better than that found by other studies utilising retinoscopy, with a standard deviation of approximately one eighth of a dioptre for sphere and cylinder on average.

Polse and Kerr (1975)[103] conducted a similar survey on 300 eyes (range +6.00 to -10.00DS, and 0 to -4.00 DC) at Berkeley, California with the help of final year optometry students. They found correlation identical to Sloan and Polse's trial, better results being obtained for the spherical equivalent value than for the cylinder power. Cumulative frequencies showed that 70% of cases were within $\pm$ 0.50DS, 87% within $\pm$ 0.50 DC and for cylinder 1.00 DC the axis findings were 80% of the time within $\pm$ 12^{o} of the monocular subjective findings. When they compared the Dioptron values to the binocularly balanced subjective results the number of values within $\pm$ 0.50 DS increased to 90%. Repeatability based on 15 measurements on one subject was good too.

Drance, Mitchell and Schulzer (1975)[104] studied 157 eyes from an ophthalmological practice, with patient's age

ranging between 16 and 87 years. They compared, in the same manner as Polse, Dioptron, Retinoscopy, Subjective and Dioptron again. They found the same correlation pattern between subjective and Dioptron, best for sphere ($r \simeq 0.98$) and similar for cylinder power and axis ($r - 0.75$). It also appeared that over 80% of cases were within $\pm$ 0.75DS, $\pm$ 0.50 DC and $\pm 25^{o}$. The repeatability appeared better again with 94% of cases within $\pm$0.50DS and DC and 85% within $\pm 20^{o}$ on cylinder axis. The author stated that there was a large rejection rate without quoting any figure.

Leigh (1975)[105] reported on the largest group of patients tested with the Dioptron, 1,877 unselected eyes from an ophthalmological practice with only 8.4% rejected by the instrument. The results show that 88% of cases were within $\pm$ 0.50 DS, 91.3% within $\pm$ 0.50 DC and 74.5% within $\pm 5^{o}$; he also reported on results with poor correlation and showed that the Dioptron and Subjective values differed by more than 1DS in 9.6% of the hyperopic cases, 5.7% of the myopic cases and by more than 1DC in 5.5% of all cases concerned.

A special part of the study was concerned with aphakia: out of 114 unselected eyes 13 gave no readings, but for the rest results seemed very good; 71.2% within $\pm$ 0.50DS, 69.2% within $\pm$ 0.50 DC and 83% within $\pm 10^{o}$.

106

Kempster (1975) at Birmingham Eye Hospital obtained very contradictory results to all previous studies, with a much larger failure rate. Out of 100 eyes from patients aged 9 to 87 years, only 30% gave usable results. From

these the average difference with the subjective results was 0.75 DS, 0.25 DC and 8^{o} axis, with the largest errors being 3.25 DS, 1.25 DC and 30^{o} and most common 0.25 DS, 0.25 DC and 4^{o}.

The most common causes for rejection were lenticular opacities (27%), corneal graft (12%), aphakia (10%) and macular degeneration (5%). Unfortunately Kempster working on this sample highly biased towards pathology did not report on the accuracy of retinoscopy, which would have helped to make a comparative judgement of the instrument in a hospital situation.

Holtmann and Kroll (1975)[107], in Germany, studying 50 patients with and without cyclopegia (1% Cyclopentolate), with a mean age of 25.9 years, obtained contrasting results. The mean spherical value they obtained with the Dioptron was higher positively than by subjective, the difference being largest without cyclopegia (+0.12DS vs +0.03DS). In comparison the negative cylinder was higher subjecticely, the largest difference again without cyclopegia (-0.14DC vs -0.06DC). They concluded that there is a good correlation between Dioptron and subjective ($r \simeq 0.98$) for the spherical equivalent.

Rassow (1975)[108], in Germany, evaluated the repeatability of the instrument by taking 10 measurements of one patient subjectively and with the Dioptron. He obtained a higher positive mean spherical value and higher negative cylindrical value with the Dioptron than subjectively. The

standard deviation for sphere, cylinder power and axis was approximately 3 times larger for the subjective than for the Dioptron.

Coherent Radiation (1976)[109] organised a two day trial of the Dioptron and the Humphrey Vision Analyzer (a new subjective refractor) in a private practice. 71% of the results were within $\pm$ 0.50 DS, 83% within $\pm$ 0.50DC, 73% within $\pm$ 10^{o}.

Krepick (1977)[110] reports on the excellent clinical results obtained by three practitioners without however giving details of the experimental procedure. The three practitioners on respective populations of 119, 156 and 104 eyes obtained a Dioptron measurement within $\pm$ 0.50DS of the subjective in 89, 81, 91% of cases; $\pm$ 0.50DC in 97,97, and 96% respectively.

4.2.3. The 6600 Auto-Refractor

This instrument appears to be the most widely used instrument with approximately 2000 models in service (Crundall, 1978)[111]. Paradoxically, it is the one which has been subjected to the fewest clinical reports. Apart from reports of panel discussions at a few regional ophthalmological meetings in the USA, there are only three clinical papers related to it.

Hill (1973)[112] reported 100 unselected eyes with refractions varying from +6.00 to -7.00 DS and cylinders

up to -2.25DC. The sample included patients with ocular pathology, the age varying between 14 and 75 years. He compared the subjective findings with the mean of three readings with the 6600 Auto Refractor and obtained the following results: 81% of cases were within ± 0.50 DS (r=0.97) 92% within ± 0.50 DC (r=0.81) and 61% ± 10° (r=0.92).

[113]

McTigue and Cornsweet (1973) tested 15 voluntary subjects aged 8 to 53, with no known pathology, for both repeatability and accuracy. Each subject was tested three times with the Auto Refractor and by three different refractionists. The Auto Refractor repeatability was comparable to subjective findings at ± 0.50 D level for both sphere and cylinder (power and axis). The accuracy, only mentioned for the cylinder power, showed that 89% of the individual Auto Refractor values were within ± 0.50DC of the mean subjective.

[114]

McTigue (1973) reported on 75 aphakic eyes from +6.50to+15 DS and with 0 to -5.75 DC. The 6600 values compared to subjective values were within ± 0.50DS in 73% of the cases, ± 0.50 DC in 68% and ± 10° in 85%.

4.2.4. Comments

(i) Accuracy

As seen above, different results for accuracy were obtained in the various studies; first of all they differ from the manufacturer's claim, which in any case seem the

most optimistic. However, the differencies in results with the same instrument do not mean that greater clinical skill was shown by certain operators, but would appear to be due to sampling differences.

Those studies concerned with unselected groups of patients will best reflect the usefulness of the instrument in a clinical situation. Table 1 summarizes those findings from unselected normal clinical samples. They revealed no apparent superiority of one instrument over the other two. In fact the variation in accuracy, measured by means of additive frequencies, for the studies involving the same instrument is greater than the variation of accuracy between instruments. This could be an indication of sampling differences: one would expect poorer results in Ophthalmological practices than in optometric ones as a larger pathological population is encountered in the former, the extreme case being reported by Kempster at Birmingham Eye Hospital.

AUTHOR	INST.	POPUL.	± 0.50 DS	± 0.50 DC	± 10°	S/D DS	S/D DC	S/D °	r_s	r_c	r_a
KNOLL (1970)	O	100	No statistical analysis								
BIZELL (1974)	O	286	56.2	71.5	59	-	-	-	-	-	-
SLOAN	D	98	-	-	-	0.54	0.39	22.9	0.98	0.77	0.9*
POLSE (1975)	D	300	70	87	80 **	0.48	-	-	0.98	0.69	0.9
DRANCE (1975)	D	157	≃68	≃ 84	≃ 55	-	-	-	0.98	0.76	0.7
LEIGH (1975)	D	1721	88	91.3	84.3	-	-	-	-	-	-
KEMPSTER (1975)	D	+100	-	-	-	++ 0.75	++ 0.25	++ 8°	-	-	-
COHERENT RAD 1975	D	60	71	83	73 (n=15)	-	-	-	-	-	-
HOLTMAN (1975)	D	50	-	-	48.3	-	x +0.12	x -0.17	0.98	-	-
HILL (1973)	A	100	81	92	68 (n=79)	-	-	-	0.97	0.81	0.9

TABLE 1

Summary of results in studies concerned with unselected normal population.

O = Ophthalmetron D = Dioptron A = Auto-Refractor

* ± 12° on cyl. > 1DC ** cyl. 0.50DC

+ only 30 eyes gave usable readings

++ average error

x mean error

(ii) Repeatability

Two types of studies refer to repeatability of results. Those concerned with a very small number of patients tested on several occasions over a short period of time reveals the "absolute clinical repeatability". Sloan and Polse (1974)[115], Polse and Kerr (1975)[116] and Rassow (1975)[117] established to be $\simeq$ 0.15DS and DC and $\pm 5^0$, for the Dioptron.

Of greater clinical value the "Real clinical repeatability" is obtained by repeating twice the automatic optometer measurement at the same or at two succesive visits. This repeatability is similar for the Ophthalmetron and retinoscopy (Safir et al, 1973)[118] with a population of children. For a normal population the instrument repeatability was demonstrated to be superior to subjective for the Dioptron by Drance et al (1975)[119] and for the 6600 Auto Refractor by McTigue (1973)[120].

(iii) Time Saving

All reports surveyed withthe exception of Kempster (1975)[121] found IR optometers useful. Few quote specific time savings. Freeman (1975-1976)[122] using the 6600 Auto-Refractor quoted an increase of 2 to 3 complete examinations per day with the Auto Refractor. McTigue and Cornsweet (1973)[123] found using the same instrument a decrease in the total time of approximately 10% per patient for the whole objective - subjective determination.

Decker (1975)[124] in a survey of 96 practitioners possessing an IR optometer found that 70% of them reported

saving time by using the Optometer, the estimated amount of time saved varying between 2 to 15 minutes per patient, increasing the work capacity by 5 to 40%.

CHAPTER 5

LABORATORY EXPERIMENTAL INVESTIGATIVE PROCEDURE

The Ophthalmetron was used clinically throughout this research. Despite the extensive available literature related to it and concerning its clinical prowess and technical description certain features of the instrument are unknown and the following experiments will attempt to elucidate them.

5.1. Experiment 1. Efficiency of the Alignment System.

5.1.1. Introduction

The purpose of the experiment was to test the efficiency of the alignment system using the Bausch and Lomb model eye (fig 50). This was done in order to find out whether the alignment system was bias free, depending on the operator.

The efficiency was considered objectively in terms of the repeatability of the ideal conditions and of the accuracy and acceptability of the graphical tracings obtained; also according to the observer's feeling about the ease or difficulty with which the target could be used for alignment.

5.1.2. Material and Method

A block of light alloy forming three reference surfaces, for the three dials was attached to the Ophthalmetron used in this experiment. These dials were used to record transverse, vertical and axial movements

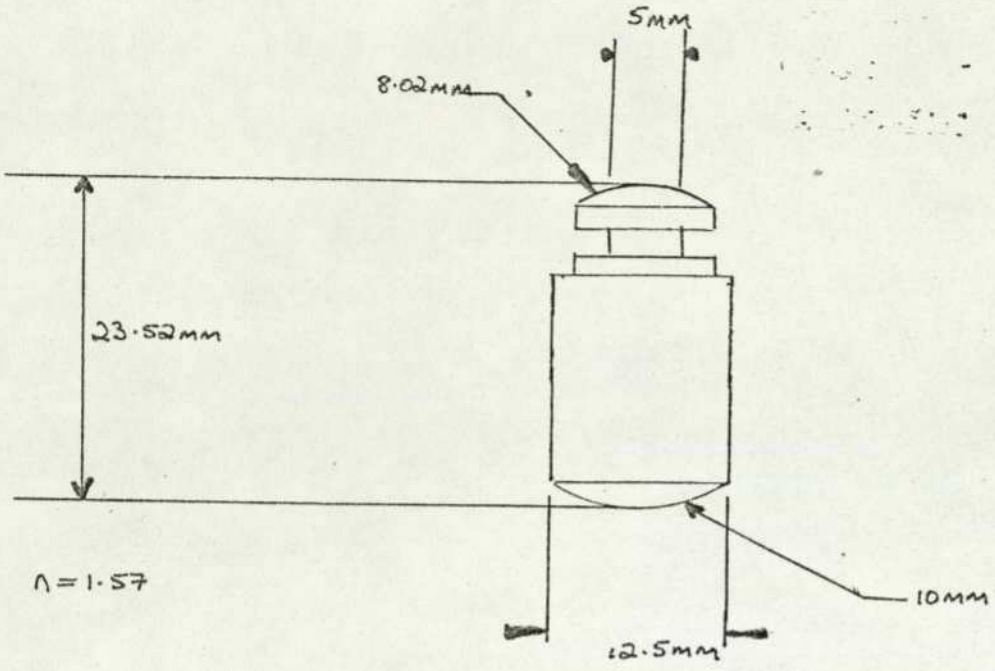


Fig. 50: The Ophthalmetron: Model Eye

(x,y,z) of the instrument relative to the model eye (fig 51).

The two dials recording vertical and axial movements covered a range of 25 mm in 0.01 mm graduations, while the dial recording the transverse movments had a range of 1/3 of an inch (≏ 8.5mm) in 0.001 inch (≏0.025mm) graduations. These particular dials were used as they were readily available.

The alignment target described in 3.1.1.(iii) was used in the conventional manner. The instrument was adjusted until the spot was centred with respect to the ring and the ring was sharply focused: the correct centration of the spot indicated correct transverse and vertical positioning and the sharpness of the ring indicated correct axial centering.

Three experimenters carried out the present experiment: two final year students (Operators A and B) familiar with the instrument and the writer (operator C). The Ophthalmetron was switched on for 10 minutes before starting the experiment, as advised by Bausch and Lomb, to permit warming up and stabilising of the electronic components.

The following protocol was then used:

_ Operator A set the instrument to the "best alignment position", considering both centration of the dot and sharpness of the ring, as proposed by Bausch and Lomb.

_ Operator C read and recorded the values found on the three dials. The two undergraduate student operators were kept unaware of the results obtained to avoid any psychological bias. Operator C then put the Ophthalmetron

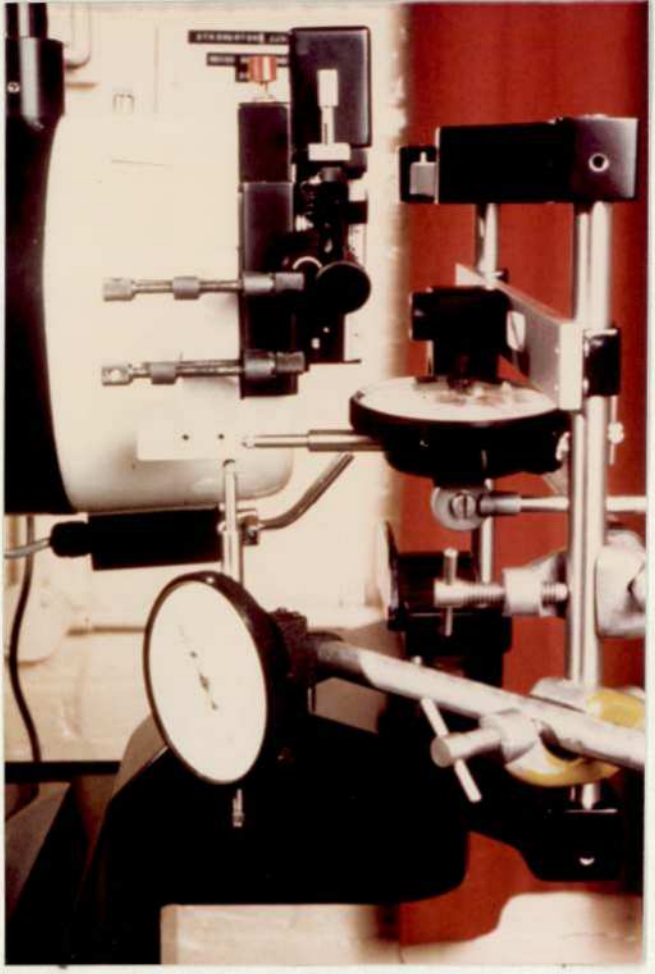


Fig. 51: The Ophthalmetron: Experimental Arrangement 5.1.
Ophthalmetron head and dials

out of alignment so that operator B could repeat the process of alignment from a new but arbitrary starting point. None of the operators observed the visual alignment of the other two, to avoid subjectivity and change in personal standard of "best alignment".

- Operator B carried out the same procedure and then C recorded the readings. The instrument was put out of alignment by A or B, so that C had no preconcieved idea of the point of focus. C then followed the same procedure as A and B.

The sequence above was repeated thirty times. After each alignment a tracing was obtained, but to save recording cards 9 tracings were registered per side; 3 on normal "range", 3 on positive and 3 on negative "ranges" as this had no link with the alignment system.

5.1.3. Results

The data obtained during the experiment (appendix 3) were computed using the Busicom 207 to obtain:
The sum of the individual readings Ex; the sum of the square of the individual readings Ex^2; the mean of the individual readings M and the standard deviation $SD = \sqrt{\frac{(x-m)^2}{N}}$

This was applied as follows:

(i) To all 90 readings to find the mean and the standard deviation.

(ii) To each operator to see if any individual variation in accurracy was present.

(iii) To each "range" (normal, negative, positive) to show that this was not an influencing factor in alignment.

The following results were obtained:

	Operator A	Operator B	Operator C	
Normal "Range"				m = 0.27; e = 0.06 v = 0.15
Negative "Range"				m = 0.28; e = 0.07 v = 0.15
Positive "Range"				m = 0.29; e = 0.06 v = 0.15
	m = 0.27 e = 0.07 v = 0.20 r = 0.28	m = 0.26 e = 0.05 v = 0.10 r = 0.20	m = 0.23 e = 0.05 v = 0.16 r = 0.20	m = 0.28 e = 0.06 v = 0.16

TABLE 2 Transverse dial results (x dial)

(m = mean; e = standard deviation; v = variance r = range)

All results were converted in mm scale.

Note: There was no point in computing the exact value related to each operator for each range as the number of readings in each case would be only 10 and would therefore be of no statistical value.

	Operator A	Operator B	Operator C	
Normal "Range"				m = 4.02; e = 0.06 v = 0.004
Negative "Range"				m = 4.03; e = 0.07 v = 0.004
Positive "Range"				m = 4.02; e = 0.08 v = 0.006
	m = 4.03 e = 0.05 v = 0.003 r = 0.27	m = 4.00 e = 0.06 v = 0.004 r = 0.21	m = 4.03 e = 0.05 v = 0.003 r = 0.14	m = 4.02 e = 0.05 v = 0.003 r = 0.28

TABLE 3 Vertical dial results (y dial)

(M = Mean; e = Standard Deviation; v = Variance; R = Range)

All values in mm.

	Operator A	Opertor B	Operator C	
Normal "Range"				m = 2.84; e = 0.98 v = 0.95
Negative "Range"				m = 2.86; e = 0.95 v = 0.98
Positive "Range"				m = 3.17; e = 1.14 v = 1.29
	m = 2.41 e = 1.04 v = 1.08 R = 4.34	m = 3.51 e = 0.91 v = 0.82 R = 3.80	m = 2.96 e = 2.02 v = 4.06 R = 2.78	m = 2.96 e = 1.03 v = 1.07 R = 4.75

TABLE 4 Axial dial results (z dial)

	Transverse (x)	Vertical (y)	Axial (z)
Observer A	Very good	Very good	Neutral
Observer B	Very good	Very good	Neutral
Observer C	Very good	Very good	Neutral

TABLE 5 Subjective appreciation of the alignment system

Five gradings were offered for choice: very good, good, neutral, poor, very poor.

5.1.4 Discussion

The findings obtained showed that for both vertical and transerse alignments, the range of results (difference between the highest and lowest findings) were very similar: 0.28 mm for the vertical range, 0.30 mm for the transverse one. Conversely the axial alignment showed a greater scatter, covering 4.75 mm. Comparable results were obtained for the standard deviation: 0.05 mm and 0.06 mm for vertical and lateral movements and 1.03 mm for the axial one.

From the above the following conclusions were reached:

(i) The difference between the scatter of the results in the axial alignment position and in the two other positions showed a higher critical judgement for the last two. This was confirmed by the operators after the experiment, who reported greater ease in centering the dot within the ring (basis of the transverse and vertical alignments) than accurately focusing the ring (basis of the axial alignment).

(ii) Vertical and transverse alignments were based on the same optical principle, so the only difference was the mechanical means of adjustment of the instrument. The similarity in the results obtained suggest that both, the joystick and screw stystems, had been used with the same accuracy.

The mean for each set of results had no intrinsic value as it depended on an arbitrary origin. However it was

very useful in comparing the results obtained by each operator. It showed that for the vertical and transverse alignments consistant results were obtained, the difference between the average for each value being well within the respective standard deviations (maximum difference of the means were 0.03 and 0.06 mm and standard deviation 0.05 mm and 0.06 mm respectively for the vertical and transverse alignments). On the other hand the difference between the means of the axial alignment for each operator (1.10 mm) was larger than the standard deviation (1.03mm), this being an indication of the greater difficulty in judging the sharpness of the ring of light which was more subject to personal judgement than the relative positioning of spot and circle of the two other alignments.

The statistical analysis of the results with regard to the use of the three different ranges had no influence on the accuracy of alignment obtained (mean value of each being far more similar than the individual operators mean value).

The refraction tracings obtained after each of the 90 alignments were very similar. but not identical: several showed an astigmatic reading of up to half a dioptre, but with no particular axis. However this fluctuating cylindrical value appeared to be random and could not be linked to any extreme alignment. It was thought to be due to the electronic components of the instrument needing some readjustment rather than to the alignment system being at fault.

In view of the excellent accuracy shown by the operator in using the alignment system (particularly for transverse movements), one can conclude that this system is adequate in clinical situations.

5.2. Experiment 2 Tolerance on linear misalignment

5.2.1. Introduction

The purpose of the experiment was to find out the minimal value of misalignment responsible for erroneous refractive readings using the Bausch and Lomb model eye. The experiment was conducted to obtain an estimate of the range of acceptable patient's head movements during measurement.

5.2.2. Material and Method

This investigation followed immediately experiment 1 and used its experimental arrangement and results as a starting point.

The mean values for all 90 readings (obtained during experiment 1) for the three dials were calculated and the instrument was set to this particular position. The vertical alignment was varied from the mean value in 0.05 mm step in one direction and the opposite. At each step a refractive measurement was made, and the process was continued until a manifestly erroneous graph resulted (fig 52). The visual aspect of the target was observed in conjunction with the tracing obtained.

The same protocol was repeated for the other two dials after returning the instrument to its normal vertical position ; 0.05 mm steps were used for the transverse movements and 0.5 mm for the longitudinal ones.

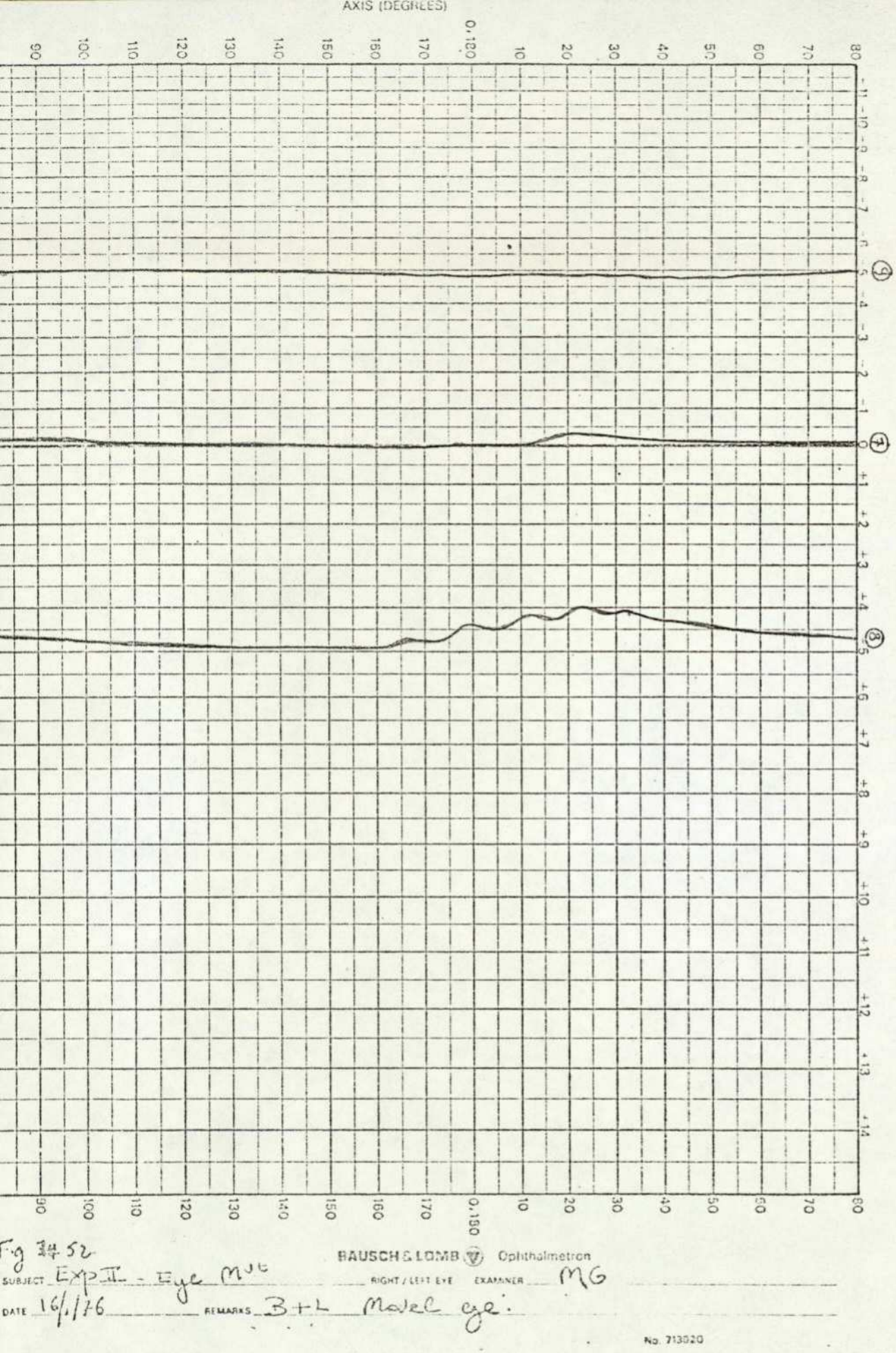


Fig 52: The Ophthalmetron Erroneous recording in Exp. 5.2.

5.2.3. Results

The results were summarized in Table 6 which indicates the minimal misalignment responsible for erroneous readings from the calculated mean value.

	Positive error (mm)	Negative error (mm)	Range (mm)
Dial V (x)	+0.30	-0.25	0.55
Dial T (y)	+0.25	-0.25	0.53
Dial L (z)	+7.00	-4.00	11.00

TABLE 6 Minimal significant misalignment

Note: Positive directionswere taken when the instrument was raised (x), moved away from the practitioner (y) or model eye (z).

5.2.4. Discussion

The visual aspect of the target was observed in conjunction with the tracing obtained. For both vertical and transverse dials a displacement of 0.20 mm in any direction revealed a marked off centre position of the spot within the circle but the first position showing a manifest erroneous tracing was at 0.26 mm away for the transverse dial, and 0.35 mm for the vertical. This suggests that the alignment target design is suitable and warns that the alignment is wrong before the tracing is manifestly erroneous, at least with respect to the Bausch and Lomb model eye and this can be assumed to be an adequate

indication of the instruments behaviour.

The axial dial showed an erroneous reading more quickly when the distance decreased from the mean than when it increased; a decrease of 2.50 mm and an increase of 3.00 mm resulted in a blurred target but still gave an acceptable tracing, while a decrease of 4.00 mm and an increase of 7.00 mm revealed the first erroneous tracings, therefore the previous conclusions are applicable.

A few clinical deductions can be made in view of the above findings. Axial adjustment showed a depth of focus of nearly 10 mm which is an advantage of the instrument when dealing with patients. Further this depth of focus is not symetrical about the mean focus and an increase in the distance between the eye and the instrument had less effect than a decrease. In practice, one must make sure that the patient is well forward, with the head against the band, the only possible movement being backward. Finally, the acceptable transverse movement is very limited with the Ophthalmetron and this may prove to be a problem with patients finding difficulties in keeping still (ie children). These clinical conclusions reached using a model eye, although very different to a human eye, could be assumed to be acceptable for a normal eye with a similar pupil diameter ($\simeq$ 5 mm) clear media, and normal fixation.

5.3. Experiment 3 Tolerance for angular movements

5.3.1. Introduction

This experiment was arranged to study the effect of angular eye movements on the refractive findings obtained with the Ophthalmetron. Both the effects of amplitude and frequency were considered.

5.3.2. Material and Method

A special supporting bar for the model eye was fitted to the Ophthalmetron head rest, to initiate and to control variable angular movements. This bar holding was of light alloy, supported the Bausch and Lomb model eye and pivoted about a vertical axis situated 13.8 mm behind the front of the eye. It was linked to a vibrator by a thread and return spring.

The vibrator was operated by an oscillator which varied the frequency and amplitude of its linear movements. The thread was taut and because the spring constantly opposed the pull of the vibrator the model eye had an angular movement of the same frequency as the vibrator.

The amplitude of the movement was controlled by two step screws, one 10.8 mm in front and the other 18 mm behind the axis of rotation. The front screw was fixed to stop the model eye in a position perpendicular to the bar (i.e. along the axis of the instrument) when the spring alone was acting; the back screw setting was varied to give different amplitudes of movements:

After the instrumental electronic stabilizing period had elapsed ($\simeq$10 min) a first reading was taken with the

eye stationary in an average position. The back screw was then set for different amplitudes (from 50′ to 6°) and for each amplitude readings were recorded for 2, 4, 6 Hz, until manifest erroneous readings were obtained. A final reading with the Bausch and Lomb model eye in the stationary control positon was performed.

5.3.3. Results

The angular amplitude for each arrangement was obtained by calculation as follows (fig 53) - a gauge was used to measure the maximal linear distance between the back screw and the model eye carrier for each position in 1/1000 of inch (x on fig 53).

- from the description of the apparatus the distance on axis between the centre of rotation and the screw was 18 mm (y on fig 53).
- from above the angular values were calculated:

x in 1/1000 of inch gave x in mm

$\frac{x}{y} = \tan \alpha$ (angular movement)

TABLE 7: Gives α in Degrees and Minutes

x in 1/1000 inch	x in mm	tan α	α (° and ′)
10	0.245	0.0141	$\simeq 50'$
21½	0.53	0.0249	$1^\circ\ 42' \rightarrow 1^\circ\ 40'$
30½	0.747	0.0466	$\simeq 2^\circ\ 40'$
46	1.1684	0.0649	$\simeq 3^\circ\ 45'$
50½	1.2827	0.0712	$\simeq 4^\circ\ 5'$
65	1.651	0.0917	$\simeq 5^\circ\ 15'$

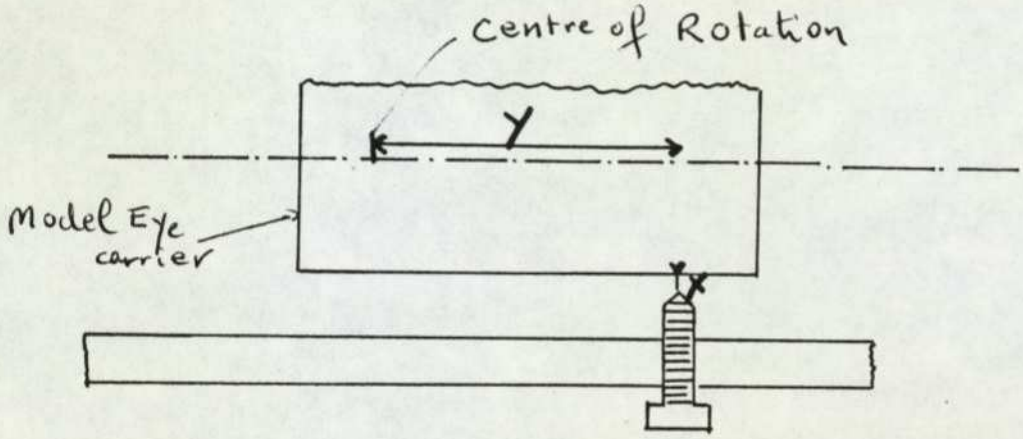


Fig 53: Experimental arrangement for 5.3

The results obtained for the above angular values are given in Table 8 , which incorporates:- a subjective comment for each set of readings, - an "unaffected time - value" (UTV), representing the time during which the reading corresponds to the know emmetropic value of the model eye, not affected by oscillations. The time was calculated on the basis that 180^{o} scanning represented 3 sec, hence each 10^{o} interval was equal to 0.16 sec.

Three readings were recorded on each side for economy's sake but for clarity purpose all three "ranges" of the instrument were used, this being without effect on accuracy, (see 5.1.3. and 5.1.4.).

RECORD No.	FREQUENCY Hz	AMPLITUDE	"UTV" sec	COMMENTS
1	2	$1^{o}40^{'}$	1.6	Initial straight lines are shown on all 3 readings A wave motion follows especially at 4 Hz. Recording 1 (2Hz) is only very slightly affected
2	4	$1^{o}40^{'}$	1.55	
3	6	$1^{o}40^{'}$	1.0	
4	2	$50^{'}$	3	All 3 readings are unaffected by the movements.
5	4	$50^{'}$	3	
6	6	$50^{'}$	3	
7	2	$3^{o}45^{'}$	2.5	Recordings at 2 & 6Hz affected very little by the eye movements while at 4 Hz wave motion pattern disturbs the recording.
8	4	$3^{o}45^{'}$	1	
9	6	$3^{o}45^{'}$	3	
10	2	$5^{o}15^{'}$	0.8	All 3 recordings initially straight, then showing myopic shift and a wave motion (largest for 2 Hz).
11	4	$5^{o}15^{'}$	0.7	
12	6	$5^{o}15^{'}$	1.00	
13	2	$2^{o}40^{'}$	3	All 3 readings unaffected.
14	4	$2^{o}40^{'}$	3	
15	6	$2^{o}40^{'}$	3	
16	2	$4^{o}5^{'}$	1.3	3 typical affected recordings: initial straight lines and a myopic shift (greatest for 2 Hz) and wave pattern.
17	4	$4^{o}5^{'}$	1.3	
18	6	$4^{o}5^{'}$	1.0	

TABLE 8

Recorded Results and comments for angular movements with the Bausch and Lomb model eye

5.3.4. Discussion

All the recordings obtained fell into one of the following groups:

- unaffected straight line, representing the exact model eye refractive value.
- an initial straight line followed by a myopic shift but for one exception (1^{o} $45^{'}$ at 6 Hz showed an hyperopic shift) and a "wave pattern".

The wave pattern, when present, was a sign of an erroneous reading, the instrument appeared to be recording the movement of the eye, since the frequency of that recording pattern increased and amplitude decreased when going from 2 to 4 and 6 Hz for the same angular value, one could argue that the electronics of the Ophthalmetron were picking up the wave signal produced by the oscillator. But this could not be so since in all experiments the oscillator signal was present and constant and for certain angular values unaffected recordings were obtained.

One point of interest, was the "Unaffected Time Value" (UTV) which represented the time during which the recording was in accordance with the true value, and could be used to decide objectively if the reading was acceptable or erroneous (Table 8). To be "acceptable" a reading must be correct over half the graph, hence half the scanning time is the minimun to obtain a valid reading, as pointed out in the Bausch and Lomb instruction manual.

As seen on fig 54 no conventional curve could be traced. This means that the Ophthalmetron was disturbed by eye

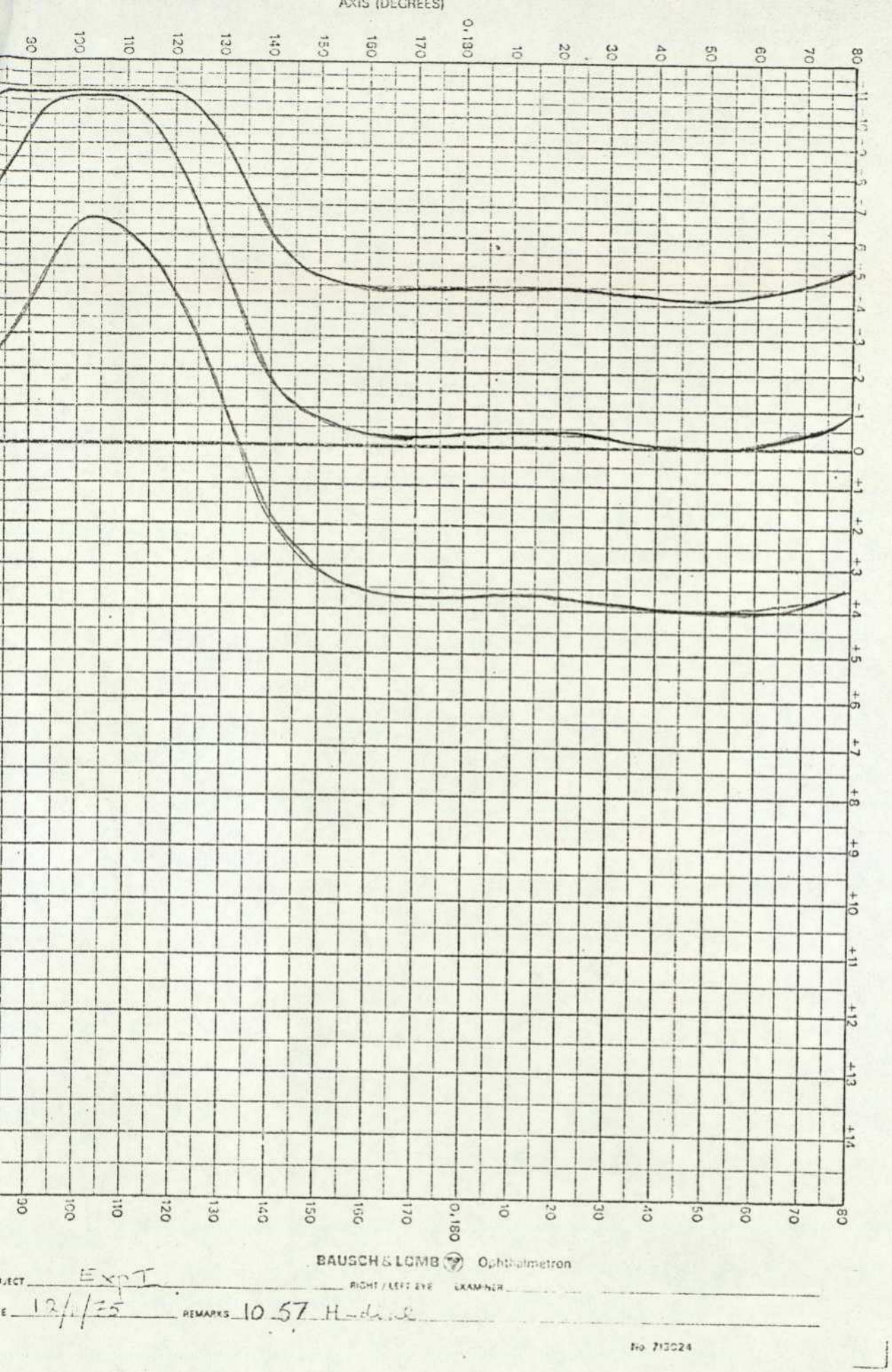


Fig. 54: The Ophthalmetron Erroneous reading

movements but can cope with a certain amount of it, though not consistantly. However, from the results obtained one can expect the instrument to cope with movements of 2 to 2½ degrees amplitudes on either side of the mean point. The different frequencies used did not introduce any significant variation in the results.

From experience with normal patients one knows that the instrument can cope adequately with micro eye movements present at fixation. These movements have 3 major components: slow drifts (average 2.5′ of arc), saccades (average 5′ of arc) (Ditchburn, 1973[125]) and tremors (average 10″ of arc) (Alpern, 1962[126]) and all are well within the instrument's capability.

Gleim and Gunther (1965[127]), working with macular degenerative patients, have shown that decrease in VA from 6/6 to 6/24 has little effect on saccadic movements, but that at a lower VA these movements increase steeply. It is therefore a possibility that in certain cases using the amount of blurring produced by two "clicks" (≏ 2.00 DS) recommended by the manufacturer to relax accommodation could create problems and it is advisable in cases of unstable fixation to try a reading with less blurring.

5.4. Experiment 4 Reproducibility of measurement with model eye

5.4.1. Introduction

From experiment 1 it is known that the practitioner can repeat accurately alignment of the instrument with the model eye, the optical characteristics of which remain constant with time. Records were therefore kept of random measurements made on the model eye over the two year period to assess the instrument's "absolute repeatability."

5.4.2. Material and Method

Throughout the experimental period the manufacturer's recommended procedure was followed: the instrument was left switched on for 10 minutes to enable the electronic components to settle before clinical measurements were taken.

At the beginning of each session a measurement with the model eye was taken to ensure correct baseline and the instrument was rezeroed if necessary, (need for rezeroing was seldom necessary).

Records for the particular experiments were made "at random", at various times after switching the instrument on, sometimes more than once in a session.

5.4.3. Results

Results of 102 measurements were recorded (appendix 4). 63 in the first hour of work, 18 in the second and 21 in the third or thereafter.

The records were read in terms of sphere and cylinder power to the nearest 1/16 diopter.

The Mean value and standard deviation for both sphere and cylindre were computed using a TI (SR56) pocket

calculator, for the total population and for each hour of operation (Table 9).

Population	N	Sphere	Cylinder
1st Hour	63	Mean=0.033 S/D =0.166 Σxi =2.09 Mean Sphere = -0.018	Mean=-0.099 S/D =0.131 Σxi =-8.63
2nd Hour	18	Mean=-0.039 S/D = 0.108 Σxi =-0.71 Mean Sphere = -0.074	Mean=-0.099 S/D = 0.131 Σxi =-6.25
3rd Hour (and above)	21	Mean=0.052 S/D =0.097 Σxi =1.1 Mean Sphere = 0.025	Mean=-0.054 S/D = 0.088 Σxi =-1.13
Total Population	102	Mean= 0.024 S/D = 0.147 Σxi = 2.48 Mean Sphere = -0.018	Mean=-0.085 S/D = 0.122 Σxi =-8.63

TABLE 9 Results obtained with model eye

5.4.4. Discussion

The mean value of 102 measurements can be considered as the true refractive value of our model eye with the particular instrument. This model eye (supposedly emmetropic), shows a small refractive error which could be due either to an inaccurate model eye or to the instrument being slightly off zero, however of negligeable clinical value (mean $\simeq$ -0.018D).

The change in the mean value over a session, is indicative of the electronic stability of the instrument and is shown to be acceptable $<$ 0.1D on the mean sphere. However, the standard deviation (which is a better indication of the expected change for individual values) is at the limit of clinical significance $\simeq$ 0.15DS and 0.12DC.

It can be concluded that the standard deviation on measurements repeatability with the model eye sets the absolute limit of the instrument to approximately 1/8th of diopter.

5.5. Experiment 5 Qualitative aspect of the IR illumination beam

5.5.1. Introduction

A photographic method was used to assess the nature of the IR beam incident on the patient's eye. Only Safir (1973)[128] in the literature has stated that the beam was focused in the patient's pupil plane. The object of this experiment was to assess the plausibility of this statement.

5.5.2. Material and Method

IR photographs of the illumination beam were taken using a high sensitivity IR Kodak Film in a Nikon F2 camera body without a lens system (the reflecting mirror was lifted out of the way).

The camera was positioned in contact with the instrument, so that the plane of the film was about 40.5 mm from the front of the instrument. (During the measurement the patient's eye is $\hat{=}$ 20 mm from the front of the instrument). Different aperture speeds were used and photographs were taken at different times during the cycle.

Before photographing precautions were taken to remove the fixation target lamp to avoid any stray light entering the camera.

5.5.3. Results

The following photographs were obtained: (fig 55), Photos 1 to 3 at 1/1000 of second early, mid and late part of the cylcle, with camera back in contact with the instrument.

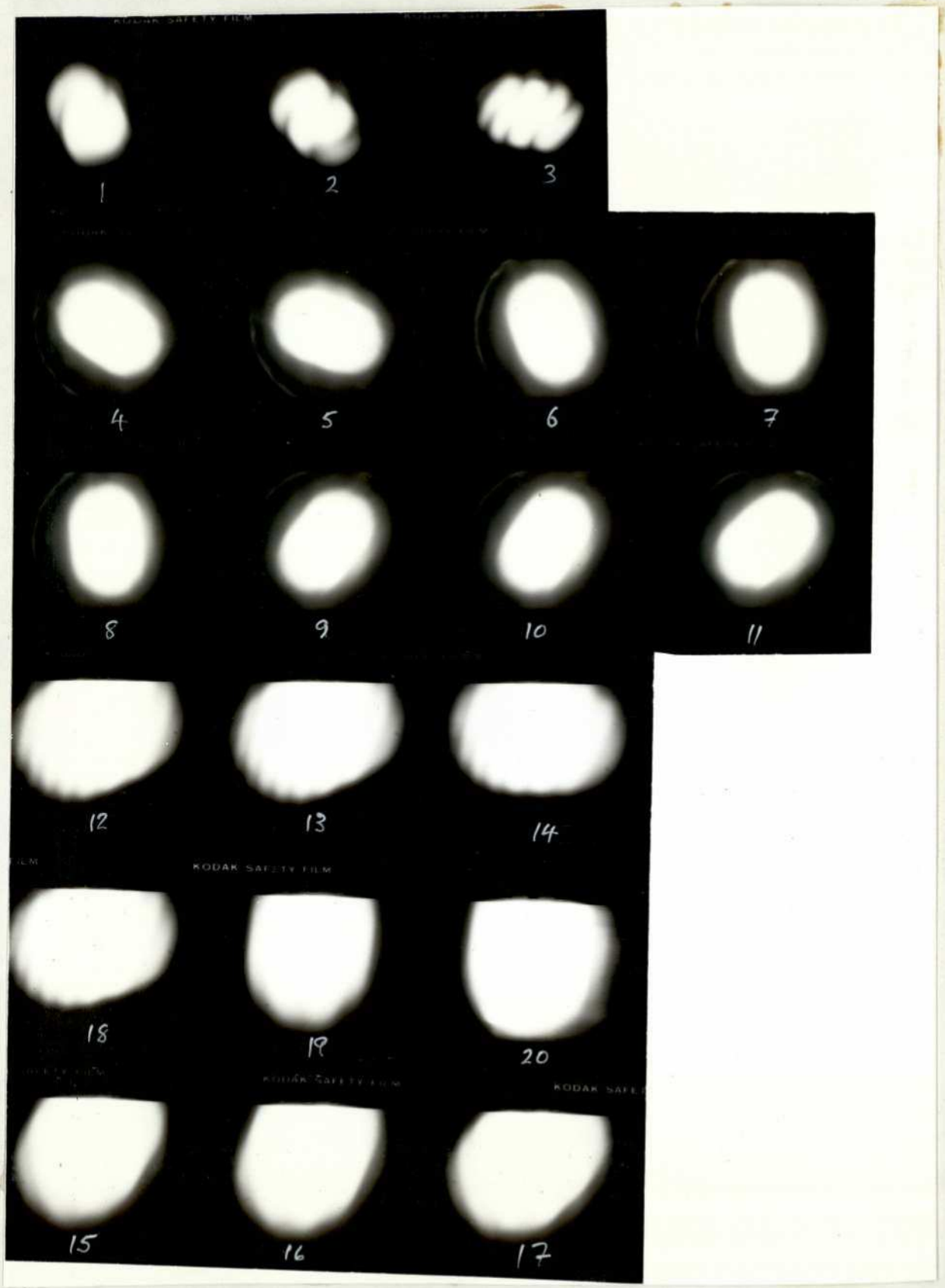


Fig. 55: Contact print of the Ophthalmetron IR beam

Photographs 4 - 11 At 1/250 seconds at different times in the cycle in the same position.

Photographs 12 - 19 At 1/250 seconds at different times in the cylcle, in a plane + 5 mm away from above position.

Photograph 20 As above but in plane + 10 mm away from the plane of photographs 4 - 12.

5,5.4. Discussion

All photographs demonstrated the elongated aspect of the filament image. Also particularly photographs 4 - 12 demonstrate the rotation of the filament during the cycle. The slight amount of blur around the image of the filament is due to the fact that at 1/250 seconds $\simeq$ 3 exposures of the incident beam are produced by the rotating drum. The photographs at 1/1000 seconds show the individual exposure with details of the filament appearance.

In no case is the filament sharply focussed onto the film plane and this had to be expected as the incident beam is supposed to converge at +20 mm and the film plane is $\simeq$ +40.5 mm. However, the photographs show that as the camera is moved away from the instrument the size of the image increases suggesting a divergent beam, therefore the plane of focus had already been reached. No quantitative evaluation was possible.

CHAPTER 6

CLINICAL EXPERIMENTAL INVESTIGATIVE PROCEDURE - GENERAL DESIGN

6.1. Introduction

Various groups of subjects, both normal and pathological, were studied to assess the instrument in various clinical situations. To that effect a group of voluntary normal subjects was used to study the accommodative factor with the Ophthalmetron. The other three groups comprised of hospital patients of particular refractive interest and were high myopia and/or high myopic astigmatism, corneal graft and aphakic patients.

The aphakic group is of particular importance (50% of patients in the contact lens department are aphakic), being the subject of several studies. The aphakic patients were used to assess the Ophthalmetron. In theory good results could be expected with the instrument (clear media and no accommodation). To evaluate our standard refractive techniques and to determine the possible causes of discrepancies encountered in the refraction of the aphakic patient, the data was appropriately analysed.

Each group has been studied using the statistical and clinical analysis described below. Particular emphasis will be put on different points of the analysis depending on the parameters or clinical factors studied.

6.2. Analysis of Results

6.2.1. Statistical Analysis. Theoretical review

(i) Object of the Statistical Analysis

The statistical analysis has several purposes. These are chiefly:-

a. To detect differences and correlation with respect to the results obtained by the various techniques on a given group of patients.

b. To relate these results to the clinical utility of the different techniques.

(ii) Statistical Methods Available

A review of possible analytical studies is introduced so that maximal information can be obtained from the data available.

For each patient there are at least three different results (by retinoscopy, subjective and Ophthalmetron) which can be studied either by pair, based on standard deviation and student t distribution or as a whole applying variance analysis.

a. Pair Analysis

The results obtained by two different techniques (ie Ophthalmetron and Subjective) can be considered to represent two samples of the same population. They are non independant samples of the same population as the same individuals are tested by the various methods so that variability diminishes as the same motivation, intelligence level and physical conditions exist. The "Null Hypothesis" is

stated: the two samples are normal and there is no difference between their means and standard deviation as a result of sampling errors. In other words all errors present would be random normal deviates and within acceptable levels. (If a significant difference was to be suspected the alternative hyopthesis should be formulated, with possibility of one-tail or two-tail). The null hypothesis will be accepted or rejected depending on the value obtained for the student t test.

If the null analysis is accepted at a certain significance level the mean results can be considered as statistically identical and no further study is needed apart from the evaluation of the possibility of erroneous conclusions (Errors type I and II).

Alternatively, if the null hypothesis is rejected (and after evaluation), a scatter diagram can be plotted using the collected data for one method (i.e. Ophthalmetron) and those obtained with the other (i.e. Subjective). The data are then correlated by means of regression lines and correlation factor (appendix 5).

b. Variance Analysis

Where more than two groups are concerned there are advantages in studying the variability between all groups at once by analysis of variance, the variance being defined by

$$S^2 = \frac{\Sigma (X-\bar{x})^2}{N-1} \quad \text{or for calculation} \quad S^2 = \frac{\Sigma X^2 - \frac{(\Sigma X^2)}{N}}{N-1}$$

If all the samples are drawn from the same normal population then the null hypothesis is true and $Xa_i = Xb_i = Xc_i = Xd_i = \mu$. Hence the sum of sum of squares within groups $\Sigma x^2 w_1 + \Sigma x^2 w_2 + \Sigma x^2 w_3$ will be equal to the total sum of squares Σx^2_T, the sum of squares between groups Σx^2_b, being equal to zero. This would mean that all the variability is caused by individual sample variation around the mean.

In fact Σx^2_b is not usually equal to zero, even with a true null hypothesis and the total variability is due to both variability within the group Σx^2_w and variability between groups Σx^2_b. The variance estimates calculation aims at studying the relative importance of the variability between groups and the variability within groups and permits to calculate the F ratio, tables of which will give the level of significance for a given sample. (appendix 6)

In practice the F ratio calculation reveals if there is any sampling difference between several groups thought to belong to the same population. Hence it is felt that this should be the initial method of choice for statistical analysis for the present investigation.

6.2.2. Application of the statistical analysis to clinical findings

(i) In the literature related to accuracy in refraction the results obtained are treated in various manners depending on the author's preconceptions or needs.

The most common approach is the comparision of the spherical equivalents, each spherocylinder being considered as the power of the two principal meridians (Knoll, Mohrman and Safir, 1970[129]; Safir, Knoll and Mohrman, 1970[130]; Bizzell et al 1974[131]; Drance et al 1975[132], Leigh, 1975[133], Coherent Radiation[134]; Hill, 1973[135]) (at times only one value is taken to represent the spherical part of the refraction, it is the "mid equivalent sphere" obtained by algebraic addition of the sphere and half the cylinder (Safir et al,(1973)[136], Safir et al(1973)[137] Floyd and Garcia,(1974)[138], Polse and Kerr(1975))[139].

The Cylinder value and axis precision are then analysed but in this situation problems are encountered as the axis precision is linked to the cylinder power (ie: the higher the cylinder, the more precise the axis finding). Also difficulties arise when one of the refractions to be compared is spherical. However, the treatment described above, (despite its poor mathem atical basis) does offer very useful information to clinicians.

Once the data are collected further variations arise in the statistical analysis. All the functions described in 6.2.1. are encountered in the literature and their clinical significance can be summarized as follows:

- Student t test and F ratio: they inform the clinician whether or not the estimates of the refractive value of the population obtained by two methods for the t test or more than two methods for the variance analysis is purely random.

- Standard deviation: it indicates, assuming a normal population, that the difference between two methods will be within ∓ one standard deviation (SD) in 68% of cases, within ± two SD in 95% of cases and that only 1% of cases can be expected to be more than ± three SD apart.

- Regression Lines: given by y=bx+a, x and y representing the values obtained by two different refractive methods b, the slope of the line through the scatter diagram indicates by how much one determination of the refractive value increases when the other is increased by unity. a the intercept, gives a measurement of the estimated accommodation bias, or of the systematic refractive shift obtained when the value for the first method is zero.

- Correlation coefficient: It varies between ±1, +1 indicating a perfect functional relationship an increase in x being associated with an increase in y, while r = 0 denotes no relationship at all.

(ii) The present use of Statistical Analysis

All the clinical results were statistically analyzed using the office computer available in the Contact Lens Department as Moorfields Eye Hospital (Computer Workshop Model 6800 using Basic Language).

For each group of results the F ratio was calculated using a program "Anavar" (appendix 5) as it is the best approach in statistical terms. However, in order to obtain maximal clinical information, a two group analysis based on standard deviation and t test was performed, systematically followed, (whether or not the t test value was significant)

by the determination of the regression line and correlation factor for the two groups (Programme "t Test" appendix 5).

The full statistical analysis was thought to be best in order to relate the findings of this investigation to previous works; they usually consider a particular aspect without any justification for that single choic.

In every group the parameters studied were the mid equivalent sphere, the cylinder power and cylinder axis for the cylinder or $\geq$ to o.50DC. In certain cases, the maximum positive equivalent sphere or different grouping for cylinder axis were used. In the groups concerned, reasons for such additions are given.

Additive frequencies were calculated; they indicated the precentage of cases within given dioptric ranges when one of the refractive methods is compared to an other.

6.3. New Approach Proposed for Clinical Analysis of Data

As discussed in 3.1.3. a spherocylinderical correction can be expressed by $S+C \sin^2 \theta$, where S represents the spherical value, C the clyinder power and θ the cylinder axis.

Using that approach Safir (1974) propsed a mathematical method of comparison for any two refractions taken as a whole. the assumed the shaded surface of fig (app. 7), bound by the two curves to be the measurement of the disparity between the two refractions. This is obtained by calculating the mean square difference between the curves by integration and taking the square root of it and gives after integration (Appendix 7).

$$\Delta = \sqrt{(S_1-S_2)^2+(S_1-S_2)(C_1-C_2)+3/8(C_1-C_2)^2+\frac{C_1 x C_2 \sin^2(A_1-A_2)}{2}}$$

Any difference in sphere power, or cylinder power or axis orientation will create a shift between the two curves. (S = Sphere, C= Cylinder power, A = Cylinder Axis. 1 denotes first method; 2 denotes second measurement).

Once the value for this function is obtained for a series of patients a statistical analysis of its depature from zero can be undertaken. The main problem is to relate Δ values to useful clinical conclusions on the whole refractive finding at once. A solution for this new approach is attempted in 7.7. with the main aphakia group.

6.4. Sampling methods

6.4.1. Purpose of the research

The research protocol undertaken planned to elucidate the usefulness of an electronic optometer (namely the Ophthalmetron) for refraction and for post-surgical follow up purposes.

Usefulness in Refraction can be based on two criteria:-

1. Accuracy (or validity), that is how close the measurement obtained with the Ophthalmetron is to the "true" refractive value.
2. Precision (or reliability), the ability of the Ophthalmetron to duplicate its own result.

The second criterian is simple to analyze. It is sufficient to test a given series of patients with the Ophthalmetron, twice with the same instrument (repeatability for a given instrument) or with two different models (interinstrumental repeatability) and to analyze statistically the results obtained. It is the "true clinical repeatability". An alternative to this is to determine the "absolute clinical repeatability" by testing a small group of patients on several occassions with the same instrument.

In each of our experimental groups some or all the patients were tested twice at the same visit with the Ophthalmetron. When not every patient was tested twice with the Ophthalmetron the selection for retest was random and dictated by the clinical workload.

The first part of the problem is far more complicated, as it involves the notion of true refractive values. In all previous studies subjective refraction was considered as the true value (Freeman and Hodd, 1955;[140] Volk 1956;[141] Safir et al 1970).[142] Still this could be accepted as the subjects involved were mainly young, cooperative with low refractive error and clear media and the same assumption will be made here for the non pathological group and for the myopic and corneal graft patients.

In the aphakic study however, conditions are very different and some factors involved make the assumption less certain. First high positive lenses were involved creating magnification effect up to 30%, so that when a VA of 6/6 is achieved, the patient's "true" V.A. is only 6/9 to 6/12. Secondly, high power lenses introduce several parameters like precision of BVD measurement, angle of tilt, centration, and tolerances on trial lenses. Finally, because of the condition concerned, a large group of patients are elderly and some show some signs of senility, a lack of alertness make them less reliable. Also if there is no broad iridectomy pupils are usually small, giving a good depth of focus. Added to the magnification effect this renders judgement of the end point of refraction far more difficult.

In view of the above a side study has been undertaken to try to assess the "true" value with better accuracy on a small group of patients. In this study patients were refracted by 3 optometrists experienced with aphakia and using their usual techniques.

6.4.2. Description of the different groups studied

(i) Normal patients

A group of young patients, all voluntary subjects, were chosen to asses the accuracy and precision of refraction and accommodative bias with the Ophthalmetron.

(ii) High myopia (and/or high myopic astigmatism and corneal graft

These two groups were assessed for accuracy and precision (7.2.;7.3).

(iii) Aphakia

This condition forms the main part of the present research. First a large group of patients were studied (7.4.) to gain a base line knowledge of the instrument in that particular condition. At the same time repeatability was assessed using the same instrument (7.5) and with two different models (7.5.).

After that the Ophthalmetron was compared to the Dioptron (7.4.) and the repeatability of refraction in aphakia was measured, (7.5.).

(iv) Surgical follow up

A small number of patients was followed post corneal grafts (7.6.) and cataract extraction (7.6.) and the relative usefulness of keratometry, subjective, retinoscopy and Ophthalmetron were assessed.

CHAPTER 7

CLINICAL EXPERIMENTAL INVESTIGATIVE PROCEDURE - RESULTS

7.1. Clinical Experiment 1. Normal population and accommodative factor with electronic optometer

7.1.1. Introduction

This first clinical experiment was purposely designed to repeat, to some extent, the investigations of certain other workers, with the Ophthalmetron or the other IR electronic optometers. The objectives were:

(i)To gather a series of data on a essentially normal population and by applying a multi approach statistical analysis to supply a means of directly comparing the present work to published data (both for sphere and cylinder). Therefore give the present work an extrinsic value and conclusively establish that any difference obtained with more abnormal groups of patients will be the effect of the population differentiation and not variation due to the operator.

(ii) To show for instrumental accommodation that, contrary to the manufacturer's claim (here for the Ophthalmetron) it is a problem with certain patient's and that it is of psychological nature; therefore it has no correlation with the typical high amplitude of accommodation available in a young population. Also to give explanations for opposite conclusions found in the literature.

(iii) To make recommendations on the statistical tests having the highest clinical significance.

7.1.2 Material and Method

The Ophthalmetron from the Optometry Department of the City University was used throughout this experiment, both by the writer and the technician in charge of the clinics in the department, who was familiar with the Ophthalmetron and other clinical instruments (ie. non contact tonometer ...).

22 voluntary subjects (11males, 11 females) aged 17 to 27 years (mean 21.4 year; S/D 2.4 years) were tested during this experiment. The range of ametropia was -6.00 to +4.00 DS and afocal to -4.50 DC. The only criteria for selection were that they possessed only lightly pigmented irides to obtain similar cyclopegic effect throughout the population when using 0.5% Cyclopentolate Hydrochloride. This particular muscarinic agent was chosen for its rapid onset of maximal cyclopegia, usually 30 to 40 minutes after instillation and remaining maximal for approximately 30 minutes (Mitchell, Linfield, and Frances, 1958).[143] The residual accommodation for the age group concerned is +1.03 D on average (Stalzer, 1953).[144] Recovery from cyclopegia is rapid, 4 to 12 hours, with possibility to read after 3 hours.

The protocol utilized and outlined in Table 10 is subject to the following comments:

- The writer was never aware of the Ophthalmetron results obtained by the technicians until the whole protocol was completed, so that no psychological bias would be introduced on the retinoscopic measurement by such information.

- All the monocular measurments reported (Ophthalmetron, Retinoscopy and subjective) were undertaken with the eye not under test completely occluded.
- The fixation target for retinoscopy was a set of concentric black circles on the green background of the duochrome test. Suitable precautions applied to minimize oblique astigmatism and other artifacts.

7.1.3. Results

Complete results were obtained for all 44 eyes included in the study (Appendix 8). These were analyzed as indicated in Chapter 6, both sphere and cylinder (power and axis) were considered.

1. Ophthalmetron measurement by Technician R+L.
2. VA with present prescription (R+L)
3. Cover Test (distance and near). Pupillary distance measurement.
4. Retinoscopy R+L (Streak Retinoscopy with distance fixation.
5. Monocular Subjective R+L (cross cylinder; duochrome maximal VA criteria; +1.00DS check)
6. Accommodation measurement R+L (push up rule).
7. Ophthalmetron measurement by writer R+L.
8. Slit lamp and Ophthalmoscopic examinations.
9. Instillation of 1dp 0.5% Cyclopentolate R+L

After 30 minutes

10. Accommodation measurement R+L (push up rule and additive lenses.
11. Ophthalmetron measurement R+L by technician.
12. Retinoscópy R+L.
13. Subjective R+L.
14. Ophthalmetron measurement by writer R+L
15. Accommodation measurement R+L.

TABLE 10 EXPERIMENT PROTOCOL-NORMAL POPULATION CYCLOPEGIC STUDY

(i) Variance Analysis

The analysis of variance, results of which are summarized in Table 11 , show no statistically significant difference for any of the parameters concerned (maximal positive sphere, mid sphere, cylinder power and axis) both for the whole population and the subgroups (male-female, Right-Left eyes) when all 8 measurements are pooled together.

(ii) Pair Analysis

More specific clinical conclusions are obtained using a t test type analysis.

a. Mid Sphere main group

The results obtained (Table 12) lead to the following comments and conclusions:

- The t test shows that there is no significant difference at both 1 and 5% levels for any of the pairing concerned when cyclopegia is used. Without cyclopegia only the comparisons between subjective and retinoscopy and the two ophthalmetron measurements are not significantly different. Also when comparing the same measurement with and without cyclopegia the results are highly significant for all refractive methods.

The Standard Deviation from the subjective result is similar for both retinoscopy and the Ophthalmetron ($\simeq$ 0.35 and 0.40D) under cyclopegia. But when no cyclopegic agent is used the standard deviation for retinoscopy decreases to $\simeq$ 0.25D, while for the Ophthalmetron measurements it

Group	Source of variation	Sum of Square	df	Mean Square	F
Sphere (whole pop.)	Between groups	32.867	7	4.695	1.382
	Within groups	1168.391	344	3.396	
	Total	1201.258			
Sphere (female)		34.373	7	4.910	0.963
		856.649	168	5.099	
		891.022			
Sphere (male)		6.531	7	0.933	0.516
		303.704	168	1.808	
		310.235			
Sphere (Right)		12.649	7	1.807	0.541
		561.186	168	3.340	
		573.835			
Sphere (Left)		21.472	7	3.067	0.855
		602.927	168	3.588	
		624.399			
Mid Sphere (whole pop.)		39.248	7	5.607	1.707
		1130.064	344	3.285	
		1169.312			
Mid Sphere (female)		41.231	7	5.890	1.325
		746.860	168	4.446	
		788.091			
Mid Sphere (male)		70.74	7	1.011	0.454
		374.126	168	2.227	
		381.200			
Mid Sphere (Right)		17.173	7	2.453	0.693
		594.837	168	3.541	
		612.010			

Group	Source of variation	Sum of Square	df	Mean Square	F
Mid Sphere (Left)	Between groups	22.846	7	3.264	1.028
	Within groups	533.457	168	3.175	
	Total	556.304			
Cyl Power (whole pop.)		0.846	7	0.121	0.172
		242.225	344	0.704	
		243.071			
Cyl Power (female)		1.711	7	0.244	0.310
		132.505	168	0.789	
		134.216			
Cyl Power (male)		0.390	7	0.056	0.085
		109.868	168	0.654	
		110.258			
Cyl Power (Right)		0.613	7	0.088	0.203
		72.382	168	0.430	
		72.995			
Cyl Power (Left)		0.402	7	0.057	0.058
		166.714	168	0.992	
		167.116			
Cyl axis (whole pop.) > 0.50		5238.02	7	748.289	0.172
		642623.69	144	4337.664	
		629861.71			

Table II Normal population Cyclopegic study
Variance Analysis results

Group	$\bar{X}_1$	$\bar{X}_2$	$\bar{D}=\bar{X}_1-\bar{X}_2$	S/D	t	n	b	a	R
$S_c v_s R_c$	-1.150	-1.216	0.066	0.266	1.642	44	1.007	-0.058	0.990
$S_c v_s O_{AC}$	-1.150	-1.111	-0.039	0.3447	-0.748	44	0.939	-0.031	0.984
$S_c v_s O_{BC}$	-1.150	-1.089	-0.061	0.398	-1.024	44	0.912	-0.039	0.979
$R_c v_s O_{AC}$	-1.216	-1.111	-0.105	0.394	-1.765	44	0.920	-0.007	0.979
$R_c v_s O_{BC}$	-1.216	-1.089	-0.127	0.430	-1.965	44	0.900	0.001	0.976
$O_{AC} v_s O_{BC}$	-1.111	-1.089	-0.023	0.311	-0.479	44	0.962	-0.019	0.985
$S_{vs} R$	-1.412	-1.452	0.040	0.253	1.045	44	1.004	-0.034	0.991
$S_{vs} O_A$	-1.412	-1.891	0.479	0.613	5.177	44	0.887	-0.638	0.944
$S_{vs} O_B$	-1.412	-2.011	0.600	0.821	4.844	44	0.793	-0.891	0.897
$R v_s O_A$	-1.452	-1.891	0.438	0.602	4.832	44	0.879	-0.615	0.948
$R v_s O_B$	-1.452	-2.011	0.560	0.778	4.774	44	0.795	-0.857	0.911
$O_A v_s O_B$	-1.891	-2.011	0.121	0.615	1.304	44	0.880	-0.347	0.936
$S_c v_s S$	-1.150	-1.412	0.262	0.285	6.088	44	0.974	-0.292	0.988
$R_c v_s R$	-1.216	-1.452	0.236	0.373	4.196	44	0.964	-0.280	0.981
$O_{AC} v_s O_A$	-1.111	-1.891	0.779	0.697	7.417	44	0.896	-0.895	0.923
$O_{BC} v_s O_B$	-1.089	-2.011	0.922	0.796	7.687	44	0.834	-1.104	0.892

Table 12 Normal Population Pair Analysis Summary of results for Mid-equivalent sphere.

(S = Subjective; R = Retinoscopy;
O_A = Ophthalmetron by Author;
O_B = Ophthalmetron by technician
c denotes with cyclopegic)

increases to 0.62 and 0.75D respectively. A reason for a larger standard deviation with retinoscopy when a cyclopegic agent is used could be the difficulty encoutered in judging the endpoint because the spherical aberrations produced by the peripheral cornea with a dilated pupil. Finally the standard deviation between the measurements taken with and without cyclopegia is double for the Ophthalmetron ($\overset{SD}{\simeq}$ 0.75D) when compared to Retinscopy and subjective (SD=0.30 and 0.35D).

The mean difference $\overline{D}$ and the intercept $\overline{a}$ (here their absolute values are directly comparable but their sign opposite: $\overline{D} = \overline{X}_1 - \overline{X}_2$ therefore when $\overline{X}_1 = o$ $\overline{D} = -\overline{X}_2$ while for $\overline{X}_2 = a+b\ \overline{X}_1$ when $\overline{X}_1 = o$; $\overline{X}_2 = a$) which illustrate the shift of one set of data from the other, are inferior to 0.12D when a cyclopegic is used for all the refractive methods and increases to 0.25D for retinoscopy and 0.62 to 0.75D for the Ophthalmetron when compared to the subjective findings; in all cases the most positive mean is obtained subjectively. When values with and without cyclopegia are compared, there is a myopic shift for all four measurements, minimal for the subjective determination ($D \simeq 0.26$) and maximal with the Ophthalmetron ($\simeq$0.75D).

The estimate of the slope b and the correlation factor R seem to vary little from 1.00 and are of poor clinical usefulness in particular R for which in the 8 cases when its values are 0.98 or better the t test values varies from 0.48 to 6.09.

It can therefore be concluded (when the subjective determination is considered as the true value) that the accuracy of retinoscopy is good and relatively independant of cyclopegia, while that of the Ophthalmetron (good with cyclopegia) decreases markedly when accommodation is present. The cause for the decrease in accuracy can conclusively be attributed to "instrumental myopia" and is best illustrated by the increase in the values of $\overline{D}$ and $\overline{a}$ when no cyclopegic is used.

b. Mid Sphere subgroups

The population was first considered in terms of right and left eyes to test whether or not accuracy of retinoscopy when compared to the subjective values differed, as bias could have been introduced by always testing the right eye first. The results in table 13 show that both with and without cyclopegia the standard deviation and mean difference were identical, respectively 0.25D and $\leq$ 0.10D. This is in agreement with the conclusions reached by Safir (1971).[145]

The second aspect was to study the suggestion that if the instrumental accommodation shown present with the Ophthalmetron was of psychological origin it could affect more male than female or vice versa.

Results given in table 14 prove this point for the present population. The standard deviation which was identical for both male and female with cyclopegia is significantly larger for the female group without cyclopegia. Further the mean difference from the subjective

Group		$\bar{X}_1$	$\bar{X}_2$	$\bar{D}=\bar{X}_1-\bar{X}_2$	S/D	t	n	b	a	R
S_c v R_c	R	-1.232	-1.261	0.030	0.247	0.566	22	1.053	0.036	0.994
	L	-1.068	-1.170	0.102	0.286	1.675	22	0.963	-0.142	0.989
S_vR	R	-1.466	-1.415	-0.051	0.252	-0.952	22	1.019	0.079	0.992
	L	-1.358	-1.489	0.131	0.223	2.747	22	0.992	-0.142	0.993
R_c v R	R	-1.261	-1.415	0.153	0.374	1.925	22	0.954	0.212	0.983
	L	-1.170	-1.489	0.318	0.361	4.131	22	0.977	-0.345	0.981

Table 13 Normal Population - Accommodation Study.
Summary of Results for mid-equivalent sphere considering Right and Left eyes separately.

(S = Subjective; R = Retinoscopy;
O_A = Ophthalmetron by Author;
O_B = Ophthalmetron by technician;
c denotes under cyclopegia)

Group		$\bar{X}_1$	$\bar{X}_2$	$\bar{D}=\bar{X}_1-\bar{X}_2$	S/D	t	n	b	a	R
$S_c VO_{AC}$	M	-1.260	-1.176	-0.084	0.311	-1.272	22	0.949	0.020	0.977
	F	-1.040	-1.046	0.007	0.377	0.082	22	0.936	-0.073	0.987
$S\ VO_A$	M	-1.494	-1.653	0.159	0.415	1.791	22	0.988	-0.177	0.963
	F	-1.329	-2.128	0.799	0.619	6.054	22	0.851	-0.996	0.963
$S_c VO_{BC}$	M	-1.260	-1.114	-0.146	0.280	-2.441	22	0.923	0.048	0.982
	F	-1.040	-1.063	0.023	0.480	0.224	22	0.912	-0.115	0.978
$S_v O_B$	M	-1.494	-1.702	0.207	0.383	2.537	22	1.008	-0.195	0.969
	F	-1.329	-2.321	0.992	0.954	4.874	22	0.706	-1.383	0.910
$O_{AC} VO_{BC}$	M	-1.176	-1.114	-0.061	0.250	-1.153	22	0.952	0.003	0.984
	F	-1.046	-1.063	0.016	0.365	0.210	22	0.968	-0.050	0.985
$O_A VO_B$	M	-1.653	-1.702	0.049	0.338	0.674	22	0.989	-0.065	0.976
	F									

Table 14 Normal population - Accommodation Study Summary of Results for mid equivalent sphere considering male and female separately.

(S = Subjective; R = Retinoscopy;
O_A = Ophthalmetron by Author;
O_B = Ophthalmetron by technician;
c denotes under cyclopegia)

value $\overline{D}$ which is identical for both male and female during the measurements under cyclopegic ($\overline{D} \simeq 0.10D$) changes very little for the male population ($\simeq 0.16D$) and very significantly for the female population (0.7D to 1.12D) for both readings.

c. Maximal positive sphere

Despite the probable shortcoming of this parameter as compared to the mid equivalent shpere it was considered useful to analyse it. Thus comparison will be possible with studies considering the maximum positive sphere for parameter and any correlation between mid and maximum sphere can be obtained.

Table 15 shows that on all points the conclusion to be deduced are absolutely indentical to those obtained for the mid sphere, for the t test. (not significant with cyclopegia, not significant without cyclopegia, only for Retinoscopy and subjective and the two Ophthalmetron and highly significant between with and without cyclopegic), the S/D (without cyclopegia it is twice as large for the Ophthalmetron than for retinoscopy) and the mean difference (it increases from less than 0.1D to 0.6D when no cyclopegia is used with the Ophthalmetron).

d. Cylinder Power

The results reproduced in table 16 differ conclusively from those obtained for the spherical values.

The t test is significant at 1% and 5% levels respectively when the Ophthalmetron values are compared to the subjective and retinoscopic findings under cyclopegia

GROUP	$\bar{X}_1$	$\bar{X}_2$	$\bar{D}=\bar{X}_1-\bar{X}_2$	S/D	t	n	b	a	R
S_C vs R_C	-0.781	-0.855	0.074	0.267	1.833	44	1.026	-0.053	0.991
S_c vs O_{AC}	-0.781	-0.801	0.020	0.358	0.369	44	0.938	-0.069	0.983
S_C vs O_{BC}	-0.781	-0.810	0.028	0.419	0.449	44	0.913	-0.096	0.977
R_C vs O_{AC}	-0.855	-0.801	-0.054	0.450	-0.796	44	0.899	-0.032	0.975
R_C vs O_{BC}	-0.855	-0.810	-0.045	0.509	-0.593	44	0.875	-0.062	0.969
O_{AC}vs O_{BC}	-0.801	-0.810	0.009	0.319	0.177	44	0.965	-0.037	0.985
S vs R	-1.080	-1.125	0.045	0.285	1.056	44	1.007	-0.038	0.989
S vs O_A	-1.080	-1.568	0.489	0.622	5.214	44	0.862	-0.637	0.946
S vs O_B	-1.080	-1.545	0.466	1.150	2.687	44	0.662	-0.831	0.800
R vs O_A	-1.125	-1.568	0.443	0.660	4.454	44	0.843	-0.619	0.942
R vs O_B	-1.125	-1.545	0.430	1.155	2.414	44	0.655	-0.809	0.805
O_A vs O_B	-1.568	-1.545	-0.023	1.038	-0.145	44	0.735	-0.392	0.810
S_C v S	-0.781	-1.079	0.298	0.279	7.088	44	0.989	-0.307	0.989
R_C v R	-0.855	-1.125	0.270	0.360	4.978	44	0.966	-0.299	0.983
O_{AC}v O_A	-0.801	-1.568	0.767	0.692	7.349	44	0.884	-0.860	0.926
O_{BC} v O_B	-0.810	-1.545	0.736	1.151	4.239	44	0.685	-0.991	0.774

Table 5: Normal Population - Pair Analysis - Summary of results for maximum positive sphere.

(S = Subjective ; R = Retinoscopy; OA = Ophthalmetron by author; OB = Ophthalmetron by technician; C denotes with Cyclopegia).

GROUP	$\bar{X}_1$	$\bar{X}_2$	$\bar{D}=\bar{X}_1-\bar{X}_2$	S/D	t	n	b	a	R
S_C v R_C	-0.748	-0.722	-0.027	0.216	-0.822	44	1.047	0.062	0.967
S_C v O_{AC}	-0.748	-0.614	-0.135	0.310	-2.879	44	0.966	0.109	0.923
S_Cv O_{BC}	-0.748	-0.592	-0.156	0.354	-2.929	44	0.967	0.131	0.903
R_cv O_{AC}	-0.722	-0.614	-0.108	0.362	-1.977	44	0.872	0.015	0.902
R_Cv O_{BC}	-0.722	-0.592	-0.130	0.352	-2.444	44	0.899	0.057	0.910
O_{AC}v O_{BC}	-0.614	-0.592	-0.022	0.261	-0.548	44	0.971	0.004	0.949
S v R	-0.676	-0.676	0	0.280	0	44	1.025	0.o17	0.951
S v O_A	-0.676	-0.673	-0.003	0.329	-0.057	44	0.972	-0.016	0.928
S v O_B	-0.676	-0.707	0.031	0.311	0.666	44	0.958	-0.060	0.933
R v O_A	-0.676	-0.673	-0.003	0.354	-0.053	44	0.895	-0.068	0.921
R v O_B	-0.676	-0.707	0.031	0.342	0.606	44	0.882	-0.111	0.926
O_A v O_B	-0.673	-0.707	0.034	0.307	0.738	44	0.919	-0.089	0.938
S_cvS	-0.748	-0.676	-0.072	0.207	-2.315	44	1.059	0.116	0.971
R_c v R	-0.722	-0.676	-0.045	0.266	-1.135	44	1.038	0.073	0.956
O_{AC}v O_A	-0.614	-0.673	0.060	0.304	1.300	44	1.025	-0.045	0.938
O_{BC}v O_B	-0.592	-0.707	0.115	0.279	2.740	44	0.989	-0.122	0.946

Table 16: Normal Population Cyclopegic study Pair Analysis summary cf results for Cylinder Power.

(S = Subjective; R = Retinoscopy ; OA = Ophthalmetron by author; OB = Ophthalmetron by technician; C denotes under Cyclopegia).

and when accommodation is present the difference is no longer significant.

The standard deviation remains constant throughout the different tests 0.25 to 0.35 DC. The difference between the means and the intercept values shows that the cylinder amplitude is large when estimated by subjective and retinoscopy than with the Ophthalmetron under cyclopegia and identical without cyclopegia. The value for the slope and correlation coefficient are high (always $>$ 0.90).

In conclusion, the accommodation does not affect the measurement of the cylinder power with the Ophthalmetron as it could have been expected (accommodation being non-astigmatic).

e. Cylinder axis

The two most important factors to consider are the t test, which is only significant at the 5% level when comparing the subjective to the second Ophthalmetron and retinoscopy to the first Ophthalmetron without cyclopegic and the SD which apart for subjective and retinoscopy under cyclopegia and subjective with and without cyclopegia (SD $<$ 10%) the difference are important. However, this should not be of great concern as the cylinder considered were of low power. (Table 17)

(iii) Additive frequencies

Additive frequencies were also computed for the mid sphere and cylinder power (Tables 18 and 19).

GROUP	$\overline{X}_1$	$\overline{X}_2$	$\overline{D}=\overline{X}_1-\overline{X}_2$	S/D	t	n	b	a	R
S_C v R_c	66.842	68.684	-1.842	8.451	-0.950	19	1.001	1.806	0.990
S_C v O_{AC}	66.842	80.316	-13.474	30.3985	-1.932	19	0.978	14.975	0.889
S_Cv O_{BC}	66.842	76.553	-9.711	26.686	-1.587	19	1.035	7.380	0.920
R_C v O_{AC}	68.684	80.316	-11.632	26.095	-1.943	19	1.001	11.584	0.919
R_C v O_{BC}	68.684	76.553	-7.868	23.105	-1.484	19	1.048	4.567	0.941
O_{AC}v O_{BC}	80.316	76.553	3.763	16.806	0.976	19	0.991	-3.038	0.969
S v R	66.868	63.947	2.921	25.837	0.493	19	0.965	-0.570	0.918
S v O_A	66.868	74.342	-7.474	28.629	-1.138	19	1.067	2.960	0.919
S v O_B	66.868	79.184	-12.316	25.417	-2.112	19	1.104	5.356	0.941
R v O_A	63.947	74.342	-10.395	18.414	-2.461	19	1.071	5.873	0.969
R v O_B	63.947	79.184	-15.237	45.980	-1.444	19	0.873	23.397	0.781
O_A v O_B	74.342	79.184	-4.842	43.745	-0.482	19	0.824	17.909	0.816
S_C v S	66.842	66.868	-0.026	9.676	-0.012	19	1.013	-0.853	0.987
R_c v R	66.684	63.947	4.737	27.104	0.762	19	0.970	-2.679	0.909
O_{AC}v O_A	80.316	74.342	5.974	26.492	0.983	19	1.007	-6.52	0.929
O_{BC}v O_B	76.553	79.184	-2.632	41.217	-0.278	19	0.887	11.27	0.829

Table 17 Normal Population Cyclopegic study Pair Analysis summary of results for cylinder axis.

(S = Subjective; R = Retinoscopy; OA = Ophthalmetron by author; OB = Ophthalmetron by technician ; C denotes under Cyclopegia).

		S_cVR_c		S_cO_{AC}		S_cO_{BC}		RvO_{AC}		RvO_{BC}	
		15.91		9.09				11.36		0	
0.25		29.55	65.90	29.55	50.00	34.09	54.55	18.18	34.09	29.55	47.73
-0.25		36.36	81.81	20.45	59.09	20.45	54.55	15.90	45.45	18.18	47.73
0.25	0.50	4.55	13.64	20.45	29.55	25.00	31.82	18.18	34.09	20.45	27.27
-0.25	-0.50	9.09	95.45	9.09	86.64	6.82	86.37	15.90	79.54	6.82	75.00
0.50	0.75			2.27	9.09	2.27	6.82	13.64	18.18	11.36	15.91
-0.50	-0.75	4.55	100.00	6.82	97.73	4.55	93.20	4.55	97.72	4.55	90.91
0.75	1.00			2.27			2.27	2.27	2.27	4.55	6.82
-0.75	-1.00				100.00	2.27	95.47		100.00	2.27	97.73
1.00	1.50					2.27	4.55				2.27
-1.00	-1.50					2.27	100.00			2.27	100.00
1.50	2.00										
-1.50	-2.00										
2.00											
-2.00											

		SvR		SvO_A		SvO_B		RvO_A		RvO_B	
0		11.36		2.27		0		9.09		4.55	
0.25		34.09	65.90	11.36	31.82	31.82	54.55	9.09	31.82	9.09	27.27
-0.25		31.82	75.26	20.45	34.09	22.73		22.73	40.91	18.18	31.82
0.25	0.50	6.82	27.73	4.55	27.27	27.27	34.09	2.27	20.45	2.27	11.36
-0.25	-0.50	15.91	100.00	22.73	61.36	6.82	88.64	18.18	61.36	9.09	43.18
0.50	0.75			2.27	11.36	2.27	6.82	2.27	11.36	2.27	15.81
-0.50	-0.75			9.09	72.72	4.55	95.46	9.09	72.72	13.64	58.99
0.75	1.00				4.55			2.27	6.82		11.36
-0.75	-1.00			4.55	77.27			4.55	79.54	11.36	70.35
1.00	1.50				15.91	2.27	4.55		15.91		15.91
-1.00	-1.50			15.91	93.18	2.27	100.00	15.91	95.45	15.91	86.26
1.50	2.00				6.82				4.55	2.27	13.63
-1.50	-2.00			6.82	100.00			4.55	100.00	11.36	100.00
2.00											
-2.00											

Table 18 Normal Population Cyclopegic Study - Additive frequency values for the mid equivalent sphere; 1st column represents the % of value within the particular intervals and for 2nd column top data. 2nd column bottom data is the Additive frequency value in %.

(S = Subjective; R = Retinoscopy; O_A = Ophthalmetron by Author; O_B = Ophthalmetron by techincian; c denotes the use of cyclopegia).

	$S_c v R_c$	$S_c v O_{AC}$	$S_c v O_{BC}$	$R_c v O_{AC}$	$R_c v O_{BC}$	S v R	S v O_A	S v O_B	R v O_A	R v O_C
0	52.27	9.09	6.82	18.18	15.91	43.18	27.27	18.18	18.18	15.91
$0 \rightarrow \leq \pm 0.25$	36.36 (88.63%)	52.27 (61.36%)	54.54 (61.36%)	43.18 (61.36%)	45.45 (61.36%)	47.72 (90.90%)	54.54 (81.81%)	61.36 (79.81%)	52.27 (70.45%)	56.82 (72.73%)
$> \pm 0.25 \leq \pm 0.50$	11.37 (100.00)		30.04 (91.40%)	25.00 (86.36%)	29.54 (90.90%)	4.55 (95.45%)	13.64 (95.45%)	15.91 (95.72%)	20.45 (90.90%)	15.91 (88.64%)
$> \pm 0.50 \leq \pm 0.75$		4.55	2.27 (93.67%)	13.64 (100.00%)	4.55 (95.45%)	2.27 (97.72%)	2.27 (97.72%)	2.27 (97.90%)	6.82 (97.72%)	11.36 (100.00%)
$> \pm 0.75 \leq \pm 1.00$		100.00%	6.82 100.00%		4.55 100.00%	2.27 100.00%		2.27 100.00%	2.27 100.00%	
$> \pm 1.00 \leq \pm 1.50$							2.27 100.00%			

Table 19 Normal Population Cyclopegic Study - Additive frequency values for the cylinder power.

Top value is the % of cases within this particular range; Bottom value is the additive.

(S = Subjective; R = Retinoscopy; O_A = Ophthalmetron by Author; O_B = Ophthalmetron by technician; c denotes cyclopegia).

Under cyclopegia the results show very good correlation: 95% of the retinoscopic findings and 87% of the Ophthalmetron measurements were within ± 0.50 D of the subjective. Without cyclopegia the additive frequency values at the same level is 100% for the retinoscopy, 88% for the Ophthalmetron by the technician and decreased to 61% for the Ophthalmetron by the writer. The same conclusions and tendencies are depticted by the Standard Deviation values of table 12 . This close relationship demonstrates that the present population behaves normally

When considering the cylinder power nealy all data have an additive frequency superior to 90% at ± 0.50D level and the same conclusions that for the D are applicable.

(iv) Determination of the correlation factor between the amplitude of accommodation and the instrumental accommodation

The values for the individual instrumental accommodation measured as the difference between the subjective mid sphere and the Ophthalmetron O_A and O_B midspheres when no cyclopegia was used and the patients' monocular accommodation (Table 20) were computed The correlation coeffiecients (-0.234 for O_A and -0.357 for O_B) show that there is no systematic correlation. Therefore the individual variation were confirmed and the psychological aspect of it reinforced.

Patient	$\bar{D}_A$	Acc	$\bar{D}_B$
VA	-0.375	+10.25	-1.875
	-1.125	+10.75	-2.375
AB	-0.25	9.50	-0.625
	-0.06	9.50	-0.19
BB	-1.25	9.75	-0.925
	-0.625	10.00	-0.625
JB	+0.25	+ 8.00	-0.50
	-0.375	+ 8.25	+0.125
NC	-0.50	+ 6.75	-0.325
	-1.625	+ 6.00	-1.00
SC	-1.25	+10.50	-1.44
	-1.625	+ 9.00	-2.00
JD	+0.125	+ 9.25	+0.375
	-0.25	+ 9.50	-0.375
DE	-0.50	8.50	-0.875
	-0.50	8.50	-0.25
VF	-0.06	9.00	-0.375
	-0.375	9.00	-0.25
AG	-0.375	9.50	-0.50
	-0.06	9.50	-0.31
TG	+0.50	9.25	+1.75
	+0.25	9.50	+1.12
JH #1	-0.06	8.50	-0.125
	+0.06	8.75	+0.125
JH #2	-0.75	11.00	-1.375
	-1.275	11.00	-0.625
PH	+0.75	10.00	+0.32
	+0.50	9.25	+0.125
RH	-0.50	8.50	-0.06
	-0.06	8.00	+0.50
SH	-1.125	11.00	-1.375
	-1.375	10.75	-1.125
HM	-0.25	10.00	-0.875
	-0.75	10.00	-0.69
RM	-2.00	9.75	-1.19
	-0.50	9.50	-2.00
DP	-0.25	9.50	-1.25
	-0.25	9.50	-1.625
SP	0.00	8.25	0.00
	+0.125	7.50	-0.125
JR	-0.625	10.00	-0.875
	-0.625	10.00	-0.375
LV	-1.125	10.00	-0.875
	-0.825	10.00	-1.425

Table 20 Normal Population Cyclopegic Study Correlation instrumental accommodation and total accommodation.

($\bar{D}_A$ = difference between sphere and O_A value;
$\bar{D}_B$ = difference between sphere and O_B value;
Acc = monocular accommodation)

7.1.4. Conclusion

(i) The accuracy obtained in that study by retinoscopy (S/D = 0.25) is similar to all the other studies published concerning essentially normal population
Therefore, one can assume that no individual bias is introduced by the present practitioner with a normal population.

(ii) Instrumental accommodation is present with a young population and is non systematic but it is an individual characteristic and is more important with our female population.

(iii) The repeatability of the instrument used by two different operators is good and at least better than the instruments accuracy.

(iv) For clinical findings the most important factors are the standard deviation and additive frequencies to denote accuracy and the mean difference and estimate of the intercept to illustrate the presence of any bias.

7.2. Clinical Experiement 2. High myopia and/or high myopic astigmatism

7.2.1. Introduction

This experiment was carried out on a population comprising only myopic and/or high myopic astigmatic patients. Its purpose was to assess the Ophthalmetron's behaviour with cases such as these as they are often encountered in Hospital Eye Departments. The assessment was based on:

i. The instrument's accuracy (by comparison to the subjective finding)

ii. The instrument's precision

iii. The instrument's clinical usefulness (by comparison of its merits relative to those of retinoscopy undertaken by the author).

7.2.2. Material and Method

Two Ophthalmetron instruments were used in that experiment, (a) that of the Department of Optometry and Visual Science of the City University, with which all the patients were tested (b) that of the Ophthalmic Optics Department of Bradford University, which was used in a small group of patients retested to establish the "instrumental precision".

The patients included in this experiment were all routinely booked, and then taken at random, in the clinic of the Contact Lens Department at Moorfields Eye Hospital. All were either new patients to the Department referred by other hospitals for contact lens fitting under the National Health Service or departmental patients scheduled for refraction,

none had worn contact lenses for at least three months.

In all, 25 patients (8 males, 17 females) aged 11 to 66 years of age (mean 32.5 years; S/D 18.6 years) were included; 46 eyes (25 Right eyes and 21 Left eyes) were used for this experiment. The highest ametropias encountered were -22.00 DS and -9.00 DC; only two had less than -5.00DS or DC for ametropia.

The protocol of Table 21 was followed throughout the experiment and the following notes elaborates some of the methods used.

The trial frame was aligned horizontally and vertically with the patient visual axis using a graticule type cross mounted in a trial lens, the patient looking straight ahead (monocularly).

The pantoscopic angle, if not controlled can introduce large discrepancies with high power lenses, so that it was decided to set the trial frame pantoscopic angle to zero in all cases unless stated. This value is different to the figure usually quoted 7 to 12^{o} (Stimson cited by Borish,1970)[92] was chosen to facilitate comparison with the Ophthalmetron results, which are obtained the patient looking straight ahead with the measurement system aligned with the patient optical axis, so with pantoscopic angle of zero. The setting of the pantoscopic angle was ensured by looking from the side and aligning the plane of the trial frame cell with the metal marker of the Fairbanks Facial Measurement Gauge, set perpendicular to the line of sight in primary position.

1. Patient History

2. Cover test (distance and near). Pupillary distance measurement.

3. Trial frame adjustment. (Horizontal and vertical alignment; frame angling).

4. Monocular refraction by retinoscopy R+L (Streak Retinoscopy, distance fixation).

5. VA with Retinoscopic finding R+L.

6. Monocular refraction by subjective method R+L (Best VA criteria and duochrome).

7. VA with subjective finding R+L (with pinhole if VA inferior to 6/6).

8. Accommodation measurement R+L.

9. Keratometry.

10. Slit lamp and Ophthalmoscopic examination.

11. Ophthalmetron measurments (1+2) R+L.

12. VA with Ophthalmetron findings.

TABLE 21 EXPERIMENTAL PROTOCOL - MYOPIC POPULATION

The Back Vertex Distance (BVD) was measured using a millimetre rule, with the clinician looking from the side perpendicularly to the patient's line of sight. The measured BVD is defined as the distance between the corneal apex and the apex of the lens in the back cell of the trial fram (fig 56). The procedure used to measure the BVD, facilitated by good lighting produced by an angle poise lamp, enable an accuracy of ± 0.50 mm, in order to round up all figures to the nearest millimetre. Measurements all showed that the average BVD of the cylinder was 8 mm greater than that of the recorded BVD, and this increased value was used during computation. The clinical values obtained usually with an accuracy of ± 0.25D for a particular BVD were recomputed to the nearest 0.01D at a BVD of 13 mm (this being the distance assumed for the Ophthalmetron results) to avoid the introduction of any bias by means of calculation.

Whenever the Visual acuity of the subjective refraction was inferior to 6/6 the VA with a 2 mm pinhole was recorded to insure that the subnormal VA was not caused by an uncorrected residual refractive error.

7.2.3. Results

From the 46 eyes included in this study full data were obtained for 41 eyes. The Ophthalmetron failed to give usable readings in 5 cases (12.2%), also retinoscopy was not possible in one of these cases (2.4%). The causes for failures of the Ophthalmetron were (for two eyes) refractive error outside the range of the instrument and (for the other

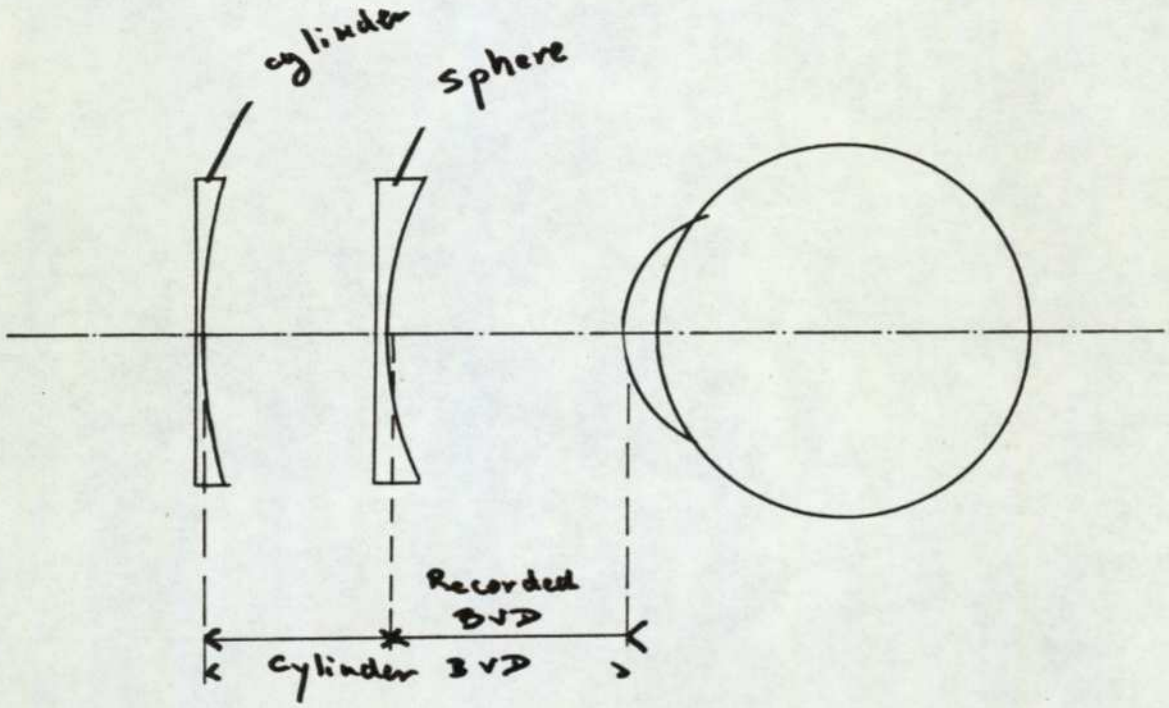


Fig 56: Trial frame arrangement for myopic patients

three eyes) lenticular opacities . Further for 28 eyes a second measurment has been recorded with the Ophthalmetron.

The clinical data obtained, usually recorded to the nearest 0.25D, are tabulated in Appendix 9 , and the recomputed data for a BVD of 13 mm to the nearest 0.01D form table 22 (for the mid equivalent sphere) 23 (for the maximum positive equivalent sphere), 24 (for the cylinder power).

(i) Variance Analysis

The results of the variance analysis of table 25 show no significant difference between the different methods of measurments for all parameters concerned (mid and maximum equivalent spheres, cyclinder power and axis).

The F ratio values for the mid and maximum positive equivalent spheres were very similar, which suggest that ulterior conclusions obtained for one of these parameters will be applicable to the other.

Further there was no difference for the F ratio between the 41 and 28 eyes populations, therefore the section of the population also concerned with the repeatability study does not differ from this overall experimental population.

(ii) Pair Analysis

a. Mid Equivalent Sphere

The results obtained are summarized in Table 26 and warrant the following conclusions:

Name	S	R	O_1	O_2	Name	S	R	O_1	O_2
K.B.	-12.42	-13.57	-12.25	-11.50	A.P.	-10.92	-10.64	-11.125	-10.50
	-11.755	-12.215	-11.43	-11.625	G.P.	-10.12	- 9.985	- 9.125	-9.629
R.B.#1	- 5.33	-5.08	-4.75	-4.875		-10.49	-10.88	-9.625	-10.00
R.B.#2	-16.00	-15.98	-15.875		K.P.	55.825	-5.55	-6.25	
	-16.00	-15.25	-16.25		J.R.	-10.645	-10.525	-10.50	-10.50
S.B.	-13.44	-13.195	-14.00			-3.28	-3.02	-3.625	-3.305
	-11.34	-9.81	-12.00		J.S.#1	-13.885	-14.20	-13.625	-14.625
E.C.	-0.57	-0.82	-1.00	-0.875		-13.375	-13.89	-15.375	-14.25
	-0.545	-1.555	-0.75	-1.25	J.S.#2	-7.81	-7.58		
A.D.	-8.595	-8.345	-7.93	-8.06	S.S.#1	-0.69	-0.69	-0.875	-0.56
	-10.725	-10.725	-9.00	-9.00		-0.75	-0.75	-0.875	-1.75
V.H.	-11.365	-13.665	-13.50		S.S.#2	-16.64	-16.64	-15.25	
	-10.82	-12.35	-12.00			-16.09	-16.64	-15.625	
T.K.	-1.845	-2.285	-0.13	-3.25	A.T.		-17.89	-18.14	
	-1.845	-1.985	-4.25	-431		-17.475	-16.875		
B.M.	-4.20	-3.94	-4.625	-4.995	A.V.	-11.845	-11.975	-12.00	-12.00
J.McK.	-23.01					-16.64	-16.09	-17.125	-16.875
	-20.83	-20.83			M.V.	-9.92	-9.955	-12.25	-10.31
B.N.	-8.66	-9.435	-8.75			-12.32	-12.075	-13.25	
	-15.01	-15.01	-14.125		C.W.	-15.14	-16.135	-15.375	-14.75
W.N.	-8.60	-8.86	-9.00	-9.00		-11.90	-11.065	-13.125	-13.00
	-1.995	-3.005	-1.995		H.W.	-12.285	-12.26	-12.75	-13.25
A.P.	-10.44	-9.68	-11.18	-10.68		-13.785	-14.105	-14.375	-13.25

Table 22 Myopic population. Mid equivalent sphere data computed for 13 mm BVD.

(S = Subjective; R = Retinoscopy; O_1 = 1st Ophthalmetron + O_2 = 2nd Ophthalmetron Readings).

Name	S	R	O_1	O_2	Name	S	R	O_1	O_2
K.B.	-9.62	-10.99	-9.50	-9.12	G.P.	-9.50	-9.00	-8.75	-9.00
R.B.#1	-5.08	-5.08	-4.25	-4.50		19.75	-10.14	-9.00	-9.50
R.B.#2	-15.75	-15.98	-15.75		K.P.	-5.08	-4.56	-5.50	
	-16.00	-15.50	-16.00		J.R.	-9.78	-9.78	-9.50	-9.50
S.B.	-12.45	-12.45	-13.00			-3.03	-2.77	-3.25	-3.12
	-10.84	-10.31	-11.50		J.S.#1	-12.66	-14.20	-12.50	-13.25
E.C.	+3.76	+3.51	+2.50	+2.75		-12.15	-12.66	-13.25	-13.00
	+4.02	+3.01	+3.00	+3.25	J.S.#2	-6.58	-6.59		
A.D.	-7.25	-7.00	-6.87	-7.00	S.S.#1	+2.96	+2.96	+2.00	+2.25
	-9.50	-9.50	-8.00	-8.00		+2.23	+2.23	+1.50	+0.75
V.H.	-10.87	-13.17	-13.00		S.S.#2	-15.16	-15.16	-13.75	
	-9.59	-11.12	-10.75			-14.61	-15.16	-13.75	
T.K.	+0.50	+0.50	-1.62	-1.25	A.T.	-17.39	-17.39	[illegible]	
	+0.50	+1.01	-1.75	-1.75		-16.48	-15.88		
B.M.	-2.50	-2.00	-3.00	-3.12	A.V.	-10.50	-10.75	-10.75	-11.00
J.McK.	-23.01					-15.16	-14.61	-16.25	-15.75
	-20.83	-20.83			M.V.	-8.20	-8.92	-10.75	-9.00
B.N.	-7.67	-8.20	-8.25			-10.84	-10.84	-12.00	
	-13.53	-13.53	-13.75		C.W.	-14.27	-15.39	-14.75	-14.00
W.N.	-7.61	-7.87	-8.25	-8.25		-10.42	-9.34	-11.75	-11.75
	-1.25	-2.26	-1.37		H.W.	-10.80	-10.53	-11.00	-11.50
A.P.	-8.72	-8.20	-10.37	-9.75		-11.08	-11.64	-11.00	-10.75
	-8.72	-8.20	-9.37	-8.75	K.B.	-9.62	-10.08	-9.75	-10.00

Table 23 Myopic population. Maximum positive equivalent sphere data computed for 13mm BvD.

(S = Subjective; R = Retinoscopy; O_1 = 1st Ophthalmetron + O_2 = 2nd Ophthalmetron Readings).

Name	S	R	O_1	O_2	Name	S	R	O_1	O_2
K.B.	-5.60	-5.16	-5.50	-4.62	A.P.	-4.40	-4.88	-2.62	-3.50
	-4.27	-4.27	-3.50	-3.25	G.P.	-1.24	-1.97	-0.75	-1.25
R.B.	-0.50	0.00	-1.00	-0.75		-1.48	-1.48	-1.25	-1.00
R.B.	-0.50	0.00	-0.25		K.P.	-1.49	-1.98	-1.50	
	0.00	-0.50	-0.50		J.R.	-1.73	-1.49	-2.00	-2.00
S.B.	-1.98	-1.49	-2.00			-0.50	-0.50	-0.75	-0.37
	-1.00	-1.00	-1.00		J.S.#1	-2.45	0.00	-2.25	-4.25
E.C.	18.66	-8.66	-7.00	-7.25		-2.45	-2.46	-2.75	-2.50
	-9.13	-9.13	-7.50	-7.25	J.S.#2	-2.46	-1.98		
A.D.	-2.69	-2.69	-2.12	-2.12	S.S.#1	-7.30	-7.30	-5.75	-5.62
	-2.45	-2.45	-2.00	-2.00		-5.96	-5.96	-4.75	-5.00
V.H.	-0.99	-0.99	-1.00		S.S.#2	-2.96	-2.96	-3.00	
	-2.46	-2.46	-2.50			-2.96	-2.96	-3.75	
T.K.	-4.69	-5.57	-3.50	-4.00	A.T.	-1.00	-1.50		
	-4.69	-5.99	-5.00	-5.12		-1.99	-1.99		
B.M.	-3.40	-3.88	-3.25	3.75	A.V.	-2.69	-2.45	-2.50	-2.00
J.McK.	0.00					-2.96	-2.96	-1.75	-2.25
	0.00	0.00?			M.V.	-3.44	-2.47	-3.00	-2.62
B.N.	-1.98	-2.47	-1.00			-2.96	-2.47	-2.50	
	12.96	-2.96	-0.75		C.W.	-1.74	-1.49	-1.25	-1.50
W.N.	-1.98	-1.98	-1.50	-1.50		-2.96	-3.45	-2.75	-2.50
	-1.49	-1.49	-1.25		H.W.	-2.97	-3.46	-3.50	-3.00
A.P.	-3.44	-2.96	-1.62	-2.75		-5.41	-4.93	-6.75	-5.00

Table 24 Myopic Population. Cylinder power data computed for 13mm BvD.

(S = Subjective; R = Retinoscopy; O_1 = 1st Ophthalmetron + O_2 = 2nd Ophthalmetron Readings).

Group	Source of Variation	Sum of square	df	Mean Square	F
Mid Sphere	Between group	1.000	2	0.5000	0.020
	Within group	3022.114	38	25.184	
	Total	3023.114		24.780	
		0.748	3	0.249	0.010
		2667.968	24	24.703	
		2668.716		24.042	
Maximum + ve sphere		4.450	2	2.225	0.073
		3651.719	38	30.431	
		3656.169		29.969	
		4.838	2	1.613	0.053
		3285.928	24	30.425	
		3290.766		29.647	
Cylinder Power		139.447	2	69.723	0.800
		10464.897	38	87.207	
		10604.344			
		5.581	3	1.860	0.423
		474.975	24	4.398	
		480.536		4.329	
Cyl axis (power 0.50)		2150.389	2	1075.195	0.265
		425772.278	33	4054.974	
		427922.667		3999.277	
		2401.644	3	800.548	0.180
		408030.356	21	4435.113	
		410432.000		4320.337	

Table 25 Myopic Population - Variance Analysis Results

GROUP	$\bar{X}_1$	$\bar{X}_2$	$\bar{D}=\bar{X}_1-\bar{X}_2$	S/D	t	n	b	a	R
S v R	-9.707	-9.850	0.142	0.676	1.348	41	0.988	-0.257	0.991
S v R	-8.660	-8.758	0.098	0.479	1.080	28	0.998	-0.118	0.995
S v O_1	-9.707	-9.925	0.217	0.954	1.459	41	0.991	-0.306	0.982
S v O_1	-9.660	-9.859	0.198	0.991	1.059	28	1.007	-0.141	0.981
S v O_2	-8.660	-8.856	0.196	0.830	1.248	28	0.939	-0.724	0.987
R v O_1	-9.850	-9.925	0.075	1.110	0.433	41	0.987	-0.202	0.976
R v O_1	-8.758	-8.859	0.101	1.147	0.464	28	0.998	-0.121	0.975
R v O_2	-8.758	-8.856	0.098	0.990	0.524	28	0.931	-0.701	0.981
O_1 v O_2	-8.859	-8.856	-0.003	0.877	-0.015	28	0.916	-0.746	0.987

Table 26 Myopic Population - Pair Analysis.
Summary of results for mid equivalent sphere.

(S = Subjective; R = Retinoscopy ;
O_1 = 1st Ophthalmetron + O_2 = 2nd
Ophthalmetron readings.)

The t test values are not significant at 5 or 1% levels for any of the pairing, the smallest values being obtained when comparing retinoscopy with the Ophthalmetron and the two Ophthalmetron readings together. Therefore the difference obtained with the normal population without cyclopegic is not repeated here, this could be linked to a less important accommodative bias in the present study attributable to the older population measured.

The Standard Deviation is lowest between retinoscopy and subjective 0.67DS. It increases for the Ophthalmetron when this instrument is compared to retinoscopy, to subjective and to a second Ophthalmetron measurement to approximately 1DS.

The mean of the present population was -9.71DS by subjective whereas the normal population previously studied had a mean of - -1.41DS. The results in the former group, with the Ophthalmetron, compare favourably in relation to those obtained by retinoscopy. It is more difficult to explain the important difference obtained when successive measurments were made with the Ophthalmetron; this suggests that patients react variably (i.e. variable instrumental accommodation) with the instrument or that repositioning the patient introduced bias; conclusions as to the possible cause will be presented when the aphakic population is studied, since there the amount of refractive error is identical but no accommodation present.

The mean difference was inferior to 0.25DS in all cases, with a tendency to be largest when comparing the

Ophthalmetron with the other two methods. The comparison between the two Ophthalmetron measurements shows no differential accommodative bias on the population as a whole, between the first and second reading, ($\bar{D}$ = -0.003 DS).

The correlation factor is always high r $\geq$ 0.98; while the estimate of the slope b shows more variability which seems linked to variation in the value of the intercept $\bar{a}$.

b. Cylinder Power

The results obtained are recorded on Table 27. The t test was significant for the Ophthalmetron when compared to subjective (at 1% level) and retinoscopy (at 5% level), all the other pairing showing no significant difference.

The standard deviation was similar for retinoscopy and Ophthalmetron when compared to subjective refraction - 0.60 DC and 0.75 DC: repeatability was of the same order.

The mean difference D varied from zero for retinoscopy to 0.50 DC for the Ophthalmetron with the subjective value as a base line. Here again there was no difference between the two Ophthalmetron results. The correlation factor is lower than for the spherical values, but varies little with the pairing, 0.93 to 0.96.

c. Cylinder axis for cylinder power $\geq$ 0.50DC

The t test values (Table 28) were highly significant when comparing the Ophthalmetron to the other methods, but not significant when compared to a repeat measurement,

GROUP	$\overline{X}_1$	$\overline{X}_2$	$\overline{D}=\overline{X}_1-\overline{X}_2$	S/D	t	n	b	a	R
S v R	-2.918	-2.891	-0.027	0.568	-0.311	41	1.010	0.054	0.965
S v R	-3.614	-3.571	-0.0425	0.664	-0.339	28	1.033	0.160	0.961
S v O_1	-3.047	-2.648	-0.399	0.788	-3.239	41	0.818	-0.155	0.926
S v O_1	-3.614	-3.127	-0.486	0.810	-3.179	28	0.816	-0.178	0.932
R v O_2	-3.614	-3.169	-0.445	0.727	-3.239	28	0.784	-0.334	0.953
R v O_1	-3.018	-2.648	-0.370	1.012	-2.340	41	0.745	-0.399	0.888
R v O_1	-3.571	-3.127	-0.444	1.101	-2.133	28	0.724	-0.541	0.889
R v O_2	-3.571	-3.169	-0.4025	1.114	-1.912	28	0.683	-0.729	0.892
O_1 v O_2	-3.127	-3.169	0.041	0.683	0.321	28	0.879	-0.419	0.936

Table 27 Myopic Population - Pair Analysis summary of results for cylinder power.

GROUP	$\overline{X}_1$	$\overline{X}_2$	$\overline{D}=\overline{X}_1-\overline{X}_2$	S/D	t	n	b	a	R
S v R	45.694	44.583	1.111	7.687	0.867	36	1.011	-1.605	0.993
S v R	46.042	45.833	0.208	6.753	0.151	24	1.040	-2.031	0.996
S v O_1	45.694	54.556	-8.861	11.494	-4.626	36	0.985	9.540	0.984
S v O_1	46.042	56.938	-10.896	8.196	-6.513	24	1.023	9.826	0.993
S v O_2	46.042	54.688	-8.646	10.759	-3.937	24	1.005	8.399	0.988
R v O_1	44.583	54.556	-9.972	10.213	-5.859	36	0.971	11.245	0.987
R v O_1	45.833	56.938	-11.104	9.005	-6.041	24	0.979	12.088	0.991
R v O_2	45.833	54.688	-8.854	13.593	-3.191	24	0.956	10.863	0.980
O_1v O_2	56.938	54.688	2.25	8.862	1.244	24	0.980	-1.102	0.991

Table 28 Myopic Population - Pair Analysis summary of results for cylinder axis.

however, the S/D was of similar amplitude 7 to 10° for all methods.

(iii) Additive frequencies

The additive frequecny results are summarized in tables, for the mid equivalent sphere, and cylinder power and axis, (for cylinder 0.50DC) respectively.

At the 0.50 DS level the retinoscopic assessments of the mid equivalent sphere are marginally better than that of the Ophthalmetron 68.3% vs. 54.7% in that range. This difference however increases and it is disconcerting that in 20% of cases the Ophthalmetron values differ by more than IDS from the subjective.

For the cylinder power, both at 0.50 D and 1D levels the retinoscopy is again marginally better than the Ophthalmetron (87.8% vs. 68.3% within ± 0.50 DC and 5% and 8 to 10% of cases outside ± 1.00 DC respectively).

As far as the cylinder axis are concerned at 10 and 20° levels the results are both for retinoscopy accuracy and Ophthalmetron precision, better than for the Ophthalmetron accuracy.

7.2.4. Conclusions

(i) The accuracy obtained by retinoscopy with this population establishes that a more difficult clinical sample had been gathered than in the previous experiment (Retinoscopic S/D increases from 0.25DS to 0.67DS).

a)

	S v R		S v O_A		S v O_B	O_A v O_B
n	41	28	41	28	28	28
o	12.20	10.71	2.44	o	o	14.29
±0.25 DS	29.27	32.14	31.71	32.14	25.00	25.00
	41.47	42.85	34.15	32.14	25.00	39.29
±0.25 ±0.50 DS	26.83	35.71	19.51	21.43	28.57	28.57
	68.30	78.57	53.66	53.57	53.57	67.86
±0.50 ±1.00 DS	19.51	17.86	26.83	25.00	32.14	21.43
	97.80	96.43	80.49	78.57	85.71	89.86
±1.00 ±1.50 DS	4.88	3.51	7.32	3.57	7.14	3.57
	92.68%	100.00%	87.80	82.14	92.86	92.86
±1.50 DS	7.32		17.86	17.86	7.14	7.14
	100.00		100.00	100.00	100.00	100.00

b)

n	41	28	41	28	28	28
o	43.90	39.29	2.44	o	o	14.29
±0.25 DC	9.76	14.29	34.15	25.00	17.86	39.29
	53.66	53.57	36.59	25.00	17.86	53.58
±0.25 ±0.50 DC	34.15	28.57	31.71	39.29	32.14	28.57
	87.80	82.14	68.29	64.29	50.00	82.15
±0.50 ±1.00 DC	7.32	10.71	12.20	10.71	32.14	7.14
	95.12	92.86	80.49	75.00	82.14	89.29
±1.00 ±1.50	2.44	3.57	9.76	14.29	7.14	3.57
	97.56	96.43	90.24	89.29	89.29	92.86
±1.50 DC	2.44	3.57	9.76	10.71	10.71	7.14
	100.00	100.00	100.00	100.00	100.00	100.00

		S v R		S v O_A		S v O_B	O_A v O_B
n		36	24	36	24	24	24
o		41.67	41.67	11.11	4.17	12.50	25.00
o	5°	36.11	37.50	33.33	37.50	25.00	50.00
		77.78	79.17	44.44	41.67	37.50	75.00
5°	10°	8.33	12.50	19.44	16.67	29.17	4
		86.11	91.67	63.89	58.34	66.67	79.17
10°	20°	13.89	8.33	27.78	33.33	20.83	20.83%
		100.00	100.00	91.67	91.67	86.50	100.00%
20°				8.33	8.33	12.50	
				100.00	100.00	100.00	

Table 29 Myopic population. Additive frequency Results.

a) = Mid equivalent sphere; b) = Cylinder power; and c) = Cylinder axis for cylinder ≥ 0.50 DC.

(S = Subjective; R = Retinoscopy; O_A + O_B = Ophthalmetron).

(ii) For all the parameters considered the retinoscopic measurements are as a whole closer to the subjective values than the Ophthalmetron. However, the difference is sometimes only marginal and it can be concluded that without question the Ophthalmetron is a useful objective method in the marjority of cases for a highly myopic population. This is presented as one of the original findings of the investigation.

(iii) It is possible that the Ophthalmetron might have been closer to the subjective if it had been used as the starting point for that part of the refraction. (This was not done, as the objective was to compare the Ophthalmetron findings obtained by the standard refraction procedure. Also the population was too small to split the group, using two different starting points for the subjective).

7.3. Clinical Experiment 3 Corneal Graft Patients

7.3.1. Introduction

Corneal grafting is now a surgical procedure regularly performed to restore sight affected by diverse corneal conditions, mainly advanced keratoconus. It involves a significant number of patients in the Contact Lens Department.

The present study proposes to evaluate two different methods of objective refraction (Retinoscopy and Ophthalmetron) and to establish whether or not they correlate with the subjective findings in those patients. It is note worthy that irregular astigmatism is often present in such cases.

7.3.2. Material and Method

The same Ophthalmetron model as in 7.2. was used throughout this study. The patients involved were chosen at random and none had worn contact lenses for at least three months.

Altogether 20 patients (12 males and 8 females) aged 21 to 54 years of age wereincluded, totalling 25 eyes (11 right and 14 left eyes). The ametropias ranged from -14.00 to +22.00DS and -1.00 to -11.00 DC.

The time elapsed since surgery varied from 3 to 120 months with a mean of 40 months. All grafts were of the penetrating type, 3 patients still had their graft sutures in situ.

The protocol used (Table 30) shows particular emphasis on the measurement and observation of the cornea. Keratometry was performed in all cases and a comment concerning the

1. Patient History

2. Cover test (distance and near) Pupillary distance measurement.

3. Trial frame adjustment (Horizontal and vertical alignment; frame angling).

4. Monocular Refraction by retinoscopy R+L (Streak Retinoscopy, Distance fixation)
   - VA with retinoscopic finding R+L.

5. Monocular Refraction by subjective method R+L (Best VA criterion and duochrome)
   - VA with subjective finding R+L (with pinhole if VA inferior to 6/6).

6. Accommodation Measurement R+L (push up Rule)

7. Keratometry

8. Pachometry

9. Slit lamp and Ophthalmoscopic examination

10. Ophthalmetron measurements ( ) R+L
    VA with Ophthalmetron findings.

TABLE 30 : EXPERIMENTAL PROTOCOL - CORNEAL GRAFT PATIENTS

quality of the image of the mires was included. Pachometry was undertaken using a Haag-Streit slit lamp and pachometer attachment, following the method advocated by Stone (146).

The precautions described in 7.2. concerning frame centration and BVD distance measurements were followed here.

7.3.3. Results

21 eyes gave data for all 3 methods of measurements. The 4 failures (19%) with the Ophthalmetron were due to decentred corneal apex in relation to the patient's pupil (2), refractive value outside the range of the instrument (1), and corneal opacity(1). (fig~~57~~58).

The clinical data obtained were recorded in appendix and recomputed for 13 mm BVD as in 3.2.3. (Tables 31 , mid equivalent sphere; 32 , maximum positive equivalent sphere; 33 , cylinder power).

(i) Variance Analysis (Table 34)

There is no significant difference for any of the groups when pooled together.

(ii) Pair Analysis

a. Mid Equivalent Sphere

For the t test (Table 35) the difference is only significant between retinoscopy and Ophthalmetron. When considering the pairings with the subjective findings the t test is not significant; the smallest value was obtained for the Ophthalmetron measurement when repeatability was considered.

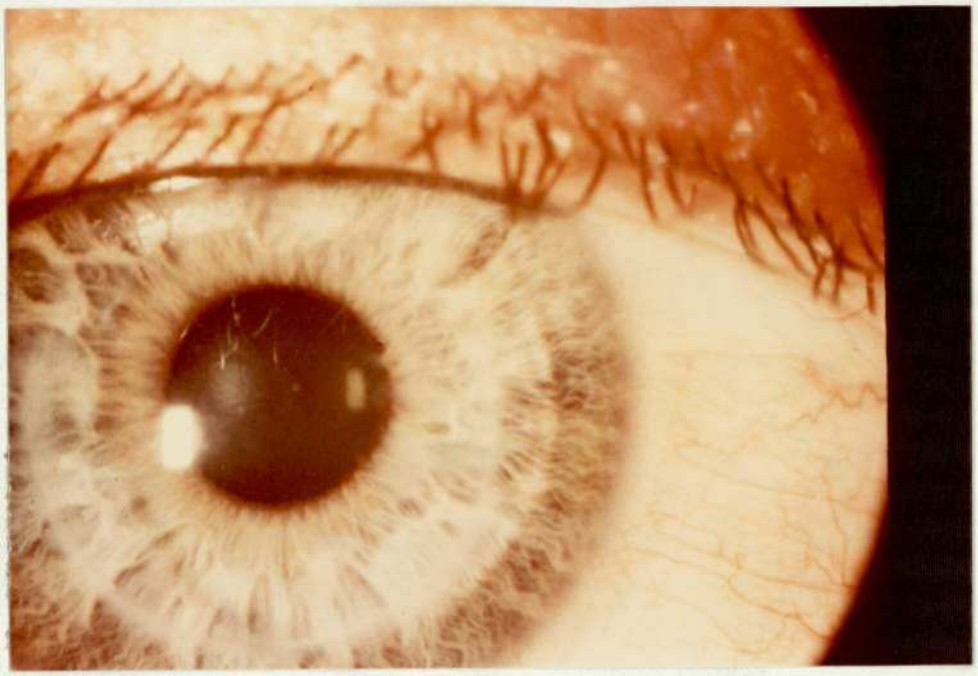


Fig. 57: Slit lamp photograph (x2) - Frontal view
Myopic patient with lenticular opacity

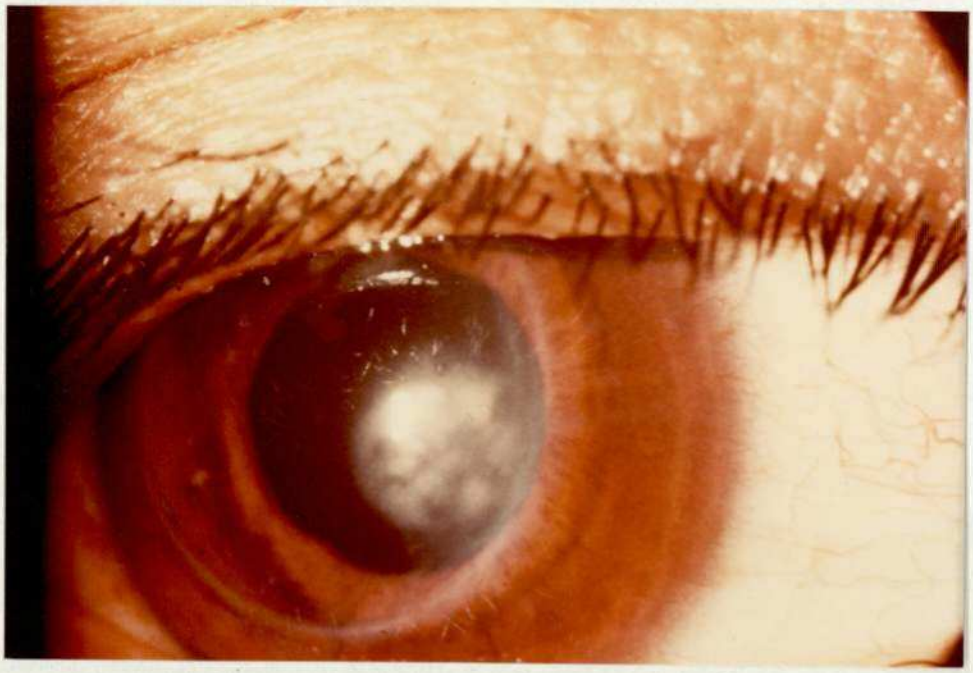


Fig. 58: Slit lamp photograph (x2) Frontal view
Corneal graft patient with corneal opacity

Name	S	R	O_1	O_2
A.A.	-8.725	-7.24	-8.25	-8.375
	-9.985	-10.225	-9.375	
M.A.	-6.525	-5.255	-5.75	-6.125
A.B.	-0.625	-1.125	-4.00	
G.B #1	-4.665	-6.595	-6.25	
G.B.#2	-3.96	-4.225	-5.50	-2.75
M.B.	+4.505	+4.505	+6.00	
R.B.#1	-11.19	-12.93	-13.875	-14.75
R.B.#2	-6.095	-6.715	-6.00	-6.50
	+0.15	-0.97	-2.75	-4.00
S.B.	-2.415	-1.985	-1.625	-1.62
W.C.	+15.865	+18.175		
E.	-5.25	-3.25		
A.H.	-1.19	-1.69	-1.375	-1.375
H.	+1.48	+2.22	plano	
P.H.	-6.395	-5.26		
	-1.70	-0.61	-2.25	-2.00
J.L.	-4.515	+2.15	-3.00	-4.625
J.M.	-8.185	-7.805	-5.75	
D.P.	-5.39	-5.39	-4.50	-4.875
P.	-2.475	-2.725	-2.625	-2.75
G.R.	-3.00	+1.00	-1.75	-1.25
	-0.50	-1.00	-1.00	-1.25
P.S.	-9.225	-9.345	-11.37	-10.25
	-16.045			

Table 31 Corneal graft Patients. Mid equivalent sphere data computed for 13mm BvD.

(S = Subjective; R = Retinoscopy; O_1 = 1st Ophthalmetron + O_2 = 2nd Ophthalmetron readings)

Name	S	R	O_1	O_2
A.A.	-17.50	-6.50	-7.50	-8.75
	-9.00	-9.00	-7.75	
M.A.	-5.05	-3.78	-4.50	-4.50
A.B.	+0.75	plano	-3.00	
G.B.#1	-3.45	-5.38	-5.50	
G.B.#2	+1.49	+0.50	-0.50	+1.50
M.B.	+5.00	+5.00	+6.50	
R.B.#1	-8.50	-10.00	-10.50	-12.00
R.B.#2	-4.27	-4.77	-4.50	5.00
	+1.50	+0.50	-1.00	-2.00
S.B.	-1.50	-1.00	-0.25	-0.37
W.C.	+19.23	+21.07		
E.	-3.50	-1.50		
A.H.	+0.50	plano	plano	plano
H.	+3.76	+5.05	+1.50	
P.H.	-5.53	-4.52		
	-1.25	+0.50	-1.50	-1.25
J.L.	-4.02	+4.98	-2.00	-2.75
J.M.	-6.59	-6.33	-4.00	
D.P.	-3.94	-3.94	-1.50	-2.00
P.	+1.74	+1.49	plano	-0.50
G.R.	-1.00	+3.00	+2.50	+3.50
	+1.25	+0.75	plano	-0.50
P.S.	-7.23	-7.92	-9.50	-8.75
	-15.05			

Table 32 Corneal graft Patients - Maximum positive equivalent sphere data computed for 13mm BvD.

(S = Subjective; R = Retinoscopy; O_1 = 1st Ophthalmetron + O_2 = 2nd Ophthalmetron Readings).

Name	S	R	O_1	O_2
A.A.	-2.45	-1.48	-1.50	-1.25
	-1.97	-2.45	-1.25	
M.A.	-2.95	-2.95	-2.50	-3.25
A.B.	-2.75	-2.25	-2.00	
G.B.#1	-2.43	-2.43	-1.50	
G.B.#2	-10.90	-9.45	-10.00	-8.50
M.B.	-0.99	-0.99	-1.00	
R.B.#1	-5.38	-5.86	-6.75	-5.50
R.B.#2	-2.36	-3.89	-3.00	-3.00
	-2.70	-2.94	-3.50	-4.00
S.B.	-1.97	-1.97	-2.75	-2.62
W.C.	-6.73	-5.79		
E.	-3.50	-3.50		
A.H.	-3.38	-3.38	-2.75	-2.75
H.	-4.56	-5.66	-3.00	
P.H.	-1.73	-1.48		
	-2.21	-2.22	-1.50	-1.50
JL	-0.99	-5.66	-4.00	-3.75
J.M.	-3.19	-2.95	-3.50	
D.P.	-2.90	-2.90	-6.00	-5.75
P.	-8.43	-8.43	-5.25	-6.50
G.R.	-4.00	-4.00	-8.50	-9.50
	-3.50	-3.50	-2.00	-1.50
P.S.	-3.95	-3.49	-3.75	-3.00
	-1.99			

Table 33 Corneal graft Patients Cylinder Power data computed for 13mm BvD.

(S = Subjective; R = Retinoscopy; O_1 = 1st Ophthalmetron + O_2 = 2nd Ophthalmetron readings).

Group	Source of Variation	Sum of Square	df	Mean Square	F
Mid Sphere	Between group	10.203	3	3.401	0.236
	Within group	807.085	56	14.412	
	Total	817.288		13.852	
		5.407	2	2.704	0.147
		1104.063	60	18.401	
		1109.470		17.895	
		3.922	1	3.922	0.113
		1591.190	46	34.591	
		1595.112		33.939	
Maximum Positive Sphere		11.065	3	3.688	0.235
		879.968	56	15.714	
		891.033		15.102	
		6.394	2	3.196	0.173
		1111.053	60	18.518	
		1117.446		18.023	
		4.896	1	4.896	0.129
		1745.030	46	37.935	
		1746.925		37.232	
Cylinder Power		0.676	3	0.225	0.037
		345.367	56	6.167	
		346.043		5.865	
		0.342	2	0.171	0.032
		317.914	60	5.299	
		318.255		5.133	
		0.120	1	0.120	0.025
		222.990	47	4.848	
		223.110		4.747	
Cylinder axis		1088.646	3	362.882	0.108
		187509.168	56	3348.378	
		188597.814		3196.573	
		792.856	2	396.428	0.113
		210905.359	60	3515.089	
		211698.215		3414.487	
		94.922	1	94.922	0.028
		158208.074	46	3439.306	
		158302.996		3368.149	

Table 34 Corneal graft Patients - Variance Analysis results

GROUP	$\bar{X}_1$	$\bar{X}_2$	$\bar{D}=\bar{X}_1-\bar{X}_2$	S/D	t	n	b	a	R
S v R	-4.450	-3.795	-0.655	2.146	-1.182	15	1.026	0.772	0.850
S v R	-4.010	-3.617	0.393	1.903	-0.949	21	1.010	0.435	0.907
S v R	-3.334	-2.762	-0.572	1.847	-1.517	24	1.048	0.732	0.955
S v O_1	-4.450	-4.775	0.325	1.408	0.893	15	1.054	-0.086	0.931
S v O_1	-4.011	-4.333	0.322	1.609	0.918	21	0.973	-0.430	0.927
S v O_2	-4.450	-4.833	0.383	1.590	0.932	15	1.047	-0.174	0.913
R v O_1	-3.795	-4.775	0.980	1.581	2.400	15	0.865	-1.494	0.922
R v O_1	-3.617	-4.333	0.716	1.719	1.910	21	0.873	-1.177	0.925
R v O_2	-3.795	-4.833	1.038	1.980	2.030	15	0.834	-1.669	0.877
O_1 v O_2	-4.775	-4.833	0.058	1.024	0.219	15	0.977	-0.166	0.965

Table 35 Corneal graft Patients - Pair Analysis
Summary of results for mid equivalent sphere.

(S = Subjective; R = Retinoscopy; O_1 = 1st Ophthalmetron + O_2 = 2nd Ophthalmetron readings).

The standard deviation for the present population (subjective mean -4.45DS) was very high when comparing two different methods (subjective vs Retinoscopy ≃ 1.80DS Subjective vs. Ophthalmetron ≃ 1.50 DS and Retinoscopy vs. Ophthalmetron between 1.50 and 2.00DS), and only slightly lower for the Ophthalmetron repeatability (≃ 1.00DS) contrarily the mean Difference $\overline{D}$ was smaller than the respective S/D and minimal for the comparison between the 1st and 2nd Ophthalmetron measurements. The particular population comprises non regular refractive components as shown by Keratometry: (Table 36)

- a. Mires were regular in 56% of cases; slightly distorted in 20% and markedly distorted in 24%.
- b. The two principal meridians were not perpendicular in 52% of cases.

As it would be expected in such cases the correlation, between objective and subjective methods of refractions is poor, but the difference is not a systematic myopic shift as shown by the $\overline{D}$ values.

The estimates of the slope b and intercept $\overline{a}$ of the regression lines, give varied correlations between the groups, the values for two given methods being independant of the 3 sample size considered.

b. Cylinder Power

The t test values (Table 37) were small and not significant, but the S/D remained important between the different methods:

Name	Keratometry	Comments
A.A.	7.20 al 145 - 7.00 x 30	D
	7.20 al 5 - 6.9 al 110	D-
M.A.	7.75 al 165 - 7.40 al 80?	D-
A.B.	7.60 al 75 - 8.45 al 155	D+
G.B. #1	7.15 al 25 - 7.45 al 115	R
G.B. #2	8.55 al 165 - 6.75 al 77½	R
M.B.	8.15 al 25 - 8.70 al 115	D-
R.B. #1	6.20 al 35 - 5.60 al 130	D-
R.B. #2	6.82 al 50 - 7.35 al 140	R
	8.26 al 35 - 7.62 al 125	R
S.B.	8.05 al 25 - 7.60 al 105	D-
W.C.	7.80 al 135 - 10.00 al 40	D+
E.	6.35 al 35 - 7.16 al 125	D
A.M.	7.40 al 42½ - 6.70 al 137½	R
H.	7.29 al 150 - 7.92 al 60	R
P.H.	7.70 al 180 - 8.30 al 90	R
	7.77 al 55 - 8.04 al 145	R
J.L.	7.00 al 55 - 6.60 al 150	R
D.P.	6.80 al 135 - 7.75 al 60	D
P.	7.00 al 30 - 8.40 al 122½	R
G.R.	8.57 al 110 - 6.87 al 20	R
	7.71 al 80 - 7.52 al 130	R
P.S.	7.50 al 20 - 7.00 al 110	R
	6.80 al 60 - 6.30 al 130	D

Table 36 Corneal graft Patients. Keratometric data.

(Image minus quality rates: R = Regular;
D- = slight distortion; D = medium distortion;
D+ = gross distortions).

GROUP	$\overline{X}_1$	$\overline{X}_2$	$\overline{D}=\overline{X}_1-\overline{X}_2$	S/D	t	n	b	a	R
S v R	-3.957	-4.141	0.183	1.334	0.532	15	0.761	-1.130	0.856
S v R	-3.583	-3.754	0.171	1.152	0.680	21	0.810	-0.850	0.870
S v R	-3.634	-3.734	0.1	1.101	0.445	24	0.810	-0.792	0.878
S v O_1	-3.957	-4.25	0.293	2.007	0.565	15	0.690	-1.519	0.694
S v O_1	-3.583	-3.619	0.036	1.763	0.093	21	0.759	-0.901	0.724
S v O_2	-3.957	-4.158	0.201	2.151	0.361	15	0.625	-1.686	0.641
R v O_1	-4.141	-4.25	0.110	1.867	0.227	15	0.792	-0.969	0.708
R v O_2	-4.141	-4.158	0.017	1.971	0.034	15	0.728	-1.142	0.665
O_1 v O_2	-4.25	-4.158	-0.092	0.760	-0.469	15	0.935	-0.183	0.955

Table 37 Corneal graft Patients - Pair Analysis summary of results for Cylinder Power.

(S = Subjective; R = Retinoscopy; O_1 = 1st Ophthalmetron + O_2 = 2nd Ophthalmetron readings).

Subjective vs. Retinoscopy $\simeq$ 1.25 DC: Subjective vs. Ophthalmetron 1.75 DC to 2.00DC; Retinoscopy vs. Ophthalmetron $\simeq$ 2.00DC and decreased for the Ophthalmetron repeatability (SD $\simeq$ 0.76 DC).

The mean difference $\bar{D}$ was small, implying that no systematic over estimation of the astigmatism was produced by the objective methods employed.

The correlation factor also illustrated the variation between the methods and decreased to 0.6 to 0.8 .

c. Cylinder Axis for Cylinder power $\geq$ 0.50 DC

The t test values (Table 38) were significant when comparing the Ophthalmetron to both the retinoscopy and subjective findings. Similarly the standard deviation was for subjective cs. Retinoscopy ($\simeq 10^{o}$) than for Ophthalmetron vs. Subjective or Retinoscopy (12 to 20^{o}). Again the smallest standard deviation concerned the Ophthalmetron repeatability ($\simeq 5^{o}$).

(iii) Addditive Frequencies

In a similar manner to the standard deviation the additive frequency results (Table 39) show the poor correlation between the different methods, with however closer results for Retinoscopy and subjective than Ophthalmetron and subjective.

At the 0.50 DS level from the subjective we only find 50% of the retinoscopic findings and 30% of the Ophthalmetron.

GROUP	$\bar{X}_1$	$\bar{X}_2$	$\bar{D}=\bar{X}_1-\bar{X}_2$	S/D	t	n	b	a	R
S v R	86.333	86	0.333	9.722	0.133	15	0.966	2.616	0.985
S v R	86.667	85.952	0.714	9.392	0.349	21	1.014	-1.942	0.989
S v R	86.146	83.333	2.813	10.767	1.280	24	1.008	-3.534	0.983
S v O_1	86.333	93.667	-7.333	11.591	-2.450	15	1.029	4.839	0.981
S v O_1	86.667	93.810	-7.143	20.082	-1.630	21	0.859	19.405	0.944
S v O_2	86.333	95.5	-9.167	11.902	-2.983	15	1.007	8.590	0.979
R v O_1	86	93.667	-7.667	17.229	-1.723	15	1.025	5.559	0.958
R v O_1	85.952	93.810	-7.857	25.924	-1.389	21	0.806	24.550	0.909
R v O_2	86	95.5	-9.5	16.987	-1.166	15	1.004	9.166	0.957
O_1 v O_2	93.667	95.5	-1.833	5.384	-1.319	15	0.977	4.010	0.996

Table 38 Corneal graft Patients - Pair Analysis summary of results for Cylinder Axis.

(S = Subjective; R = Retinoscopy; O_1 = 1st Ophthalmetron + O_2 = 2nd Ophthalmetron readings).

a)

	S v R		S v O_A		S v O_B	O_A v O_B
n	21	15	21	15	15	15
o	9.52	6.87	o	o	o	6.67
±0.25 DS	14.28	13.33	14.29	20.00	13.33	33.33
±0.25 ±0.50 DS	28.57	26.67	9.53	13.33	33.33	26.67
	53.37	46.67	23.81	33.33	46.67	66.67
±0.50 ±1.00 DS	9.52	6.67	23.81	26.67	20.00	13.33
	61.89	53.33	47.62	60.00	66.67	80.00
±1.00 ±2.00 DS	28.57	33.33	33.33	26.67	20.00	13.33
	90.46	86.66	80.95	86.67	86.67	93.33
±2.00 ±3.00 DS	o	o	19.05	13.33	o	6.67
			100.00	100.00		100.00
±3.00 DS	9.52	13.33			13.33	
	100.00	100.00			100.00	

b)

n	21	15	21	15	15	15
o	42.86	46.67	o	o	o	20.00
±0.25 DC	19.05	20.00	9.52	6.67	6.67	26.67
±0.25 ±0.50 DC	19.05	13.33	9.52	6.67	6.67	13.33
	80.05	80.00	19.05	13.33	13.33	60.00
±0.50 ±1.00 DC	4.76	6.67	47.62	46.67	33.33	20.00
	85.71	86.67	66.67	60.00	46.67	80.00
±1.00 ±1.50 DC	9.52	6.67	14.29	13.33	13.33	20.00
	92.24	93.34	76.19	73.33	60.00	100.00
±1.50 DC	4.76	6.67	23.81	26.07	40.00	
	100.00	100.00	100.00	100.00	100.00	

		S v R		S v O_A		S v O_B	O_A v O_B
n		21	15	21	15	15	15
o		23.81	20.00	4.76	o	o	46.67
5^o		33.33	40.00	14.28	20.00	33.33	40.00
5^o	10^o	19.05	13.33	42.86	40.00	26.67	6.67
		76.19	73.33	57.14	60.00	60.00	93.33
10^o	20^o	23.81	26.67	23.81	33.33	26.67	6.67
		100.00	100.00	80.95	93.33	86.67	100.00
20^o				19.05	6.67	13.33	
				100.00	100.00	100.00	

Table 39 Corneal graft Patients. Additive frequency Results.

a) = mid equivalent sphere; b) = cylinder power; and c) = cylinder axis for cylinder 0.50 DC.

(S = Subjective; R = Retinoscopy; O_A + O_B = Ophthalmetron).

Further in 40% of the cases both, Retinoscopy and Ophthalmetron differed by more than 1.00 DS of the subjective and equivalent sphere.

For the cylinder power the Retinoscopic estimate is better than that of the Ophthalmetron both at ± 0.50DC (80% of cases were within ± 0.50DC of the subjective by retinoscopy against 20% with the Ophthalmetron) and at ± 1.00 DC level (only 15% were outside it by retinoscopy vs. 40% by the Ophthalmetron).

For the cylinder axis the estimate by retinoscopy is better than with the Ophthalmetron, but the difference is no so large (75% of the retinoscopy within ± 10^{o}, vs. 60% of Ophthalmetron).

For all the previous parameters, repeatability with the Ophthalmetron was a least equal or better than the accuracy by retinoscopy or the Ophthalmetron.

7.3.4. Conclusion

(i) Compared to the previous studies there is less correlation between the different refractive methods and this can be attributed to the irregular nature of the dioptric systems encountered here.

(ii) The Ophthalmetron estimate of the subjective end point is lightly less accurate than that of retinoscopy for every refractive parameter (mid equivalentsphere, cylinder power and axis) but remains of the same order.

(iii) Because the Ophthalmetron repeatability is relatively

good with corneal graft patients, it can be concluded that this method gives a consistent estimation of the refractive error for a given patient and therefore will be useful to follow up post surgical changes.

7.4. Clinical Experiment 4. Aphakia

7.4.1. Introduction

The present investigation proposes to determine refractive accuracy and precision (repeatability) in aphakia. Retinoscopy and the two IR electronic optometers at present available in the UK (the Ophthalmetron and the Dioptron) are compared to subjective refraction.

The main group of patients were refracted by means of retinoscopy and, also the Ophthalmetron, making it possible to isolate particular parameters during the analysis of results.

7.4.2. Material and Method

The two Ophthalmetron instruments used during experiment 7.2. were again utilised. Also for a short period of time a Dioptron II was available. The Ophthalmetron from the City Universtiy was used throughout the experiment.

The patients included in the experiment were all tested in the Contact Lens Department at Moorfields Eye Hospital, and randomly chosen as in 7.2.

The population studied with the Ophthalmetron included 113 patients (71 males and 42 females) aged 13 to 73 years (mean 55.78 years; S/D 13.04 years); 97 patients were monocular aphakes and 16 bilateral aphakes so that altogether 129 eyes (68 right and 61 left eyes) were studied. The ametropias recorded subjectively varied from -2.00 to +17.25 DS and afocal to -8.00DC.

Previous to extraction the origin of the cataract had been diagnosed as follows: Senile (81), Presenile(6), Traumatic(14), Secondary (7), Diabetic (3), Congential (3) Unknown, (15).

The surgical procedures utilized were intracapsular extractions (79 eyes),extracapsular extraction (19 eyes), lens aspiration (6 eyes). For the remaining patients no information was available on the type of surgery utilized.

For the Dioptron, the population was 19 patients (12 males and 7 females) aged 39 to 82 years (mean 60.1 years; S/D 10.01 years); all but one were monocular aphakes. The recorded subjective values for the 20 eyes (12 right and 8 Left) ranged from +10.00 to +15.50 DS for the sphere and afocal to -3.00 DC for the cylinder.

The origin of the cataract had been diagnosed as senile (13) traumatic (1), congenital (1) and unknown (5). The surgical procedure was known in 14 cases; intracapsular extraction (13) and extracapsular extraction (1).

In all cases at least six weeks had elapsed since surgery and no contact lenses had been worn for at least 3 months.

The protocol followed (Table 40) warrants the following comments:

Contrary to all the previous experiments near fixation was used for Retinoscopy, the refractionist aligning himself with the patient's line of sight while in the primary position and the patient was asked to gaze at the red fixation spot of the retinoscope. This is to ensure proper

1. Patient History

2. Cover test (distance and near) Pupillary distance measurement

3. Trial frame adjustment (Horizontal, vertical and frame angling)

4. Monocular refraction by retinoscopy R+L (Streak Retinoscopy, near fixation) and VA with retinoscopic finding R+L.

5. Ophthalmetron measurement R+L and VA with the Ophthalmetron finding R+L.

or

6. Monocular refraction by subjective method R+L (Best VA criterion and duochrome)

7. Ophthalmetron (and/or Dioptron) measurement R+L and VA with the Ophthalmetron (and/or Dioptron) finding R+L.

8. Keratometry R+L

9. Slit lamp examination (and photography) Ophthalmoscopic examination.

TABLE 40 : EXPERIMENTAL PROTOCOL - APHAKIA POPULATION

alignment to avoid the possible aberrations introduced by the high postive lenses used.

The subjective end point was not tested with a +1.00DS lens; because the large variation in pupil size and shape and the magnification due to the corrective lenses the blur produced by such a lens is not constant.

The Ophthalmetron measurement was performed randomly either before or after the subjective refraction. In the former case it was used as the starting point for the subjective while in the latter the retinoscopic finding was used at the beginning of the subjective testing.

During the slit lamp and Ophthalmoscopic examination particular attention was paid to the shape and size of the pupil and to the clarity of the media present.

For the Dioptron the same protocol was used; the Dioptron measurement however was always performed after the subjective refraction.

7.4.3. Results

With the Opthalmetron, for which clinical data obtained are recorded in Appendix 11 , 3 eyes were eliminated from the study (RC^1, PM, AW^2) because of their very low refractive error (near emmetropic). This is acceptable statistically; the values are more than 3 SD away from the mean of the population and clinically: the present study is concerned with the problem of refraction using high powered lenses in aphakia.

From the 126 eyes studied (fig 59), no results could be obtained by retinoscopy in 1 case (0.79%) and for subjective refraction in one other (0.79%). Of the remaining 124 eyes the Ophthalmetron failed to give interpretable results in 26 cases (20.97% failure).

The reasons for failure were:

- an off centre corneal reflection with regard to the pupil position (7 eyes) (≏27%) (fig 60a)
- small pupil for 6 eyes (≏23%) (fig 60b)
- Opacities (Capsular remnants, vitreous floatters) 8 cases (≏ 31%) (fig 60c).
- a combination of two of the above cases 5 eyes (≏19%)

The Ophthalmetron measurement was repeated with the same instrument for 35 eyes and with the second instruement for 33 other eyes.

In the Dioptron series all 20 eyes gave usable measurements for retinoscopy, subjective and the Dioptron (in all cases 2 measurements were taken). The Ophthalmetron failed in 7 cases of that population, but for 4 of these it was caused by a breaking down of the instrument. Therefore only 3 cases can be considered as failures (11.54%) (1 eye because of a small pupil and the 2 other due to opacities). The clinical results obtained are recorded in appendix .

The results of Appendix 11 were computed for 13 mm BVD. The lenses used were in accordance to British Standards BS 3162: 1959;[48] the convex surface of the spherical lenses used were nearest to the eye. The average distance between the back

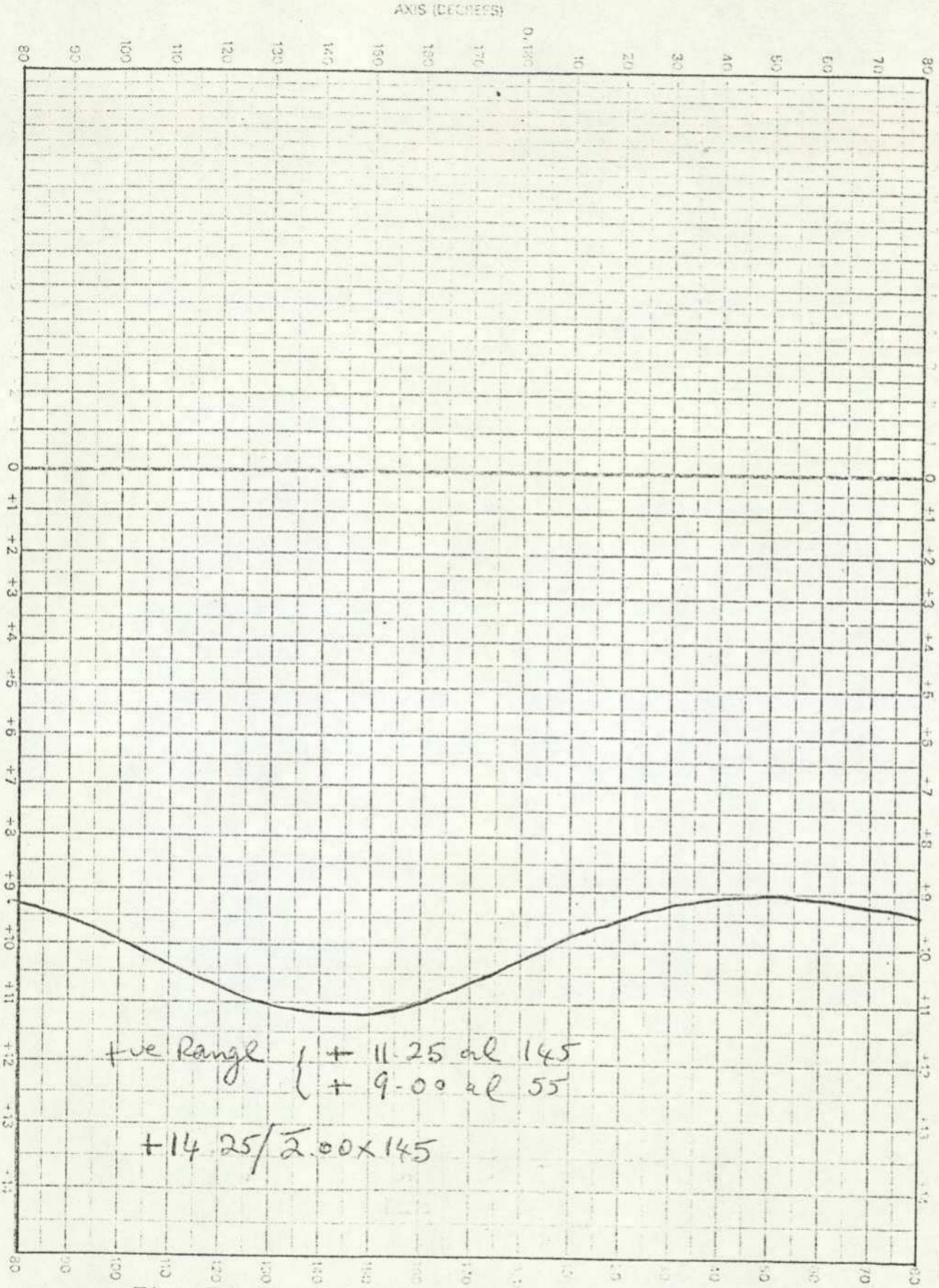


Fig. 59 The Ophthalmetron Typical Aphakic recording using positive range

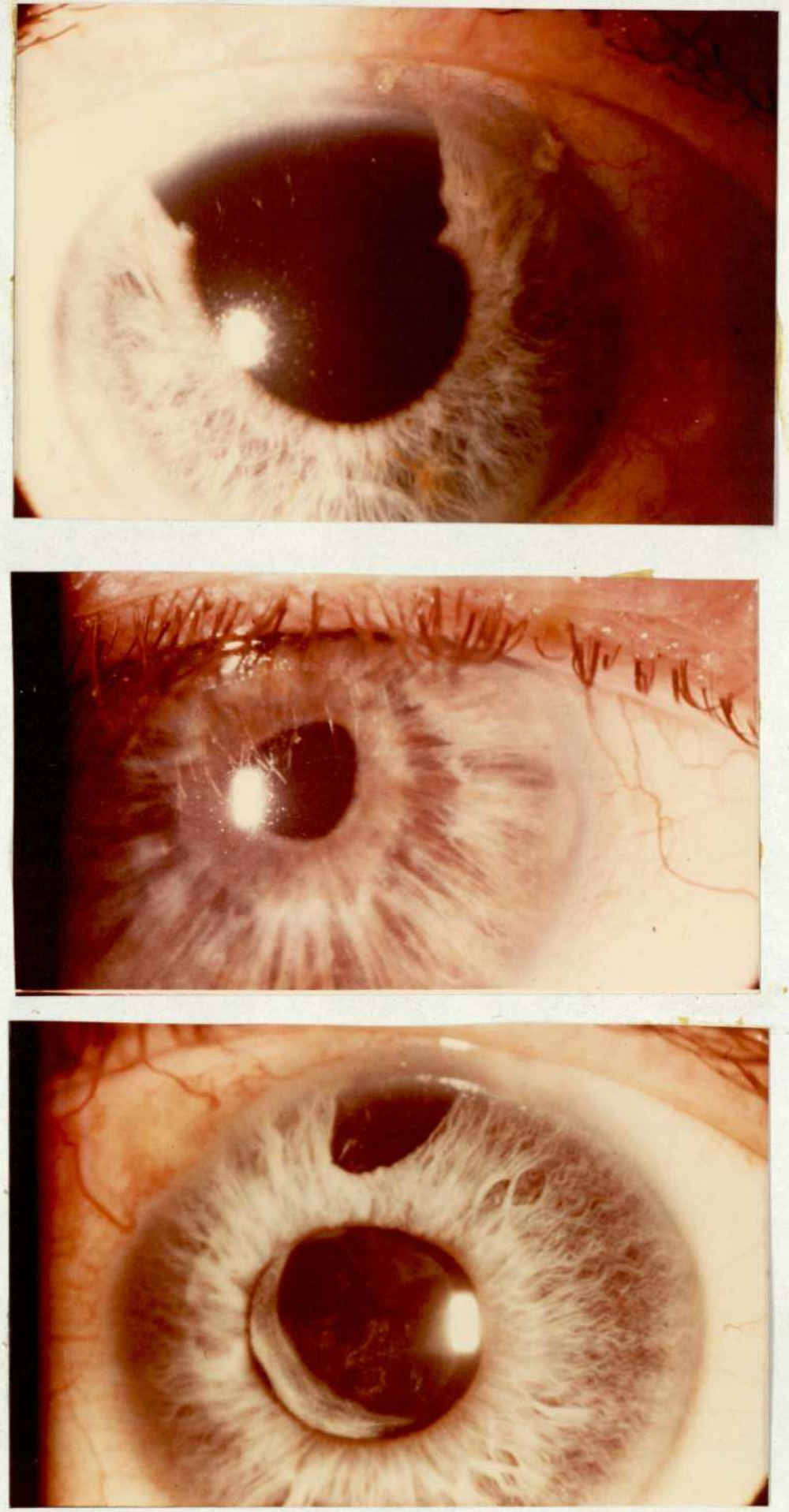


Fig. 60: Slit lamp photographs (x2) Frontal View Aphakic Patients

a. Corneal reflection off centre
b. Small pupil
c. Opacities

plane of the spherical lens and the back plane of the cylinder was 11 mm (fig 61). However, the BVD for the cylinder was taken as the recorded BVD + 10 mm after taking into consideration the thickness of the spherical lenses. (From fig 61 SC= 11 mm; SC = SA+AC = 11 mm. For SC in air n = 1 with SA in glass n = 1.523 the conversion to SA in air is given by $\frac{t}{1.523}$; t was measured as 3.37 mm for +12.00DS trial lens ——> 2.21mm ——> hence 1 mm is systematically deduced from +11.00 mm). The results obtained were recorded in appendix 12

The values obtained by keratometry were also computed for 13 mm BVD for the Ophthalmetron study (Appendix 12). The method used was as advocated by Bennett (1966).[147] The cylinder value at the eye was given by

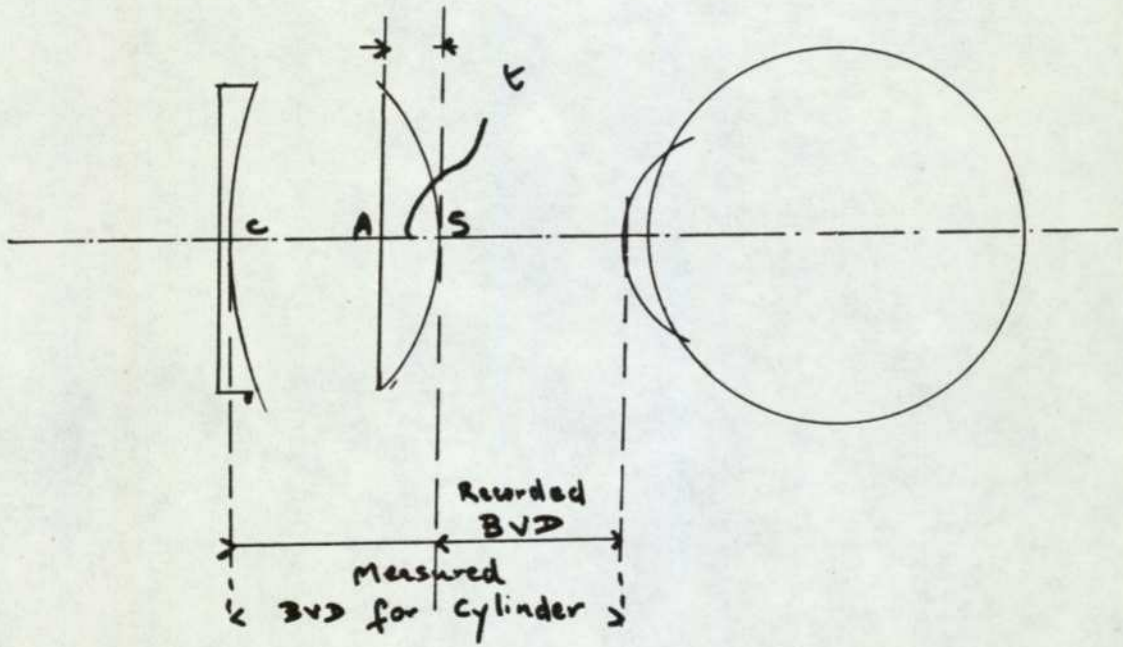
$$C = \left(\frac{1.3375 - 1}{ra_m}\right) - \left(\frac{1.3375 - 1}{r(a+90^{o})_m}\right)$$

$$C = \frac{337.5}{ra_{mm}} - \frac{337.5}{ra+90^{o}_{mm}}$$

Bennett obtained 1.3375 from the schematic eyes of Landolt and Helmholtz, this assumes the effect of the posterior cornea to be one tenth of that of the anterior surface and of opposite sign (n cornea = 1.376).

(i) Accuracy Study

The total population measured with the Ophthalmetron and the Dioptron were first considered as a whole. Further for the Ophthalmetron several aspects or possible bias were studied and lead to various sub groups:



Rig 61 Trial frame arrangement for aphakic patients

- 3 subgroups based on their cylinder values for selection (i:C≥2.00DC; ii: 1.00DC≤C<2.00DC; iii: C<1.00DC). The axis determination was studied there.
- 2 subgroups; the values for the right and left eyes separately; the mid equivalent sphere and cylinder power were considered.
- 2 subgroups separating the patients refracted subjectively with the Ophthalmetron for starting point and those refracted with retinoscopy for starting point; the mid equivalent sphere was analyzed.

a. Variance Analysis

The results obtained for the variance analysis are summarized for the Ophthalmetron in the following tables:

Table 41 : For the overall population for mid equivalent sphere, maximum positive sphere, cylinder power and axis.

Table 42 : For the cylinder axis when considering the 3 subgroups linked to the cylinder power.

Table 43 : For the mid quivalent sphere when considering the right and left eyes separately.

Table 44 : For the cylinder power when considering the right and left eyes separately.

Table 45 : For the mid equivalent sphere when considering separately the Ophthalmetron and Retinoscopy as a starting point for subjective [illegible].

Table 46 : For the overall population for mid equivalent sphere, for maxi positive sphere, for cylinder power, for the Dioptron.

Group	Source of Variation	Sum of Square	df	Mean Square	F
Mid equivalent Sphere	Between group	1.538	2	0.769	0.228
	Within group	982.119	291	3.375	
	Total	983.657		3.357	
		0.001	1	0.001	0.0001
		891.094	246	3.622	
		891.095		3.608	
Maximum positive Sphere		4.523	2	2.262	0.700
		939.715	291	3.229	
		944.239		3.223	
		0.001	1	0.001	0.0002
		845.474	246	3.437	
		845.475		3.423	
Cylinder Power		3.183	2	1.591	2.136
		216.827	291	0.745	
		220.010		0.751	
		8×10^{-6}	1	8×10^{-6}	1×10^{-5}
		187.904	246	0.764	
		187.904		0.761	
Cylinder Axis		8593.75	2	4296.875	3.835
		312590.53	279	1120.396	
		321184.28		1143.005	

Table 41 Aphakia Population Ophthalmetron Variance Analysis Results.

Group	Source of Variance	Sum of Square	df	Mean Square	F
Cylinder ≥ 2.00DC	Between groups	1234.077	2	617.039	0.502
	Within groups	73767.933	60	1229.466	
	Total	75002.010		1209.710	
1.00 DC≥ Cylinder ≤ 2.00 DC		6754.57	2	3377.285	3.391
		152388.68	153	996.004	
		159143.25		1026.731	
Cylinder <1.00 DC		1100.756	2	550.378	0.397
		87235.229	63	1384.686	
		88335.985		1359.015	

Table 42 Aphakic Population Ophthalmetron Variance Analysis Results for cylinder axis in subgroups with different cylinder powers.

Group	Source of Variation	Sum of Square	df	Mean Square	F
Mid equivalent Sphere - RE	Between groups	0.8603	2	0.430	0.145
	Within groups	419.005	141	2.972	
	Total	419.865		2.936	
		0.102	1	0.102	0.034
		388.762		3.037	
		388.864		3.014	
Mid equivalent Sphere - LE		1.109	2	0.554	0.145
		562.507	147	3.827	
		563.615		3.783	
		0.1308	1	0.1308	0.03
		485.904	114	4.262	
		486.034		4.226	

Table 43 Aphakic Population Ophthalmetron Variance Analysis Results for mid equivalent sphere, subgroups for R and L eyes.

Group	Source of Variation	Sum of Square	df	Mean Square	F
Cylinder Power RE	Between groups	16.526	3	5.509	4.592
	Within groups	225.523	188	1.120	
	Total	242.048		1.267	
		19.380	2	9.690	7.147
		264.382	195	1.356	
		283.762		1.440	
		0.013	1	0.013	0.016
		108.966	130	0.838	
		108.979		0.8322	
Cylinder Power LE		12.776	3	4.259	4.999
		166.977	196	0.852	
		179.753		0.903	
		12.858	2	6.429	6.790
		167.618	171	0.947	
		180.476		1.008	
		0.010	1	0.010	0.015
		81.844	115	0.694	
		81.854		0.688	

Table 44 Aphakic Population Ophthalmetron. Variance Analysis Results for Cylinder Power, subgroups for R & L eyes.

Group	Source of Variation	Sum of Square	df	Mean Square	F
Mid Equivalent Sphere from O	Between groups	1.112	2	0.556	0.156
	Within groups	556.531	150	3.568	
	Total	557,643		3.529	
		0.012	1	0.012	0.004
		361.934	99	3.480	
		361.948		3.447	
Mid equivalent Sphere from R		0.567	2	0.284	0.085
		461.47	138	3.344	
		462.04		3.300	
		0.005	1	0.005	0.001
		303.632	92	3.300	
		303.636		3.265	

Table 45 Aphakia Population Ophthalmetron Variance Analysis Results. Mid equivalent sphere sub-groups with different starting point.

Groups	Source of Variation	Sum of Square	df	Mean Square	F
Mid-equivalent Sphere (whole pop.)	Between groups	9.070	4	3.023	1.978
	Within groups	116.182	76	1.529	
		125.252		1.585	
Mid-equivalent Sphere (Incl. O)		3.822	5	0.985	0.623
		92.055	60	1.534	
		95.877		1.498	
Mid-equivalent Sphere (Excl. O)		3.801	4	1.267	0.995
		61.149	48	1.274	
		64.950		1.274	
Maximum Positive Equivalent (whole pop.)		5.377	4	1.772	1.237
		108.901	76	1.433	
		114.219		1.445	
Maximum Positive Equivalent (Incl. O)		1.837	5	0.459	0.308
		89.539	60	1.492	
		91.376		1.428	
Maximum Positive Equivalent (Excl. O)		1.643	4	0.548	0.436
		60.231	48	1.255	
		61.874		1.213	
Cylinder Power (Whole pop.)		3.127	4	1.042	1.233
		64.277	76	0.846	
		67.404		0.853	
Cylinder Power (Incl. O)		2.883	5	0.721	1.113
		38.858	60	0.648	
		41.739		0.652	
Cylinder Power (Excl. O)		2.450	4	0.817	1.244
		31.502	48	0.656	
		33.952		0.666	

Table 46 Aphakia population. Accuracy and precision study with the Dioption Variance Analysis Results.

For the total population measured with the Ophthalmetron only for the cylinder axis the difference is significant at 5% level, while for the Dioptron none of the parameters show a significant difference.

The various subgroups considered with the Ophthalmetron showed greater variability:

- the values of the cylinder axis determination are again significantly different at 5% level for the cylinder powers varying between 1 and 2 diopters when considering the various subgroups selected on the basis of their cylinder power.
- the cylinder power values for the right and left eyes separately and including their determination by keratometry are significant both at 1 and 5% levels.
- all the other parameters are not significant.

b. Pair Analysis Total population

Mid Equivalent Sphere

The results obtained are summarized in tables 47 and 48

The t test values are only significantly different when pairing the IR optometers values with the subjective values both for the Ophthalmetron and the Dioptron.

The standard deviation shows that the Ophthalmetron gives a slightly closer estimate of the subjective (SD = 0.54 DS) than even retinoscopy (SD$\simeq$ 0.68DS). On the contrary, with the Dioptron far poorer results are obtained (SD = 1.19DS), the accuracy of retinoscopy being similar in both groups. However, when considering the section of the population whose

GROUP	$\bar{X}_1$	$\bar{X}_2$	$\bar{D}=\bar{X}_1-\bar{X}_2$	S/D	t	n	b	a	R
S v R	11.359	11.363	-0.004	0.668	-0.057	124	0.881	1.355	0.940
S v R	11.309	11.282	0.026	0.680	0.386	98	0.851	1.662	0.934
S v O	11.309	11.144	0.165	0.544	3.001	98	0.948	0.418	0.959
R v O	11.283	11.144	0.138	0.816	1.679	98	0.979	0.103	0.901

Table :47 Aphakia Population - The Ophthalmetron Pair Analysis results for mid equivalent sphere.

S v R	11.947	11.858	0.089	0.578	0.686	20	0.850	1.704	0.856
S v R	11.752	11.637	0.115	0.636	0.650	13	0.867	1.451	0.846
S v D_1	11.947	12.573	-0.627	1.193	-2.348	20	0.719	3.982	0.560
S v D_1	11.752	12.135	-0.383	0.586	-2.359	13	0.804	2.683	0.859
S v O	11.752	12.00	-0.248	1.015	-0.881	13	1.103	-0.966	0.778
R v D_1	11.858	12.573	-0.715	0.977	-3.275	20	0.926	1.598	0.715
R v D_1	11.637	12.135	-0.498	0.536	-3.348	13	0.811	2.700	0.887
R v O	11.637	12.00	09.363	0.847	-1.543	13	1.191	-1.863	0.860

Table :48 Aphakia Population - The Dioptron Pair Analysis results for mid equivalent sphere.

S v R	12.133	12.137	-0.004	0.686	-0.059	124	0.877	1.496	0.933
S v R	12.089	12.092	-0.003	0.717	-0.035	98	3.430	2.896	0.922
S v O	12.089	11.828	0.262	0.606	4.277	98	0.936	0.506	0.946
R v O	12.092	11.828	0.264	0.882	2.968	98	0.946	0.385	0.878

Table :49 Aphakia Population - The Ophthalmetron Pair Analysis results for maximum positive sphere.

measurements were possible with the Dioptron and the Ophthalmetron, the accuracy of the former reaches the level of the other methods (SD = 0.59DS).

The mean difference ($\bar{D}$) from the subjective is near zero for both groups for retinoscopy. It varies between +0.15DS and -0.20 DS for the Ophthalmetron and -0.38 and -0.63DS for the Dioptron. The striking conclusion is that the sign of this difference for the IR optometrs is not always the same, disproving any systematic bias.

The correlation factor for the Ophthalmetron group remains high and consistant $\simeq$ 0.94, while for the Dioptron group it decreases; this had to be expected because of the smaller population.

It also shows a difference between retinoscopy ($r \simeq 0.86$) and Dioptron ($r = 0.56 \longrightarrow 0.77$).

The estimates of the regression curve 'a' and 'b' show widely variable values, but these must be considered together and limited to the range of refractive values encountered here; they then show good correlation(ie: X_1 = 12.00DS X_2 = 11.904 DS for b = 0.850 and a = 1.704). It is important to remember that in this present experiment 'a' does not represent the "myopic shift" as one cannot extrapolate the curve for a value of X_1 = O (The same applied to the high myopic group).

The maximum positive sphere was also analyzed for the Ophthalmetron. The results (Table 49) are in very close agreement to those obtained with the mid equivalent sphere. Identical conclusions, clinical and statistical, are

obtained for both parameters, therefore in the remaining aphakic study only the mid equivalent sphere will be considered.

Cylinder Power

The results are summarized in Table 50-51 For the Ophthalmetron, compared to the subjective finding, the t test is significant at 1% level, while the Dioptron is only significant at the 5% level. For the Ophthalmetron population the cylinder was also measured by keratometry and the results obtained are highly significantly different when compared to any other methods.

The standard deviation from the subjective finding was the same for retinoscopy in the two studies ($\simeq$ 0.51DC) and for the Ophthalmetron (=0.53DC), while it increases to 0.80 DC for keratometry and 0.88 DC for the Dioptron.

The mean difference from the subjective result is smallest with retinoscopy ($\lesssim$ 0.06DC) and still not clinically significant for the Ophthalmetron. ($\simeq \overline{0}$.15DC). It however showed a clinically unacceptable level by keratometry ($\overline{D} \simeq$+0.61DC for a mean cylinder of -1.47DC).

The correlation coefficient is constant for the Ophthalmetron group $\simeq$ 0.80 (including keratometry) and worse for the Dioptron population: r = 0.73 for retinoscopy and $\simeq$ 0.35 for the Dioptron.

The regression curves underline the tendency illustrated by the correlation factor r of a very poor correlation with the Dioptron.

GROUP	$\bar{X}_1$	$\bar{X}_2$	$\bar{D}=\bar{X}_1-\bar{X}_2$	S/D	t	n	b	a	R
S v R	-1.548	-1.548	0.000	0.541	0.007	127	0.776	-0.347	0.809
S v R	-1.560	-1.619	0.058	0.516	1.115	98	0.779	-0.403	0.827
S v O	-1.560	-1.375	-0.186	0.534	-3.447	98	0.760	-0.189	0.814
S v K	-1.548	-2.158	0.61	0.886	7.663	124	1.254	-0.217	0.794
S v K	-1.560	-2.112	0.551	0.788	6.926	98	0.811	1.883	0.839
R v O	-1.619	-1.375	-0.244	0.647	-3.731	98	0.700	-0.242	0.706
R v K	-1.548	-2.158	0.610	1.023	6.634	124	1.142	-0.390	0.693
R v K	-1.619	-2.112	0.493	0.927	5.264	98	1.211	-0.151	0.748
O v K	-1.375	-2.112	0.737	0.874	8.345	98	1.292	-0.336	0.791

Table 50 Aphakia Population. The Ophthalmetron Pair Analysis. Summary of results for cylinder power.

GROUP	$\bar{X}_1$	$\bar{X}_2$	$\bar{D}=\bar{X}_1-\bar{X}_2$	S/D	t	n	b	a	R
S v R	-1.474	-1.423	-0.051	0.529	-0.427	20	0.706	-0.382	0.732
S v R	-1.468	-1.467	-0.002	0.534	-0.010	13	0.737	0.558	0.787
S v D_1	-1.474	-0.966	-0.508	0.878	-2.584	20	0.381	-0.405	0.349
S v D_1	-1.468	-0.97	-0.498	0.882	-2.038	13	0.309	-0.517	0.376
S v D_2	-1.474	-1.296	-0.176	1.372	-0.579	20	0.329	-0.811	0.186
S v D_2	-1.468	-1.125	-0.343	1.272	-0.973	13	-0.031	-1.171	-0.029
S v O	-1.468	-1.462	-0.007	1.073	-0.023	13	0.135	-1.264	0.148
R v D_1	-1.423	-0.966	-0.457	0.906	-2.255	20	0.322	0.642	0.285
R v D_1	-1.467	-0.97	-0.497	0.830	-2.159	13	0.327	-0.490	0.347
R v D_2	-1.423	-1.296	-0.127	1.301	-0.437	20	0.505	-0.578	0.275
R v D_2	-1.467	-1.125	-0.342	1.137	-1.083	13	0.089	-0.994	0.073
R v O	-1.467	-1.462	-0.005	0.804	-0.024	13	0.470	-0.771	0.449
D_1 v D_2	-0.966	-1.296	0.33	1.530	0.964	20	-0.001	-1.297	-0.001
D_1 v D_2	-0.97	-1.125	0.155	1.135	0.494	13	0.042	-1.085	0.032
D_1 v O	-0.97	-1.462	0.492	0.841	2.107	13	0.404	-1.069	0.364
D_2 v O	-1.125	-1.462	0.336	1.022	1.186	13	0.242	-1.189	0.282

Table 51 Aphakia Population. The Dioptron Pair analysis - summary of results for cylinder power.

Cylinder Axis

The cylinder axis results (Table 52, 53) are only significantly different for the t test at 5 and 1% levels for the Ophthalmetron.

The standard deviation (for cylinder power $\geq$ 0.50DC) is for each group slightly better for retinoscopy than for the Ophthalmetron (17^{o}vs.19^{o}) and the Dioptron (12^{o}vs18^{o}).

The correlation factor is also good ranging from 0.87 to 0.92 for the Dioptron group and 0.80 to 0.87 for the Ophthalmetron group.

The accuracy for the cylinder axis was considered for the various cylinder power subgroups (Table 54). For retinoscopy and the Ophthalmetron the S/D increases as the cylinder decreases. The accuracy of retinoscopy varies little above 1DC (S/D for retinoscopy above 2DC $\pm 12.5^{0}$ and between 1 and 2DC 15.5^{o}). For the Ophthalmetron, however, accuracy increases above 2DC (8.5^{o}v 16^{o}). By keratometry the axis is most accurate for cylinder between 1 and 2 DC but the standard deviation remains high (14^{o} and 26^{o} above 2DC).

Dioptron "Confidence Factor"

For the Dioptron a "confidence factor" was available for each eye (Table 55). When considering all 40 Dioptron measurements 44% of cases had optimal values (between 0.1 and 1.00) and a further 36% had acceptable (between 1.00 and 20.00) ones for the confidence factor, the remaining 20% being considred unacceptable by the manufacturers.

GROUP	$\bar{X}_1$	$\bar{X}_2$	$\bar{D}=\bar{X}_1-\bar{X}_2$	S/D	t	n	b	a	R
S v R	95.809	93.856	1.952	16.751	1.130	94	0.802	17.053	0.876
S v O	95.809	106.420	-10.612	19.104	-5.385	94	0.835	26.426	0.845
S v K	95.809	98.511	-2.702	21.587	-1.214	94	0.816	20.309	0.807
R v O	93.856	106.420	-12.564	17.640	-6.905	94	0.926	19.464	0.859
R v K	93.856	98.511	-4.654	21.704	-2.079	94	0.875	16.409	0.792
O v K	106.420	98.511	7.910	22.378	3.427	94	0.809	12.388	0.790

Table 52 Aphakia Population. The Ophthalmetron Pair Analysis. Summary of results of cylinder axis.

S v R	91.833	97.083	-5.25	10.966	-2.031	18	0.937	11.044	0.960
S v R	80.929	87.321	-6.393	12.226	-1.957	14	0.915	13.265	0.916
S v R	74.5	82.25	-7.75	13.665	-1.793	10	0.915	14.102	0.914
S v D_1	80.929	82.286	-1.357	18.468	-0.275	14	1.062	-3.690	0.866
S v D_1	74.5	78.7	-4.2	19.737	-0.673	10	1.171	-8.569	0.898
S v D_2	74.5	94	-19.5	26.497	-2.327	10	1.323	-4.568	0.873
R v D_1	87.321	82.286	5.036	24.034	0.784	14	0.931	0.946	0.758
R v D_1	82.25	78.7	3.55	27.070	0.415	10	1.012	-4.508	0.776
R v D_2	82.25	94	71.75	32.600	-1.140	10	1.155	-0.997	0.763
D_1 v D_2	78.7	94	-15.3	24.595	-1.967	10	1.010	14.536	0.870

Table 53 Aphakia Population. The Dioptron Pair Analysis. Summary of results of cylinder axis.

GROUP	$\bar{X}_1$	$\bar{X}_2$	$\bar{D}=\bar{X}_1-\bar{X}_2$	S/D	t	n	b	a	R
S v R	100.720	99.643	1.077	12.579	0.393	21	0.939	5.035	0.934
S v O	100.720	109.524	-8.804	8.504	-4.744	21	1.012	7.631	0.972
S v K	100.720	94.048	6.673	26.535	1.152	21	0.910	2.352	0.766
R v O	99.643	109.524	-9.881	14.947	-3.029	21	0.943	15.543	0.911
R v K	99.643	94.048	5.595	32.891	0.780	21	0.749	19.408	0.634
O v K	109.524	94.048	15.476	25.856	2.743	21	0.892	-3.691	0.782
S v R	93.096	92.596	0.5	15.615	0.231	52	0.856	12.915	0.876
S v O	93.096	106.798	-13.702	16.226	-6.089	52	0.885	24.450	0.871
S v K	93.096	96.538	-3.442	13.382	-1.855	52	0.985	4.816	0.919
R v O	92.596	106.798	-14.202	11.109	-9.219	52	0.974	16.462	0.939
R v K	92.596	96.538	-3.942	13.962	-2.036	52	0.999	3.992	0.911
O V K	106.798	96.538	10.260	12.723	5.815	52	0.978	-7.946	0.927
S v R	98.636	93.409	5.227	22.479	1.091	22	0.654	28.925	0.841
S v O	98.636	103.409	-4.773	29.103	-0.769	22	0.668	37.513	0.732
S v K	98.636	102.955	-4.318	39.807	-0.509	22	0.454	58.175	0.496
R v O	93.409	103.409	-10	29.681	-1.580	22	0.762	32.251	0.649
R v K	94.409	102.955	-9.545	38.045	-1.177	22	0.490	57.141	0.416
O v K	103.409	102.955	0.455	41.373	0.052	22	0.400	61.589	0.399

Table 54 Aphakia Population. The Ophthalmetron. Cylinder Axis for different cylinder power groups. Top : Cyl $\geq$ 2 DC. Middle : Cyl $\geqslant$ 1 $<$ 2 DC. Bottom : Cyl $<$ 1D

Name	Mid Sph ($S - D_1$)	Cyl $S - D_1$	Coefficient D_1	Mid Sph ($S - D_1$)	Cylinder ($S - D_1$)	Coefficient D_2
J.A.	+0.27	-0.40	3.61	-0.105	-0.67	
F.B.	-4.435	-1.97	0.00	-2.245	3.53	.40
H.B.	-0.075	+0.35	1.07	-0.585	+0.25	
A.C.	-0.515	-0.51	2.64	0.13	-0.76	.48
D.C.	0.565	1.23	3.15	0.075	+0.29	1.16
	0.335	-0.99	0.00	0.555	+2.27	
L.E.	-2.935	-0.99	0.00	-3.215	-0.99	0.00
H.F.	0.075	-0.23	0.79	-0.17	-0.04	12.67
J.F.	-0.415	-0.37	0.49	-0.165	-0.57	3.79
E.G.	-1.45	-0.70	0.07	-2.08	-2.00	0.31
B.H.	-0.805	-0.23	0.43	-0.785	+0.01	56.03
M.K.	-0.45	-2.24	0.99	-0.705	-2.57	0.18
A.M.	-0.885	0.35	0.19	-0.665	0.55	4.36
W.P.	-0.485	0.99	0.00	-0.995	0.47	59.2
I.S.	0.455	-0.99	0.44	0.45	2.38	4.42
W.S.	-0.44	0.94	0.93	0.395	0.51	
H.V.	-0.595	-0.53	0.11	-0.165	-0.45	0.22
A.W. #1	0.085	+0.27	1.70	0.12	+0.06	2.50
A.W. #2	-0.965	-1.68	0.24	-1.605	-1.81	0.24
L.W.	0.41	-0.56	19.17	-0.665	-1.03	2.39

Table 55 Aphakic population - measured with the Dioptron: 'Confidence coefficient' results.

To evaluate the clinical usefulness of such a factor the scatter diagrams between the "confidence factor" and the individual differences for the mid sphere and cyl power was plotted (fig 62). Also the correlation coefficient between the "confidence factor" and the two same parameters was calculated. None show any correlation; for the values between 0.10 and 1.00 r = -0.44 for the mid sphere and 0.03 for the cylinder; for the value between 0.10 and 20.00 r = 0.25

c. Additive frequencies Total Population

The values obtained here (Tables 56-61) are in general agreement with S/D values.

For the mid equivalent sphere at the 0.50 and 1.00 DS levels, retinoscopy and the Ophthalmetron perform indentically (73% for Retinoscopy vs 75% for the Ophthalmetron at 0.50DS level and 98% vs 97% at 1 DS Level); the Dioptron however shows more variability with 10% fewer eyes than the retinoscopy being found at 0.50 and 1.00DS levels. Here again the values for the maximum sphere agree with those of the mid equivalent sphere.

For the cylinder power, again the retinoscopy and Ophthalmetron behave the same at 0.50 DC level while the performance of the Dioptron acceptable at 1DC level is very poor at 0.50 DC, with only 35% of eyes found in this range.

The additive frequency for the Ophthalmetron group is better at 10^{o} with retinoscopy (71.58%) than with the Optometer (44.22%), all cylinders being $\geq$ 0.50 DC. This

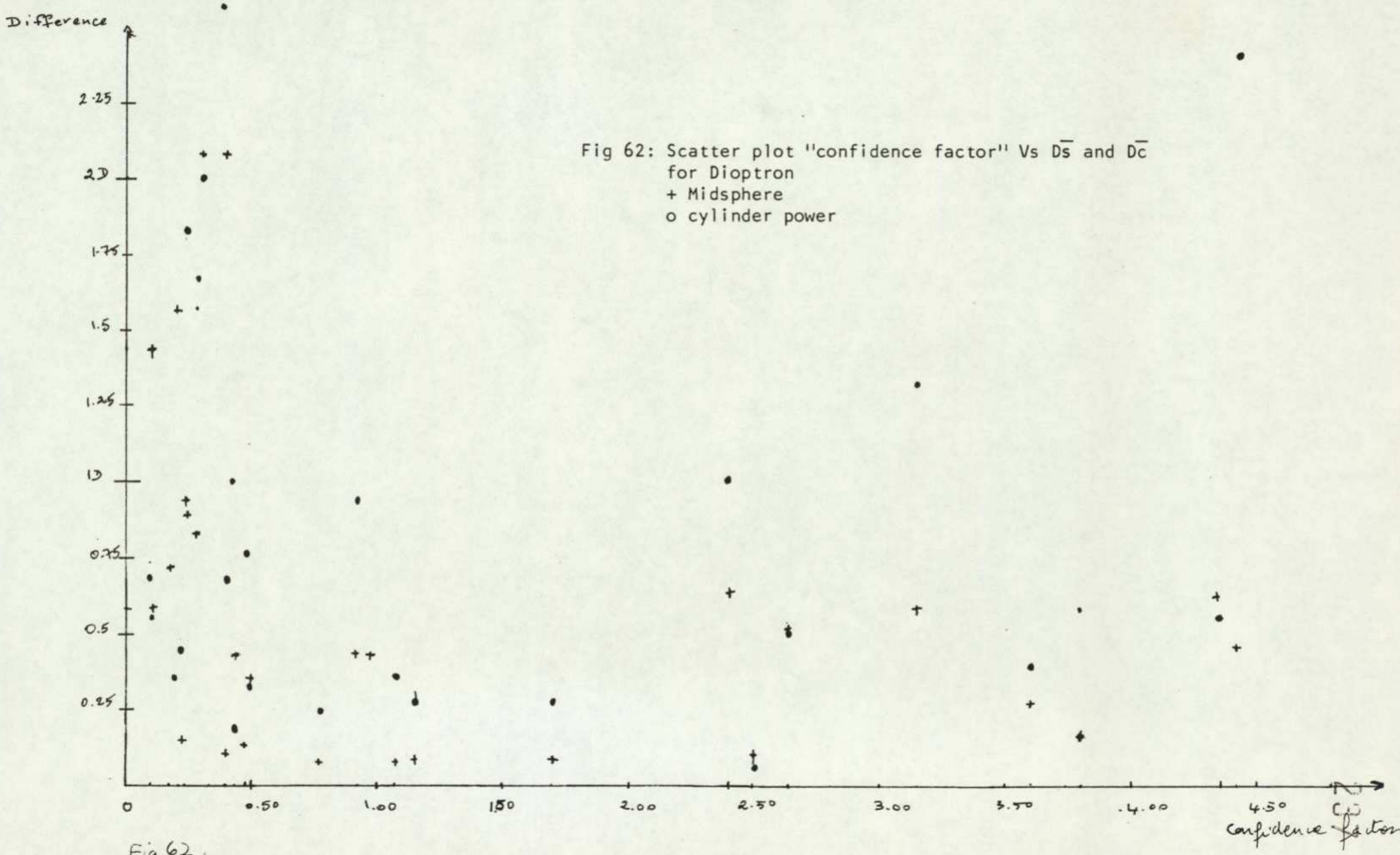


Fig 62: Scatter plot "confidence factor" Vs $\bar{Ds}$ and $\bar{Dc}$
for Dioptron
+ Midsphere
o cylinder power

Fig 62.

	n	S v R	S v O	R v O
≤ ±0.25DS	98	43.88	42.86	35.71
> ±0.25 ≤ ±0.50	98	28.57 72.45	31.63 74.49	26.53 62.24
> ±0.50 ≤ ±1.00	98	21.43 93.88	15.31 89.80	21.43 83.67
> ±1.00 ≤ ±1.50	98	4.08 97.96	7.14 96.94	12.25 95.92
> ±1.50 ≤ ±2.00	98	0.00	3.06 100.00	2.04 97.96
> ±2.00	98	2.04 100.00		2.04 100.00

Table 56 Aphakia Population Ophthalmetron Mid equivalent Sphere Additive frequency results. Top value % of cases in group. Bottom value additive frequency.

	n	S v R	S v O	R v O
≤ ±0.25 DS	98	41.84	43.88	29.59
> ±0.25 ≤ +0.50	98	34.69 76.53	27.55 71.43	18.37 47.96
> ±0.50 ≤ ±1.00	98	18.37 94.90	16.33 87.76	32.65 80.61
> ±1.00 ≤ ±1.50	98	3.06 97.96	10.20 97.96	15.31 95.92
> ±1.50 ≤ ±2.00	98	0.00	2.04 100.00	2.04 97.96
> ±2.00	98	2.04 100.00		2.04 100.00

Table 57 Aphakia Population Ophthalmetron Maximum Positive Sphere Additive frequency results. Top value % of cases in group; Bottom value additive frequency.

	n	S v R	S v O	R v O
≤ ±0.25 DS	98	55.10	51.02	37.76
> ±0.25 ≤ ±0.50	98	23.47 78.57	20.41 7.143	26.53 64.29
> ±0.50 ≤ ±1.00	98	17.35 95.92	22.45 93.88	25.51 89.80
> ±1.00 ≤ ±1.50	98	3.06 98.98	4.08 97.96	7.14 96.94
> ±1.50 ≤ ±2.00	98	1.02 100.00	2.04 100.00	2.04 98.98
> ±2.00	98			1.02 100.00

Table 58 Aphakia Population Ophthalmetron Cylinder power additive frequency results. Top value % of cases in group; Bottom value additive frequency.

	n	S v R	S v O	R v O
≤ 5°	94	44.21	25.26	20.00
> 5° ≤ 10°	94	27.37 71.58	18.96 44.22	20.00 40.00
> 10° ≤ 20°	94	15.79 87.37	34.74 78.96	38.95 78.95
> 20°	94	12.63 100.00	21.L4 100.00	21.05 100.00

Table 59 Aphakia Population Ophthalmetron Cylinder axis additive frequency results. Top value% of cases in group; Bottom value additive frequency.

	n	S v R	S v D_1	S v D_2	S v O	D_1 v D_2
O	20	5.00	O	O		O
	13	7.69	O	O	15.38	O
	20	35.00	20.00	30.00		30.00
		40.00	20.00	30.00		30.00
±0.25 DS						
	13	23.08	15.38	30.77	7.69	30.77
					23.07	
	20	25.00	35.00	15.00		30.00
		65.00	55.00	45.00		60.00
±0.25 ±0.50 DS						
	13	30.77	30.77	7.69	7.69	30.77
					30.76	
	20	30.00	30.00	35.00		30.00
		35.00	85.00	80.00		90.00
±0.50 ±1.00 DS						
	13	30.77	46.15	46.15	38.46	38.45
					69.22	
	20	5.00	5.00	O		O
		100.00	90.00			
±1.00 ±1.50 DS						
	13	7.69	7.69	O	23.08	O
					92.30	
	20	O	10.00	20		10.00
			100.00	100.00		100.00
±1.50 DS						
	13	O		15.38	7.69	O
					99.99	

Table 60 Aphakic Population - Dioptron Mid Equivalent last sphere Additive frequency results.

Top value % of cases in group; Bottom value = additive frequency; (S = Subjective; R = Retinoscopy; D_1 + D_2 = Dioptron 1st and 2nd; O = Ophthalmetron).

	n	S v R	S v D_1	S v D_2	S v O	D_1 v D_2
0	20	30.00	0	0		5.00
	13	30.77	0	0	0	0
	20	15.00	10.00	20.00		50.00
		45.00	10.00	20.00		55.00
±0.25 DC						
	13	23.08	15.38	23.08	23.08	61.54
					23.08	
	20	35.00	25.00	15.00		20.00
		80.00	35.00	35.00		75.00
±0.25 ±0.50 DC						
	13	23.08	23.08	23.08	23.08	7.69
					46.16	
	20	20.00	45.00	35.00		0
		100.00	80.00	70.00		75.00
±0.50 ±1.00DC						
	13	23.08	38.46	23.08	23.08	0
					59.24	
	20	0	20.00	30.00		25.00
			100.00	100.00		100.00
±1.00 DC						
	13	0	23.08	30.77	30.77	30.77
					100.01	

Table 61 Aphakic population Dioptron - cylinder Power - Additive frequency results.

Top value = % of cases in group; Bottom value = additive frequency (S = Subjective; R = Retinoscopy; D_1 + D_2 = 1st and 2nd Dioptron; O = Ophthalmetron).

aspect was not studied for the Dioptron because of the population size.

d. Pair Analysis Ophthalmetron Subgroups

Right and Left eyes separately

The two groups are comparable for size (Right 66; Left 58) and refractive values (mean sphere R=+11.625; L=+11.055; cylinder R=-1.598 L=-1.465). So any differential conclusions can be attributed to experimental differences and not sampling differences.

The suggestion was that because the refractionist used his Right eye throughout the experiment, both for the patients right and left eyes, better accuracy would result for the retinoscopy of the right eye.

The results obtained in Tables 62+63 show for the Ophthalmetron and Keratometry a similar level of significance for the t test with one exception (subjective vs. Ophthalmetron significant at 5% level for the right eye for the mid equivalent sphere and not the left eye), and for the S/D for right and left eyes.

In the case of retinoscopy the t test is significant for the right eye at 5% level and not for the left one for the mid sphere, while for the cylinder power the right eye is significant at 5% level and the left eye at 1%.

The S/D is clinically different for the mid sphere with better results obtained with the right eye (SD = 0.50DS) than the left eye (SD = 0.81DS), but no difference is present for the cylinder power.

GROUP	$\bar{X}_1$	$\bar{X}_2$	$\bar{D}=\bar{X}_1-\bar{X}_2$	S/D	t	n	b	a	R
S v R	11.627	11.570	0.056	0.554	0.818	65	0.960	0.408	0.950
S v R	11.372	11.254	0.118	0.501	1.637	48	0.918	0.810	0.958
S v O	11.372	11.185	0.187	0.545	2.381	48	0.948	0.404	0.951
R v O	11.254	11.185	0.069	0.693	0.689	48	0.955	0.437	0.919
S v R	11.055	11.122	-0.067	0.782	-0.654	58	0.828	1.963	0.935
S v R	11.249	11.310	-0.062	0.811	-0.537	50	0.807	2.247	0.919
S v O	11.249	11.105	0.144	0.548	1.852	50	0.949	0.427	0.964
R v O	11.310	11.105	0.205	0.921.	1.575	50	1.000	-0.200	0.890

Table 62: Aphakia Population. The Ophalmetron Pair Analysis of mid equivalent sphere. Top : Right Eye. Bottom : Left Eye.

GROUP	$\overline{X}_1$	$\overline{X}_2$	$\overline{D}=\overline{X}_1-\overline{X}_2$	S/D	t	n	b	a	R
S v R	-1.598	-1.578	-0.020	0.597	-0.274	66	0.727	-0.417	0.791
S v R	-1.674	-1.744	0.070	0.539	0.895	48	0.714	-0.549	0.832
S v O	-1.674	-1.499	-0.175	0.551	-2.193	48	0.756	-0.234	0.828
S v K	-1.598	-2.252	0.653	0.904	5.870	66	1.366	-0.069	0.842
S v K	-1.674	-2.285	0.611	0.798	5.304	48	1.424	0.099	0.896
R v O	-1.744	-1.499	-0.244	0.714	-2.370	48	0.699	-0.280	0.657
R v K	-1.578	-2.252	0.673	1.139	4.804	66	1.213	-0.338	0.68
R v K	-1.744	-2.285	0.541	1.088	3.447	48	1.361	0.088	0.735
O v K	-1.499	-2.285	0.785	1.049	5.184	48	1.312	-0.318	0.754
S v R	-1.465	-1.484	0.019	0.480	0.299	58	0.862	-0.221	0.835
S v R	-1.452	-1.499	-0.047	0.499	0.666	50	0.854	-0.260	0.823
S v O	-1.452	-1.255	-0.197	0.522	-2.668	50	0.752	-0.163	0.790
S v K	-1.465	-2.041	0.576	0.846	5.277	58	1.051	-0.502	0.714
S v K	-1.452	-1.946	0.494	0.782	4.465	50	1.074	-0.386	0.750
R v O	-1.499	-1.255	-0.247	0.584	-2.952	50	0.688	-0.224	0.748
R v K	-1.484	-2.041	0.558	0.877	4.926	58	0.978	-0.589	0.687
R v K	-1.499	-1.946	1.389	0.751	4.212	50	1.067	-0.346	0.772
O v K	-1.255	-1.946	0.691	0.673	7.259	50	1.262	-0.362	0.839

Table63 Aphakia Population. The Ophthalmetron Pair Analysis for cylinder power. Top : Right Eye, Bottom: Left Eye

In conclusion, the accuracy for the right and left eyes is identical for the Ophthalmetron and keratometry. For Retinoscopy (despite some variation in results between right and left eyes) the values on the whole have no clinically significant difference. Therefore retinoscopy undertaken by the practitioner using the same eye to perform retinoscopy on the patient's right and left eye does not introduce bias linked to aberrations in aphakia, as long as the precautions taken for alignment and described in (7.4.2.) are followed.

Differential "starting point"

The starting point for the subjective refraction, either retinoscopy or the Ophthalmetron, could introduce experimental bias. The hypothesis was tested on the mid equivalent sphere parameter.

The two groups obtained were statistically and clinically comparable - (n Ophthalmetron = 51; n Retinoscopy = 47). Mean Subjective for Ophthalmetron group = +11.31DS, for Retinoscopy = +11.40DS).

Despite a few variations (Table 64) there is no definite influence from the starting point. The Ophthalmetron measurements show that the t test value is significant at 5% level for the group where the Ophthalmetron is the starting point and not for the other group. The standard deviation ($\simeq$ 0.54DS) and the correlation factor ($r \simeq$ 0.96) are the same in both groups.

In the case of retinoscopy the t test is not significant for both right and left eyes, but the S/D shows better

GROUP	$\overline{X}_1$	$\overline{X}_2$	$\overline{D}=\overline{X}_1-\overline{X}_2$	S/D	t	n	b	a	R
S v R	11.314	11.293	0.021	0.831	0.188	51	0.783	2.433	0.911
S v O	11.314	11.127	0.187	0.556	2.449	51	0.929	0.618	0.961
R v O	11.293	11.127	0.166	0.885	1.364	51	1.000	-0.170	0.889
S v R	11.399	11.385	0.014	0.452	0.211	47	0.968	0.350	0.969
S v O	11.399	11.258	0.141	0.523	1.848	47	0.978	0.111	0.960
R v O	11.385	11.258	0.127	0.728	1.196	47	0.940	0.556	0.921

Table 64: Aphakia Population. The Ophthalmetron.
Pair Analysis for mid equivalent sphere.
Top : Ophthalmetron starting point.
Bottom : Retinoscopy starting point.

agreement with the subjective for the group where retinoscopy is used as a starting point.

ii. Precision

The Ophthalmetron measurement was repeated with the same instrument for 35 eyes and with the second instrument for 38 eyes; for the Dioptron all 20 eyes were measured twice. The results are summarized in Tables, 65, 66, 67, 68, 69.

a. Variance Analysis

For all the parameters, the only significant difference was obtained for the Ophthalmetron repeatability with the same instrument for the cylinder axis at 5% level.

b. Pair Analysis

The t test for the mid equivalent sphere and cylinder power was significant at 1% level for the Ophthalmetron repetition when the second instrument was used. Similarly the t test for the Ophthalmetron accuracy is significant at 1% level for that group. The t test for the cylinder axis is significant at 1% level for the second instrument and 5% level for the same Ophthalmetron. All the other parameters considered are not significant.

The standard deviation, for the mid equivalent sphere, for the precision with the Ophthalmetron or the Dioptron is better than the accuracy when the same instrument is used, (0.21DS vs 0.65DS and 0.70 vs 1.19 DS), or identical when a second instrument is used (0.50 vs 0.55DS).
For the cylinder power the precision is identical to the accuracy for the Ophthalmetron and better for the Dioptron.

Group	Source of Variance	Sum of Square	df	Mean Square	F
Mid equivalent sphere - City	Between groups	0.760	3	0.253	0.077
	Within groups	446.300	136	3.282	
	Total	447.080		3.216	
		0.717	2	0.358	0.108
		338.332	102	3.317	
		339.049		3.260	
Mid equivalent sphere - Bradford		4.382	3	1.461	0.444
		486.958	148	3.290	
		491.340		3.254	
		1.006	2	0.503	0.169
		331.380	111	2.985	
		332.386		2.941	
Maximum positive sphere - City		1.3616	3	0.454	0.136
		452.4371	136	3.327	
		453.7987		3.265	
		0.898	2	0.449	0.131
		350.288	102	3.434	
		351.186		3.377	
Maximum positive sphere - Bradford		11.318	3	3.773	1.181
		472.805	148	3.195	
		484.113		3.206	
		3.214	2	1.607	0.549
		325.066	111	2.929	
		328.280		2.905	

Table 65 Aphakia Population Ophthalmetron Variance Analysis Results for repeatability study - mean sphere and maximum positive sphere

Group	Source of Variance	Sum of Square	df	Mean Square	F
Cyl. power - City	Between groups	1.316		0.439	0.618
	Within groups	96.724		0.711	
	Total	98.040		0.705	
		0.162		0.081	0.110
		75.079		0.736	
		75.241		0.723	
Cyl. power - Bradford		6.025		2.008	1.998
		148.768		1.005	
		154.793		1.025	
		2.412		1.206	1.398
		95.747		0.863	
		98.159		0.869	
Cyl. Axis - City		3942.23		1314.077	2.838
		62962.1		462.957	
		66904.33		481.326	
Cyl. Axis - Bradford		2134.09		711.363	0.520
		180675.29		1368.752	
		182809.38		1354.144	
		2068.98		1034.49	0.725
		141181.72		1426.080	
		143250.70		1418.324	

Table 66 Aphakia Population Ophthalmetron Variance Analysis Results for repeatability study cylinder axis and cylinder power.

a)

GROUP	$\bar{X}_1$	$\bar{X}_2$	$\bar{D}=\bar{X}_1-\bar{X}_2$	S/D	t	n	b	a	R
S v R	11.678	11.488	0.190	0.700	1.605	35	0.894	1.044	0.928
S v O_1 City	11.678	11.523	0.155	0.580	1.584	35	0.917	0.815	0.951
S v O_2 City	11.678	11.523	0.155	0.561	1.641	35	0.911	0.883	0.954
O_1 City v O_2 City	11.523	11.523	1×10^{-4}	0.219	0.008	35	0.983	0.195	0.993

b)

S v R	11.097	11.104	-0.007	0.476	-0.089	38	0.903	1.088	0.964
S v O_1 City	11.097	10.901	0.196	0.534	2.261	38	0.913	0.768	0.955
S v O_2 Brad	11.097	11.378	-0.281	0.589	-2.941	38	1.101	-0.840	0.962
O_1 City v O_2 Brad	10.901	11.378	-0.477	0.504	-5.833	38	1.173	-1.405	0.980

c)

S v R	12.528	12.339	0.188	0.709	1.571	35	0.933	0.651	0.928
S v O_1 City	12.528	12.325	0.203	0.656	1.833	35	0.926	0.719	0.937
S v O_2 City	12.528	12.264	0.263	0.639	2.439	35	0.877	1.282	0.939
O_1 City v O_2 City	12.325	12.264	0.060	0.310	1.149	35	0.932	0.783	0.986

d)

S v R	11.744	11.781	-0.037	0.409	-0.555	38	0.922	0.954	0.973
S v O_1 City	11.744	11.408	0.336	0.631	3.287	38	0.899	0.852	0.934
S v O_2 Brad	11.744	12.178	-0.433	0.649	-4.115	38	1.074	-0.433	0.948
O_{1C} v O_{2B}	11.408	12.178	-0.770	0.550	-8.635	38	1.141	-0.837	0.969

Table 67 Aphakia Population The Ophthalmetron Repeatability Pair Analysis for mid equivalent sphere a) with same instrument, b) with second instrument. Pair Analysis for maximum positive sphere c) with same instrument d) with second instrument.

GROUP	$\bar{X}_1$	$\bar{X}_2$	$\bar{D}=\bar{X}_1-\bar{X}_2$	S/D	t	n	b	a	R
S v R	11.947	11.858	0.089	0.578	0.686	20	0.850	1.704	0.856
S v R	11.752	11.637	0.115	0.636	0.650	13	0.867	1.451	0.846
S v D_1	11.947	12.573	-0.627	1.193	-2.348	20	0.719	3.982	0.560
S v D_1	11.752	12.135	-0.383	0.586	-2.359	13	0.804	2.683	0.859
S v D_2	11.947	12.573	-0.626	0.992	-2.821	20	0.868	2.201	0.691
S v D_2	11.752	12.298	-0.546	0.725	-2.715	13	0.821	2.646	0.800
S v O	11.752	12.00	-0.248	1.015	-0.881	13	1.103	-0.966	0.778
R v D_1	11.858	12.573	-0.715	0.977	-3.275	20	0.926	1.598	0.715
R v D_1	11.637	12.135	-0.498	0.536	-3.348	13	0.811	2.700	0.887
R v D_2	11.858	12.573	-0.715	0.939	-3.401	20	0.918	1.688	0.726
R v D_2	11.637	12.298	-0.661	0.765	-3.113	13	0.784	3.175	0.783
R v O	11.637	12.00	-0.363	0.847	-1.543	13	1.191	-1.863	0.860
D_1 v D_2	12.573	12.573	0.00	0.711	0.005	20	0.847	1.928	0.867
D_1 v D_2	12.135	12.298	-0.163	0.427	-1.374	13	1.0193	-0.0717	0.930
D_1 v O	12.135	12.00	0.135	1.106	0.441	13	1.102	-1.377	0.728
D_2 v O	12.298	12.00	0.298	1.332	0.807	13	0.797	2.196	0.577

Table68 Aphakia Population The Dioptron Repeatability Pair analysis for mid equivalent sphere.

a)

GROUP	$\bar{X}_1$	$\bar{X}_2$	$\bar{D}=\bar{X}_1-\bar{X}_2$	S/D	t	n	b	a	R
S v R	-1.699	-1.702	0.003	0.495	0.041	35	0.833	-0.287	0.824
S v O_1City	-1.699	-1.617	-0.081	0.472	-1.020	35	0.932	-0.035	0.855
S v O_2City	-1.699	-1.463	-0.236	0.507	-2.753	35	0.777	-0.144	0.807
O_1v O_2	-1.617	-1.463	-0.154	0.447	-2.043	35	0.768	-0.222	0.869

b)

S v R	-1.501	-1.557	0.056	0.524	0.657	38	0.755	-0.423	0.868
S v O_1City	-1.501	-1.224	-0.277	0.548	-3.115	38	0.650	-0.248	0.861
S v O_2Brad	-1.501	-1.783	0.282	0.517	3.365	38	1.024	-0.246	0.902
O_1v O_2	-1.224	-1.783	0.559	0.594	5.804	38	1.351	-0.129	0.899

c)

S v R	91.814	88.857	2.957	12.586	1.390	35	0.792	16.112	0.795
S v O_1City	91.814	99.357	-7.543	13.877	-3.216	35	1.095	-1.168	0.843
S v O_2City	91.814	101.829	-10.014	12.161	-4.872	35	0.855	23.328	0.817
O_1v O_2	99.357	101.829	-2.471	16.137	-0.906	35	0.625	39.765	0.776

d)

S v R	98.676	98.015	0.662	17.681	0.218	34	0.796	19.512	0.908
S v O_1City	98.676	107.882	-9.206	21.793	-2.463	34	0.693	39.545	0.856
S v O_2Brad	98.676	99.926	-1.25	21.189	-0.344	34	0.712	29.700	0.865
O_1v O_2	107.882	99.926	7.956	11.035	4.204	34	0.965	-4.215	0.948

Table 69 Aphakia Population. The Ophthalmetron Repeatability pair analysis for cylinder power a) with same instrument b) with second instrument and for cylinder axis c) with same instrument, d) with second instrument.

The mean difference when using the same instrument (Dioptron or Ophthalmetron) is nil while with two different Ophthalmetrons it is larger than for the Ophthalmetron accuracy (≃0.40 vs 0.16DS) for the mid equivalent sphere.

The correlation coefficient is always good, better than the accuracy for the Ophthalmetron and just smaller for the Dioptron for the mid sphere.

In conclusion, the Ophthalmetron and the Dioptron, when using the same instrument exhibit better precision than accuracy and similar precision and accuracy when two different ophthalmetron models are used in aphakia.

7.5. Clinical Experiment 5.

Repeatability of conventional and automatic Refraction in aphakia

7.5.1. Introduction

The refraction of the aphakic patient shows poorer correlation between the different methods of refraction than when dealing with low refractive error (see 7.4.). Therefore one could expect poorer precision (repeatability), but this information is not available at the moment and is investigated here. This investigation involves subjective refraction, retinoscopy and Ophthalmetron measurement.

7.5.2. Material and Method

The Ophthalmetron from the City University was used throught this experiment.

In total 8 practioners, all working full time or part time in the Hospital Eye Service and experienced with aphakic refraction, were included in this study and followed their habitual methods of retinoscopy and Subjective refraction. Three practitioners used positive cylinder and the other five negative cylinders to refract. The patient selection was similar to experiment 7.4.

The population utilised was composed of 25 patients (18 males and 17 females) aged 26 to 80 years (mean 56.36 years); of these the first 17 (13 males and 4 females) aged 38 to 80 years (mean 57.06 years; S/D 10.63 years) were tested by the same 3 optometrists (A,B,C). Therefore in total 29 eyes were studied (17 right and 12 left), 21 (11 right and 10 left) being tested by A,B and C. The recorded subjective findings varied from +6.50DS to +18.00DS and plano to -3.50DC.

The protocol used is decribed in Table 70
The order of refraction, by the various optometrists was totally random. Contrary to other studies (Safir, 1970;[149] French and Jennings, 1974[150]) with normal population the patients were not volunteers but had routine clinical appointments and to maintain as normal an environment as possible, 3 refractions on the same day was thought to be the maximal acceptable number to avoid bias caused patient tiredness and/or boredom. It was not possible to bring any of the patients back at a short notice for retest so that one could not compare further finds because of the risks of refractive changes having occured between the two visits.

Each optometrist used his/her own method of refraction, but retinoscopy always preceeded subjective refraction. For practitioners, A,B,C who examined 21 eyes the following methods were employed.

A: Streak retinoscopy (near fixation) followed by subjective right and left with negative cylinders, using best VA criterion and Duochrome.

B: Spot retinoscopy (distance fixation), followed by subjective right and left, with positive cylinders using best VA criterion.

C: Streak retinoscopy (distance fixation), followed by subjective right and left, with positive cylinders for best VA criterion and duochrome.

All Ophthalmetron measurement were undertaken by the author for the question of convenience. But this should not

1. Patient History

2. Monocular Refraction by 1st Optometrist (A,B or C) each optometrist follows his/her own method and includes frame setting, retinoscopy (and VA) Subjective (and VA) right and left.

3. Ophthalmetron measurement by author. Right and Left (and VA).

4. Monocular Refraction by 2nd Optometrist (as in 2).

5. Ophthalmetron measurement by author right and left (and VA).

6. Monocular refraction by 3rd Optometrist (as in 2).

7. Ophthalmetron measurement by author, Right and Left (and VA)

8. Keratometry by author

9. Slit lamp and Ophthalmoscopic examination

TABLE 70 : PROTOCOL FOLLOWED DURING EXPERIMENT 7.5.

REPEATABILITY OF APHAKIC REFRACTION

introduce a bias as:

a. with normal population it was shown that repeatability by two different examiners was good (Experiment 7.1.).

b. with a model eye (Experiment 5.1.) the alignment of the instrument by 3 operators was identical.

7.5.3. Results

Out of the 29 eyes studied, only 25 gave usable tracings with the Ophthalmetron (13.79% failures). All four failures occured with patients tested by practitioners A,B, and C.

The results obtained (Appendix 13) were computed for 13 mm BVD for the maximum positive sphere,mid equivalent sphere and cylinder power . Also the "mean" refractive value of the 3 refractions was calculated for each method for the maximum positive sphere, mid equivalent and cylinder (Appendix 13).

The maximum positive sphere and mid sphere were both considered here because the different refractive methods used here (positive and negative cylinders). It was possible that this differentiation introduce bias affecting one parameter more than the other, in particular for retinoscopy where neutralisation was approached for a different side ("with" vs "against" movement).

The results of the pair analysis were recorded in Appendix 14

(i) Study limited to Optometrist A,B and C

The conclusions for the t test are summarized in Tables 71 ~ 72 for each parameters concerned.

- When considering the different refractive methods

a. for the same practitioners. Optometrists A and C show the best correlation between their own subjective and retinoscopic finds, while B exhibits significant differences at 1% level both for maximum positive and mid equivalent sphere. Conversely the subjective values of B best agree with the Ophthalmetron, while A and C show significant differences for the maximum positive sphere.

b. for the various parameters considered individually, cylinder power and axis give statistically the most consistant results while the maximum positive sphere appeared the most variable parameter.

- When considering the same method:

For the subjective determination the best agreement is reached between A and C while B seems away from these: significant differences at 1 or 5% level from the two other for the maximum positive sphere and cylinder power. For retinoscopy, A and C are in closest agreement, while B is significantly different at 1% level for maximum positive sphere, cylinder power and axis.

For the Ophthalmetron, the only significant difference is at 5% level for the cyl axis.

Parameter		S v R	S v O	S	R	O
Mid equivalent Sphere	Practitioner A	Not	Not			
	Practitioner B	1%	Not			
	Practitioner C	Not	Not			
	Practitioner A v B			Not sign	1%	Not
	Practitioner A v C			Not sign (smallest)	Not	Not
	Practitioner B v C			Not	1%	Not
Maximum positive Sphere	Practitioner A	Not	5%			
	Practitioner B	1%	Not			
	Practitioner C	5%	1%			
	Practitioner A v B			Just 5%	1%	Not
	Practitioner A v C			Not	Not	Not
	Practitioner B v C			1%	1%	Not

Table 71 Summary of Pair analysis results for repeatability on mid equivalent and maximum positive sphere: t test significance.

Parameter		S v R	S v O	S	R	O
Cylinder Power	Practitioner A	Not	1%			
	Practitioner B	Not	Not			
	Practitioner C	Not	5%			
	Practitioner A v B			Not	Not	Not
	Practitioner A v C			Not	lowest	
	Practitioner B v C			1%	Not	
Cylinder Axis	Practitioner A	Not	1%			
	Practitioner B	Not	Not			
	Practitioner C	5%	5%			
	Practitioner A v B			Not	Not	Not
	Practitioner A v C			Not (Lowest)		5%
	Practitioner B v C			Not		Not

Table 72 Summary of Pair Analysis Results for repeatability on cylinder power and axis: t test significance.

Therefore it can be concluded that

a. the best precision (repeatability) is obtained by the ophthalmetron, followed by subjective (by the 3 practitioners) and Retinoscopy (by 3 practitoners).

b. streak retinoscopy seems in greater accordance with subjective refraction than spot retinoscopy for a given practitioner.

c. refraction with positive or negative cylinders do not affect precision.

For the standard deviation the conclusions are summarized in Tables 73 & 74

When considering the different methods;

the individual subjective and retinosocpic findings are in closer agreement than subjective and Ophthalmetron for all the parameters for individual practitioners.

When considering the same method individually;

the standard deviation confirms that conclusions obtained with the t test. The Ophthalmetron gives better precision than subjectives and retinoscopy by different practitioners for all parameters.

Finally the mean difference $\overline{D}$ (Appendix 14) show that retinoscopy by B and C underestimate the spherical value. For the same method A and C are closest while B underestimated the sphere compared to the other values by retinoscopy.

		S v R	S v O	S	R	O
Mid equivalent Sphere	Practitioner A	0.46				
	Practitioner B	0.70	0.75			
	Practitioner C	0.44				
	Practitioner A v B					
	Practitioner A v C			0.59 to 0.65	0.60 to 0.90	0.25 to 0.34
	Practitioner B v C				largest c B	
Maximum Positive Sphere	Practitioner A					
	Practitioner B	0.45 to 0.60	0.79 to 0.80			
	Practitioner C					
	Practitioner A v B					
	Practitioner A v C			0.65 to 0.71	0.66 to 1.00	0.31 to 0.44
	Practitioner B v C				(lower A v C)	

Table 73 Summary of Pair analysis results for repeatability on mid equivalent and maximum positive sphere: standard deviation values.

		S v R	S v O	S	R	O
Cylinder Power	Practitioner A	0.36	0.58			
	Practitioner B	0.26	0.65			
	Practitioner C	0.34	0.85			
	Practitioner A v B			0.54	0.60	
	Practitioner A v C			0.66		0.30 to 0.57
	Practitioner B v C			0.45	0.53	
Cylinder Axis	Practitioner A	9.5^{o}				
	Practitioner B	8^{o}	12^{o} to 16^{o}			
	Practitioner C	4^{o}				

Table 74 Summary of pair analysis results for repeatability on cylinder power and axis: S/D values.

Additive frequency study

The mean values obtained by each method were computed (Appendix 13). For the mid equivalent sphere and cylinder power the additive frequency of the individual retinoscopic and Ophthalmetron readings were compared to the mean subjective (Table 75). The mean subjective can be considered as the best estimate of the refraction.

The results show that the Ophthalmetron is better than retinoscopy to estimate the spherical part of the refraction as determined subjectively at 0.50DS level (72.55% vs.58.82%). The opposite conclusion applies to the cylinder power.

(ii) Study involving all the practitioners

Because of the large number of practitioners the refractive values obtained were computed in the same order as they were recorded, without taking into account the practitioner involved. (Appendix 13).

Using the t test it showed that

a. As expected, no experimental bias introduced by the different practitioner is present and $S_1vR_1, S_2vR_2 \ldots\ldots$ show the same level of significance.

b. The t test also confirms that there is no bias due to tiredness, results for refraction (3) are comparable to those for refraction (1). On the basis of standard deviation.

it showed that

c. The conclusions reached for the controlled group A,B,C on the different methods are applicable to this larger group, similar S/D values are obtained for n = 29,25 and 17 for individual parameters.

(A)

	Sm vs R ind %	Sm vs O ind %
$\leq \pm$ 0.25	33.33	41.18
$> \pm$ 0.25 $\leq \pm$ 0.50	25.49 58.82	31.38 12.56
$> \pm$ 0.50 $\leq \pm$ 1.00	23.53 82.35	11.76 84.32
$> \pm$ 1.00 $\leq \pm$ 1.50	11.76 94.11	7.84 92.16
$> \pm$ 1.50	5.89 100.00%	7.84 100.00%

(B)

	Sm vs R ind %	Sm vs O ind %
$\leq \pm$ 0.25	49.02	25.49
$> \pm$ 0.25 $\leq \pm$ 0.50	29.41 78.43	23.53 49.02
$> \pm$ 0.50 $\leq \pm$ 1.00	19.61 98.04	35.29 84.31
$> \pm$ 1.00	1.96 100.00%	15.69 100.00%

Table 75 Aphakic Population - Repeatability -Additive Frequency Results:

(A) Mid equivalent Sphere

(B) Cylinder Power

(Top value = % of cases in group.
Bottom value = additive frequency.

Sm = mean subjective value for each incividual
R ind = individual Retinscopic findings;
O ind ——— Ophthalmetron findings)

7.6. Clinical Experiment 6: Post Operative Follow up

Both cataract extraction and corneal grafting aim to re-establish clear ocular media instead of the previously opaque or scarred; they give a totally new refractive status to the eye operated on. But before settling down to its new refraction the eye goes through a recovery period of variable duration.

The Ophthalmic Surgeon follows closely this recovery phase, mainly by means of biomicroscopic and ophthalmoscopic examination. The only objective indication of the refractive changes taking place is obtained by means of keratometry.

The optometrist is also interested in the progress of the operated eye: when can the first prescription be issued to the patient in a definitive form? In aphakia, a minimal period of six weeks is usually considered necessary, but this does not take into consideration individual variations. The only alternative to this would be to perform, at each visit, keratometry and a full routine monocular refraction.

Keratometry, however, gives information limited to the para central corneal radii and it has been shown (7.4.) that its correlation to the cylindrical part of the subjective refraction is only weak. Further it gives no indication of the spherical component or of changes not linked to the cornea.

The alternative is to refract the patient accurately, (ideally the same practitioner should repeat the refraction) at each visit. But refraction of post operative patients is often difficult and time consuming and renders this alternative non acceptable in terms of the clinical time involved.

The obvious solution is therefore to train anxillary or nursing staff to perform automatic refraction at each visit. This does not take longer than to perform keratometry and gives information concerning the whole eye and indicates for each patient at which time the final correction can be prescribed.

Further there is a great advantage in using an optometer producing an analog tracing (ie the Ophthalmetron) than one giving a digital print out (i.e. the Dioptron). In the post operative period often the refraction is irregular and it is more useful to know that than to obtain the spherocylindrical values representing the best fitting regular curve as determined by the computer.

Two examples are given here to illustrate this particualr use of the Ophthalmetron.

Example 1: Patient PR, male, aet - 22 years, Marfan Syndrome. Left intracapsular extraction (cryo extraction) with limbal incision and peripheral iridectomy.

Day 2

Ophthal: No interpretable results (fig 62)

Retinos: +13.00/-4.00 x 167½ $6/12^{-3}$ (scissors mvt) BVD = 16mm

Subjective: +13.50/-3.50 x 170 $6/9^{-2}$ BVD = 16 mm

Kerat: 8.05 al 170/7.60 al 90 (Distortions +)

Day 3

Ophthal: +11.00/-1.25 x 170 BVD = 13 mm (fig 63)

Retinos: +12.50/-4.00 x 165 $6/12^{+3}$ (Some distortions) BVD = 14mm

Subjective: +13.00/-2.75 x 165 6/9 BVD = 14 mm

Kerat: 8.15 al 175/7.70 al 87½ (Regular)

Day 6

Ophthalmetron: +10.75/-0.87 x 145 6/9^{-} BVD = 13 mm (fig 64)

Retinoscopy: +12.00/-2.50 x 100 6/18 BVD = 16 mm

Subjective: +12.50/-2.50 x 150 6/9$^{-1}_{+1}$ BVD = 16 mm

Keratometry: 8.30 al 150/7.80 al 60 (slight distortion)

Day 20

Ophthalmetron: +10.57/-3.00 x 130 6/9^{+} BVD = 13 mm (fig 65)

Retinoscopy: +11.25/-3.50 x 135 6/6^{-3} BVD = 12 mm

Subjective: +10.75/-3.50 x 130 6/6$^{-1}_{+1}$ BVD = 12 mm

Keratometry: 7.50 al 35 8.30 al 120 (Regular)

Day 48

Ophthalmetron: +11.00/-3.75 x 135 6/6 (fig 66) BVD = 13 mm

Retinoscopy: +12.00/-4.00 x 130 6/9 BVD = 13 mm

Subjective: +11.00/-4.00 x 130 6/6 BVD = 12 mm

Keratometry: 7.65 al 35 8.50 al 125 (regular)

The refraction changed little between Day 20 and 48 subjectively. The same tendancy (and regular tracings) is demonstrated by the Ophthalmetron. Both would lead to give a final prescription on day 48.

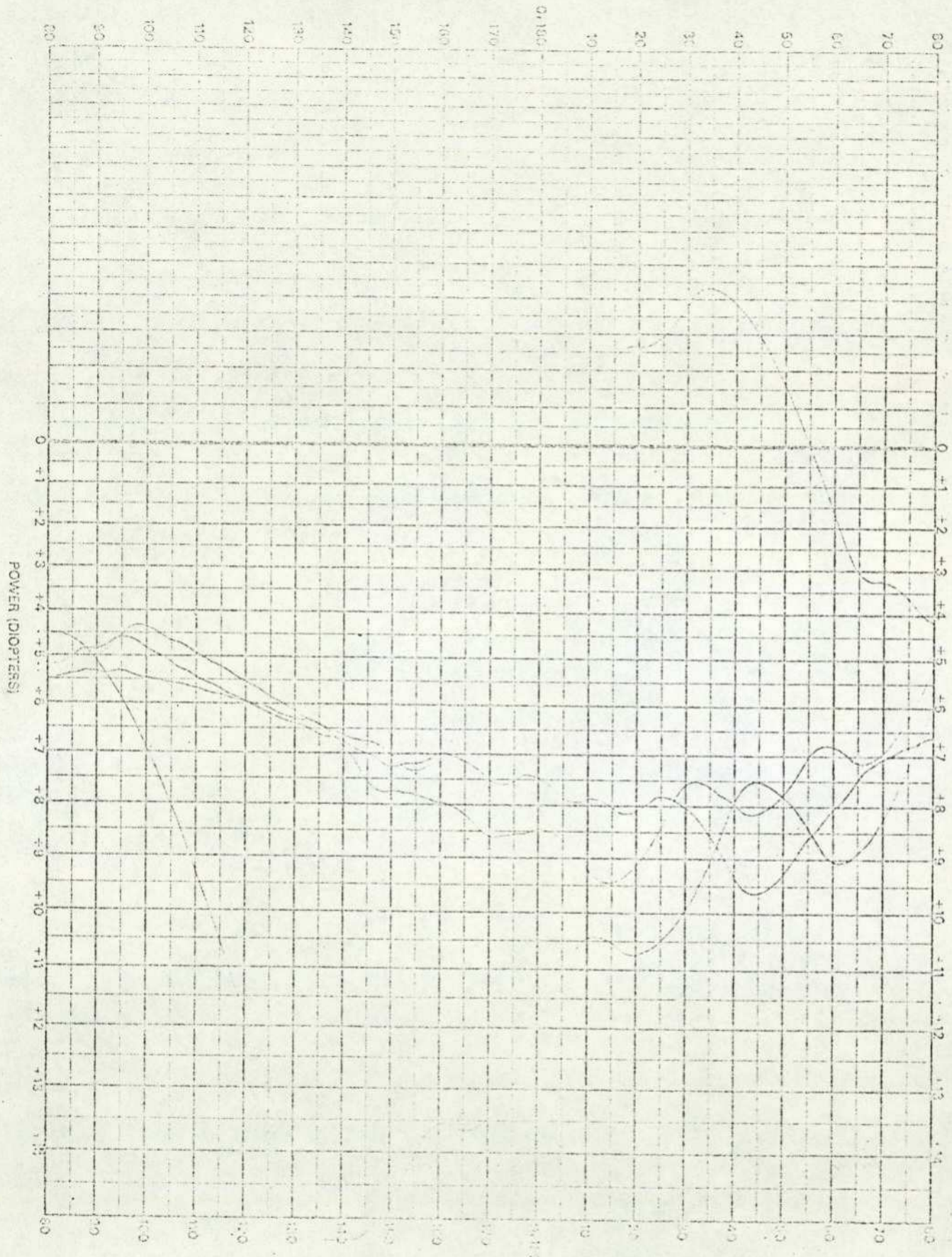


Fig. 62. The Ophthalmetron Aphakia Post Operative follow up Day 2

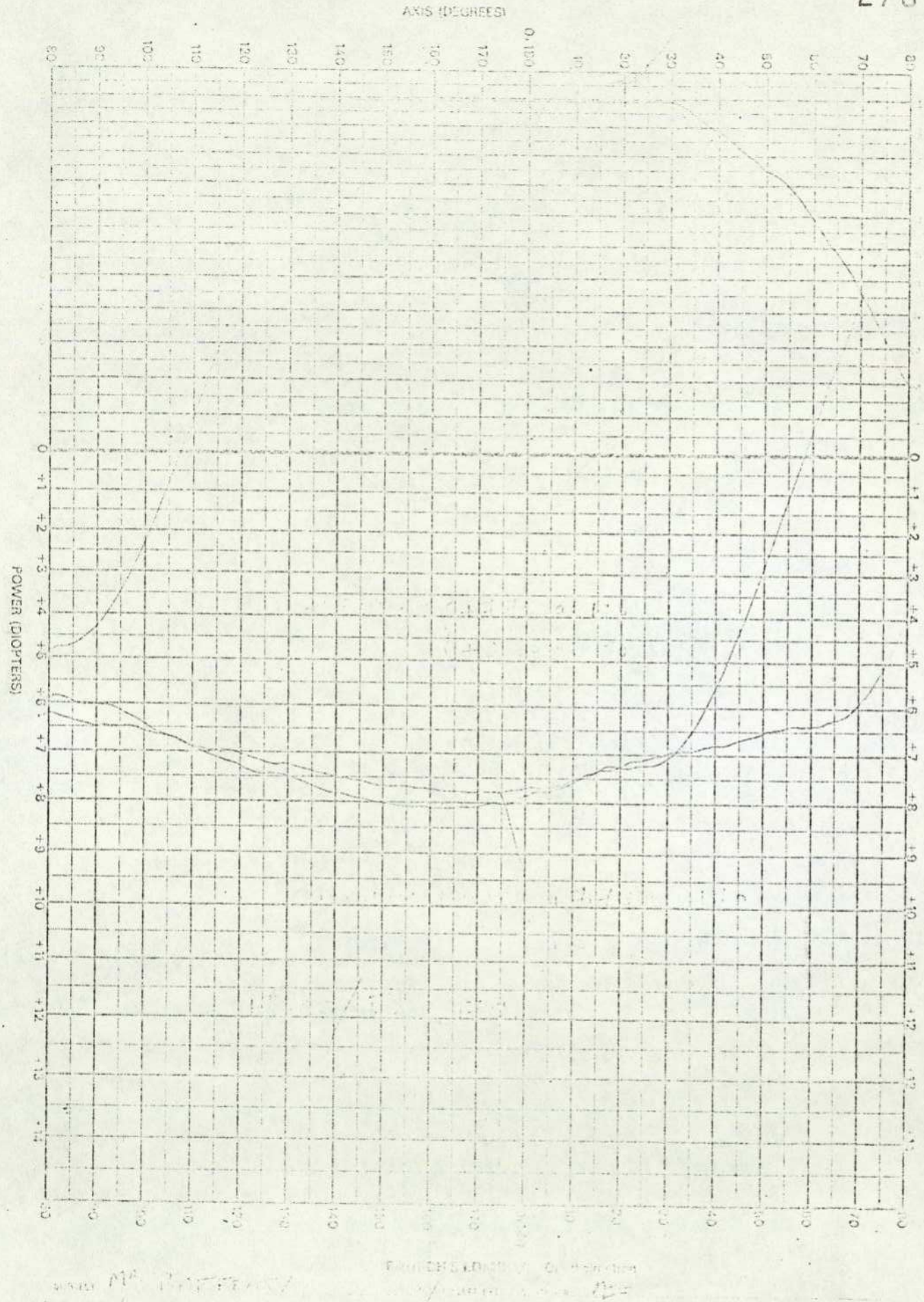


Fig. 63 : Day 3

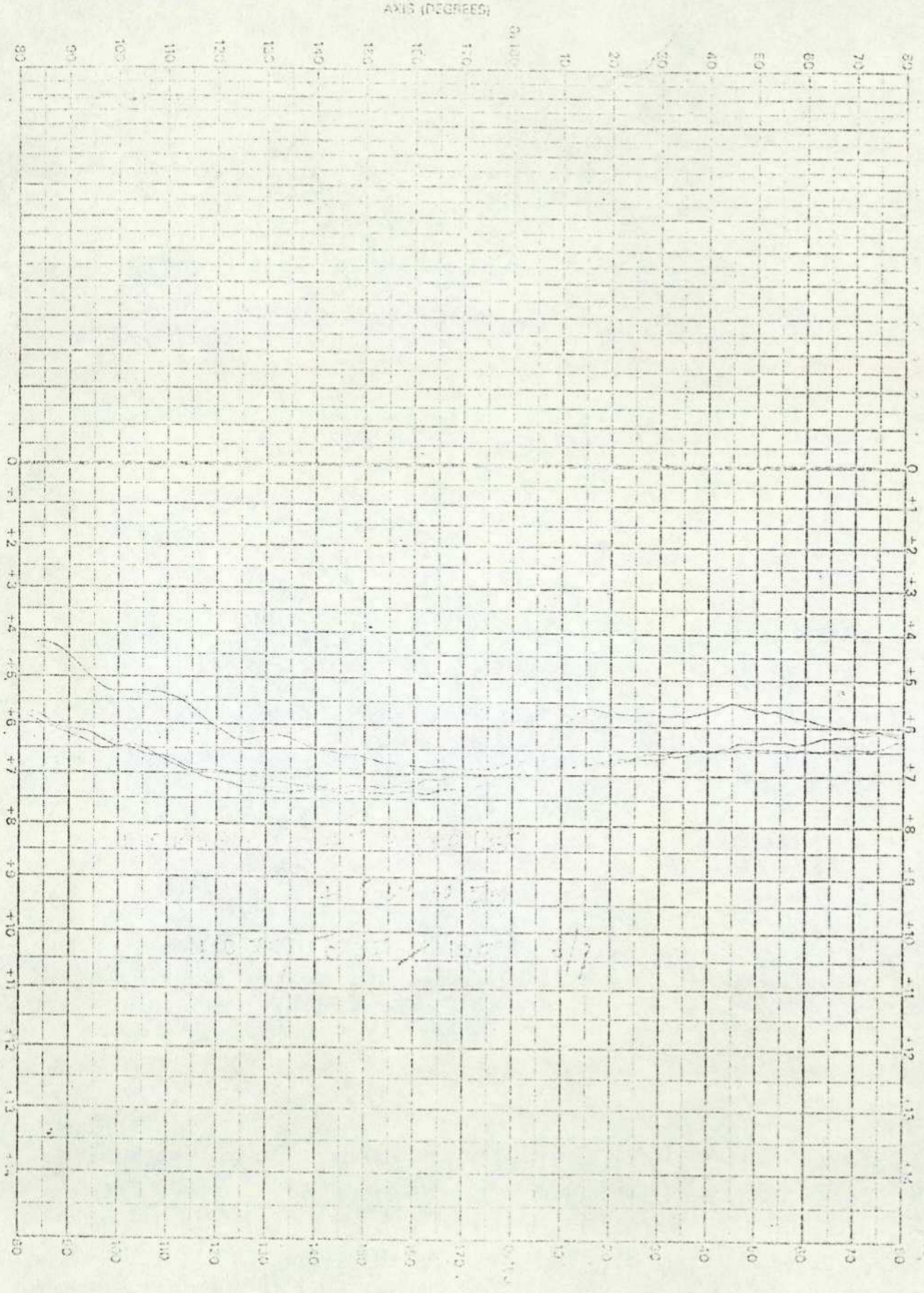


Fig 64: Day 6

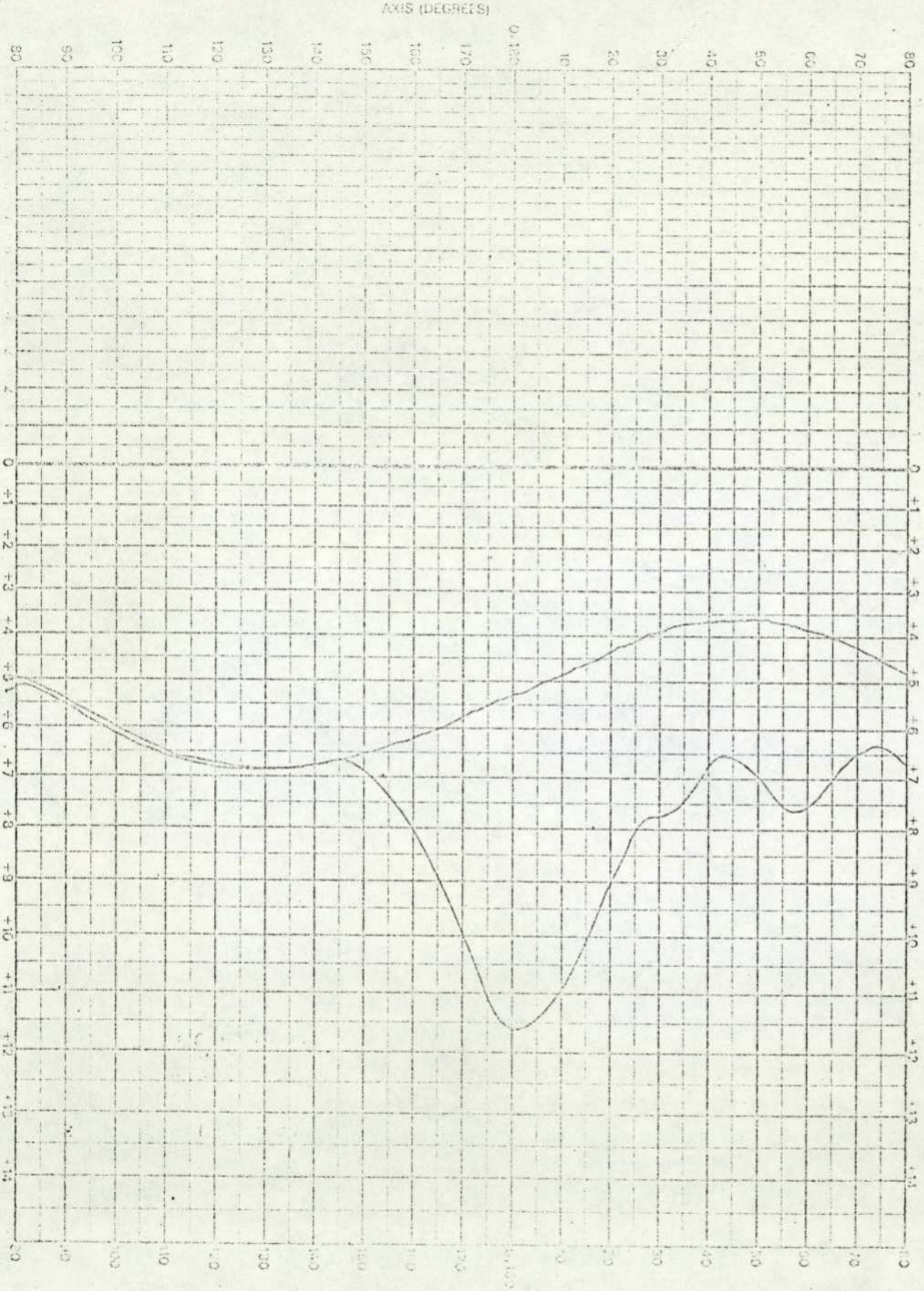


Fig 65 Day 20

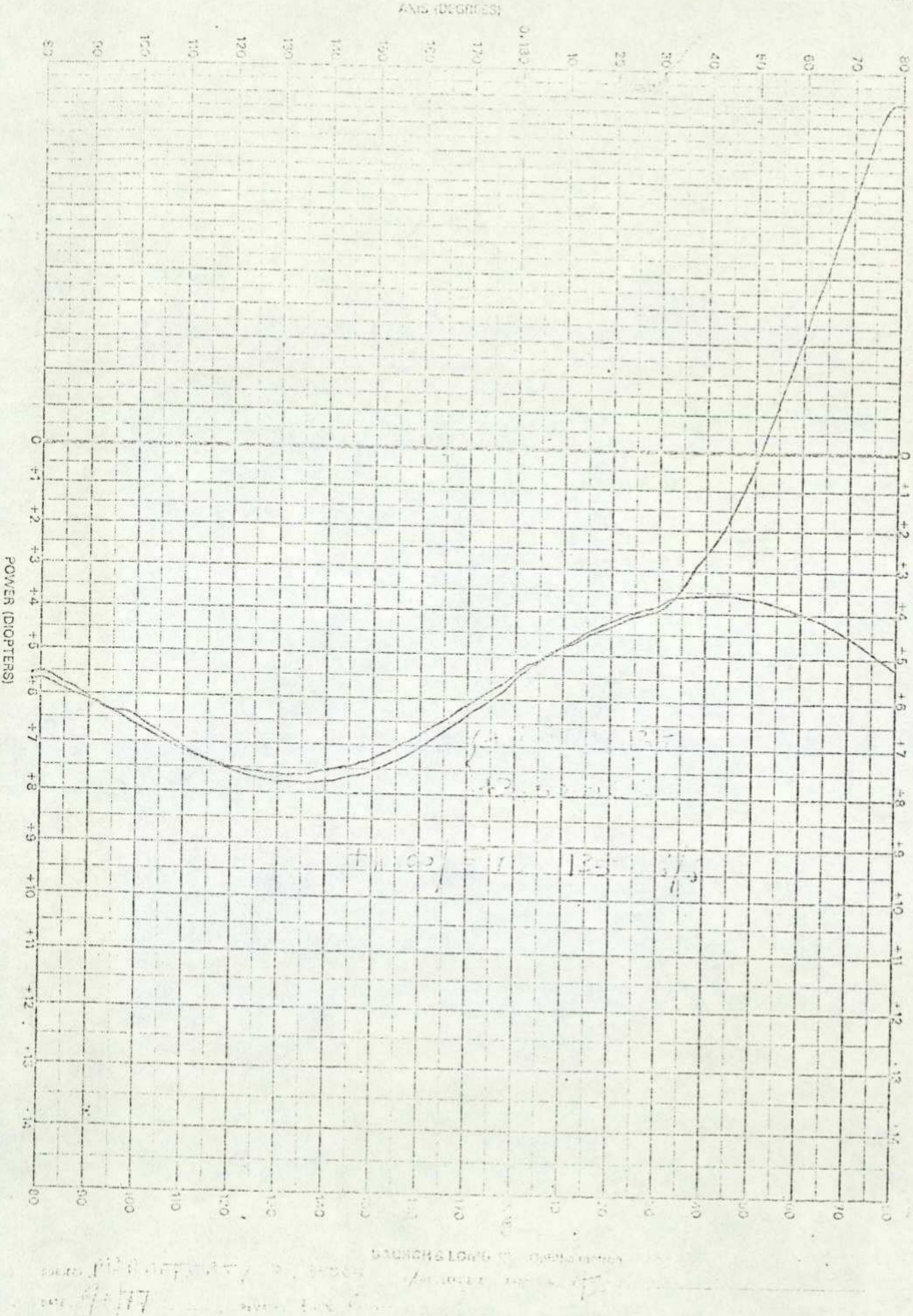


Fig 66: Day 48

Example 2: Patient ME female, aet 45 years, Keratoconus.

Left penetrating graft, 7 mm diameter.

Day 3:

Ophthalmetron:	+9.50/-2.25 x 130 or 145 (fig 67)
Retinoscopy:	+8.50 DS ? 3/18 (Poor reflex - dim) BVD = 18 mm
Subjective:	+9.00/-2.00 x 140 3/18 BVD = 18 mm
Keratometry:	8.80 ? al 175 ? a l 90 ? (very distorted)

Day 7:

Ophthalmetron:	Peak at 10.75 D al 150 BVD = 13 mm (fig 63)
Retinoscopy:	+10.50/-4.00 x 165 $3/9^{-2}$ $6/12^{-1}$ BVD = 18 mm
Subjective:	+12.00/-4.00 x 130 $6/12^{-}$
Keratometry:	9.40 al 180 ? very distorted

Day 15:

Ophthalmetron:	+9.75/-2.75 al 155 $6/18^{-1}_{+2}$ BVD 13 mm (fig 69)
Retinoscopy:	+12.50/-3.50 x 155 6/36 (Split reflex)
Subjective	+12.00/-4.00 x 130 $6/12^{-1}_{+1}$ BVD = 13 mm
Keratometry:	Distortions. Greasy tear film does not allow measurement.

Day 43:

Ophthalmetron:	+8.75/-2.25 al 165 $6/12^{-1}$ BVD = 13 mm (fig 70)
Retinoscopy:	+10.50/-3.00 x 160 6/18 BVD = 10 mm
Subjective:	+10.00/-2.00 x 160 $6/9^{+3}$ BVD = 10 mm
Keratometry:	9.70 al 160 10.00 al 70 (very distorted)

Day 54:

Ophthalmetron: +11.75/-3.25 x 10 or 180 (fig 71)

Retinoscopy: +12.00/-1.00 x 160 6/36 (opacities within reflex) BVD = 13 mm.

Subjective: +14.00/-2.00 x 175 $6/9^{-2}$ (fluctuating VA and dioptric value) BVD = 13 mm.

Keratometry: 10.60 al 160? al 11.00 al 70 ? (distortions ++)

Day 97:

Ophthalmetron: +9.00/-4.00 x 10 6/18 BVD = 13 mm (fig 72)

Retinoscopy: +8.50/-2.50 x 160^{-1} BVD = 11 mm

Subjective: +9.00/-2.50 x 30 $6/12^{+3}$ BVD = 11 mm

Keratometry: 9.40 al 180 9.10 al 90 (distortions +)

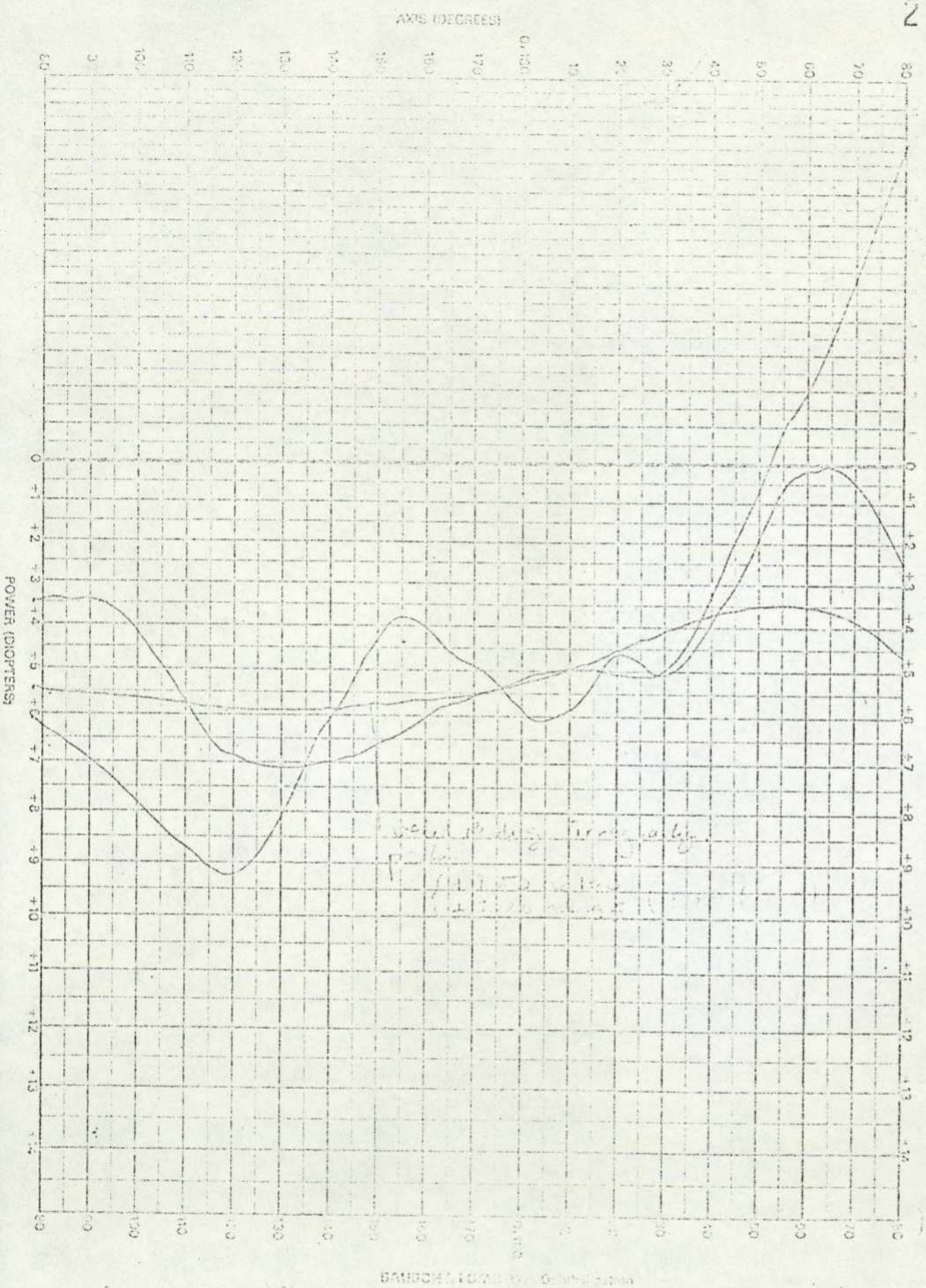


Fig 67 The Ophthalmetron Corneal Graft Post Operative follow up Day 3

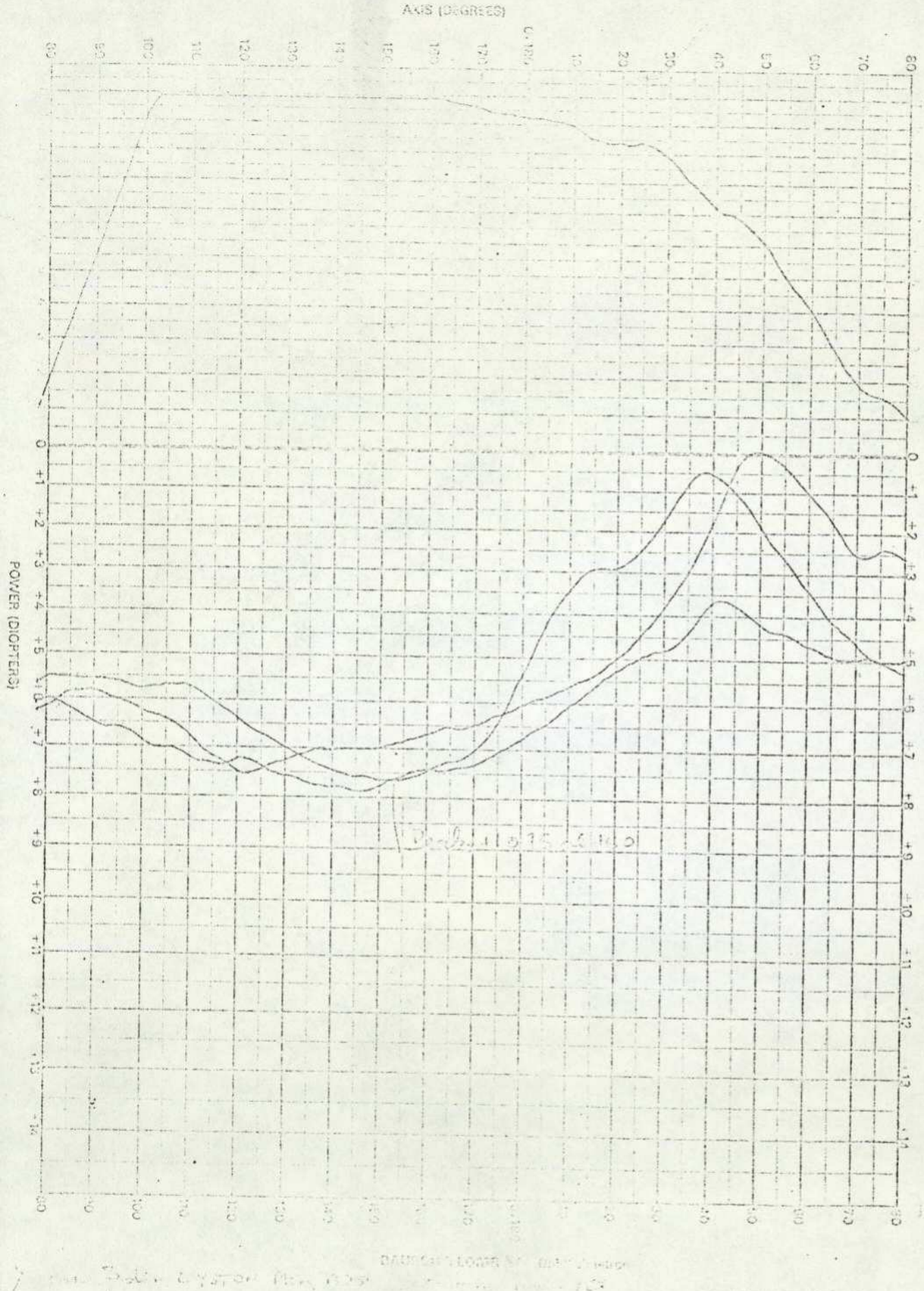


Fig. 68 Day 7

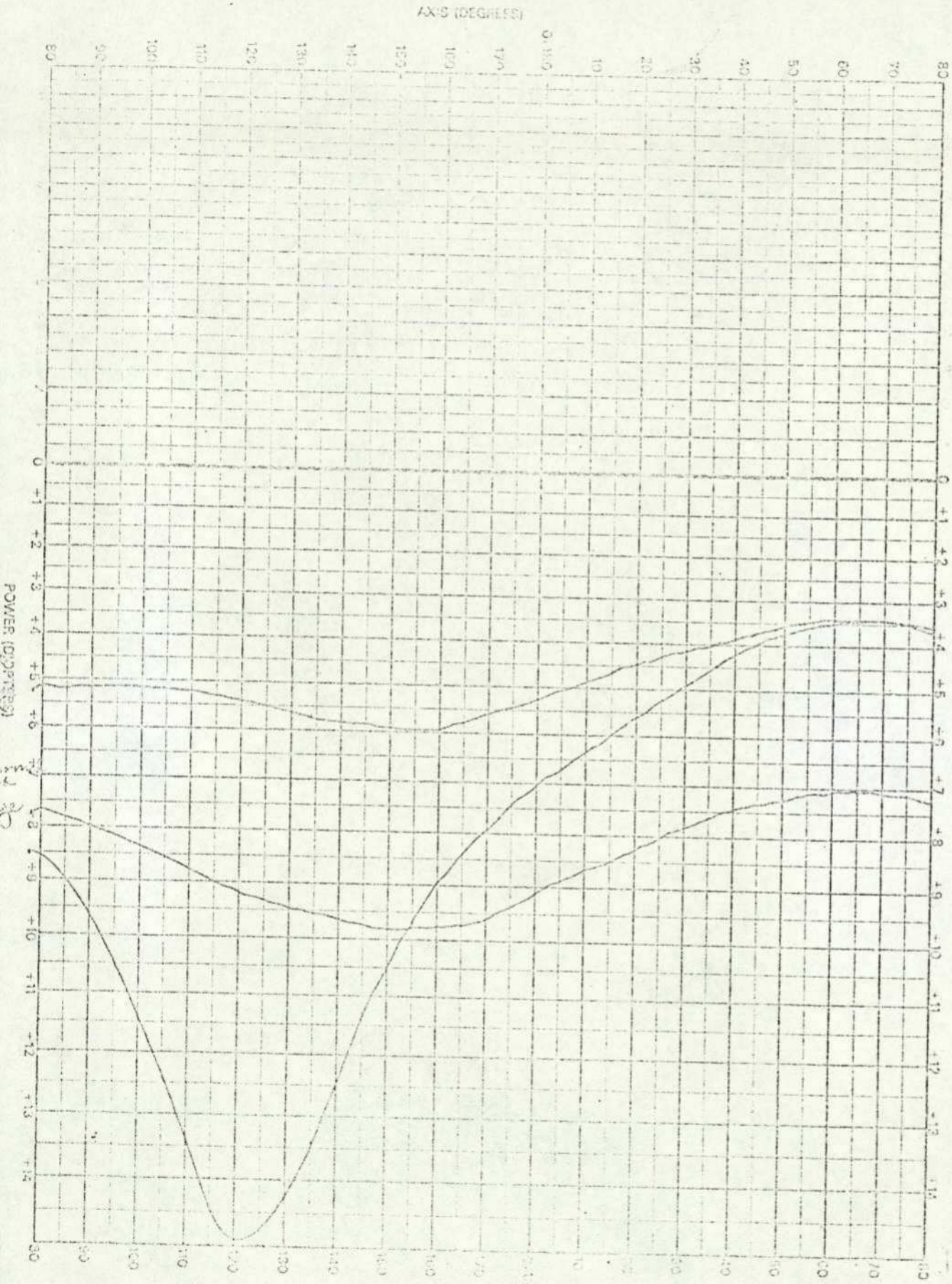


Fig 69 Day 15

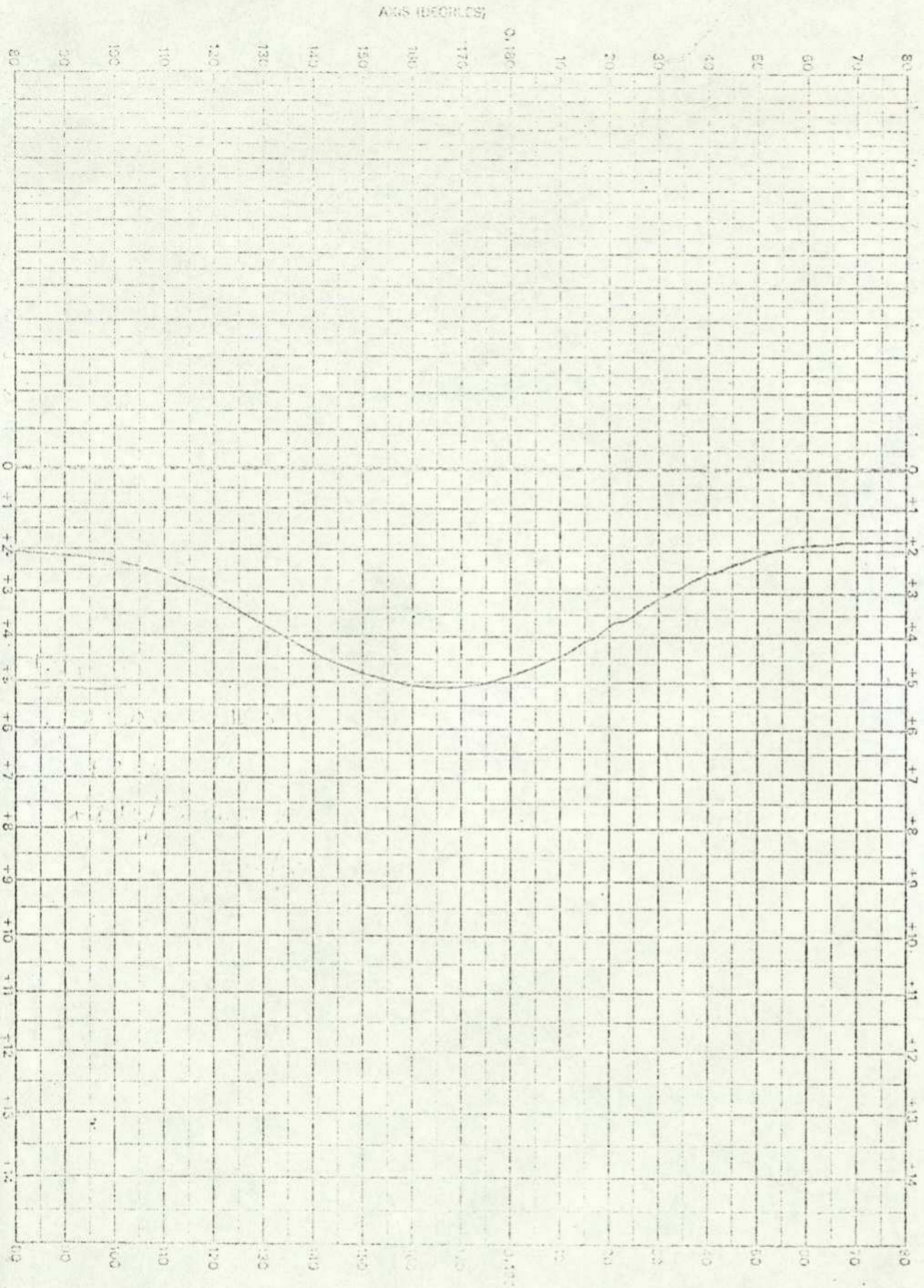


Fig. 70 Day 43

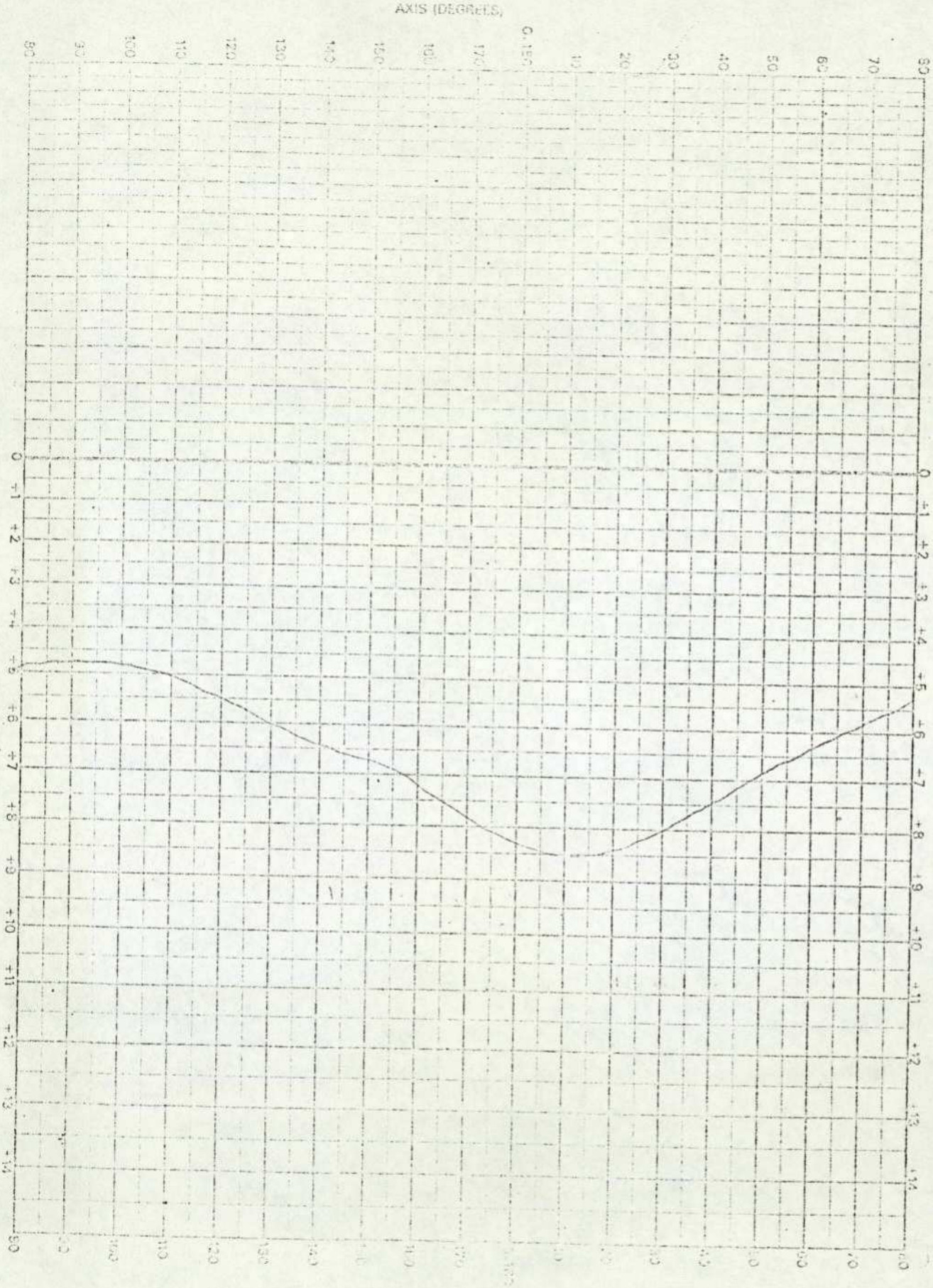


Fig 71 Day 54

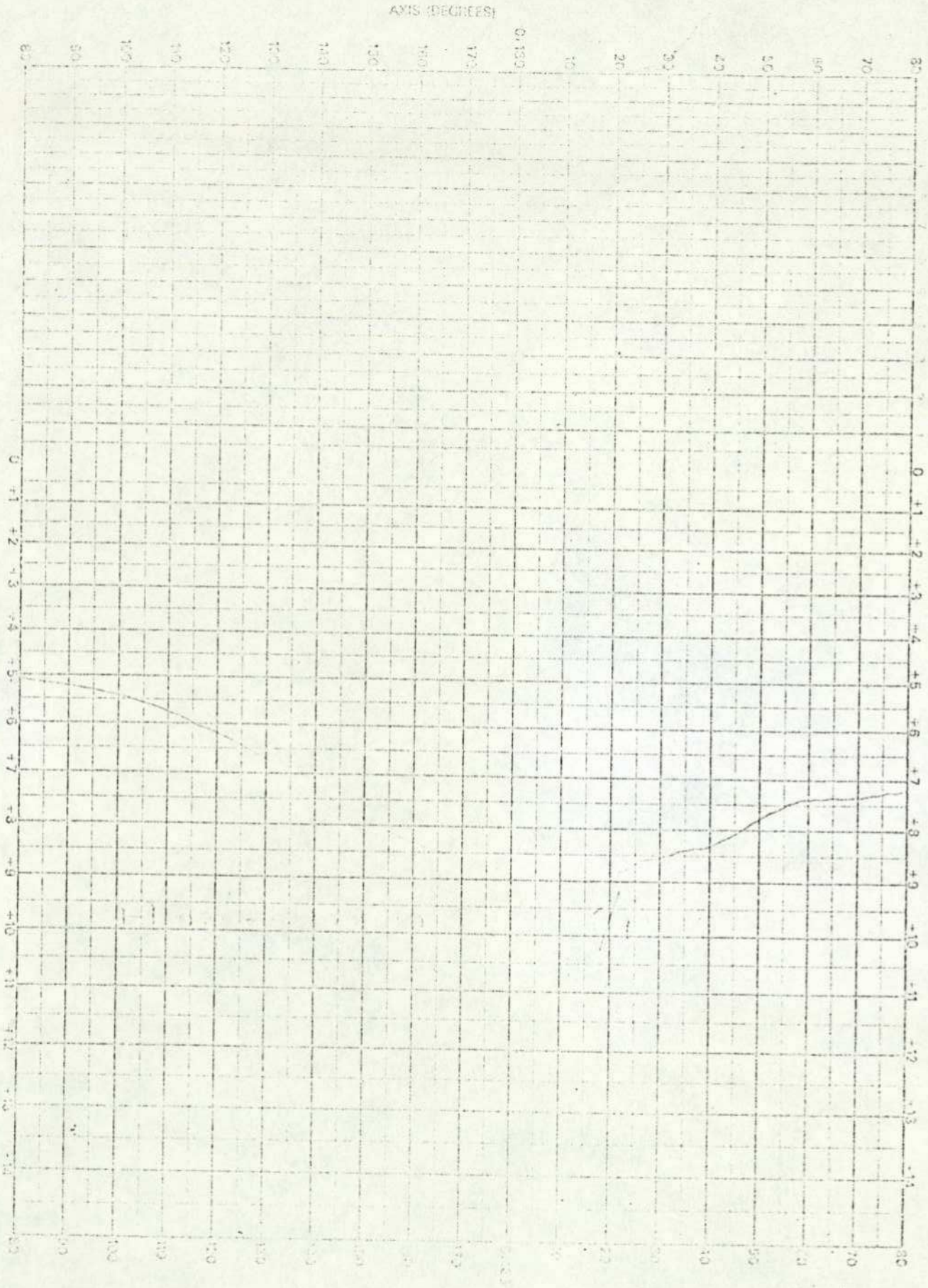


Fig. 72 Day 97

7.7 Analysis of Results by Safir's Method

The accuracy of refraction can be considered as a whole by using formula Δ (see6.3.). This has the advantage of representing the real situation for which the error on the cylinder power for example could minimize the influence of the spherical error or vice versa (i.e. -1.00/-2.00 x 45 vs. -1.25/.2.25 x 45 -1.25/-1.75 x 45).

This approach is applied to the aphakic population studied with the Ophthalmetron and giving results for all three methods (Subjective, Retinoscopy and Ophthalmetron). The results obtained are recorded in table 76 .

The pair analysis applied to the values of for subjective vs Retinoscopy and for subjective vs Ophthalmetron show that the mean Δ for retinoscopy (Δ = 6.254) is greater than Δ for the Ophthalmetron (Δ = 5.782). This therefore demonstrates that the Ophthalmetron gives a better estimate of the subjective refraction than retinoscopy. That conclusion was not previously possible: the results for the different parameters were contradictory (S/D for the spherical value was smaller with the Ophthalmetron and for the cylinder axis smaller by retinoscopy) and there was no way of knowing which error was the most influencial.

Further by applying the t test to the two set of values it is possible to see if the difference is significant (t = 0.550)

In clinical terms, the delta values supply a single scale to measure the influence of errors on various parameter, and table 77 gives a list of values obtained by comparing different refractive errors to zero.

Name	SvR	SvO	Name	SvR	SvO	Name	SvR	SvO	Name	SvR	SvO
H.A.[1]	4.043	2.502	D.G.	5.818	3.697	D.R.	5.794	5.784	A.C.[#2]	6.834	8.795
H.A.[2]	1.204	6.415	J.G.	2.938	1.223		8.306	3.597	D.J.	1.531	2.50
J.A.	3.660	7.268	K.G.	6.402	5.413	I.R.	0.763	3.703			
C.B.	7.074	5.356				J.R.	4	1.531			
D.B.[1]	31.013	18.955	R.G.[2]	1.441	4.083	O.R.	1.706	5.248			
D.B.[3]	8.778	9.108	A.H.	3.169	7.216	P.R.	6.325	5.314			
D.B.[4]	1.768	5.377				R.R.	4.349	10.196			
E.B.[1]	4.722	6.351	L.H.[2]	2.774	5.227	A.S.	5.940	9.274			
E.B.[2]	5.091	5.367	P.H.	9.378	10.382	B.S.	10.349	14.576			
J.B.	8.5	5.380	E.K.	4.394	3.771	E.S.[1]	2.544	4.755			
L.B.	1.603	2.443	J.K.[2]	10.103	7.036	E.S.[2]	1.6	1.531			
M.B.	4.890	8.857	M.K.[1]	5.687	8.927	E.S.[3]	10.352	7.5			
R.B.[1]	0.759	5.114	C.L.	2.625	2.550	H.S.[1]	6.381	4.018			
R.B.[2]	2.3	3.686		2.696	5.134						
V.B.	6.154	12.318	M.L.[2]	6.303	4.680	J.S.[1]	4.173	7.722			
W.B.	0	5.262	A.M.	5.180	3.936	J.S.[3]	9.340	9.998			
B.C.	3.183	5.038	E.M.[1]	10.208	12.450	K.S.	10.938	9.866			
	3.011	3.767	E.M.[2]	6.736	10	W.S.	5.282	5.236			
D.C.[1]	4.858	6.768	F.M.	38.751	12.372	M.T.[1]	7.046	2.519			
	2.280	4.830	I.M.	3.215	2.948	M.T.[2]	4.071	7.366			
D.C.[2]	8.765	4.534	J.M.	2.888	5.322	A.W.[1]	13.355	2.656			
	2.283	3.148	T.M.	1.945	4.220						
D.C.[3]	3.792	5.768	D.McK.	0.610	5.670	A.W.[3]	76.144	4.777			
I.C.	3.024	4.961	D.N.	8.407	6.420	B.W.	3.640	1.879			
M.C.	0.616	8.711	C.P.	7.242	10.178	G.W.	5	6.144			
R.C.[2]	4.151	4.535	E.P.	8.038	11.944	J.W.	3.235	5.327			
J.D.	4.465	10.419	H.P.	3.673	5.369	L.W.	3.646	0.614			
K.E.	2.595	8.301	M.P.	9.915	4.950	P.W.	5.373	4.050			
C.F.	2.190	4.071	S.P.	5.281	17.277	W.W.	7.124	1.910			
M.F.	4.878	3.566		3.572	1.501		1.283	2.110			
V.F.	7.263	5.188	W.P.	3.784	2.714	B.Y.	7.222	3.423			
	1.149	3.589		4.067	4.033		12.171	6.386			
C.G.	7.632	4.635	A.R.	4.8	2.836	A.C.[#1]	4.796	3.445			

Table 76: Delta valves for subjective Vs Retinoscopy and subjective Vs Ophthalmetron for main aphakic group

Refractive error	Delta
0.50 DS	5.00
1.00 DS	10.00
0.50 DC	3.06
1.00 DC	6.12
5° ≠ on 1 DC	0.62
10° ≠ on 2 DC	1.24
5° ≠ on 2 DC	1.24
10° ≠ 2 DC	2.48

Table 71: Delta valves for various refractive errors compared to plano

8. DISCUSSION AND CONCLUSIONS

The clinical accuracy obtained for the different methods for various groups have been individually discussed. It is now necessary to look at the theoretical accuracy obtainable and the influence of the various factors affecting it (with the exception of accommodation, already discussed) and to establish whether or not they introduce an unacceptable bias. The groups considered will be the aphakic and cyclopegic ones. The factors involved have interacting effects and are of 3 sorts: achromatic and chromatic aberrations, and retinal reflection. They will be discussed separately with a final appraisal of their interaction.

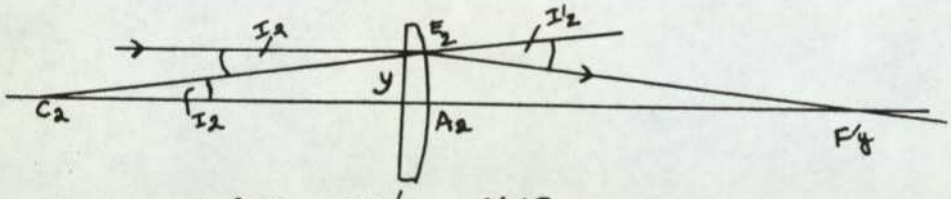
The chromatic aberration is of particular interest because of the I/R nature of the detecting light used with the electronic optometer. The chromatic aberrations have been well documented in the literature both by experimental determination and by calculation. The earliest work is due to Young (1801) [151] who obtained a value of 1.3 D between the two ends of the spectrum by subjective methods. Later Ames and Proctor (cited by Jenkins 1936) [152] and Hartridge (1947) [153], Ivanoff (1953) [154] and Jenkins (1963) [155] obtained similar values: 1.45 D chromatism between C and G lines for Ivanoff; a mean of 1.58 D (range 1.20 to 1.90) for the range 445 to 670 nm. Jenkins also found the aberration for white light compared to 575 nm to be + 0.12 D and to decrease with a decrease of the pupil diameter.

The previous determinations were subjective and a criterion of focus has to be taken into account; this criterion was established by Koomen, Tousey and Scolnik (1951) [156] to be 0.80 DS. Charman and Jennings (1976) [157] compared the chromatic aberration obtained objectively and subjectively and concluded to a good agreement with, however, a variable discrepancy according to the wavelength. The objective methods gave a more positive value in the blue (+0.15) and more negative in the red(-0.05) with no difference at 540 nm. Their objective method used a double ophthalmoscopic system and different retinal reflective layers could be thoughtto affect the measurement. No definite conclusion was however possible as the change in the focusing criterion can be up to 0.2 D.

The calculated values assuming the refractive index of water obtained by Tucker (1974) [158] agreed with the experimental findings. For the reduced eye, assuming n = 1.333, an emmetropic eye of power + 60.00 D will have a radius of 5.555 mm, giving for n = 1.3276 (value for λ = 850 nm) a power of + 58.97 D, therefore an aberration of 1.03 D. For the aphakic eye no experimental data are available but following the same calculation and assuming a single surface of radius 7.8 mm. the values will respectively be + 42.73 D and + 42.00 D, therefore an aberration of 0.73 D.

Monochromatic aberrations are divided into defects of the axial pencil (spherical aberration) and defects of the oblique pencil (coma, oblique astigmatism, distortion, curvature of image). Both the aberration produced by the eye and the corrective lens have to be considered. For the eye itself Bennett (1954) [159], using Gullstrands simplified schematic eye found for 3^{o} eccentricity a difference ≤ 0.2D. Duke Elder (1972) [160] commenting on central vision that the effect of aberrations relevent to a point off axis are "negligibly small".

The aberrations produced by the corrective lens are only of significance for high power lenses as in aphakia. Spherical aberration could affect the accuracy in this case but using an exact calculation as advocated by Bennett (1977) [161] proves this to be minimal e.g. for +20.00 DS lens and a centration error of 2 mm gives a spherical aberration of 0.14 DS.



$r_2 = A_2C_2 = 523/20 = 26.15\text{mm}$

$I_2 = \arcsin y/r_2 = 2/26.15 = 4°35'$

$I'_2 = \arcsin(n \sin I_2) = 6°689$

$\left.\begin{matrix}\\\\\end{matrix}\right\} I'_2 - I_2 = 2°.303$

Triangle $C_2 E_2 F'_y$

$C_2F'_y = r_2 \dfrac{\sin I'_2}{\sin(I'_2 - I_2)} = 75.800\text{mm} \rightarrow A_2F'_y = C_2F'_y - r_2 = 49.650\text{mm}$

$\rightarrow$ Lens power at $y = 1000/49.65 = +20.14\text{D}$.

In conclusion accurate centration of the lens is required and the method used experimentally giving an

accuracy of $\pm$ 1.00 mm. is shown to be suitable.

The defects linked to oblique pencils are of importance: if the lens is tilted with regard to the patient's line of sight (pantoscopic angle different to O) a spherical lens could have a different effective spherical power and induce astigmatism. These are given by Borish (1970) [162]

$$\text{new fs} = \text{fl} + \frac{\sin^2 \theta}{2n} \qquad \theta = \text{angle of tilt.}$$

$$\text{induced Fcyl} = F \times \tan^2 \theta$$

The method used experimentally gave an accuracy of $\pm$ 2½° and showed the aberration to be negligable (eg. for + + fl = +20.00 DS and θ = 2½°

new fs = +20.01 DS and induced cyl = 0.04 axis 180)

The nature of the retinal reflection and the position of the reflecting layer have been the subject of numerous studies. Varying opinions have been expressed and can be grouped as follows:

- Reflection at the pigment epithelium: Brindley and Willmer (1952) [163], Fry (1967) [164], Hodd (1951) [165], Borish (1954) [166].

- Reflection at the choroid : Brindley and Willmer (1952), Ham (1975) [167], Weale (1966) [168], Le Grand (1965) [169], Walls (1942) [170].

- Reflection at the vitreous retinal interface: Hirschberg (1882), Beer (1894), Kahneman (1930) (All cited by Millodot

(1972))[171], Glickstein & Millodot (1970) [172].

The opinion concerning the type of reflection varies from that of perfect diffuser(Brindley & Willmer (1952)[173], Ham (1975) [174], Vos Munnik and Boogaard (1965) [175], Le Grand (1965)) [176] to a mixed type partly specular (usually anteriorly) and partly diffuse (due to the deeper layers)

The present writer's opinion is that more than one layer is responsible for fundus reflectance and depending on the layer concerned, the type of reflection varies. This is based on the recent work of Millodot (1972) [177] and several clinical observations.

For retinoscopy the nature of the reflection is specular. This was already claimed by Hodd (1951) [178] and clinically supported by the fact that the brightness of the reflex is only slightly affected by decrease in pupil diameter. Millodot establishes beyond doubt that the layer responsible for the reflection is the vitreous-retina interface: the refractive index of the vitreous being superior to that of the retina. This is further supported by the clinical appearance of the human fundus when observed by ophthalmoscopy. In the young, there is a sheen present in front of the retinal details; this sheen disappears in older subjects and this corresponds to a decrease in the refractive value of the vitreous-retina interface. The proteinic content of

the vitreous increases with age (Boyer et al (1956) [179] cited by Duke Elder (1972))

All these parameters are now considered together and their effect on the clinical data obtained is analysed.

When comparing retinoscopy to subjective the problem of chromatic aberration is not relevant and only the difference in reflecting layers and monochromatic aberrations could affect the results. For the young group studied under cycloplegic, the mean difference $\bar{D}$ is between retinoscopy and subjective is near zero (0.066) for the mid-equivalent sphere, revealing more myopia by retinoscopy. This is in slight disagreement with Millodot and O'Leary (1978) [180] who found for a similar age group a mean difference 0.25 DS. The detailed experimental method of the latter work is not at present known and it is therefore not possible to discuss the source of discrepancy.

The monochromatic aberrations due to the corrective lenses are negligible here and only the ocular aberrations will be considered. The optometrist during retinoscopy concerns himself with the general aspect of the central retinoscopic reflex and sphericity present at the periphery is not relevant. Oblique aberrations are the only possible cause of discrepancy.

Hodd (1951) [181] studied this aspect using 3 - 4° obliquity on 25 subjects. Nasal corneal areas were

involved in the right eye and temporal in the left. His conclusions were that firstly, on changing from a 2^{o} inferior fixation to 4^{o} lateral the mean spherical refraction changed predominantly towards hyperopia in either eye, and consequently that the customary instruction given to patients in static retinoscopy to "look just past my ear" was inadequate.

An analysis of Hodd's results suggests that the mean difference does not exceed reasonable tolerance (0.21D and SD 0.30 D) and is the same for the right eye at a point 4^{o} nasal (0.22 D and SD 0.34 D) and at a point 4^{o} temporal for the left eye. Aberration is unlikely to account for an equal amount of ametropia (Hyperopia) when the obliquity from the line of sight is 3 - 4^{o} either temporal or nasal. In the temporal case the retinoscopic axis would probably come close to the classical approximate optic axis of the eye. It is probable that the increased hypermetropic value is due to the greater relaxation in accommodation connected to distance fixation.

In the main aphakic group the mean difference between retinoscopy and subjective is −0.04. When proper care is taken regarding back vertex distance, pantoscopic angle and lens centration, the limiting factor for accuracy will be the tolerance of manufacture of the trial-case lenses. Suppose the value obtained is 14.50 DS, this would be made up of + 14.00 DS with a tolerance of $\pm$ 0.12 D and a + 0.50 DS with a tolerance of $\pm$ 0.03 D. Hence the tolerance of the system used would be $\pm$ 0.15 D.

For the difference between subjective and Opthalmetron, monochromatic aberrations (spherical and oblique pencil aberrations) do not apply because of the nature of the alignment system. It ensures centration on the corneal apex and has an angular tolerance of less than $2\frac{1}{2}^{o}$. The layers responsible for retinal reflection are the only variables to consider. Both will err towards higher positive values for the Ophthalmetron. This is shown to be true for the aphakic group.

Finally the comparison between Ophthalmetron and retinoscopy shows that the difference in readings is linked to the wavelength difference.

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Appendix 1. Principle of Direct Ophthalmoscopy

There are three requirements:

1. The patient's retina must be illuminated.
2. The diffuse light originating from the retina must leave the patient's eye and enter the observer's eye.
3. The image of the patient's retina must be in sharp focus on the retina of the observer.

In fact the patient's retina is illuminated by a source S via a blurred pseudo image and not by means of the source S conjugate to the retina., . The patient's retina is seen in focus by conjugating it with the observer through a system of lenses . All the modern instruments are derived from Helmholtz's principle, formulated in 1851.

The optical system constituted by the patient's eye gives an erect image of his retina at infinity, and acts as a x 15 times magnifier (G = D/4 - 60/4 x=15) for the patient and observer's spherical ametropia.

Appendix 2 Principle of Indirect Ophthalmoscopy

A convex lens, (the Ophthalmoscopic lens) is placed at a short distance in front of the patient's eye. this gives an inverted image of the retina at the focal point of the lens if the patient is emmetropic, at a shorter distance if myopic and further away if hyperopic. The lens used is usually a +13D which gives a 4 times magnification (G=D/4 - 4). A concave mirror enables the observer to see the patient's fundus

Modern instruments are free from disturbing corneal reflections, using Gullstrand's principle, where one half of the pupil is devoted to the illumination system and the other to the observation system

Reading No.	Axial dial (mm)	Vertical dial (mm)	Transversal dial (inch)	Operator	Range used
1	3.18	4.00	0.008	A	
2	4.22	4.09	0.010	B	Normal
3	2.95	4.07	0.010	C	
4	2.85	4.02	0.012	A	
5	3.14	4.03	0.009	B	Negative
6	4.11	4.07	0.016	C	
7	4.24	4.05	0.013	A	
8	4.22	4.10	0.007	B	Positive
9	3.76	4.05	0.013	C	
10	0.58	4.08	0.009	A	
11	4.01	4.00	0.007	B	Normal
12	3.61	4.02	0.015	C	
13	2.80	4.03	0.012	A	
14	3.83	4.06	0.011	B	Negative
15	4.38	4.10	0.012	C	
16	4.92	4.06	0.012	A	
17	5.33	3.90	0.012	B	Positive
18	2.88	4.08	0.012	C	
19	1.57	4.07	0.013	A	
20	2.85	4.05	0.012	B	Normal
21	1.64	4.07	0.010	C	
22	1.99	4.01	0.012	A	
23	3.66	4.00	0.009	B	Negative
24	3.20	4.02	0.014	C	
25	1.91	4.09	0.004	A	
26	3.45	3.98	0.010	B	Positive
27	4.40	4.04	0.013	C	
28	4.12	4.05	0.012	A	
29	4.81	4.02	0.011	B	Normal
30	3.32	4.07	0.014	C	
31	1.92	4.03	0.010	A	
32	3.82	4.08	0.008	B	Negative
33	3.24	4.05	0.011	C	
34	0.72	4.04	0.008	A	
35	4.29	4.00	0.013	B	Positive
36	2.54	4.08	0.012	C	
37	2.75	4.17	0.010	A	
38	2.87	3.99	0.008	B	Normal
39	3.16	3.96	0.013	C	

Reading No	Axial dial (mm)	Vertical dial (mm)	Transversal dial (inch)	Operator	Range used
40	1.37	4.04	0.006	A	
41	1.87	3.99	0.007	B	Negative
42	1.97	4.02	0.012	C	
43	1.39	4.03	0.010	A	
44	2.79	4.02	0.012	B	Positive
45	1.88	4.01	0.011	C	
46	2.69	4.02	0.004	A	
47	2.56	4.02	0.009	B	Normal
48	2.01	3.99	0.011	C	
49	2.51	4.08	0.008	A	
50	1.53	3.99	0.010	B	Negative
51	1.62	3.99	0.011	C	
52	1.86	4.09	0.012	A	
53	3.89	3.97	0.011	B	Positive
54	4.18	4.01	0.015	C	
55	2.40	3.99	0.008	A	
56	2.88	4.01	0.010	B	Normal
57	2.38	3.97	0.013	C	
58	2.60	4.02	0.015	A	
59	2.55	4.04	0.012	B	Negative
60	1.82	4.01	0.013	C	
61	1.35	3.97	0.012	A	
62	2.27	3.98	0.009	B	Positive
63	2.01	4.00	0.014	C	
64	1.22	3.99	0.012	A	
65	2.70	3.95	0.011	B	Normal
66	2.00	3.98	0.008	C	
67	1.05	3.99	0.012	A	
68	4.89	3.95	0.011	B	Negative
69	3.71	4.06	0.013	C	
70	3.00	3.99	0.013	A	
71	3.24	3.94	0.012	B	Positive
72	3.28	4.04	0.014	C	
73	1.98	4.04	0.012	A	
74	4.30	3.99	0.012	B	Normal
75	3.55	3.99	0.015	C	
76	2.59	4.01	0.014	A	
77	3.02	3.95	0.011	B	Negative
78	3.49	4.01	0.016	C	

Reading No	Axial dial (mm)	Vertical dial (mm)	Transversal dial (inch)	Operator	Range used
79	2.53	4.04	0.013	A	
80	4.31	3.96	0.010	B	Positive
81	3.02	3.98	0.012	C	
82	2.54	3.98	0.010	A	
83	4.25	3.89	0.014	B	Normal
84	2.08	3.97	0.009	C	
85	3.63	4.09	0.009	A	
86	3.34	4.01	0.006	B	Negative
87	3.32	4.00	0.009	C	
88	3.91	3.90	0.015	A	
89	4.36	4.02	0.006	B	Positive
90	3.25	4.08	0.013	C	

APPENDIX 4 REFRACTIVE VALUES OBTAINED WITH THE BAUSCH AND LOMB MODEL EYE

DATE	ON	READING	HOUR	SPHERE	CYLINDER	AXIS
26.1.76.	4.20	4.35 5.25	1 2	plano plano		
28.1.76.	10.40	10.35 11.25	1 1	+0.06 plano	-0.12 -0.12	20 10
29.1.76	4.00	4.15 5.40	1 2	plano 0.09		
6.2.76.	11.50	2.50	3	+0.18	-0.12	10
10.2.76.		Start End	1 3	-0.25 plano		
23.4.76.	2.50	3.05 4.50	1 3	plano plano	-0.25 -0.09	
30.4.76.	9.35 2.00	S S 4.00	1 1 2	-0.37 -0.27 plano		
5.5.76.	2.45	3.00	1	-0.25		
7.5.76.	9.30	4.15	3	-0.25		
20.10.76.		S E	1 3	+0.25 +0.25	-0.25	10
26.1.77.	2.50	3.05 3.20 5.30	1 1 3	+0.25 +0.25 +0.25	-0.25 -0.25 -0.25	170 180
28.1.77.	9.30 1.00	10.15 11.35 1.20	1 3 1	+0.12 plano +0.18	-0.12 -0.37	160 180
3.2.77.	310	3.30 4.00	1 1	+0.25 plano	-025	170
4.2.77.	10.05 3.00	10.20 11.30 3.15 3.35	1 2 1 1	plano plano -0.25 plano	-0.37	
9.2.77.	9.45 1.25	9.55 1.00 1.40 3.30	1 3 1 3	plano plano -0.12 -0.12	-0.06	160
10.2.77.	3.20	3.35 4.00	1 1	-0.12 -0.12		
11.2.77.	9.55 3.00	10.10 12.20 3.15 4.35	1 2 1 2	+0.06 plano +0.06 -0.12	-0.06 -0.06	 170

DATE	ON	READING	HOUR	SPHERE	CYLINDER	AXIS
16.2.77.	9.50	10.15	1	plano	-0.12	
		11.00	2	plano	-0.09	
	3.10	3.25	1	-0.12		
		4.30	2	-0.12		
17.2.77.	3.05	3.20	1	+0.09	-0.12	180
		3.45	1	-0.09		
25.2.77.	10.15	10.25	1	+0.12	-0.37	170
		11.05	1	plano	-0.06	170
	3.00	3.10	1	plano	-0.12	
		4.30	2	-0.06		
3.3.77.	2.00	2.10	1	plano		
		2.30	1	plano	-0.37	40
		4.00	2	+0.18	-0.18	
4.3.77.	9.30	9.45	1	+0.25		
		9.45	1	+0.25		
10.3.77.	1.45	2.05	1	plano		
		3.30	2	plano	-0.37	
11.3.77.	9.50	10.20	1	plano		
		11.50	2	plano		
16.3.77.	9.50	10.10	1	-0.37		
		11.00	2	-0.25		
	1.30	2.00	1	plano		
		4.05	3	plano		
17.3.77.	2.00	2.20	1	plano		
		4.00	2	plano		
18.3.77.	9.55	10.05	1	-0.12		
	1.55	3.15	2	plano		
		4.00	3	plano		
23.3.77.	9.30	10.00	1	plano		
		12.45	3	plano	-0.18	
	2.00	3.30	2	-0.25		
		3.40	2	-0.12	-0.12	
25.3.77.	3.20	3.40	1	plano	-0.09	
		4.50	3	plano		
30.3.77.	10.00	10.10	1	plano		
1.4.77.	9.35	9.50	1	-0.12	-0.12	
6.4.77.	4.00	4.20	1	+0.12		

DATE	ON	READING	HOUR	SPHERE	CYLINDER	AXIS
5.4.77.	9.20	10.20 12.20 4.00	1 3 3	plano +0.12 +0.12		
7.4.77.	9.25	10.20	1	+0.37		
20.4.77.	4.00	4.20	1	+0.25		
21.4.77.	1.45	2.00 4.35	1 3	+0.18 +0.12	-0.18 -0.06	
28.4.77.		+ 20 min end	1 3	plano plano		
29.4.77.		after 35min	1	plano		
3.5.77.	9.15	9.45	1	plano		
5.5.77.	9.30	9.45 12.35	1 3	plano plano	-0.50	120
9.5.77.	9.25 2.00	9.50 4.50	1 3	+0.15 +0.18	-0.25 -0.18	125 120
10.577.	9.15	9.30	1	+0.12	-0.25	
13.5.77.	9.30	9.45 1.50	1 3	+0.25 plano	-0.25	150
18.5.77.	9.15	9.55	1	plano		
20.5.77.	2.00	3.15	2	+0.12	-0.12	
22.9.77.	3.30	3.40 4.00	1 1	+0.25 +0.06	-0.12 -0.06	
23.9.77.	9.30	10.00 11.00	1 2	+0.37 plano	-0.37	140

Appendix (5) Computer Programme for 'T Test Study

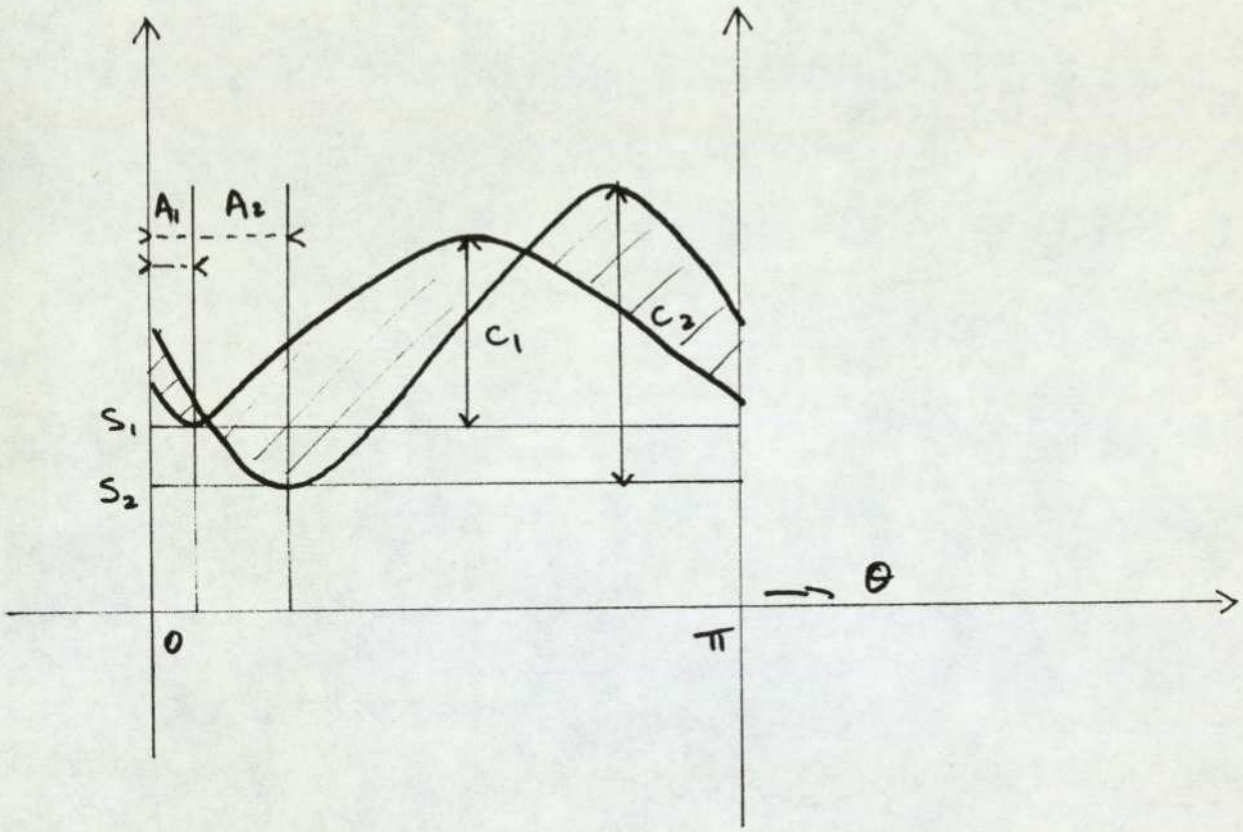
```
0100 REM STUDENT'S T DISTRIBUTION
0105 LET H=9
0110 DIM X(9),K(2),L(2)
0150 INPUT "ENTER X COL NO.",I1
0160 INPUT "ENTER Y COL NO.",I2
0170 IF I1>0.1 THEN 200
0180 PRINT "ERROR IN COLUMN NUMBERS"
0190 END
0200 IF I1>H THEN 180
0210 IF I2<0.1 THEN 180
0220 IF I2>H THEN 180
0225 IF I1=I2 THEN 180
0230 INPUT "ENTER NO. OF SAMPLES",J
0240 OPEN #1,1,RDATA1.TXT
0250 READ #1,X(1),X(2),X(3),X(4),X(5),X(6),X(7),X(8),X(9)
0260 IF X(I1)>=J THEN 290
0270 PRINT "ERROR IN NO. OF SAMPLES"
0280 END
0290 IF J>X(I2) THEN 270
0300 LET T2=0:LET T7=0:LET T8=0
0310 FOR S=1 TO J
0320 READ #1,X(1),X(2),X(3),X(4),X(5),X(6),X(7),X(8),X(9)
0330 LET T2=T2+X(I1)-X(I2)
0333 LET T7=T7+X(I1)
0336 LET T8=T8+X(I2)
0340 NEXT S
0350 LET T2=T2/J
0353 LET T7=T7/J
0356 LET T8=T8/J
0360 RESTORE #1
0370 READ #1,X(1),X(2),X(3),X(4),X(5),X(6),X(7),X(8),X(9)
0380 LET T1=0:LET T3=0:LET T4=0:LET T5=0:LET T6=0
0400 LET L1=0:LET L2=0
0405 LET S1=0:LET S2=0
0410 FOR S=1 TO J
0420 READ #1,X(1),X(2),X(3),X(4),X(5),X(6),X(7),X(8),X(9)
0440 LET L1=L1+X(I1)*X(I1)
0445 LET L2=L2+X(I2)*X(I2)
0450 LET T1=T1+X(I1)*X(I2)
0453 LET S1=S1+(X(I1)-T7)*(X(I1)-T7)
0456 LET S2=S2+(X(I2)-T8)*(X(I2)-T8)
0460 LET R=X(I1)-X(I2)-T2
0470 LET T3=T3+R
0480 LET T4=T4+R*R
0490 LET R=X(I1)-T7
0500 LET T5=T5+R
0510 LET T6=T6+R*R
0520 NEXT S
0530 CLOSE #1
0533 LET S1=S1/(J-1):LET S2=S2/(J-1)
0540 PRINT T7,T8,L1,L2,T1,T2,T3,T4,T5,T6
0550 PRINT "VARIANCE OF X(I1)",S1,"VARIANCE OF X(I2)",S2
0560 LET S=SQR(T4/(J-1))
0570 LET T=T2/(S/(SQR(J)))
0580 LET B=(T1-J*T7*T8)/(L1-J*T7*T7)
0590 LET A=T8-B*T7
0600 LET S3=L2-A*T8*J-B*T1
0610 LET S3=S3/(J-2)
0620 LET S4=SQR(S3)
0630 LET R=(L1-T7*T7*J)*(L2-T8*T8*J)
0640 LET R=SQR(R)
0650 LET R=(T1-T7*T8*J)/R
0660 PRINT "S/D",S,"T",T
0670 PRINT "ESTIMATE OF SLOPE B",B,"ESTIMATE OF INTERCEPT A",A
0680 PRINT "ESTIMATE OF VARIANCE ON REGRESSION S2Y/X",S3
0685 PRINT "ESTIMATE OF S/D ON REGRESSION SY/X",S4
0690 PRINT "CORRELATION COEFFICIENT.R",R
0700 REM ESTIMATE OF VARIANCE ON A
0710 LET S5=(1+J*T7*T7/T6))*S3/J
0720 LET S6=SQR(S5)
0730 REM ESTIMATE OF VARIANCE ON B
0740 LET S7=S3/T6
0750 LET S8=SQR(S7)
0760 REM STATISTICS ON SLOPE
0770 LET T9=B*SQR(T6)/S4
0780 REM STATISTICS ON CORRELATION COEFFICIENT
0790 LET T2=(R*SQR(J-2))/SQR(1-R*R)
0800 PRINT S5,S6
0810 PRINT S7,S8
0820 PRINT T9,T2
0900 END
```

Appendix (6) Computer Programme for 'Analysis of Variance'

```
0050 REM ANALYSIS OF VARIANCE
0090 LET H=9
0100 DIM I(H),J(H),K(H),L(H),M(H),N(H),X(H),I1(H)
0110 PRINT "INPUT NO. OF SAMPLES IN EACH COLUMN OR 0 IF NOT USED"
0120 INPUT I(1),I(2),I(3),I(4),I(5),I(6),I(7),I(8),I(9)
0140 OPEN #1 AVDATA.TXT
0150 READ #1,I1(1),I1(2),I1(3),I1(4),I1(5),I1(6),I1(7),I1(8),I1(9)
0160 FOR S=1 TO H
0170 IF I(S)<=I1(S) THEN 200
0180 PRINT "NO. OF SAMPLES IN COLUMN",S,"IS INCORRECT"
0190 END
0200 IF I(S)<0 THEN 180
0210 NEXT S
0220 LET R=1
0230 READ #1,X(1),X(2),X(3),X(4),X(5),X(6),X(7),X(8),X(9)
0240 LET R1=0
0250 FOR S=1 TO H
0260 IF I(S)<R THEN 300
0270 LET R1=R1+1
0280 LET J(S)=J(S)+X(S)
0290 LET K(S)=K(S)+X(S)*X(S)
0300 NEXT S
0310 IF R1<0.1 THEN 330
0320 LET R=R+1
0322 GOTO 230
0325 REM SUMS & SUMS OF SQUARES CALCULATED NOW
0330 CLOSE #1
0335 LET T1=0:LET T3=0:LET T4=0:LET T5=0:LET T6=0:LET T7=0
0340 FOR S=1 TO H
0345 IF I(S)<0.1 THEN 410
0350 LET L(S)=J(S)/I(S)
0360 LET M(S)=J(S)*J(S)
0370 LET N(S)=M(S)/I(S)
0375 LET T6=T6+N(S)
0380 LET T1=T1+I(S)
0390 LET T3=T3+J(S)
0400 LET T4=T4+K(S)
0410 NEXT S
0420 LET T5=T3*T3
0430 LET T7=T5/T1
0440 PRINT T1,T3,T4,T5,T6,T7
0450 LET S1=T4-T7
0460 LET S2=T6-T7
0470 LET S3=T4-T6
0480 PRINT S1,S2,S3
0490 LET R1=0
0500 FOR S=1 TO H
0510 IF I(S)>0.1 THEN R1=R1+1
0520 NEXT S
0530 REM R1=NO. COLUMNS USED
0550 LET B1=S1/(T1-1)
0560 LET B2=S2/(R1-1)
0570 LET B3=S3/(T1-R1)
0580 LET F=B2/B3
0590 PRINT B1,B2,B3
0600 PRINT "F RATIO=",F
0610 PRINT "NO. COL=",R1
```

APPENDIX 7 Derivation of formula "Delta"

No published derivation of Safir's Delta formula is available, therefore the following is included to establish its exactitude.



The measurement of the error is:

$$\Delta = \sqrt{\int_0^{\pi} \left[S_1 - S_2 + C_1 \sin^2\theta - C_2 \sin^2(\theta - \underbrace{A_2 + A_1}_{\delta})\right]^2 d\theta}$$

$$= \sqrt{\int_0^{\pi} \left[(S_1-S_2)^2 + C_1^2 \sin^4\theta + C_2^2 \sin^4(\theta-\delta) + \cdots\right.}$$

$$\cdots + 2(S_1-S_2) C_1 \sin^2\theta - 2(S_1-S_2) \times C_2 \sin^2(\theta-\delta) - 2C_1C_2 \sin^2\theta$$

$$\left. \times \sin^2(\theta-\delta)\right] d\theta$$

① $\int_0^{\pi} (S_1-S_2)^2 \, d\theta = (S_1-S_2)^2 \pi$

② As $\sin^4\theta = (\sin^2\theta)^2 = \left(\frac{1 - \cos 2\theta}{2}\right)^2 = \frac{1}{4}\left(1-2\cos 2\theta + \cos^2 2\theta\right)$

$= \frac{1}{4}\left(1-2\cos 2\theta + \frac{1+\cos 4\theta}{2}\right)$

$\int_0^{\pi} \sin^4\theta \, d\theta = \frac{\pi}{4} - \theta + \frac{\pi}{8} + \theta \longrightarrow \int_0^{\pi} C_1^2 \sin^4\theta \, d\theta = \frac{3}{8} C_1^2 \pi$

③ Similarly $C_2^2 \sin^4(\theta - \delta) =$

$\frac{1}{4} C_2^2 (1-2\cos(2\theta - 2\delta) \times \frac{1}{2} + \frac{1}{2}\cos(4\theta - 4\delta)$

$\int_0^{\pi} \cdots = \frac{1}{4} C_2^2 (\pi - 0 + \frac{\pi}{2} + 0) = \frac{3}{8} C_2^2 \pi$

④ $\sin^2\theta = \frac{1 - \cos 2\theta}{2}$ $\qquad \int_0^{\pi} \sin^2\theta \, d\theta = \frac{\pi}{2} + 0$

$\int_0^{\pi} 2(S_1-S_2) C_1 \sin^2\theta \, d\theta = \pi (S_1-S_2) C_1$

⑤ Similarly

$- \int_0^{\pi} 2 (S_1-S_2) C_2 \sin^2(\theta - \delta) \, d\theta = -\pi (S_1-S_2) C_2$

⑥ $\sin^2\theta \sin^2(\theta-\delta) = \frac{1 - \cos 2\theta}{2} \times \frac{1 - \cos(2\theta-2\delta)}{2}$

$= \frac{1}{4}\left[1 - \cos(2\theta - 2\delta) - \cos 2\theta + \cos 2\theta \cos(2\theta-2\delta)\right]$

N.B. $\cos\alpha \times \cos\beta = \frac{1}{2}\left[\cos(\alpha+\beta) + \cos(\alpha-\beta)\right]$

$\longrightarrow \cos 2\theta \cos(2\theta-2\delta) = \frac{1}{2}\left[\cos(4\theta-2\delta) + \cos 2\delta\right]$

$\longrightarrow -2C_1C_2 \int_0^{\pi} \sin^2\theta \sin^2(\theta-\delta) \, d\theta$

$= -\frac{C_1C_2}{2}\left[\pi - 0 - 0 + \frac{1}{2}(0 + \pi \cos 2\delta)\right]$

$= \frac{-C_1C_2}{4}\pi (2+\cos 2\delta)$

Thus the original integral is:

$$\Delta = (S_1-S_2)^2\frac{\pi}{4} + \frac{3}{8} C_1^2\frac{\pi}{4} + \frac{3}{8} C_2^2\frac{\pi}{4} + \pi(S_1-S_2)\, C_1 - \pi(S_1-S_2)\, C_2$$

$$- \frac{C_1C_2}{4}\pi(2+\cos 2S)$$

$$= \pi\left[(S_1-S_2)^2 + 3/8\ (C_1^2 + C_2^2)^2 + (S_1-S_2)(C_1-C_2) - \frac{C_1C_2}{4}^3 - 2\sin^2 S\right.$$

$$= (S_1-S_2)^2 + 3/8\ (C_1-C_2)^2 + (S_1-S_2)(C_1-C_2) + \tfrac{1}{2}\, C_1C_2 \sin^2 S$$

In order to obtain 10 integrated dioptic units per unit (S_1-S_2) with $C_1=C_2$ and $S=0$ a scaling factor of $\frac{100}{\pi}$ must be applied before the square root is taken and gives

$$\Delta = \sqrt{(S_1-S_2)^2 + (S_1-S_2)(C_1-C_2) + 3/8\,(C_1-C_2)^2 + \frac{C_1 x C_2}{2} \sin^2 S}$$

Appendix 8 Clinical Experiment 1: Normal population cyclopegic study - Refractive data

(S_c = Subjective under cyclopegia; R_c = retinoscopy under cyclopegia; OA_c = Ophthalmetron measurement by technician under cyclopegia.

S = subjective without cyclopegia; R = retinoscopy without cyclopegia; OA and OB = Ophthalmetron without cyclopegia.)

Name	Age	Sex	R/L		Refraction	VA	Comments
V.A.	19	F	R	SC	-0.50 / -0.50 x 75	6/4.5	
				RC	-0.50 / -0.50 x 90	6/6 -1	
				OAC	-0.875 DS		
				OBC	-0.625 / -0.375 x 60		*
				S	-0.75 / -0.50 x 75	6/6+	
				R	-0.75 / -0.25 x 90	6/9+	
				OA	-1.375		
				OB	-2.625 / -0.50 x 110		*
			L	SC	-0.50 / -0.50 x 110	6/4.5 -1	
				RC	-0.25 / -0.50 x 100	6/6 -	
				OAC	-0.625 / -0.375 x 45		
				OBC	-0.25 / -0.375 x 30		*
				S	-0.50 / -0.25 x 95	6/6+	
				R	-0.75 / -0.50 x 180	6/6-	
				OA	-1.625 / -0.25 x 180		
				OB	-2.625 / -0.75 x 160		*
A.B.	22	M	R	SC	+0.75 DS	6/4	
				RC	+1.00 / -0.25 x 180	6/6-	
				OAC	+0.50 / -0.50 x 20		
				OBC	+0.625 / -0.25 x 25		*
				S	+0.75 / -0.25 x 80	6/4	
				R	+1.00 DS	6/9	
				OA	+0.375 DS		
				OB	Plano		V. poor fixation *
			L	SC	+0.75 / -0.25 x 180	6/4.5 +1	
				RC	+0.50 / -0.25 x 180	6/6 -3	
				OAC	+1.00 / -0.625 x 52½		
				OBC	+1.00 / -0.625 x 177½		*
				S	+0.50 DS	6/4	
				R	+0.25 DS	6/4.5	
				OA	+0.625 / -0.375 x 178		
				OB	+0.625 / -0.625 x 177½		*

Name	Age	Sex	R/L		Refraction	VA	Comments	
B.B.	22	M	R	SC	-1.625 / -1.50 x 2½	6/6		
				RC	-1.625 / -2.00 x 10	6/9 -2	Split reflex	
				OAC	-2.00 / -2.00 x 15			*
				OBC	-2.00 / -2.50 x 15			
				S	-2.125 / -1.50 x 5	6/4.5 -2		
				R	-1.50 / -2.50 x 15	6/9 +2		
				OA	-2.75 / -2.75 x 20			*
				OB	-2.625 / -2.375 x 10			
			L	SC	-1.00 / -2.00 x 2½	6/6		
				RC	-1.75 / -2.00 x 5	6/12-	Split reflex	
				OAC	-1.25 / -2.625 x 15			*
				OBC	-1.00 / -3.00 x 15			
				S	-1.50 / -2.50 x 2½	6/6+		
				R	-2.00 / -2.50 x 5	6/6 -4		
				OA	-2.00 / -2.75 x 15			*
				OB	-2.00 / -2.75 x 15			
J.B.	19	M	R	SC	+0.50 / -0.375 x 100	6/4.5		
				RC	+0.50 / -0.50 x 100	6/6 +1		
				OAC	+0.625 / -0.50 x 120			
				OBC	+0.25 / -0.25 x 105			*
				S	Plano / -0.50 x 100	6/4.5		
				R	+0.50 / -0.50 x 100	6/6		
				OA	+0.125 / -0.25 x 130			
				OB	-0.75 DS			*
			L	SC	+0.75 / -0.25 x 90	6/4.5		
				RC	+0.50 / -0.50 x 100	6/9+		
				OAC	+0.75 DS			
				OBC	+0.50 DS			*
				S	Plano / -0.25 x 105	6/6 +2		
				R	-0.25 DS	6/6		
				OA	-0.25 / -0.50 x 70			
				OB	+0.375 / -0.75 x 105			*

Name	Age	Sex	R/L		Refraction	VA	Comments
N.C.	25	F	R	SC	+2.00 / -1.75 x 10	6/6	
				RC	+2.50 / -1.50 x 15	6/12	
				OAC	+2.25 / -1.25 x 15		
				OBC	+2.50 / -1.375 x 17½		*
				S	+1.50 / -1.50 x 5	6/6 -1	
				R	+2.00 / -2.00 x 165	6/9	
				OA	+0.875 / -1.25 x 5		
				OB	+1.00 / -1.375 x 15		*
			L	SC	+4.50 / -4.00 x 170	6/9-	
				RC	+4.50 / -4.50 x 165	6/12-	
				OAC	+4.00 / -3.75 x 177½		
				OBC	+3.25 / -3.75 x 175		*
				S	+4.00 / -4.50 x 168	6/5	
				R	+4.00 / -4.50 x 165	6/9-	
				OA	+2.25 / -4.25 x 172½		
				OB	+3.00 / -4.50 x 180		*
S.C.	21	F	R	SC	+0.50 / -0.25 x 45	6/4.5	
				RC	+0.25 DS	6/6	
				OAC	+0.875 / -0.125 x 20		
				OBC	+0.875 / -0.375 x 162		*
				S	Plano	6/6 +4	
				R	+0.25 / -0.25 x 180	6/6 +3	
				OA	-1.25 DS		*
				OB	-1.375 / -0.125 x 15		
			L	SC	+0.75 / -0.25 x 150	6/4.5	
				RC	Plano / -0.25 x 170		
				OAC	+0.75		
				OBC	+1.00 / -0.375 x 180		*
				S	+0.25 / -0.25 x 165	6/6	
				R	Plano / -0.25 x 180	6/6	
				OA	-1.375 / -0.25 x 140		*
				OB	-1.875		

Name	Age	Sex	R/L		Refraction	VA	Comments	
J.D.	23	M	R	SC	-0.625 / -0.125 x 90	6/4 -1		
				RC	-0.75 / -0.25 x 90	6/4.5		
				OAC	-0.25 / -0.25 x 175			
				OBC	-0.50 DS			*
				S	-0.75 / -0.25 x 90	6/4.5		
				R	-0.75 DS	6/4.5		
				OA	-0.625 / -0.25 x 145			
				OB	-0.50 DS			*
			L	SC	-0.75 / -0.125 x 80	6/4		
				RC	-0.75 / -0.25 x 90	6/4 -1		
				OAC	-0.50 DS			
				OBC	-0.375 DS			*
				S	-0.50 / -0.25 x 90	6/4		
				R	-1.00 DS			
				OA	-0.875			
				OB	-1.00			*
D.E.	25	M	R	SC	-1.25 / -2.75 x 15	6/4.5		
				RC	-1.75 / -2.75 x 15	6/9		
				OAC	-1.375 / -2.125 x 22½			
				OBC	-1.625 / -1.875 x 17			*
				S	-1.50 / -2.50 x 12½	6/4.5		
				R	-1.25 / -2.50 x 15	6/6		
				OA	-2.25 / -2.00 x 20			
				OB	-2.50 / -2.25 x 17½			*
			L	SC	-1.25 / -2.00 x 160	6/4.5		
				RC	-1.50 / -2.00 x 165	6/6		
				OAC	-1.00 / -2.00 x 180			
				OBC	-0.75 / -2.00 x 5			*
				S	-1.25 / -2.00 x 160	6/4.5		
				R	-1.25 / -2.00 x 165			
				OA	-1.75 / -2.00 x 5			
				OB	-1.50 / -2.00 x 7			*

Name	Age	Sex	R/L		Refraction	VA	Comments
V.F.	22	M	R	SC	+0.75 / -0.50 x 90	6/4.5	
				RC	+0.50 / -0.25 x 90		
				OAC	+0.75 / -0.50 x 110		
				OBC	+0.625 / -0.125 x 120		*
				S	+0.50 / -0.50 x 90	6/4.5	
				R	+0.50 / -0.25 x 90	6/4.5 -1	
				OA	+0.25 / -0.125 x 110		
				OB	Plano / -0.25 x 115		*
			L	SC	+0.50 / -0.625 x 75	6/4.5	
				RC	+0.50 / -0.50 x 65	6/6	
				OAC	+0.50 / -0.50 x 90		
				OBC	+0.625 / -0.50 x 85		
				S	+0.25 / -0.50 x 75	6/4.5 -1	
				R	+0.25 / -0.50 x 110	6/9	
				OA	Plano / -0.75 x 95		
				OB	Plano / -0.50 x 80		*
A.G.	21	M	R	SC	-2.75 / -0.675 x 120	6/6	
				RC	-2.75 / -0.50 x 115		
				OAC	-2.50 / -0.50 x 120		
				OBC	-2.625 / -0.50 x 130		*
				S	-3.25 / -0.75 x 110	6/4.5 -3	
				R	-3.75		
				OA	-3.75 / -0.50 x 120		
				OB	-3.75 / -0.625 x 140		*
			L	SC	-2.50 / -0.50 x 75	6/6	
				RC	-2.25 / -0.50 x 90	6/9-	
				OAC	-2.25 / -0.375 x 90		*
				OBC	-2.50 / -0.25 x 90		
				S	-2.75 / -0.50 x 75	6/4.5 -3	
				R	-2.75 / -0.50 x 80	6/6	
				OA	-2.625 / -0.875 x 85		
				OB	-3.00 / -0.625 x 115		*

Name	Age	Sex	R/L		Refraction	VA	Comments
T.G.	22	F	R	SC	-5.50 / -0.25 x 165	6/6	
				RC	-5.50 DS	6/6 -1	
				OAC	-5.00 DS		
				OBC	-5.25 / -0.25 x 25		*
				S	-6.00 DS	6/4.5-	
				R	-5.75 / -0.25 x 90	6/6 -1	
				OA	-5.50 DS		
				OB	-4.00 / -0.50 x 60		*
			L	SC	-5.00 / -0.50 x 15	6/6 -1	
				RC	-5.00 DS	6/9	
				OAC	-4.375 / -0.125 x 135		
				OBC	-4.125 / 0.125 x 30		*
				S	-5.50 / 0.50 x 12½	6/6 -3	
				R	-5.25 / -0.50 x 140	6/6	
				OA	-5.50 DS		
				OB	-4.25 / -0.625 x 100		*
J.H. ##1	19	M	R	SC	-0.25 / -0.25 x 7½	6/4.5	
				RC	-0.25 / -0.25 x 180	6/4.5 -2	
				OAC	Plano / -0.375 x 120		
				OBC	-0.25 / -0.125 x 15		*
				S	-0.375 DS		
				R	-0.25 DS		
				OA	-0.375 / -0.125 x 10		
				OB	-0.25 / -0.50 x 150		*
			L	SC	-0.50 DS	6/4.5	
				RC	-0.50 DS	6/4.5	
				OAC	-0.25 / -0.25 x 40		
				OBC	-0.25 / -0.125 x 45		*
				S	-0.50 / -0.25 x 135	6/4.5	
				R	-0.25 DS		
				OA	-0.50 / -0.125 x 40		
				OB	-0.375 / -0.25 x 50		*

Name	Age	Sex	R/L		Refraction	VA	Comments
J.H. #2	17	F	R	SC	+0.75 / -0.50 x 15	6/6 +	
				RC	+1.25 / -0.50 x 30	6/6 +	
				OAC	+0.75 DS		
				OBC	+0.875		*
				S	+0.25 / -0.25 x 35	6/6	
				R	+0.50 /-0.50 x 25	6/6 -1	
				OA	-0.50 / -0.375 x 30		
				OB	-1.25 / -0.125 x 130		*
			L	SC	+0.75 / -0.50 x 155	6/6 -1	
				RC	+1.00 / -0.50 x 160	6/6	
				OAC	+0.875 / -0.25 x 25		
				OBC	+1.00 / -0.25 x 15		*
				S	Plano / -0.25 x 180	6/5	
				R	Plano / -0.50 x 150	6/6 +1	
				OA	-1.375 / -0.125 x 170		
				OB	-0.75 -DS		*
P.H.	23	M	R	SC	-3.50 / -0.50 x 75	6/4.5	
				RC	-3.75 / 0.50 x 105	6/6 -4	
				OAC	-3.75 DS		
				OBC	-3.25 DS		*
				S	-4.25 DS	6/4.5 -2	
				R	-4.00 DS	6/6 -3	
				OA	-3.125 / -0.75 x 175		
				OB	-3.875 / -0.125 x 50		*
			L	SC	-3.25 / -0.75 x 150	6/4.5 -1	
				RC	-3.50 / -0.75 x 150	6/6-	
				OAC	-2.875 /-0.50 x 164		
				OBC	-2.875 / -0.675 x 170		*
				S	-3.50 /-0.75 x 147½	6/4.5 -3	
				R	-4.00 /-0.75 x 150	6/6 -3	
				OA	-3.00 /-0.75 x 170		
				OB	-3.50 /-0.50 x 155		*

Name	Age	Sex	R/L		Refraction	VA	Comments	
R.H.	27	M	R	SC	-1.25 / -0.75 x 97½	6/4.5 -3		
				RC	-1.50 / -0.50 x 95	6/6		
				OAC	-0.875 / -0.625 x 120	6/4.5 -5		
				OBC	-0.75 / -0.50 x 120	6/9 -1 +2		*
				S	-1.25 / -0.50 x 95	6/4.5 -1		
				R	-1.50 / -0.50 x 85	6/4.5		
				OA	-1.75 / -0.50 x 120	6/6 +		
				OB	-1.375 / -0.375 x 120	6/4 -2		*
			L	SC	-1.00 / -0.75 x 75	6/4 -3		
				RC	-1.00 / -0.75 x 80	6/4-		
				OAC	-0.50 / -1.00 x 75	6/9+		
				OBC	-0.75 / -0.375 x 65	6/6 -2		*
				S	-1.50 / -0.50 x 80	6/4-		
				R	-1.50 / -0.25 x 95	6/4 -2		
				OA	-1.625 / -0.375 x 85	6/6		
				OB	-1.00 / -0.50 x 80	6/4.5		*
S.H.	18	F	R	SC	-1.50 / -0.50 x 80	6/4.5		
				RC	-1.25 / -0.50 x 90	6/6 -1		
				OAC	-1.75 / -0.375 x 90	6/6 -1		
				OBC	-1.75 / -0.375 x 100	6/9 +3		*
				S	-1.25 / -0.50 x 75	6/4.5 -2		
				R	-1.25 DS	6/9		
				OA	-2.25 / -0.75 x 107½			
				OB	-2.50 / -0.75 x 120			*
			L	SC	-0.25 / -0.50 x 150	6/6+		
				RC	-0.50 / -0.50 x 165	6/6-		
				OAC	-0.375 / -0.50 x 180	6/6 -3		
				OBC	-0.50 / -0.375 x 20	6/6 -1		*
				S	-0.50 / -0.25 x 175	6/4.5 -2		
				R	0.50 / -0.25 x 165	6/6+		
				OA	-1.75 / -0.50 x 40			
				OB	-1.50 / -0.50 x 20			*

Name	Age	Sex	R/L		Refraction	VA	Comments
H.M.	21	F	R	SC	-1.875 / -0.50 x 45	6/4	
				RC	-2.25 / -0.50 x 65	6/6+	
				OAC	-2.625 / -0.125 x 155		
				OBC	-2.00 / -0.50 x 90		
				S	-2.00 / -0.50 x 50	6/4.5-	
				R	-2.25 / -0.50 x 70	6/6 +4	
				OA	-2.25 / -0.50 x 60	6/4.5	
				OB	-3.00 / -0.25 x 160		
			L	SC	-2.00 / -0.50 x 110	6/4.5	
				RC	-2.25 / -0.50 x 110	6/6+	
				OAC	-1.625 / -0.375 x 80		
				OBC	-2.875 DS		
				S	-2.25 / -0.50 x 110	6/6-	
				R	-2.25 / -0.75 x 110	$6/4.5^{-1}_{+4}$	
				OA	-3.25 DS	6/4.5-	
				OB	-2.875 / -0.625 x 90		
R.M.	21	F	R	SC	-1.00 / -0.75 x 37½	6/4 -3	
				RC	-1.25 / -0.75 x 30	6/6	
				OAC	-1.50 / -0.25 x 50	6/6 -3	
				OBC	-1.00 / -0.375 x 40	6/4.5 -2	
				S	-1.75 / -0.50 x 15	6/6+	
				R	-2.00 / -0.75 x 15	6/6 -1	
				OA	-3.75 / -0.50 x 40	6/9	difficult
				OB	-3.00 / -0.375 x 30	6/6 -4	
			L	SC	+0.25 / -1.50 x 170	6/6+	
				RC	Plano / -1.00 x 165	6/6	
				OAC	+0.125 / -1.25 x 5	6/4.5 -3	
				OBC	Plano / -0.75 x 10	6/6	
				S	-0.75 / -1.25 x 170	6/4.5	
				R	-1.25 / -1.00 x 165	6/6 -2	
				OA	-1.25 / -1.25 x 10	6/6 -2	
				OB	-3.00 / -0.75 x 10	6/9	

Name	Age	Sex	R/L		Refraction	VA	Comments
D.P.	21	F	R	SC	+0.75 / -0.50 x 75	6/4.5 -1	
				RC	+0.75 / -0.50 x 90	6/4.5	
				OAC	+0.375 DS		
				OBC	Plano / -0.25 x 15		
				S	+0.75 / -0.50 x 82½	6/4.5 -1	
				R	+0.25 / -0.50 x 90		
				OA	+0.375 / -0.25 x 45		
				OB	-0.625 / -0.25 x 25		
			L	SC	+1.00 / -0.50 x 95	6/4.5 -1	
				RC	+1.00 / -0.75 x 90	6/6 +2	
				OAC	+0.50 DS		
				OBC	+0.625 / -0.375 x 35		
				S	0.75 / -0.50 x 112½	6/4.5 -1	
				R	+0.50 / -0.50 x 115	6/4.5 -1	
				OA	+0.375 / -0.25 x 10		
				OB	-1.00 / -0.25 x 175		
S.P.	19	M	R	SC	-0.50 / -0.25 x 180	6/6	
				RC	-0.50 DS		
				OAC	-0.625 / -0.375 x 30	6/6	
				OBC	-0.50 / -0.375 x 25	?	
				S	-0.50 / -0.25 x 75	6/4.5-	
				R	-0.50 DS	6/6	
				OA	-0.50 / -0.25 x 20	6/6 -3	
				OB	-0.375 / -0.50 x 30	6/6 -4	
			L	SC	-2.125 / -0.25 x 40	6/4.5	
				RC	-2.25 DS	6/4.5 -1	
				OAC	-1.875 / -0.25 x 60	6/4.5 -3	
				OBC	-1.875 DS	6/4 -3	
				S	-2.00 / -0.25 x 60	6/4.5	
				R	-2.25 DS	6/4.5 -2	
				OA	-2.00 DS	6/4 -2	
				OB	-2.125 / -0.25 x 10	6/6 -4	

Name	Age	Sex	R/L		Refraction	VA	Comments
J.R.	21	F	R	SC	-4.25 / -1.25 x 10	6/4.5 -4	
				RC	-4.50 / 1.25 x 15	6/6 +2	
				OAC	-4.375 / -0.875 x 5	6/6 -2	
				OBC	-4.375 / -0.875 x 5	6/6 -2	
				S	-4.25 / -1.00 x 10	6/4	
				R	-4.50 / -1.00 x 20	6/6-	
				OA	-4.75 / -1.25 x 180		
				OB	-5.25 / -0.75 x 10		
			L	SC	-4.125 / -1.25 x 5		
				RC	-4.25 / -0.75 x 180	6/12+	
				OAC	-4.25 / -1.50 x 12½	6/6 -1	
				OBC	-4.125 / -0.875 x 20	6/9	
				S	-4.25 / -1.00 x 180	6/6	
				R	-4.50 / -0.75 x 180	6/6-	
				OA	-4.75 / -1.25 x 25		
				OB	-4.625 / -1.00 x 20		
L.V.	23	F	R	SC	+0.50 / -0.50 x 175	6/6	
				RC	+0.75 / -0.50 x 15	6/9	
				OAC	0.00	6/9 -3	
				OBC	-0.25 DS	6/12+	
				S	+0.25 / -0.25 x 175	6/6	
				R	+0.25 / -0.50 x 15	6/9	
				OA	-1.00 DS	6/6-	
				OB	-0.75 DS	6/9-	
			L	SC	+0.50 / -0.50 x 90	6/6	
				RC	+0.75 / -0.75 x 80	6/12+	
				OAC	-0.25 DS	6/6-	
				OBC	-0.375 DS	6/12	
				S	+0.25 / -0.25 x 90	6/6	
				R	+0.25 / -0.50 x 75	6/9	
				OA	-0.50 / -0.375 x 90	6/6-	
				OB	-1.00 / -0.625 x 72	6/6-	

APPENDIX 9 : CLINICAL EXPERIMENT 2. MYOPIC ASTIGMATIC POPULATION - REFRACTIVE DATA.

(S=Subjective; R=Retinoscopy; O_1 and O_2= Ophthalmetron 1st and 2nd readings).

NAME	AGE	SEX	R/L		REFRACTION	BVD	VA	COMMENTS	
AD	30	F	L	S	-9.50/-2.50 x 177½	13	6/5^{-2}		
				R	-9.50/-2.50 x 175	13	6/5^{-3}		*
				01	-8.00/-2.00 x 10	13	6/18^{+1}		C
				02	-8.00/-2.00 x 10	13	6/9^{+1}		C
HV VH	34	F	R	S	-10.75/-1.00 x 180	12	6/6		
				R	-10.75/-1.00 x 175	12	6/6		*
				01	-13.00/-1.00 x 10	13	6/9^{-1}		C
				02					
			L	S	-9.50/-2.50 x 180	12	6/6^{+}		
				R	-11.00/-2.50 x 180	12	6/9		*
				01	-10.75/-2.50 x 110	13	6/6		C
				02					
TK	15	F	R	S	+0.50/-5.00 x 10	18	6/12		
				R	+0.50/-6.00 x 10	18	6/12		*
				01	-1.62/-3.50 x 20 or 25	13	6/18		C
				02	-1.25/-4.00 x 20	13	6/18		C
			L	S	+0.50/-5.00 x 180	18	6/12^{-}		
				R	+1.00/-6.50 x 170	18			*
				01	-1.75/-5.00 x 10	13	6/18		C
				02	-1.75/-5.12 x 10	13	6/18		C
BM	26	F	R	S	-2.50/-3.50 x 2 2½	13	6/6^{-3}		
				R	-2.00/-4.00 x 20	13	6/6^{-3}		*
				01	-3.00/-3.25 x 22½	13	6/6^{-1}		C
				02					
JMcK	53	M	R	S	-22.00 DS	11	1/60		
				R	Not possible				
				01	No reading possible				
				02					
			L	S	-20.00 DS	11	3/36		
				R	-20.00 DS	11		Doubtful	
				01	No reading possible			1 Cataract 2 Outside range	
				02					
BN	15	F	R	S	-7.50/-2.00 x 15	10	6/5^{-2}		
				R	-8.00/-2.50 x 15	10	6/5^{-2}		*
				01	-8.25/-1.00 x 45	13	6/9^{-2}		C
				02					
			L	S	-13.00/-3.00 x 150	10	6/9	ph 6/9	
				R	-13.00/-3.00 x 165	10	6/9^{-}	Opacity in reflex	*
				01	-13.75/-0.75 x 5	13	6/12^{-1}		C
				02					

NAME	AGE	SEX	R/L		REFRACTION	BVD	VA	COMMENTS	
KB	15	F	R	S	-10.00/-6.00 x 15	17	6/12	ph 6/9^{-}	
				R	-11.50/-5.50 x 15	17	6/12		*
				01	-9.50/-5.50 x 20	13			C
				02	-9.12/-4.62 x 15	13			C
			L	S	-10.00/-4.50 x 165	17	6/12	ph 6/12	
				R	-10.50/-4.50 x 165	17	6/12		*
				01	-9.75/-3.50 x 180	13			C
				02	-10.00/-3.25 x 175	13			C
RB[1]	65	M	R	S	-5.00/-0.50 x 30	10	6/9		
				R	-5.00 DS	10	6/9		*
				01	-4.25/-1.00 x 40	13	6/9^{-}		C
				02	-4.50/-0.75 x 60	13	6/9^{-}		C
RB[2]	11	M	R	S	-15.75/-0.50 x 90	13	6/9		
				R	-15.25DS	10	6/9		
				01	-15.75/-0.25 x 180	13	6/12^{+}		C*
				02					
			L	S	-16.00 DS	13	6/12		
				R	-15.50/-0.50 x 90	13	6/12		
				01	-16.00/-0.50 x 180	13	6/36		C*
				02					
SB	58	F	R	S	-12.00/-2.00 x 90	10	6/9^{-}		
				R	-12.00/-1.50 x 90	10	6/9^{-2}		*
				01	-13.00/-2.00 x 75	13	6/9		C
				02	2nd Inst. not used			Pt. very nervous	
			L	S	-10.50/-1.00 x 120	10	6/9^{-3}		
				R	-10.00/-1.00 x 100	10	6/12		*
				01	-11.50/-1.00 x 120	13	6/9^{-3}		
				02					
EC	13	F	R	S	+3.75/-9.00 x 5	14/20/24	6/12^{-}		
				R	+3.50/-9.00 x 5	14/20/24	6/12^{-3}		*
				01	+2.50/-7.00 x 5	13	6/24		C
				02	+2.75/-7.25 x 5	13	6/24		C
			L	S	+4.00/-9.50 x 180	14/20/24	6/9^{-2}		
				R	+3.00/-9.00 x 180	14/20/24	6/12		*
				01	+3.00/-7.50 x 180 or 10	13	6/12:6/18		C
				02	+3.25/-7.25 x 10 or 180	13	6/12:6/18		C
AD	30	F	R	S	-7.25/-2.75 x 15	13	6/5^{-3}		
				R	-7.00/-2.75 x 10	13	6/6^{-}		*
				01	-6.87/-2.12 x 20	13	6/7.5		C
				02	-7.00/-2.12 x 20	13	6/7.5		C

NAME	AGE	SEX	R/L		REFRACTION	BVD	VA	COMMENTS	
WN	38	M	R	S	-7.50/-2.00 x 160	11	6/9		
				R	-7.75/-2.00 x 165	11	6/9		*
				01	-8.25/-1.50 x 170	13	$6/9^{-1}$		C
				02	-8.25/-1.50 x 175	13	$6/9^{-1}$		C
			L	S	-1.75/-1.50 x $172\frac{1}{2}$		6/6		
				R	-2.25/-1.50 x 170		$6/6^{-2}$		*
				01	-1.37/-1.25 x 180		$6/6^{-2}$		C
				02					
AP	23	M	R	S	-8.50/-3.50 x $27\frac{1}{2}$	10	6/12		
				R	-8.50/-3.00 x 30	10	6/18	Good reflex	*
				01	-10.37/-1.62 x 52	13	6/36		C
				02	-9.75/-2.75 x 35	13	6/18		B
			L	S	-8.50/-4.50 x 155	10	6/12		
				R	-8.00/-5.00 x 170	10	6/36	Good reflex	*
				01	-9.37/-2.62 x 167	13	6/60		C
				02	-8.75/-3.50 x 150	13	$6/24^{-}$		B
GP	31	F	R	S	-9.50/-1.25 x 180	13	$6/6^{-2}$		
				R	-9.00/-2.00 x 20	13	$6/6^{-1}$		
				01	-8.75/-0.75 x 20	13	$6/9^{+}$		C*
				02	-9.00/-1.25 x 10	13	$6/9^{+}$		B
			L	S	-9.75/-1.50 x 180	13	6/6		
				R	-10.25/-1.50 x 170	14	$6/6^{-1}$		
				01	-9.00/-1.25 x 10	13	$6/9^{-}$		C*
				02	-9.50/-1.00 x 30	13	$6/12^{+}$		B
KP	63	F	R	S	-5.00/-1.50 x 110	10	$6/9^{+}$		
				R	-4.50/-2.00 x 110	10	6/9		*
				01	-5.50/-1.50 x 105	13	6/12		C
				02					
JR	16	F	R	S	-9.50/-1.75 x $177\frac{1}{2}$	10	$6/12^{-2}$		
				R	-9.50/-1.50 x 170	10	$6/12^{-1}$		*
				01	-9.50/-2.00 x 15	13			C
				02	-9.50/-2.00 x 20	13			C
			L	S	-3.00/-0.50 x 30	10	$6/9^{-1}$		
				R	-2.75/-0.50 x 10	10	6/9	Slight distortion	*
				01	-3.25/-0.75 x 10	13			C
				02	-3.12/-0.37 x 20	13			C
JS[1]	66	F	R	S	-12.50/-2.50 x 180	12	6/36	Poor sub response	
				R	-14.00 DS	12	?	Central opacities	*
				01	-12.50/-2.25 x 180	13	6/36		C
				02	-13.25/-4.25 x 160	13	$6/36^{-}$		B

NAME	AGE	SEX	R/L		REFRACTION	BVD	VA	COMMENTS	
JS[1]	66	F	L	S	-12.00/-2.50 x 30	12	6/18	Poor sub response	
				R	-12.50/-2.50 x 30	12	6/18	Dull reflex	*
				01	-13.25/-2.75 x 35	13	6/18		C
				02	-13.00/-2.50 x 35	13	6/18		B
JS[2]	55	M	R	S	-6.50/-2.50 x 95	11	6/9		
				R	-6.50/-2.00 x 105	11	6/9	Dull reflex	*
				01	No reading			opacities	
				02				Good fixation	
SS[1]	17	M	R	S	+3.00/-7.25 x 15	8/12	$6/9^{-1}$		
				R	+3.00/-7.25 x 15	8/13	$6/9^{-1}$		*
				01	+2.00/-5.75 x 25 or 15	13	$6/12^{-}$		C
				02	+2.75/-6.50 x 15	13			B
			L	S	+2.25/-6.00 x 160	10/14	$6/9^{-2}$		
				R	+1.75/-6.00 x 160	10/14	$6/9^{-2}$		*
				01	+1.50/-4.75 x 165	13	$6/18^{+2}$		C
				02	+0.75/-5.00 x 160 or 165	13	6/18		B
SS[2]	11	F	R	S	-14.50/-3.00 x 10	10	6/24		
				R	-14.50/-3.00 x 10	10	6/24		*
				01	-13.75/-3.00 x 10	13	6/24		C
				02					
			L	S	-14.00/-3.00 x 180	10	6/24		
				R	-14.50/-3.00 x 180	10	6/24		*
				01	-13.75/-3.75 x 5	13	6/24		C
				02					
AT	52	F	R	S	-15.75/-1.00 x 90	7	6/9		
				R	-15.75/-1.50 x 95	7	$6/9^{-2}$		*
				01	Not possible				C
				02					
			L	S	-15.00/-2.00 x 150	7	6/12		
				R	-14.50/-2.00 x 90	7	6/24	Poor reflex	*
				01	Not possible				C
				02					
AV	21	M	R	S	-10.50/-2.75 x 15	13	$6/9^{+}$		
				R	-10.75/-2.50 x 10	13	6/9		*
				01	-10.75/-2.50 x 35 Or 25	13	$6/18^{+3}$		C
				02	-11.00/-2.00 x 35 or 30	13	6/12		C
			L	S	-14.50/-3.00 x 145	10	$6/9^{+}$		
				R	-14.00/-3.00 x 150	10	$6/12^{+3}$		*
				01	-16.25/-1.75 x 180	13	$6/18^{-1}$		C
				02	-15.75/-2.25 x 175	13	6/18		C

NAME	AGE	SEX	R/L		REFRACTION	BVD	VA	COMMENTS	
MV	36	F	R	S	-8.00/-3.50 x 10	10	$6/18^{+}$	Poor sub response	
				R	-8.50/-2.50 x 10	10	$6/18^{+1}$		*
				01	-10.75/-3.00 x 25	13	6/18		C
				02	-9.00/-2.62 x 30	13	6/24		C
			L	S	-10.50/-3.00 x 5	10	6/18	ph $6/18^{-1}$ Poor sub respons	
				R	-10.50/2.50 x 180	10	6/18		*
				01	-12.00/-2.50 x 180	13	6/18		C
				02					
CW	30	F	R	S	-13.50/-1.75 x 30	9	$6/5^{-4}$		
				R	-14.50/-1.50 x 25	9	$6/6^{-2}$		*
				01	-14.75/-1.25 x 35	13			C
				02	-14.00/-1.50 x 35	13			C
			L	S	-10.00/-3.00 x 145	9			
				R	-9.00/-3.50 x 145	9	$6/18^{-}$		*
				01	-11.75/-2.75 x 150	13			C
				02	-11.75/-2.50 x 155	13			C
HW	18	F	R	S	-10.25/-3.00 x $7\frac{1}{2}$	8	$6/6^{-4}$		
				R	-10.00/-3.50 x 5	8	$6/9^{+3}$		*
				01	-11.00/-3.50 x 10 or 15	13	$6/9^{-3}$		C
				02	-11.50/-3.50 x 175	13	$6/9^{-1}$		B
			L	S	-10.50/-5.50 x 180	8	6/9		
				R	-11.00/-5.00 x 175	8	$6/9^{-1}$		*
				01	-11.00/-6.75 x $7\frac{1}{2}$	13	6/9		C
				02	-10.75/-5.00 x $172\frac{1}{2}$	13	6/12		B

APPENDIX 10: CLINICAL EXPERIMENT 3. CORNEAL GRAFT PATIENTS REFRACTIVE DATA

(S = Subjective; R = Retinoscopy; O_1 and O_2 = Ophthalmetron 1st and 2nd readings).

NAME	AGE	SEX	R/L		REFRACTION	BVD	VA	COMMENTS	
AA	39	M	R	S	-7.50/-2.50 x 135	13	6/12^{+}		
				R	-6.50/-1.50 x 120	13	6/24^{+}		*
				01	-7.50/-1.50 x 170	13	6/18^{-}		
				02	-7.75/-1.25 x 170	13	6/18^{-}		
			L	S	-9.00/-2.00 x 170	13	6/6^{-}		
				R	-9.00/-2.50 x 160	13	6/9		*
				01	-8.75/-1.25 x 50	13	6/12		
				02					
MA		M	R	S	-5.00/-3.00 x 165	11	6/9^{+}		
				R	-3.75/-3.00 x 165	11	6/12	Split reflex	*
				01	-4.50/-2.50 x 175	13	6/12		
				02	-4.50/-3.25 x 170	13	6/9^{-}		
AB	54	M	R	S	+0.75/-2.75 x 180	12	6/24		
				R	Plano/-2.25 x 180	12	6/24	central opacity	*
				01	-3.00/-2.00 x 170	13	6/24		
				02					
GB[1]	29	M	L	S	-3.50/-2.50 x 90	17	6/6^{+}		
				R	-5.50/-2.50 x 90	17	6/9	Split reflex	*
				01	-5.50/-1.50 x 100	13	6/9^{+1}		
				02					
GB[2]	34	M	L	S	+1.50/-11.00 x 165	7/13/17	6/9^{-1}		
				R	+0.50/-9.50 x 155	7/13/17	6/36		*
				01	-0.50/-10.00 x 180	13			
				02	+1.50/-8.50 x 177½	13			
MB	36	F	L	S	+5.00/-1.00 x 165	13	6/9		
				R	+5.00/-1.00 x 180	13	6/9^{-}	Split reflex	*
				01	+6.50/-1.00 x 120 x 110	13			
				02					
RB[1]	21	M	R	S	-8.50/-5.50 x 37½	13/17	6/6^{-}		
				R	-10.00/-6.00 x 35	13/17	6/6^{-}		*
				01	-10.50/-6.75 x 45	13	6/18^{+1}		
				02	-12.00/-5.50 x 45	13			
RB[2]	32	M	R	S	-4.25/-3.75 x 45	12	6/6^{-2}		
				R	-4.75/-4.00 x 50	12	6/9^{-}		*
				01	-4.50/-3.00 x 57½	13	6/9^{-1}		
				02	-5.00/-3.00 x 57	13	6/9^{-}		
			L	S	+1.50/-2.75 x 135	12	6/6^{-4}		
				R	+0.50/-3.00 x 120	12	6/9^{-4}		*
				01	-1.00/-3.50 x 125	13	6/18^{+2}		
				02	-2.00/-4.00 x 130	13	6/24		

NAME	AGE	SEX	R/L		REFRACTION	BVD	VA	COMMENTS	
SB	26	F	L	S	-1.50/-2.00 x 27½		6/5^{-3}		
				R	-1.00/-2.00 x 20		6/6^{-3}	Split reflex	*
				01	-0.25/-2.75 x 40	13			
				02	-0.37/-2.62 x 45	13			
WC	45	M	L	S	+20.00/-7.00 x 37½	11/19	6/18^{-2}	ph 6/12	
				R	+22.00/-6.00 x 30	11/19	3/24	Distorted reflex	*
				01	No reading			off scale	
				02	No reading			reflex at edge pupil	
E	39	F	L	S	-3.50/-3.50 x 125		6/18^{-1}		
				R	-1.50/-3.50 x 105				*
				01	No interpretable readings				
				02					
AH	49	F	R	S	+0.50/-3.50 x 42½	15	6/12^{-1}		
				R	Plano/-3.50 x 45	15	6/12^{-1}		*
				01	Plano/-2.75 x 55	13	6/18^{-1}	Patient never saw	
				02	Plano/-2.75 x 70	13	6/24^{-1}	double target	
DH	28	M	R	S	+10.00/-2.50 x 10	13	6/12^{-3}	ph 6/12^{-}	
				R	+11.25/-2.00 x 10	12	6/18^{-1}	scissors mvt	*
				01	+11.50/-2.00 x 15	13	6/18		
				02					
			L	S	+11.00/-2.00 x10	13	6/18^{+1}	ph 6/12^{-}	
				R	+11.00/-2.00 x 5	12	6/18^{-}	scissors mvt	*
				01	+10.12/-2.62 x 40	13	6/36		
				02					
H		F	R	S	+3.75/-4.75 x 70	14	6/6		
				R	+5.00/-6.00 x 60	14	6/9^{-2}	Poor reflex	*
				01	+1.50/-3.00 x 70	13	6/9^{-1}+2		
				02					
PH	40	M	R	S	-5.50/-1.75 x 85	12	6/9		
				R	-4.50/-1.50 x 60	12	6/12^{+3}	Some distortion	*
				01	No reading				
				02					
			L	S	-1.25/-2.25 x 55		6/9		
				R	+0.50/-2.25 x 75		6/12^{-1}+4		*
				01	-1.00/-1.75 x 45	13	6/12^{+}		
				02					
JL	41	F	R	S	-4.00/-1.00 x 95	12	6/9		
				R	+5.00/-6.00 x 100	12	?	Definite mvt	*
				01	-2.00/-4.00 x 100	13	6/6^{-}		
				02	-2.75/-3.75 x 110	13	6/9		

NAME	AGE	SEX	R/L		REFRACTION	BVD	VA	COMMENTS	
JM	32	M	L	S	-6.50/-3.25 x 30	11	$6/6^{-}$		
				R	-6.25/-3.00 x 25	11	$6/6^{-2}$	Some distortion	*
				01	-4.00/-3.50 x 55	13	$6/6^{-}$		
				02					
DP	27	M	L	S	-4.00/-3.00 x 80	17	6/9	ph6/6^{-}	
				R	-4.00/-3.00 x 75	17	6/9		*
				01	-1.50/-6.00 x 70	13	6/9		
				02	-2.00/-5.75 x 70	13	6/9		
P	37	F	L	S	+1.75/-8.50 x 120	10	$6/6^{-3}$		
				R	+1.50/-8.50 x 120	10	$6/6^{-3}$		*
				01	+0.50/-6.50 x 125	13	6/24		
				02					
GR	26	M	R	S	-1.00/-4.00 x 15				
				R	+3.00/-4.00 x 15			Distorted reflex	*
				01	+2.50/-8.50 x $27\frac{1}{2}$	13	6/18		
				02	+3.50/-9.50 x $22\frac{1}{2}$	13			
			L	S	+1.25/-3.50 x 165		$6/6^{+1}$		
				R	+0.75/-3.50 x 180				*
				01	Plano/-2.00 x 175	13	6/9		
				02	-0.50/-1.50 x 175	13			
PS	32	F	R	S	-7.00/-4.00 x $12\frac{1}{2}$	8	$6/6^{-3}$		
				R	-7.50/-3.50 x 15	8	$6/9^{+2}$		*
				01	-9.50/-3.75 x 15	13	6/9		
				02	-8.75/-3.00 x 15	13	$6/9^{+}$		
			L	S	-14.00/-2.00 x 160	8	6/24	ph 6/12	
				R	Not possible				
				01	No reading				
				02					

APPENDIX II : CLINICAL EXPERIMENT 4.

APHAKIA - REFRACTIVE DATA

(S = Subjective; R = Retinoscopy; O_1 and O_2 = Ophthalmetron 1st and 2nd reading; D_1 and D_2 = 1st and 2nd Dioptron readings)

* Indicates the finding used at the start of the subjective refractions.

B stands for Ophthalmetron from Bradford University

C stands for Ophthalmetron from City University

NAME	AGE	SEX	R/L		REFRACTION	BVD	VA	COMMENTS	
HA [1]	52	M	L	S	+13.00/-3.00 x 100	9	$6/4^{-1}$		
				R	+13.00/-3.25 x 90	9	$6/6^{-1}$		*
				01	+12.50/-2.75 x 100	13	6/6		C
				02	+12.50/-2.75 x 100	13	6/6		C
HA [2]	71	M	L	S	+13.50/-1.00 x 50	13	$6/6^{+2}$		
				R	+14.25/-1.25 x 45	10	$6/9^{+3}$	Good reflex	
				01	+14.25/-1.25 x 40	13	$6/12^{+2}$		B
				02	+13.25/-1.00 x 70	13	6/12		C
JA	48	M	R	S	+11.75/-1.00 x 40	13	$6/5^{-}$		
				R	+12.00/-1.50 x 60	12	$6/5^{-4}$	Peripheral distortion	
				01	+12.50/-1.25 x 65 or 70	13	$6/9^{+3}$		B
				02	+11.75/-1.00 x 70	13	6/6		C
AB	62	M	R	S	+13.50/-1.50 x 80	10	6/6		
				R	+14.50/-1.50 x 95	13	$6/12^{+2}$		*
				01	No reading			Steady fixation	
				02	No reading			Slightly out of focus	
CB	63	M	R	S	+11.75/-2.25 x 95	13	$6/5^{-3}$		
				R	+12.50/-1.50 x 95	10	$6/9^{-1}$	Reflex satisfactory	
				01	+12.50/-3.50or105or100	13	6/24		B
				02	+11.75/-2.25 x 110	13	6/12		C
DB [1]	38	F	L	S	+11.25/-0.75 x 60	13	6/6		
				R	+11.00/-0.75 x 70	11	6/9		
				01	+12.00/-0.75 x 20	13	6/18		C
				02	+12.25/-0.75 x 110	13	6/18		C
DB [2]	31	M	R	S	+14.50/-0.25 x 30	7	6/5		
				R	+14.50 D.S.	7	$6/5^{-3}$	Poor reflex	*
				01	No reading				
				02	No reading				
DB [3]	13	M	L	S	+10.00/-3.50 x 170	10	6/36		
				R	+11.00/-4.00 x 180	10	$6/36^{-}$	Some distortions	*
				01	+9.50/-1.75 x 180	13	6/60		C
				02	+10.50/-3.00 x 160	13	6/36		B
DB [4]	64	M	R	S	+13.50/-0.50 x 135	8	6/5	Good subjective	
				R	+13.50/-0.50 x 105	8	$6/6^{-1}$		*
				01	+12.25/-0.75 x 125	13	$6/6^{-}$		C
				02	+13.00/-0.50 x 140	13	6/5		B
EB [1]	66	M	R	S	+14.25/-1.50 x $52\frac{1}{2}$	11	6/5		
				R	+13.75/-1.50 x 50	11	6/5	Clear-some distortion	*
				01	+12.75 DS	13	$6/12^{+1}$	Nystagmus	C

NAME	AGE	SEX	R/L		REFRACTION	BVD	VA	COMMENTS	
EB [2]	67	F	L	S	+13.75/−1.50 x 130	12	$6/6\overline{+1}$		
				R	+13.50/−2.00 x 130	12	$6/9^{-1}$	Distorted reflex	*
				01	+14.25/−2.00 x 145 or 140	13	$6/6^{-}$		C
				02	+14.25/−2.25 x 140	13	$6/6^{-}$		C
JB		M	L	S	+12.25/−1.75 x 80	18	$6/6^{-}$		
				R	+13.00/−1.75 x 80	18	6/18		*
				01	+12.50/−1.50 x 95	13	6/6		C
				02					
LB	52	M	R	S	+10.75/−2.00 x 115	13	6/6		
				R	+11.00/−2.00 x 110	10	$6/6^{-1}$	Small pupil	
				01	+10.75/−2.00 x 125	13	6/9		C
				02	+10.62/−1.87 x 127½	13	6/9		C
MB	41	F	R	S	+10.00/−1.50 x 65	13	$6/9\overline{+4}$		
				R	+10.25/−1.75 x 60	7	$6/9\overline{+2}$	Central opacity	
				01	+9.50/−2.00 x 75 Or 85	13	$6/9^{-1}$		B
				02	+9.50/−1.25 x 90 or 80	13	$6/9^{-}$		C
RB [1]	65	M	L	S	+10.00/−2.50 x72½	10	$6/5^{+}$		
				R	+10.00/−2.50 x 75	10	6/6		*
				01	+9.00/−2.00 x 85	13	$6/12^{-}$		C
				02	+9.50/−2.25 x 75	13	$6/9^{-2}$		B
RB [2]	62	M	L	S	+11.75/−2.50 x 100	8	$6/9^{-}$	Head tilt to left	
				R	+11.50/−2.50 x 100	8	$6/9^{-1}$	Central opacity	*
				01	+10.75/−1.50 x 100	13	$6/6^{+3}$		C
				02					
TB	42	M	L	S	+11.50/−1.50 x 122½	9	$6/12^{+}$	Variable ph no ↑	
				R	+10.50/−1.50 x 135	9	$6/18^{-1}$	Central opacity	*
				01	No reading				
				02	No reading				
VB	64	M	R	S	+11.25/−2.00 x 90	13	$6/9^{-}$	Variable ph 6/12	
				R	+10.75/−2.00 x 75	13	$6/12^{-3}$	Some distortion	*
				01	+9.75/−1.25 x 70	13			C
				02	+9.50/−1.00 x 75	13			C
WB	58	M	L	S	+13.00/−1.00 x 95	13	6/5		
				R	+13.00/−1.00 x 95	13	6/5	Good reflex	
				01	+13.25/−0.50 x 100	13	$6/5^{-2}$		C
				02	+13.12/−0.62 x 95	13			C
AC [1]	72	F	R	S	+11.25/−1.50 x 135	13	$6/6^{-}$	Variable	
				R	+12.50/−2.50 x 130	10	$6/12^{+3}$	Clear reflex	
				01	No reading				B
				02	+10.75/−1.00 x 145	13	$6/6^{-2}$		C

NAME	AGE	SEX	R/L		REFRACTION	BVD	VA	COMMENTS	
AC[2]	71	M	R	S	+9.00/−0.50 x 35	13	6/18	V.A. Varies	
				R	+10.00/−1.50 x 105	9	6/24^{-}	Central opacity	
				01	No reading				B
				02	+8.75/−1.25 x 125	13	6/36	Poor fixation	C
BC	51	M	R	S	+10.75/−0.50 x 40	13	6/5		
				R	+11.50/−0.75 x 15	10	6/6^{-1}		
				01	+10.25/−0.50 x 40	13	6/6^{-1}		B
				02	+10.25/−1.00 x 50	13	6/9		C
			L	S	+11.25/−1.25 x 102½	13	6/5^{+}		
				R	+12.00/−2.00 x 110	10	6/9	Satisfactory reflex	
				01	+11.50/−1.50 x 100	13	6/6		B
				02	+11.00/−1.25 x 110	13	6/5^{-1}		C
DC[1]	55	M	R	S	+13.00/−1.50 x 95	9	6/4^{-3}		
				R	+13.50/−1.50 x 105	9	6/5^{-1}		*
				01	+11.50/−2.12 x 110 or 102½	13	6/18		C
				02					
			L	S	+13.50/−1.50 x 102½	9	6/5^{+2}		
				R	+13.50/−1.50 x 115	9	6/6^{-1}		*
				01	+12.75/−1.62 x 127½	13	6/12		C
				02					
DC[2]	66	F	R	S	+12.50/−2.25 x 90	13	6/9		
				R	+12.50/−1.00 x 90	14	6/9		
				01	+12.00/−1.25 x 105	13	6/9^{-}		C
				02	+12.75/−2.25 x 105	13	6/9		B
			L	S	+13.25/−1.00 x 70	9	6/6		
				R	+13.00/−1.00 x 75	9	6/6^{-2}		*
				01	+12.25/−0.50 x 100	13	6/9^{-2}		C
				02	+12.50/−0.50 x 70	13	6/9		B
DC[3]	59	M	L	S	+14.25/−1.25 x 77½	11	6/6		
				R	+14.00/−1.50 x 77½	11	6/6^{-2}		*
				01	+13.50/−0.75 x 90	13	6/9^{-}		C
				02					
EC[1]	47	F	R	S	+14.00/−1.25 x 165	8	6/9^{+1}		
				R	+13.00/−1.25 x 165	8	6/18		*
				01	No reading			Cycle did not start	C
				02					
			L	S	+14.25/−1.50 x 170	8	6/5^{+3}		
				R	+13.50/−1.00 x 25	8	6/6^{+3}		*
				01	No reading			Cycle did not start	
				02					

NAME	AGE	SEX	R/L		REFRACTION	BVD	VA	COMMENTS	
EC[2]	72	F	R	S	+16.00/-2.50 x 80	15	6/9^{+4}		
				R	+16.00/-3.00 x 80	15	6/9		*
				01	No reading			Good fixation 2½mm pupil	B
				02	No reading			vitreous pbm	C
EC[3]	54	M	L	S	+11.00/-3.00 x 110	8	6/6$^{-2}_{+3}$		
				R	+11.50/-2.50 x 105	8	6/9^{-}	Dull reflex	*
				01	No reading			Ecc corneal reflex	C
				02					
IC	69	F	L	S	+13.50/-1.50 x 92½	12	6/5		
				R	+13.00/-1.00 x 95	12	6/6^{+1}	Good reflex	*
				01	+12.75/-1.00 x 115	13	6/9		C
				02					
KC	43	M	R	S	+12.50/-2.00 x 50	9	6/18	ph 6/12^{+} Variable	
				R	+12.50/-2.00 x 75	9	6/12^{-3}	Opacity - split reflex	*
				01	No reading			Cycle did not start	C
				02	No reading			Good fixation	B
LC	57	F	R	S	+13.75/-0.50 x 180	13	6/6^{-3}		
				R	+14.00 DS	13	6/12^{+2}	Difficult reflex	*
				01	No reading			Cycle did not start	C
				02					
			L	S	+13.50/-1.50 x 180	13	6/5		
				R	+14.00/-1.50 x 180	13	6/9		*
				01	No reading			Cycle did not start	C
				02					
MC	56	F	L	S	+12.50/-1.00 x 100	7	6/4		
				R	+12.50/-1.00 x 95	7	6/4		*
				01	+13.00/-2.25 x 105	13	6/12		B
				02	+12.25/-1.25 x 115	13	6/4		C
RC[1]	21	M	R	S	-2.00/-8.00 x 15	9/13	3/60	$\bar{c}$ ph	
				R	-2.50/-6.00 x 15	13/23		Difficult reflex	*
				01	-3.25/-11.25 x 20	13	3/60		C
				02	-1.75/-12.00 x 180	13	3/60		C
RC[2]	55	M	R	S	+12.00/-2.50 x 90	13	6/5		
				R	+13.25/-2.50 x 90	8	6/9		
				01	+12.00/-2.50 x 90	13	6/5		B
				02	+10.75/-1.75 x 105	13	6/9		C*
HD	57	M	R	S	+12.50/-0.25 x60	12	6/5^{-2}		
				R	+12.00/-0.50 x 45	12	6/6^{-3}	Small pupils	*
				01	No reading				C
				02					

NAME	AGE	SEX	R/L		REFRACTION	BVD	VA	COMMENTS	
JD	67	M	R	S	+12.25/-2.50 x 90	13	6/9		
				R	+12.25/-2.50 x 92½	10	6/9		
				01	+10.75/-1.00 x 115	13	6/12		C*
				02	+12.25/-2.25 x 90	13	6/9		B
SD	53	M	R	S	+11.50/-0.75 x 110	8		Not reliable No English	
				R	+11.50DS	8	$6/5^{-1}$	Dull reflex	*
				01	No reading			Good fixation	B
				02	No reading			Pupil too small	C
			L	S	Not obtained			Unreliable	
				R	+11.00/-1.00 x 65	8	$6/5^{-4}$		
				01	No reading			Good fixation	
				02	No reading			Reflex at pupil margin	
KE	66	F	R	S	+9.00/-1.75 x 75	13	$6/6^{-}$	Poor sub response	
				R	+9.00/-1.25 x 85	11	6/9	Very variable reflex	
				01	+9.75/-2.00 x 75	13	$6/9^{+}$	Poor fixation - very	B
				02	+9.00/-1.75 x 100	13	6/12	nervous patient	C*
CF	51	M	R	S	+11.00/-0.75 x 75	13	6/5		
				R	+11.00/-1.00 x 90	15	$6/6^{+}$	Some distortion	
				01	+11.25/-0.50 x 95	13	$6/5^{-}$		C*
				02	+11.25/-0.50 x 90	13	$6/5^{-2}$		C
MF	50	F	L	S	+12.50/-1.25 x 117½	13	6/5	Poor sub response	
				R	+12.50/-0.50 x 70	11	6/9	split reflex	
				01	+12.75/-1.25 x 135	13	6/5		C*
				02	+12.67/-1.37 x 135	13	6/5		C
VF	65	F	R	S	+14.50/-1.75 x 80	13	6/6		
				R	+14.25/-2.25 x 85	12	$6/12^{+2}$	Good reflex	
				01	+14.50/-1.75 x 105	13	$6/9^{-1}$		C*
				02	+15.50/-2.25 x 95	13	6/9		B
			L	S	+13.50/-1.00 x 92½	13	6/9		
				R	+13.75/-1.25 x 90	12	$6/9^{-1}$	Good reflex	*
				01	+13.50/-0.75 x 125	13	$6/12^{+4}$		C
				02	+14.75/-1.75 x 120	13	6/18		B
CG	62	M	L	S	+10.50/-1.50 x 100	13	$6/6^{+4}$		
				R	+11.25/-1.25 x 90	12	$6/6^{-4}$		*
				01	+9.75/-0.75 x 100	13	$6/9^{-1}$		C
				02					
DG	48	M	R	S	+8.00/-0.50 x 90	7	6/5		
				R	+7.50/-0.75 x 90	7	6/9		*
				01	+8.00/-0.62 x 120	13	$6/6^{-}$		C
				02	+8.00/-0.62 x 110	13	$6/6^{-}$		C

NAME	AGE	SEX	R/L		REFRACTION	BVD	VA	COMMENTS	
JG	75	M	R	S	+13.75/-1.00 x 90	13	6/9		
				R	+14.00/-1.50 x 80	12	$6/9^{-2}$	Some distortion	*
				01	+13.75/-1.00 x 100	13	$6/9^{-4}$		C
				02	+13.75/-0.75 x 90	13	$6/9^{-1}$		C
KG	65	M	L	S	+7.00/-1.75 x 65	13	$6/4^{-3}$		
				R	+8.00/-1.50 x 65	5	$6/5^{-1}$	Good reflex	
				01	+7.00/-2.50 x 70 or 75	13	$6/9^{-1}$		B
				02	+7.00/-1.50 x 75	13	$6/5^{-2}$		C*
PG	65	M	R	S	+15.00/-2.00 x 65	10	$6/12^{\mp 2}$		
				R	+14.50/-1.00 x 90	11	6/18	Large central opacity	*
				01	No reading			Cycle did not start	C
				02	No reading			No useful graph	B
			L	S	+13.00/-1.75 x 115	11	6/4		
				R	+12.75/-1.75 x 90	11	$6/4^{-2}$	Good reflex	*
				01	+13.00/-1.25 x115	13	6/4		C
				02	No reading			No useful graph	B
RG[1]	43	M	R	S	+14.50/-2.00 x 45	9	6/9	$\pm$ 0.50makes no difference	
				R	+14.50/-2.00 x 45	9	6/9	Poor reflex distortion	*
				01	No reading			Very good fixation	B
				02	No reading			Cycle did not start	C
RG[2]	59	M	L	S	+12.00/-2.25 x 120	13	$6/5^{+}$		
				R	+13.00/-2.25 x 125	7	$6/5^{-}$		
				01	+12.00/-2.25 x 140	13	$6/5^{\mp 4}$		B
				02	+11.50/-1.25 x 135	13	6/7.5		C*
AH	61	M	L	S	+12.25/-1.00 x 15	15	$6/6^{+4}$		
				R	+12.00/-1.00 x 180	15	$6/6^{-2}$	slight distortion	*
				01	+12.00/-1.25 x 180	13	$6/6^{-}$		C
				02					
LH[1]	56	M	L	S	+12.00/-0.75 x 85	13	6/6-3		
				R	+12.75/-1.25 x 80	11	$6/6^{+1}$		
				01	+12.50/-1.00 x 30	13	$6/12^{\mp 2}$		B*
				02	No reading				
LH[2]	67	M	R	S	+12.75/-1.25 x $77\frac{1}{2}$	13	6/5		
				R	+13.50/-1.50 x 70	8	6/12		*
				01	+12.25/-1.25 x 70	13	$6/6^{-}$		C
				02	+12.37/-1.25 x 75	13	$6/6^{-1}$		C
PH[1]	52	M	L	S	+13.25/-2.00 x $97\frac{1}{2}$	10	$6/9^{+3}$		
				R	+12.25/-2.00 x 90	10	6/18	Distorted reflex	*
				01	+14.00/-2.75 x 80	13	$6/12^{+1}$		C
				02	+13.50/-2.25 x 85	13	$6/9^{-3}$		C

NAME	AGE	SEX	R/L		REFRACTION	BVD	VA	COMMENTS	
DJ	53	F	L	S	+13.00 DS	13	6/6	Poor subjective response	
				R	+13.25/-0.25 x 45	13	6/6	Good reflex	
				01	No reading			Good fixation	B
				02	+12.75 DS	13	$6/6^{-2}$		C*
EK	41	F	R	S	+12.25/-1.25 x $57\frac{1}{2}$	13	6/9		
				R	+13.00/-2.00 x 65	10	6/9		
				01	+12.00/-1.25 x 80	13	6/12		C*
				02					
JK[1]	13	M	R	S	+17.25/-1.00 x 80	7	$6/6^{-3}$		
				R	+17.50/-1.50 x 80	7	$6/6^{-4}$		*
				01	No reading			Poor fixation pupil gap	
				02					
JK[2]	16	F	R	S	+14.50/-4.00 x 175	9	$6/12^{-}$		
				R	+14.00/-2.00 x 170	9	6/18		*
				01	No reading			Clear central reflex	
				02					
			L	S	+15.00/-2.75 x 165	13	$6/9^{-3}$		
				R	+15.50/-2.50 x 175	9	6/18		
				01	+16.00/-4.00 x 165	13	$6/12^{-1}$		B
				02	+13.50/-2.75 x 175	13	$6/18^{+2}$		C*
LK	60	M	L	S	+8.00/-2.50 x 90	8	$6/6^{+}$		
				R	+8.50/-2.50 x 100	8	$6/9^{+}$		*
				01	No reading			abnormal pupil	C
				02	No reading				B
MK[1]	52	M	R	S	+13.00/-1.50 x 105	13	$6/6^{-3}$		
				R	+12.50/-1.50 x 90	13	6/9	Opacities within reflex	
				01	+12.00/-1.25 x 110	13	$6/9^{-}$		C*
				02					
MK[2]	68	M	R	S	+13.25/-2.00 x 80	11	$6/18^{-1}$	Poor discrimination	
				R	+13.25/-1.50 x 75	11	$6/18^{-1}$	Central opacity distortion	*
				01	No reading				C
				02					
CL	68	M	R	S	+12.25/-0.75 x 75	13	6/5		
				R	+13.00/-1.00 x 95	10	6/5		
				01	+12.00/-0.75 x 75	13	6/5		C*
				02	+12.25/-0.75 x 80	13	6/5		B
			L	S	+11.50/-0.75 x 110	13	$6/6^{+2}$		
				R	+12.00/-1.50 x 105	12	$6/6^{-2}$	Large pupil-aberration	
				01	+12.00/-0.75 x 125	13	6/9		C*
				02	+13.50/-1.75 x 110	13	6/18		B

NAME	AGE	SEX	R/L		REFRACTION	BVD	VA	COMMENTS	
JL	62	M	L	S	+13.50/−0.50 x 10	13	$6/5^{-}$		
				R	+13.00/−0.50 x 175	13	$6/6^{-3}$	Good reflex	*
				01	No reading				
				02					
ML[1]	60	F	R	S	+12.50/−1.00 x 10	12	$6/9^{+3}$		
				R	+12.00/−0.50 x 165	12	$6/9^{-1}$	Split reflex	*
				01	No reading			Pupil not central	
				02					
ML[2]	63	F	L	S	+16.50/−2.75 x 100	9	6/6		
				R	+18.00/−2.50 x 100	6	$6/18^{+}$		*
				01	+14.75/−2.00 x 100	13	$6/6^{-}$		C
				02	+14.37/−1.62 x 110	13	$6/6^{-}$		C
AM	48	M	R	S	+12.75/−2.25 x 85	13	6/9	Poor sub response	
				R	+14.00/−3.00 x 95	10	$6/12^{+2}$		
				01	+12.25/−1.25 x 95	13	$6/12^{-}$		C*
				02	+12.37/−1.50 x 100	13	$6/12^{-}$		C
EM[1]	63	F	R	S	+14.00/−0.75 x 120	13	6/6	Poor response	
				R	+14.00/−1.25 x 135	9	$6/9^{-2}$	Split reflex	
				01	+15.25/−0.75 x 95	13	6/6		B
				02	+14.50/−1.25 x 125 or 115	13	6/7.5		C*
EM[2]	67	F	L	S	+11.75/−0.50 x 45	13	$6/6^{-1}$		
				R	+12.50/−0.50 x 165	12	$6/9^{-2}$	Scissors mvt	
				01	+12.25/−0.50 x 135	13	6/9		C*
				02	+13.25/−0.75 x 130	13	6/24		B
FM	16	M	L	S	+7.00/−2.00 x 140	13	6/9	ph $6/6^{-}$	
				R	+11.50/−3.50 x 100	12	6/24	Distorted reflex	
				01	+6.50/−3.00 x 160	13	6/18		C*
				02					
IM	69	M	L	S	+11.00/−0.25 x 80	13	$6/6^{-2}$		
				R	+12.00/−0.25 x 90	7	$6/9^{+4}$		
				01	+11.50/−1.00 x 70	13	$6/6^{-3}$		B
				02	+10.50/−0.25 x 75	13	6/9		C*
JM	42	F	R	S	+12.75/−1.75 x $67\frac{1}{2}$	11	6/4		
				R	+12.75/−1.50 x 80	11	$6/5^{+}$		*
				01	+12.50/−1.25 x 90	13	6/9		C
				02	+12.75/−1.25 x 90	13	6/9		C
PM	39	F	R	S	−0.25/−1.75 x $52\frac{1}{2}$		$6/9^{-2}$		
				R	−0.50/−1.50 x 45		$6/9^{-1}$		*
				01	−0.25/−1.25 x 60		$6/9^{-3}$		C
				02	Plano/−2.00 x 60		6/12		C

NAME	AGE	SEX	R/L		REFRACTION	BVD	VA	COMMENTS	
TM	52	M	L	S	+13.00/-2.25 x 100	16	$6/4^{-1}$		
				R	+13.00/-2.00 x 105	16	6/7.5	Scissors mvt	*
				01	+13.00/-1.75 x 110	13	6/7.5		C
				02	+13.25/-1.75 x 110	13	6/9		C
DMacK	73	F	L	S	+15.50/-1.00 x 80	10	$6/7.5^{-1}$		
				R	+15.50/-1.00 x 75	10	$6/9^{+2}$		*
				01	+15.00/-0.50 x 120	13	$6/12^{-1}$		C
				02					
DN	55	F	R	S	+12.50/-2.25 x 90	13	$6/5^{+2}$		
				R	+11.50/-1.50 x 10	12	6/6	central opacity	
				01	+13.00/-2.25 x 105	13	$6/6^{-}$		C*
				02					
CP	54	F	R	S	+13.00/-3.50 x $102\frac{1}{2}$	13	6/12		
				R	+13.75/-3.50 x 120	9	6/18	Distorted reflex split	
				01	+11.75/-2.50 x $117\frac{1}{2}$	13	6/18		C*
				02	+12.75/-3.50 x 100	13	$6/12^{-1}$		B
EP	68	F	R	S	+13.00/-3.25 x $172\frac{1}{2}$	12	6/12	ph 6/9	
				R	+13.00/-2.25 x 10	12	6/18		*
				01	+12.50/-1.75 x 30	13	6/18		C
				02					
HP	64	F	R	S	+12.75/-2.25 x $92\frac{1}{2}$	9	$6/5^{-2}$		
				R	+12.50/-2.50 x 90	9	6/6		*
				01	+11.50/-1.50 x 110	13	$6/5^{-1}$		C
				02	+11.75/-1.25 x 110	13	$6/5^{-1}$		C
KP	63	F	L	S	+7.50/-1.00 x 80	12	6/18		
				R	+8.00/-1.00 x 90	12	6/24		*
				01	No reading			Eccentric reflex	
				02					
MP	70	M	R	S	+10.50/-1.50 x 40	8	$6/18^{-}$	Poor sub response	
				R	+9.50/-2.00 x 45	8	$6/18^{-2}$	Central opacity	*
				01	No reading			Central opacity	C
				02					
			L	S	+9.25/-1.00 x 160	13	$6/24^{-2}$	Poor sub response	
				R	+9.50/-2.00 x 120	8	$6/24^{-1}$		C*
				01	+9.75/-1.00 x 160	13	6/36		
				02					
SP	60	F	R	S	+12.75/-2.25 x 90	13	6/6		
				R	+13.00/-2.50 x 90	9	$6/6^{-2}$		*
				01	+11.00/-2.00 x 110	13	$6/12^{+}$		C
				02	+11.25/-2.25 x 100	13	$6/12^{+}$		C

NAME	AGE	SEX	R/L		REFRACTION	BVD	VA	COMMENTS	
SP	60	F	L	S	+11.50/−1.50 x 96	11	6/5		
				R	+12.00/−1.50 x 90	10	$6/6^{+}$		*
				01	+11.00/−1.25 x 95	13	$6/5^{-4}$		C
				02	+11.00/−1.12 x 100	13	$6/5^{-}$		C
WP	49	M	R	S	+13.00/−1.50 x 55	8	6/5		
				R	+13.00/−1.00 x 40	8	$6/6^{+}$	Good reflex	*
				01	+12.00/−1.12 x 70	13	$6/5^{-}$		C
				02	+11.75/−1.00 x 70	13	6/5		C
			L	S	+10.59/−1.75 x 110	10	$6/6^{+}$		
				R	+10.00/−1.50 x 120	10	$6/6^{-2}$	Good reflex	*
				01	+9.75/−1.25 x $127\frac{1}{2}$	13	$6/6^{-1}$		C
				02	+10.00/−1.25 x 130	13	$6/6^{-}$		C
AR	61	M	R	S	+12.25/−0.75 x 95	11	$6/4^{-1}$	Good response	
				R	+11.75/−0.75 x 95	11	$6/6^{-4}$		*
				01	+12.37/−1.12 x 105	13	$6/5^{-2}$		C
				02	+12.37/−1.00 x 105	13	$6/5^{-2}$		C
DR	51	F	R	S	+13.50/−1.50 x 140	13	$6/6^{+2}$	Poor very nervous	
				R	+14.00/−1.50 x 110	9	6/12		
				01	+13.00/−1.50 x 125	13	$6/6^{-4}$		C*
				02	+13.50/−1.50 x130	13	$6/6^{-3}$		B
			L	S	+12.50/−0.75 x 80	13	$6/9^{-1}$	Poor very nervous	
				R	+12.75/−1.50 x 60	9	6/18		
				01	+12.75/−0.75 x 50	13	$6/18^{-1}$		C*
				02	+14.00/−1.25 x 55	13	6/24		B
IR	58	F	R	S	+15.50/−2.50 x $72\frac{1}{2}$	8	6/5		
				R	+15.50/−2.50 x 75	8	6/5	Black lines in reflex	*
				01	+14.25/−2.25 x 85	13	$6/9^{+4}$		
				02	+14.25/−1.75 x 90	13	6/9		
JR	63	M	R	S	+11.50/−0.25 x 90	13	$6/4^{+3}$		
				R	+12.50/−0.75 x 90	9	6/4		
				01	+11.50 DS	13	$6/4^{+4}$		C*
				02	+12.50/−0.75 x 125	13	$6/5^{+}$		B
OR	56	M	L	S	+10.50/−0.75 x 140	7	6/4		
				R	+10.50/−0.50 x 130	7	$6/5^{-2}$		*
				01	+9.25/−0.50 x 155	13	$6/4^{-2}$		C
				02	No reading				B
PR	64	M	R	S	+14.50/−3.50 x $97\frac{1}{2}$	11	6/9		
				R	+13.50/−2.50 x 90	11	6/18		*
				01	+14.37/−4.12 x $107\frac{1}{2}$	13	6/24		C
				02	+13.50/−2.00 x 95	13	6/18		C

NAME	AGE	SEX	R/L		REFRACTION	BVD	VA	COMMENTS	
RR	61	M	L	S	+11.75/-0.75 x 90	13	6/6		
				R	+11.50/-0.50 x 80	15	$6/9^{-3}$		
				01	+12.75/-0.75 x 110	13	6/18		B
				02	+12.00/-0.75 x 115	13	$6/6^{-}$		C*
AS	29	M	L	S	+11.50/-3.00 x 125	9	$6/12^{+3}$		
				R	+11.50/-2.00 125	9	$6/18^{+1}$	Distorted reflex	*
				01	+10.75/-3.75 x 140	13	$6/7.5^{+3}$		C
				02	+10.75/-3.75 x 140	13	6/7.5		C
BS	67	M	L	S	+13.00/-2.75 x 135	13	6/9		
				R	+13.00/-1.00 x 135	13	6/12	Distortion and opacities	*
				01	+10.75/-0.75 x 140	13	6/12		C
				02	+12.75/-2.25 x 140	1	6/9		B
ES[1]	71	M	R	S	+14.50/-1.25 x 75	13	6/5		
				R	+15.00/-1.00 x 80	9	$6/9^{+2}$		
				01	+14.75/-1.75 x 100	13	6/9		C*
				02	+14.00/-0.75 x 100	13	6/9		C
ES[2]	51	F	L	S	+13.00DS	13	6/18		
				R	+13.00DS	12	6/18	Few central opacities	
				01	+13.00/-0.25 x 160	13	6/18		C*
				02	+13.37/-0.37 x 170	13	6/18		C
ES[3]	65	F	R	S	+14.75DS	13	6/4		
				R	+15.50/-0.50 x 10	6	$6/6^{-4}$		
				01	+14.00 DS	13	6/4		B
				02	+13.25 DS	13	$6/6^{-1}$	Fixation variable	C*
HS[1]	64	M	R	S	+11.50/-5.00 x 180	13	6/12		
				R	+11.00/-4.00 x 170	12	6/18		
				01	+11.25/-4.00 x 5	13	$6/18^{+1}$		C*
				02	+11.75/-6.25 x 175	13	6/18		B
HS[2]	28	M	R	S	+8.75/-1.00 x 45	13	3/36		
				R	Not possible				
				01	+7.75/-2.25 x 40	13	3/60		C*
				02	+7.50/-1.50 x 35	13	3/60		C
JS[1]	56	M	L	S	+15.50/-1.50 x 107½	9	$6/5^{-1}$		
				R	+15.50/-2.00 x 100	9	$6/6^{-3}$		*
				01	+13.50/-0.75 x 100	13	$6/4^{-1}$		C
				02	+13.75/-0.75 x 100	13	$6/4^{-1}$		C
JS[2]	55	M	L	S	+9.00/-2.50 x 120	11	$6/9^{+}$		
				R	+9.50/-2.50 x 135	11	$6/12^{+2}$		*
				01	No reading			good fixation	
				02					

NAME	AGE	SEX	R/L		REFRACTION	BVD	VA	COMMENTS	
JS[3]	63	F	L	S	+9.50/-3.00 x 90	8	6/12		
				R	+10.50/-3.00 x 85	8	6/24	Poor reflex	
				01	+9.87/-2.87 x 105	13	6/24		C*
				02					
KS	54	F	L	S	+16.25/-1.25 x 112½	13	$6/5^{-2}$		
				R	+16.00/-1.00 x 110	9	6/6	reflex good	
				01	+15.62/-1.87 x 120	13	$6/6^{-}$		C*
				02	+15.00/-1.25 x 120	13	6/9		C
WS	50	M	R	S	+12.50/-3.50 x 70	13	6/5		
				R	+12.50/-4.00 x 60	13	$6/18^{+1}$		
				01	+11.75/-2.75 x 75	13	6/6		C*
				02	+11.75/-2.75 x 75	13	6/6		C
FT	37	M	R	S	+12.00/-0.75 x 60	14	6/5		
				R	+12.00/-0.75 x 67½	14	6/5	peripheral disturbance	*
				01	No reading			poor fixation unsteady	B
				02	No reading				C
MT[1]	60	M	L	S	+10.75/-0.25 x170	13	$6/4^{-4}$		
				R	+11.00/-0.75 x 160	7	$6/9^{+4}$	large pupil→distortion	
				01	+10.50/-0.25 x 160	13	$6/5^{-3}$		C*
				02	+10.75/-1.00 x 145	13	6/6		B
MT[2]	61	F	L	S	+10.75/-2.50 x 100	13	$6/5^{-1}$		
				R	+11.75/-3.00 x 100	10	$6/6^{+4}$		
				01	+11.25/-2.25 x 105 or 95	13	$6/9^{-}$		B
				02	+10.50/-2.00 x 105	13	6/6		C*
AW[1]	66	M	R	S	+14.50/-1.25 x 97½	13	$6/9^{-}$		
				R	+15.00/-2.50 x 75	8	6/18	Distorted reflex	
				01	+14.50/-1.50 x 110	13	6/12		C*
				02	+14.25/-1.12 x 120	13	6/12		C
AW[2]	57	F	R	S	+1.00/-3.00 x 90		$6/9^{-1}$		
				R	Plano/-2.50 x 92½		6/12		*
				01	+0.25/-2.12 x 90 or 100		$6/12^{-}$		C
				02					
AW[3]				S	+14.50/-2.00 x 105	11	$6/5^{-2}$		
				R	+14.00/-2.50 x 105	11	$6/6^{-3}$		*
				01	+14.25/-1.50 x 115	13	$6/9^{+4}$		C
				02					
BW				S	+8.25/-1.00 x 155	9	$6/4^{-2}$		
				R	+8.50/-0.75 x 150	9	$6/6^{-2}_{+3}$	Good reflex	*
				01	+8.00/-0.75 x 165	13	$6/6^{-2}$		C
				02					

NAME	AGE	SEX	R/L		REFRACTION	BVD	VA	COMMENTS	
GW	50	M	R	S	+12.00/-1.25 x 90	13	6/4		
				R	+12.50/-1.25 x 90	13	$6/5^{-3}$		
				01	+12.50/-1.25 x 115	13	$6/4^{-}$		B
				02	+12.25/-1.00 x 115	13	$6/5^{-1}$		C*
JW	70	F	L	S	+11.25/-2.25 x $72\frac{1}{2}$	13	$6/6^{-3}$		
				R	+11.25/-1.50 x 80	11	6/9		
				01	+11.25/-2.00 x 65	13	6/9		C*
				02	+11.50/-1.75 x 70	13	$6/6^{-}$		C
LW	47	F	L	S	+10.50/-0.50 x 30	13	6/9		
				R	+11.25/-1.00 x 70	9	$6/12^{-3}$	Distortion	
				01	+10.50/-0.50 x 35	13	$6/9^{-}$		B
				02	+10.25/-0.50 x 40	13	$6/9^{-2}$		C*
PW		M	R	S	+7.25/-0.75 x 70	13	$6/9^{+2}$		
				R	+6.75/-0.75 x 85	13	6/12		*
				01	+7.00/-1.00 x 90	13	6/12		B
				02	+7.25/-0.75 x 80	13	6/9		C
RW	52	M	R	S	+13.00/-1.50 x 35	11	$6/24^{+}$	Variable	
				R	+13.50 DS	11	6/18	Central opacities	*
				01	No reading				B
				02	No reading				C
WW	70	F	R	S	+14.50/-0.75 x 90	13	$6/5^{-}$		
				R	+17.00/-1.25 x 100	7	$6/6^{-2}$		
				01	+14.25/-0.50 x 100 or 110	13	$6/6^{-2}$		*C
				02	+13.87/-0.62 x 100	13	$6/6^{-}$		C
			L	S	+14.00/-0.50 x 90	13	$6/6^{-1}$		
				R	+14.50/-0.50 x 75	11	$6/6^{-}$		
				01	+13.87/-0.25 x 140	13	$6/9^{+}$		*
				02					
BY	50	F	R	S	+12.25/-2.50 x 130	8	6/12	ph no	
				R	+12.00/-1.50 x 105	8	6/24	split reflex large pupil	*
				01	+11.75/-2.75 x 140	13	6/24		C
				02	+12.25/-3.00 x $132\frac{1}{2}$ or 135	13	6/24		C
			L	S	+11.00/-2.00 x $82\frac{1}{2}$	13	6/9		
				R	+13.00/-2.50 x 100	9	6/24	distortion	*
				01	+11.50/-2.00 x 100	13			C
				02	+11.37/-1.87 x 100 or 105	13	6/18		C

Name	Age	Sex	R/L		Refraction	BVD	VA	Comments
J.A.	61	M	R	S	+15.50 / -1.50 x 27½	8	6/6	
				R	+15.50 / -1.25 x 30	8	6/6 -1	Some distortion *
				D_1	+14.12 / -1.09 x 44	12	6/5	
				D_2	+14.36 / -0.82 x 61	12	6/7.5	
				O	+15.75 / -1.50 x 55	13	6/9 -1	
F.B.	60	M	R	S	+12.00 / -2.00 x 90	11	6/18 -1	
				R	+12.50 / -2.00 x 90	11	6/24+	
				D_1	+15.04 DS	12	6/60	
				D_2	+15.61 / -5.46 x 97	12	6/36 +1	
				O	No reading			
H.B.	58	M	R	S	+12.50 DS	8	6/5	V. critical on eye position
				R	+11.50 / -1.00 x 70	8	6/9	Clear but distorted reflex*
				D_1	+12.15 / -0.35 x 97	12	6/9-	
				D_2	+12.62 / -0.25 x 57	12	6/6	
				O	+12.25 / -1.00 x 110	13	6/18	
A.C.	62	F	L	S	+15.00 / -1.00 x 110	4	6/6 $^{-1}_{+2}$	
				R	+15.00 / -0.75 x 110	4	6/6 -2	*
				D_1	+13.66 / -0.49 x 87	12	6/6 +2	
				D_2	+12.87 / -0.24 x 98	12	6/9 -1	
				O	+14.00 / -0.50 x 70	13	6/6	
D.C.	39	M	R	S	+12.00 / -0.50 x 110	13	6/6 +1	
				R	+11.50 / -0.75 x 100	13	6/6 -2	Good reflex *
				D_1	+13.20 / -1.73 x 158	12	6/9 +1	
				D_2	+12.22 / -0.79 x 175	12	6/9	
				O	+13.00 / -2.50 x 180	13	6/12	
			L	S	+12.50 / -1.00 x 160	13	6/6	
				R	+12.00 / -1.00 x 165	13	6/9 -1	Opacity in reflex *
				D_1	+11.81 DS	12	6/9	
				D_2	+13.25 / -3.25 x 147	12	6/12	
				O	+12.00 / -1.25 x 170	13	6/9 -1	

Name	Age	Sex	R/L		Refraction	BVD	VA	Comments
L.C.	61	M	L	S	+14.50 / -1.00 x 120	10	6/9-	
				R	+14.00 DS	10	6/12-	Poor reflex *
				D_1	+16.60 DS	12	6/24 -1	
				D_2	+16.89 DS	12	6/36+	
				O	No reading			Inst out of order
H.F.	64	M	L	S	+13.75 / -2.25 x 90	7	6/6 -2	
				R	+14.00 / -3.00 x 95	7	6/9 -3	*
				D_1	+12.67 / -2.00 x 87	12	6/5 -4	
				D_2	+13.02 / -2.19 x 82	12	6/6 -3	
				O	+12.75 / -2.00 x 90	13	6/5	
J.F.	57	M	R	S	+14.25 / -1.00 x 105	7	6/5	
				R	+14.50 / -1.00 x 120	7	6/6 -2	*
				D_1	+13.54 / -0.63 x 103	12	6/6	
				D_2	+13.18 / -0.43 x 138	12	6/6	
				O	No reading			Pupil - fixation good
E.G.	73	F	L	S	+14.50 / -2.50 x 85	7	6/9 +2	
				R	+15.00 / -2.00 x 85	7	6/9	Poor reflex *
				D_1	+14.65 / -1.78 x 75	12	6/18 -1	
				D_2	+14.63 / -0.48 x 89	12	6/24	
				O	+13.25 / -1.50 x 80	13	6/7.5	
B.H.	53	M	L	S	+13.00 / -1.50 x 100	6	6/4	
				R	+13.50 / -1.00 x 120	6	6/7.5	Some distortion*
				D_1	+12.77 / -1.26 x 85	12	6/5+	
				D_2	+12.87 / -1.50 x 161	12	6/18 -1	
				O	+12.75 / -1.25 x 100	13	6/4	
M.K.	73	F	R	S	+15.50 / -3.00 x 88	8	6/5 -2	
				R	+15.00 / -3.00 x 85	8	6/6 -3	Good reflex *
				D_1	+13.91 / -0.72 x 100	12	6/18 -1	
				D_2	+14.00 / -0.39 x 3	12	6/18 -1	
				O	+14.75 / -2.50 x 85	13	6/7.5	

Name	Age	Sex	R/L		Refraction	BVD	VA	Comments
A.M.	64	M	R	S	+10.00 / -1.50 x 92½	10	6/5 -1	
				R	+10.50 / -1.50 x 92½	10	6/6 +2	One black line in reflex *
				D_1	+10.83 / -1.83 x 104	12	6/5 -2	
				D_2	+10.76 / -2.03 x 99	12	6/5 -1	
				O	+11.25 / -2.25 x 100	13	6/5-	
W.P.	54	M	R	S	+12.50 / -1.00 x 90	10	6/6	Thru eccentric pupil
				R	+11.75 / -1.50 x 90	10	6/12+	Opacity in reflex *
				D_1	+12.19 DS	12	6/12	
				D_2	+13.46 / -1.45 x 86	12	6/36	
				O	+10.25 / -2.25 x 85	13	6/36	
I.S.	56	F	R	S	+13.75 / -1.50 x 80	7	6/6 -2	
				R	+13.50 / -2.00 x 90	7	6/9 +3	*
				D_1	+12.17 / -0.58 x 79	12	6/9 +2	
				D_2	+12.09 / -0.89 x 95	12	6/12 -3	
				O	No reading			Inst. out of order
W.S.	68	F	R	S	+14.25 / -2.00 x 75	11	6/12 -1 +2	Very inconsisten answers
				R	+14.00 / -1.50 x 100	11	6/24	Good reflex
				D_1	+14.99 / -2.90 x 91	12	6/12 -2	
				D_2	+13.91 / -2.47 x 93	12	6/18	
				O	Erroneous reading			Inst. out of order
H.V.	82	M	L	S	+14.00 / -1.00 x 180	4	6/6 -1	
				R	+14.00 / -1.00 x 180	4	6/6 -1	Clear - good reflex *
				D_1	+12.93 / -0.47 x 42	12	6/4	
				D_2	+12.52 / -0.55 x 32	12	6/4 -2	
				O	+13.00 / -0.25 x 50	13	6/4	

Name	Age	Sex	R/L		Refraction	BVD	VA	Comments
A.W. ~~#~~1	43	M	R	S	+13.50 / -1.00 x 60	10	6/6 -2	Poor subjective response
				R	+13.50 / -1.50 x 90	10	6/9 -3	*
				D_1	+13.19 / -1.26 x 59	12	6/6 $^{-3}_{+4}$	
				D_2	+13.05 / -1.05 x 50	12	6/6 $^{-2}_{+3}$	
				O	No reading			Inst. out of order
A.W. ~~#~~ 2	61	F	L	S	+13.00 / -2.50 x 100	6	6/9 -1	Poor subjective response
				R	+13.00 / -1.50 x 90	6	6/12 -1	Opacity within reflex *
				D_1	+12.24 / -0.89 x 89	12	6/9 -2	
				D_2	+12.78 / -0.67 x 117	12	6/12	
				O	+10.50 DS	13	6/12	
L.W.	54	F	R	S	+14.00 / -2.00 x 10	10	6/9	Poor response - inconsistent
				R	+13.00 / -1.50 x 15	10	6/12	Two black lines in reflex *
				D_1	+13.87 / -0.94 x -9	12	6/9	
				D_2	+12.91 / -1.41 x 7	12	6/12	
				O	No reading			

APPENDIX 12 : CLINICAL EXPERIMENT 4

APHAKIA - RECOMPUTED DATA FOR 13mm BVD

(S = Subjective; R = Retinoscopy; O_1 = 1st Ophthalmetron; O_2 = 2nd Ophthalmetron; D_1 = 1st Dioptron; D_2 = 2nd Dioptron; K = Keratometry; * Indicates measurement taken with Bradfor Ophthalmetron).

Pages 359 : Mid Sphere Ophthalmetron study

Pages 361 : Maximum positive sphere Ophthalmetron study

Pages 363 : Cylinder Power Ophthalmetron study

Pages 365 : Mid Sphere Dioptron Study

Pages 366 : Cylinder Power Dioptron study

Pages 367 : Cylinder Power Ophthalmetron study by Keratometry

me	S	R	O_1	O_2	Name	S	R	O_1	O_2
A. #1 C	+10.885	+10.765	+11.125	+11.125	K.C.	+10.91	+11.37		*
A. #2	+13.005	+13.05	+13.625*	+12.75	L.C.	+13.50	+14.00		
A.	+11.255	+11.12	+11.875*	+11.25		+12.76	+13.26		
B.	+12.23	+13.76		*	M.C.	+11.13	+11.135	+11.875*	+11.625
B. C	+10.65	+11.31	+10.75*	+10.625					
B. #1	+13.49	+10.39	+11.625	+11.875	R.C. #2 C	+10.78	+11.195	+10.75*	+9.875
B. #2	+13.215	+13.33			H.D.	+12.225	+11.61		
B. #3 C	+8.00	+8.705	+8.625	+9.00*	J.D.C	+11.03	+10.59	+10.25	+11.125*
B. #4	+12.40	+12.40	+11.875	+12.75*	S.D.	+10.495	+10.87	*	
B. #1	+13.11	+12.64	+12.75						
B. #2	+12.82	+12.34	+13.25	+13.125	K.E.	+8.14	+8.22	+8.75*	+8.125
B.	+12.195	+13.045	+11.75		C.F.	+10.63	+10.75	+11.00	+11.00
B.	+9.77	+9.665	+9.75	+9.685	M.F.	+11.885	+11.95	+12.125	+11.985
B.	+9.26	+8.79	+8.50*	+8.875	V.F.	+13.64	+12.945	+13.625	+14.375*
B. #1 C	+8.48	+8.48	+8.00	+8.375*		+13.005	+12.94	+13.125	+13.875*
B. #2 C	+9.865	+9.635	+10.00		C.G.	+9.76	+10.50	+9.375	
B.	+10.245	+9.335		*	D.G.	+7.38	+6.805	+7.69	+7.69
B. C	+10.27	+9.77	+9.125	+9.00	J.G.	+13.255	+13.07	+13.25	+13.375
B.	+12.505	+12.505	+13.00	+12.81	K.G.	+6.14	+6.775	+5.75*	+6.25
C. #1	+10.51	+10.82	*	+10.25	P.G.	+13.365	+13.595		*
C. #2	+8.75	+8.875	*	+8.125		+11.805	+11.565	12.375	*
C.	+10.50	+10.745	+10.00*	+9.75	R.G. #1	+12.71	+12.71	*	
	+10.635	+10.595	+10.75*	+10.375	R.G. #2 C	+10.90	+10.945	+10.875*	+10.875
C. #1	+11.615	+12.065	+10.44		A.H.	+12.065	+11.805	+11.375	
	+12.065	+12.065	+11.94		L.H. #1	+11.63	+11.81	+12.00*	
C. #2 C	+11.40	+12.165	+11.375	+11.625*	L.H. #2	+12.135	+11.905	+11.625	+11.645
	+12.085	+11.865	+12.00	+12.25*	P.H.	+11.755	+10.835	+12.625	+12.375
. #3	+13.24	+12.88	+13.125		D.J.	+13.00	+13.125	*	+12.75
. #1	+12.46	+11.59			E.K.	+11.20	+11.525	+11.375	
	+12.555	+12.155			J.K. #1	+15.13	+15.095		
. #2	+15.315	+15.08	*		J.K. #2	+11.745	+12.27	*	
. #3	+8.95	+9.635	*		C	+13.66	+13.37	+14.00*	+12.125
.	+12.58	+12.335	+12.25		L.K.	+6.455	+6.915		*

ame	S	R	O_1	O_2
K. #1	+12.26	+11.76	+11.375	
K. #2	+11.925	+12.17		
L.	+11.88	+12.015	+11.625	+11.875*
	+11.13	+11.12	+11.625	+12.625*
.	+13.25	+12.75		
. #1	+11.855	+11.61		
. #2	+14.125	+14.75	+13.75	+13.56
I.	+11.65	+11.97	+11.625	+11.62
I. #1	+13.63	+12.64	+14.875*	+13.875
I. #2	+11.50	+12.10	+12.00	+12.875*
I.	+6.02	+9.68	+5.00	
I.	+10.875	+11.195	+11.00*	+10.375
I.	+11.565	+11.69	+11.875	+12.125*
L.	+12.435	+12.555	+12.125	+12.375
cK.	+14.315	+14.315	+14.75	
.	+11.40	+10.63	+11.875	
.	+11.31	+11.315	+10.50	+11.00*
.	+11.255	+11.725	+11.625	
.	+11.02	+10.67	+10.75	+11.125
.	+6.945	+7.445		
.	+9.235	+8.08		
	+8.755	+8.08	+9.25	
.	+11.65	+11.13	+10.00	+10.125
	+10.50	+10.84	+10.375	+10.44
.	+11.465	+11.75	+11.44	+11.25
	+9.315	+8.97	+9.125	+9.375
.	+11.585	+11.105	+11.81	+11.87
.	+12.76	+12.515	+12.25	+12.75*
	+12.13	+11.385	+12.375	+13.375*
	+13.155	+13.16	+13.125	+13.50
	+11.375	+11.525	+11.50	+12.125*
	+9.505	+9.63	+9.00	*

Name	S	R	O_1	O_2
P.R.	+12.39	+11.925	+12.31	+12.50
R.R.	+11.38	+11.80	+12.375*	+11.625
A.S.	+9.515	+10.00	+8.875	+8.875
B.S.	+11.66	+12.505	+10.375	+11.625*
E.S. #1 #2	+13.885	+13.655	+13.875	+13.625
E.S.	+13.00	+12.84	+12.875	+13.185
E.S. #3	+14.75	+13.73	+14.00*	+13.25
H.S. #1	+9.12	+8.95	+9.25	+8.625*
J.S. #1	+13.845	+13.60	+13.125	+13.375
J.S. #2	+7.615	+8.095		
J.S. #3	+7.59	+8.50	+8.435	
K.S.	+15.635	+14.545	+14.685	+14.375
W.S.	+10.81	+10.575	+10.375	+10.375
F.T.	+11.78	+11.78	*	
M.T. #1	+10.625	+9.945	+10.375	+10.25*
M.T. #2	+9.53	+9.88	+10.125*	+9.50
A.W. #1	+13.885	+12.715	+13.75	+13.69
A.W. #3	+13.105	+12.395	+13.50	
B.W.	+7.495	+7.845	+7.625	+7.375
G.W.	+11.385	+11.885	+11.875*	+11.75
J.W.	+10.15	+10.26	+10.625	+10.25
L.W.	+10.25	+10.275	+10.25*	+10.00
P.W.	+6.88	+6.36	+6.50*	+6.875
R.W.	+11.77	+12.97		
W.W.	+14.13	+14.81	+14.00	+13.56
	+13.75	+13.84	+13.75	
B.Y.	+10.305	+10.575	+10.375	+10.75
	+10.02	+11.13	+10.50	+10.435

e	S	R	O_1	O_2	Name	S	R	O_1	O_2
#1	+12.36	+12.36	+12.50	+12.50	I.C.	+13.32	+12.83	+12.75	
#2	+13.50	+13.67	+14.25*	+13.25	K.C.	+11.90	+12.26		*
	+11.75	+11.86	+12.50*	+11.75	L.C.	+13.75	+14.00		
	+12.97	+14.50		*		+13.50	+14.00		
	+11.75	+12.05	+12.50*	+11.75	M.C.	+11.63	+11.63	+13.00*	+12.25
#1	+13.86	+10.76	+12.00	+12.25	R.C. #1	-2.02	_2.50	-3.25	-1.75*
#2	+13.34	+13.33			R.C. #2	+12.00	+12.43	+12.00*	+10.75
#3	+9.71	+10.65	+9.50	+10.50*	H.D.	+12.35	+11.86		
#4	+12.65	+12.65	+12.25	+13.00*	J.D.	+12.25	+11.82	+10.75	+12.25*
#1	+13.85	+13.38	+12.75		S.D.	+10.87	+10.87	*	
#2	+13.56	+13.32	+14.25	+14.25	K.E.	+9.00	+8.84	+9.75*	+9.00
	+13.05	+13.90	+12.50		C.F.	+11.00	+11.25	+11.25	+11.25
	+10.75	+10.65	+10.75	+10.62	M.F.	+12.50	+12.20	+12.75	+12.67
	+10.00	+9.66	+9.50*	+9.50	V.F.	+14.50	+14.05	+14.50	+15.50*
#1	+9.71	+9.71	+9.00	+9.50*		+13.50	+13.56	+13.50	+14.75*
#2	+11.10	+10.87	+10.75		C.G.	+10.50	+11.12	+9.75	
	+10.99	+10.08		*	D.G.	+7.63	+7.18	+8.00	+8.00
	+11.25	+10.75	+9.75	+9.50	J.G.	+13.75	+13.81	+13.75	+13.75
	+13.00	+13.00	+13.25	+13.12	K.G.	+7.00	+7.52	+7.00*	+7.00
#1	+11.25	+12.05	*	+10.75	P.G.	+14.35	+14.09		*
#2	+9.00	+9.62	*	+8.75		+12.67	+12.43	+13.00	*
					R.G. #1	+13.70	+13.70	*	
	+10.75	+11.12	+10.25*	+10.25	R.G. #2	+12.00	+12.06	+12.00*	+11.50
	+11.25	+11.58	+11.50*	+11.00	A.H.	+12.56	+12.30	+12.00	
#1	+12.36	+12.81	+11.5-		L.H. #1	+12.00	+12.43	+12.50*	
	+12.81	+12.81	+12.75		L.H. #2	+12.75	+12.65	+12.25	+12.37
#2	+12.50	+12.66	+12.00	+12.75*	P.H.	+12.74	+11.82	+14.00	+13.50
	+12.58	+12.36	+12.25	+12.50*	D.J.	+13.00	+13.25	*	+12.75
#3	+13.86	+13.62	+13.50		E.K.	+11.82	+12.51	+12.00	
#1	+13.08	+12.21			J.K. #1	+15.63	+15.84		
	+13.30	+12.65			J.K. #2	+13.70	+13.26	*	
#2	+16.53	+16.53	*			+15.00	+14.60	+16.00*	+13.50
#3	+10.43	+10.87	*		L.K.	+7.69	+8.15		*

ne	S	R	O_1	O_2	Name	S	R	O_1	O_2
.#1	+13.00	+12.50	+12.00		P.R.	+14.09	+13.15	+14.37	+13.50
.#2	+12.91	+12.91			R.R.	+11.75	+12.05	+12.75*	+12.00
..	+12.25	+12.51	+12.00	+12.25*	A.S.	+10.99	+10.99	+10.75	+10.75
	+11.50	+11.86	+12.00	+13.50*	B.S.	+13.00	+13.00	+10.75	+12.75*
..	+13.50	+13.00			E.S.#1	+14.50	+14.15	+14.75	+14.00
..#1	+12.35	+11.86		*	E.S.#2	+13.00	+12.84	+13.00	+13.37
..#2	+15.48	+15.99	+14.75	+14.37	E.S.#3	+14.75	+13.98	+14.00*	+13.25
I.	+12.75	+13.44	+12.25	+12.37	H.S.#1	+11.50	+10.88	+11.25	+11.75*
I.#1	+14.00	+13.26	+15.25*	+14.50					
I.#2	+11.75	+12.35	+12.25	+13.25*	J.S.#1	+14.59	+14.59	+13.50	+13.75
I.	+7.00	+11.37	+6.50		J.S.#2	+8.84	+9.32		
I.	+11.00	+11.32	+11.50*	+10.50	J.S.#3	+9.07	+9.98	+9.87	
I.	+12.43	+12.43	+12.50	+12.75*	K.S.	+16.25	+15.04	+15.62	+15.00
.	-0.25	-0.50	-0.25	Plano	W.S.	+12.50	+12.50	+11.75	+11.75
I.	+13.53	+13.53	+13.00	+13.25	F.T.	+12.15	+12.15	*	
cK.	+14.81	+14.81	+15.00		M.T.#1	+10.75	+10.32	+10.50	+10.75*
.	+12.50	+11.37	+13.00		M.T.#2	+10.75	+11.35	+11.25*	+10.50
.	+13.00	+13.03	+11.75	+12.75*	A.W.#1	+14.50	+13.95	+14.50	+14.25
.	+12.83	+12.83	+12.50		A.W.#2	+1.00	Plano	+0.25	
.	+12.13	+11.90	+11.50	+11.75	A.W.#3	+14.09	+13.62	+14.25	
.	+7.44	+7.94			B.W.	+7.99	+8.22	+8.00	+7.75
.	+9.98	+9.07			G.W.	+12.00	+12.50	+12.50*	+12.25
	+9.25	+9.07	+9.75		J.W.	+11.25	+11.00	+11.50	+11.25
.	+12.75	+12.36	+11.00	+11.25	L.W.	+10.50	+10.77	+10.50*	+10.25
	+11.24	+11.58	+11.00	+11.00	P.W.	+7.25	+6.73	+7.00*	+7.25
.	+12.21	+12.21	+12.-0	+11.75	R.W.	+12.51	+12.97		
	+10.18	+9.71	+9.75	+10.00	W.W.	+14.50	+15.43	+14.25	+13.87
.	+11.96	+11.48	+12.37	+12.37		+14.00	+14.09	+13.87	
.	+13.50	+13.26	+13.00	+13.50*	B.Y.	+11.54	+11.32	+11.75	+12.25
	+12.50	+12.13	+12.75	+14.00*		+11.00	+12.36	+11.50	+11.37
.	+14.39	+14.39	+14.25	+14.25					
.	+11.50	+11.90	+11.50	+12.50*					
.	+9.88	+9.88	+9.25	*					

me	S	R	O_1	O_2	Name	S	R	O_1	O_2
A.#1	-2.95	-3.19	-2.75	-2.75	K.C.	-1.98	-1.98		*
A.#2	-0.99	-1.24	-1.25*	-1.00	L.C.	-0.50	-0.00		
A.	-0.99	-1.48	-1.25*	-1.00		-1.48	-1.48		
B.	-1.48	-1.48		*	M.C.	-1.00	-0.99	-2.25*	-1.25
B.	-2.20	-1.48	-3.50*	-2.25	R.C.#1	-7.97	-5.69	-11.25	-12.00*
B.#1	-0.74	-0.74	-0.75	-0.75	R.C.#2	-2.44	-2.47	-2.50*	-1.75
B.#2	-0.25	-0.00			H.D.	-0.25	-0.50		
B.#3	-3.42	-3.89	-1.75	-3.00*	J.D.	-2.44	-2.46	-1.00	-2.25
B.#4	-0.50	-0.50	-0.75	-0.50*	S.D.	-0.75	-0.00	*	
B.#1	-1.48	-1.48	-0.00				-0.99		
B.#2	-1.48	-1.96	-2.00	-2.25	K.E.	-1.72	-1.24	-2.00*	-1.75
B.	-1.71	-1.71	-1.50		C.F.	-0.74	-0.99	-0.50	-0.50
B.	-1.96	-1.97	-2.00	-1.87	M.F.	-1.23	-0.50	-1.25	-1.37
B.	-1.48	-1.74	-2.00*	-1.25	V.F.	-1.72	-2.21	-1.75	-2.25*
B.#1	-2.46	-2.46	-2.-0	-2.25*		-0.99	-1.24	-0.75	-1.75*
B.#2	-2.47	-2.47	-1.50		C.G.	-1.48	-1.24	-0.75	
B.	-1.49	-1.49		*	D.G.	-0.50	-0.75	-0.62	-0.62
B.	-1.96	-1.96	-1.25	-1.00	J.G.	-0.99	-1.48	-1.00	-0.75
B.	-0.99	-0.99	-0.50	-0.62	K.G.	-1.72	-1.49	-2.50*	-1.50
C.#1	-1.48	-2.46	*	-1.00	P.G.	-1.97	-0.99		*
C.#2	-0.50	-1.49	*	-1.25		-1.73	-1.73	-1.25	*
C.	-0.50	-0.75	-0.50*	-1.00	R.G.#1	-1.98	-1.98	*	
	-1.23	-1.97	-1.50*	-1.25	R.G.#2	-2.20	-2.23	-2.25*	-1.25
D.#1	-1.49	-1.49	-1.12		A.H.	-0.99	-0.99	-1.25	
	-1.49	-1.49	-1.62		L.H.#1	-0.74	-1.24	-1.00*	
D.#2	-2.20	-0.99	-1.25	-2.25*	L.H.#2	-1.23	-1.49	-1.25	-1.25
	-0.99	-0.99	-0.50	-0.50*	P.H.	-1.97	-1.97	-2.75	-2.25
D.#3	-1.24	-1.48	-1.50		D.J.	0.00	-0.25	*	0.00
D.#1	-1.24	-1.24			E.K.	-1.24	-1.97	-1.25	
	-1.49	-0.99			J.K.#1	-1.00	-1.49		
D.#2	-2.43	-2.90	*		J.K.#2	-3.91	-1.98	*	
D.#3	-2.96	-2.47	*			-2.68	-2.46	-4.00*	-2.75
D.	-1.48	-0.99	-1.00		L.K.	-2.47	-2.47		*

e	S	R	O_1	O_2	Name	S	R	O_1	O_2
#1	-1.48	-1.48	-1.25		P.R.	-3.40	-2.45	-4.12	-2.00
#2	-1.97	-1.48			R.R.	-0.74	-0.50	-0.75*	-0.75
	-0.74	-0.99	-0.75	-0.75*	A.S.	-2.95	-1.98	-3.75	-3.75
	-0.74	-1.48	-0.75	-1.75*	B.S.	-2.68	-0.99	-0.75	-2.25*
	-0.50	-0.50			E.S. #1	-1.23	-0.99	-1.75	-0.75
#1	-0.99	-0.50		*	E.S. #2	0.00	0.00	-0.25	-0.37
#2	-2.71	-2.48	-2.00	-1.62	E.S. #3	0.00	-0.50	0.00*	0.00
	-2.20	-2.94	-1.25	-1.50	H.S. #1	-4.76	-3.86	-4.00	-6.25*
#1	-0.74	-1.24	-0.75*	-1.25	H.S. #2	-0.99		-2.25	-1.50
#2	-0.50	-0.50	-0.50	-0.75*	J.S. #1	-1.49	-1.98	-0.75	-0.75
	-1.96	-3.38	-3.00		J.S. #2	-2.45	-2.45		
	-0.25	-0.25	-1.00*	-0.25	J.S. #3	-2.96	-2.96	-2.87	
	-1.73	-1.48	-1.25	-1.25*	K.S.	-1.23	-0.99	-1.87	-1.25
	-1.72	-1.48	-1.25	-2.00	W.S.	-3.38	-3.85	-2.75	-2.75
	-2.19	-1.95	-1.75	-1.75	F.T.	-0.74	-0.74	*	
K.	-0.99	-0.99	-0.50		M.T. #1	-0.25	-0.75	-0.25	-1.00*
	-2.20	-1.48	-2.25		M.T. #2	-2.44	-2.94	-2.25*	-2.00
	-3.38	-3.43	-2.50	-3.50*	A.W. #1	-1.23	-2.47	-1.50	-1.12
	-3.15	-2.21	-1.75		A.W. #2	-2.90	-2.43	-2.12	
	-2.22	-2.46	-1.50	-1.25	A.W. #3	-1.97	-2.45	-1.50	
	-0.99	-0.99			B.W.	-0.99	-0.75	-0.75	-0.75
	-1.49	-1.98			G.W.	-1.23	-1.23	-1.25*	-1.00
	-0.99	-1.98	-1.00		J.W.	-2.20	-1.48	-1.75	-2.00
	-2.20	-2.46	-2.00	-2.25	L.W.	-0.50	-0.99	-0.50*	-0.50
	-1.48	-1.48	-1.25	-1.12	P.W.	-0.74	-0.74	-1.00*	-0.75
	-1.49	-0.99	-1.12	-1.00	R.W.	-1.48	0.00		
	-1.73	-1.48	-1.25	-1.25	W.W.	-0.74	-1.24	-0.50	-0.62
	-0.75	-0.75	-1.12	-1.00		-0.50	-0.50	-0.25	
	-1.48	-1.49	-1.50	-1.50*	B.Y.	-2.47	-1.49	-2.75	-3.00
	-0.74	-1.49	-0.75	-1.25*		-1.96	-2.46	-2.00	-1.87
	-2.47	-2.46	-2.25	-1.50					
	-0.25	-0.75	0.00	-0.75*					
	-0.75	-0.50	-0.50	*					

e	S	R	O_1	O_2	Name	S	R	O_1	O_2
#1	-1.48	-1.48	-1.25		P.R.	-3.40	-2.45	-4.12	-2.00
#2	-1.97	-1.48			R.R.	-0.74	-0.50	-0.75*	-0.75
	-0.74	-0.99	-0.75	-0.75*	A.S.	-2.95	-1.98	-3.75	-3.75
	-0.74	-1.48	-0.75	-1.75*	B.S.	-2.68	-0.99	-0.75	-2.25*
	-0.50	-0.50			E.S. #1	-1.23	-0.99	-1.75	-0.75
#1	-0.99	-0.50		*	E.S. #2	0.00	0.00	-0.25	-0.37
#2	-2.71	-2.48	-2.00	-1.62	E.S. #3	0.00	-0.50	0.00*	0.00
	-2.20	-2.94	-1.25	-1.50	H.S. #1	-4.76	-3.86	-4.00	-6.25*
#1	-0.74	-1.24	-0.75*	-1.25	H.S. #2	-0.99		-2.25	-1.50
#2	-0.50	-0.50	-0.50	-0.75*	J.S. #1	-1.49	-1.98	-0.75	-0.75
	-1.96	-3.38	-3.00		J.S. #2	-2.45	-2.45		
	-0.25	-0.25	-1.00*	-0.25	J.S. #3	-2.96	-2.96	-2.87	
	-1.73	-1.48	-1.25	-1.25*	K.S.	-1.23	-0.99	-1.87	-1.25
	-1.72	-1.48	-1.25	-2.00	W.S.	-3.38	-3.85	-2.75	-2.75
	-2.19	-1.95	-1.75	-1.75	F.T.	-0.74	-0.74	*	
K.	-0.99	-0.99	-0.50		M.T. #1	-0.25	-0.75	-0.25	-1.00*
	-2.20	-1.48	-2.25		M.T. #2	-2.44	-2.94	-2.25*	-2.00
	-3.38	-3.43	-2.50	-3.50*	A.W. #1	-1.23	-2.47	-1.50	-1.12
	-3.15	-2.21	-1.75		A.W. #2	-2.90	-2.43	-2.12	
	-2.22	-2.46	-1.50	-1.25	A.W. #3	-1.97	-2.45	-1.50	
	-0.99	-0.99			B.W.	-0.99	-0.75	-0.75	-0.75
	-1.49	-1.98			G.W.	-1.23	-1.23	-1.25*	-1.00
	-0.99	-1.98	-1.00		J.W.	-2.20	-1.48	-1.75	-2.00
	-2.20	-2.46	-2.00	-2.25	L.W.	-0.50	-0.99	-0.50*	-0.50
	-1.48	-1.48	-1.25	-1.12	P.W.	-0.74	-0.74	-1.00*	-0.75
	-1.49	-0.99	-1.12	-1.00	R.W.	-1.48	0.00		
	-1.73	-1.48	-1.25	-1.25	W.W.	-0.74	-1.24	-0.50	-0.62
	-0.75	-0.75	-1.12	-1.00		-0.50	-0.50	-0.25	
	-1.48	-1.49	-1.50	-1.50*	B.Y.	-2.47	-1.49	-2.75	-3.00
	-0.74	-1.49	-0.75	-1.25*		-1.96	-2.46	-2.00	-1.87
	-2.47	-2.46	-2.25	-1.50					
	-0.25	-0.75	0.00	-0.75*					
	-0.75	-0.50	-0.50	*					

Name	S	R	D_1	D_2	O
J.A.	+13.645	+13.77	+13.375	+13.75	+15.00
F.B.	+10.375	+11.215	+14.81	+12.62	
H.B.	+11.75	+10.37	+11.825	+12.335	+11.75
A.C.	+12.72	+12.845	+13.235	+12.59	+13.75
D.C.	+11.75	+11.13	+11.185	+11.675	+11.75
	+12.005	+11.505	+11.67	+11.45	+11.375
L.C.	+13.395	+13.44	+16.33	+16.61	
H.F.	+11.585	+11.44	+11.51	+11.755	+11.75
J.F.	+12.63	+12.84	+13.045	+12.795	
E.G.	+12.10	+12.77	+13.55	+14.18	+12.625
B.H.	+11.175	+11.83	+11.98	+11.96	+12.125
M.K.	+12.91	+12.47	+13.36	+13.615	+13.50
A.M.	+ 8.97	+ 9.44	+ 9.855	+ 9.635	+10.125
W.P.	+11.555	+10.61	+12.04	+12.55	+ 9.125
I.S.	+11.955	+11.50	+11.77	+11.505	
W.S.	+12.875	+12.88	+13.315	+12.48	
H.V.	+11.93	+11.93	+12.525	+12.095	+12.875
A.W. #1	+12.475	+12.23	+12.39	+12.355	
A.W. #2	+10.68	+11.175	+11.645	+12.285	+10.25
L.W.	+12.455	+11.77	+12.045	+13.21	

Name	S	R	D_1	D_2	O
J.A.	-1.49	-1.24	-1.09	-0.82	-1.50
F.B.	-1.97	-1.97	0.00	-5.50	
H.B.	0.00	-1.00	-0.35	-0.25	-1.00
A.C.	-1.00	-0.75	-0.49	-0.24	-0.50
D.C.	-0.50	-0.74	-1.73	-0.79	-2.50
	-0.99	-0.99	0.00	-3.26	-1.25
L.C.	-0.99	0.00	0.00	0.00	
H.F.	-2.23	-2.96	-2.00	-2.19	-2.00
J.F.	-1.00	-1.00	-0.63	-0.43	
E.G.	-2.48	-1.98	-1.78	-0.48	-1.25
B.H.	-1.49	-1.00	-1.26	-1.50	-1.25
M.K.	-2.96	-2.96	-0.72	-0.39	-2.50
A.M.	-1.48	-1.48	-1.83	-2.03	-2.25
W.P.	-0.99	-1.48	0.00	-1.46	-2.25
I.S.	-1.49	-1.98	-0.50	-0.89	
W.S.	-1.97	-1.48	-2.91	-2.48	
H.V.	-1.00	-1.00	-0.47	-0.55	-0.25
A.W. #1	-0.99	-1.48	-1.26	-1.05	
A.W. #2	-2.48	-1.49	-0.89	-0.67	-0.50
L.W.	-1.97	-1.48	-1.41	-0.94	

Name	K	Mer.	K	Mer.	Cyl at eye	Cyl at 13mm
H.A. #1	7.90	5	8.60	90	3.48	3.64
H.A. #2	8.35	135	8.65	35	1.17	1.19
J.A.	7.25	140	7.55	50	1.85	1.90
A.B.	7.80	165	8.10	75	1.60	1.63
C.B.	7.20	5	7.75	95	3.33	3.48
D.B. #1	7.60	40	7.70	130	0.58	0.58
D.B. #2	7.35	60	7.50	150	0.92	0.93
D.B. #3	7.85	80	8.60	170	3.75	3.94
D.B. #4	8.00	45	8.15	135	0.78	0.79
E.B. #1	7.30	150	7.45	57½	0.93	0.94
E.B. #2	7.30	40	7.80	130	2.96	3.08
J.B.	7.50	175	7.85	85	2.01	2.06
L.B.	7.40	25	7.90	115	2.89	3.00
M.B.	7.95	170	8.30	75	1.79	1.83
R.B. #1	7.80	162½	8.30	72½	2.61	2.70
R.B. #2	7.50	35	7.80	125	1.73	1.77
T.B.	7.30	90	7.70	180	2.40	2.48
V.B.	7.90	170	8.15	85	1.31	1.33
W.B.	7.90	90	8.00	180	0.53	0.53
A.C. #1	7.45	55	7.90	145	2.58	2.69
A.C. #2	7.70	180	7.85	95	0.84	0.85
B.C.	7.45	125	7.70	30	1.47	1.50
	7.30	10	7.70	100	2.40	2.48
D.C. #1	7.55	17½	7.95	100	2.25	2.32
	7.65	25	8.05	115	2.19	2.25
D.C. #2	7.65	10	8.10	100	2.45	2.53
	7.65	180	7.80	80	0.85	0.86
D.C. #3	8.20	165	8.45	75	1.22	1.24
E.C. #1	7.10	100	7.75	10	3.99	4.21
	7.00	90	7.80	180	4.95	5.29
E.C. #2	7.35	172½	8.40	85	5.74	6.20
E.C. #3	7.85	25	8.55	115	3.52	3.69
I.C	7.95	180	8.20	80	1.29	1.31

Name	K	Mer.	K	Mer.	Cyl at eye	Cyl at 13mm
F.C.	7.90	140	8.30	45	2.06	2.12
L.C.	7.45	45	7.65	125	1.18	1.20
	7.50	75	7.90	160	2.28	2.35
M.C.	7.60	5	7.85	95	1.41	1.44
R.C. #1	7.35	95	8.25	5	5.01	5.36
R.C. #2	7.90	180	8.45	90	2.78	2.88
H.D.	8.00	90	8.05	5	0.26	0.26
J.D.	7.65	5	8.10	92½	2.45	2.53
S.D.	7.85	125	8.10	35	1.33	1.35
	7.85	145	8.05	55	1.07	1.08
K.E.	7.65	165	8.15	75	2.71	2.81
C.F.	7.70	160	7.90	55	1.11	1.13
M.F.	7.55	30	7.80	120	1.43	1.46
V.F.	7.45	175	7.90	85	2.58	2.67
	7.45	30	7.70	120	1.47	1.50
C.G.	7.62	5	7.90	90	1.57	1.60
D.G.	8.10	5	8.20	90	0.51	0.51
J.G.	7.60	10	7.70	100	0.58	0.58
K.G.	7.60	157½	8.00	67½	2.22	2.29
P.G.	7.75	150	8.35	60	3.13	3.26
	7.85	15	8.30	100	2.33	2.40
R.G. #1	7.45	15	7.70	120	1.47	1.50
R.G. #2	7.60	35	8.10	125	2.74	2.84
A.H.	7.65	95	8.05	5	2.19	2.25
L.H. #1	8.20	180	8.40	105	0.98	0.99
L.H. #2	7.55	155	7.70	65	0.87	0.88
P.H.	7.55	180	7.70	90	0.87	0.88
D.J.	7.80	175	7.85	85	0.28	0.28
E.K.	7.95	152½	8.30	60	1.79	1.83
J.K. #1	8.00	90	8.20	5	1.03	1.04
J.K. #2	7.50	105	8.25	15	4.09	4.32
	7.50	80	8.40	160	4.82	5.14
L.K.	7.80	180	8.30	85	2.61	2.70

Name	K	Mer.	K	Mer.	(-ve) Cyl at eye	(-ve) Cyl at 13mm
M.K. #1	8.05	30	8.37	133½	1.60	1.64
M.K. #2	7.20	15	7.80	110	3.56	3.73
C.L	7.45	165	7.65	70	1.18	1.20
	7.30	30	7.60	120	1.82	1.86
J.L.	7.95	5	7.60	95	1.955	2.01
M.L. #1	6.80	125	7.15	15	2.43	2.50
M.L. #2	7.40	5	7.90	95	2.89	3.00
A.M.	7.50	175	8.05	85	3.07	3.20
E.M. #1	7.70	20	7.85	105	0.84	0.85
E.M. #2	7.95	10	8.05	100	0.53	0.53
F.M.	6.60	50	7.00	140	2.92	-3.04
I.M.	7.70	180	7.75	90	0.28	0.28
J.M.	7.75	175	8.05	85	1.62	1.65
P.M.	7.80	135	8.15	45	1.86	1.90
T.M.	8.00	15	8.40	102½	2.01	2.06
DMcK	7.50	10	7.80	95	1.73	1.77
D.N.	7.70	180	8.40	90	3.65	3.83
C.P.	8.05	15	8.85	105	3.79	3.99
E.P.	7.00	100	7.90	10	5.49	5.91
H.P.	7.45	180	7.90	90	2.58	2.67
K.P.	7.30	160	7.50	65	1.23	1.25
M.P.	7.90	125	8.35	30	2.30	2.37
	7.80	70	8.40	160	3.09	3.22
S.P.	7.50	180	8.00	90	2.81	2.92
	7.60	5	7.95	90	1.96	2.01
W.P.	7,70	140	8.10	50	2.16	2.22
	7.70	10	8.15	100	2.42	2.50
A.R.	7.90	5	8.05	95	0.80	0.81
D.R.	7.25	35	7.60	125	2.14	2.20
	7.60	55	7.75	145	0.86	0.87
I.R.	7.35	170	8.00	75	3.73	3.92
J.R.	7.90	80	8.00	170	0.53	0.53
O.R.	7.60	55	7.95	145	1.96	2.01
P.R.	7.75	10	8.40	100	3.37	3.52
R.R.	7.60	10	7.80	110	1.14	1.16
A.S.	7.60	35	8.45	130	4.47	4.75
B.S.	7.30	70	7.50	160	1.23	1.25
E.S. #1	7.45	5	7.70	80	1.47	1.50
E.S. #2	7.45	90	7.50	180	0.30	0.30
E.S. #3	7.80	90.	7.90	5	0.55	0.55
H.S. #1	7.05	87½	8.15	177½	6.46	7.05
H.S. #2	7.70	115	7.95	25	1.38	1.41
J.S. #1	7.80	10	8.00	95	1.08	1.10
J.S. #2	8.00	20	8.60	110	2.94	3.06
J.S. #3	7.75	10	8.60	95	4.30	4.55
K.S.	7.50	25	7.90	115	2.28	2.35
W.S.	7.30	160	8.30	70	5.57	6.00
F.T.	8.00	145	8.15	55	0.78	0.79
M.T. #1	7.55	70	7.65	160	0.58	0.58
M.T. #2	7.50	5	8.00	95	2.81	2.92
A.W. #1	7.80	17½	8.05	110	1.34	1.36
A.W. #2	7.45	180	7.90	85	2.58	2.67
A.W. #3	8.10	20	8.60	110	2.42	2.50
B.W.	7.90	70	8.10	155	1.05	1.06
G.W.	8.05	180	8.30	95	1.26	1.28
J.W.	7.95	150	8.15	60	1.04	1.05
L.W.	7.70	120	7.85	30	0.84	0.85
P.W.	7.90	165	8.10	75	1.05	1.06
R.W.	7.70	155	7.80	65	0.56	0.56
W.W.	7.80	5	8.00	95	1.08	1.10
	7.75	180	7.85	90	0.55	0.55
B.Y.	6.90	45	7.60	125	4.51	4.79
	7.20	5	7.90	95	4.15	4.39

APPENDIX 13 : CLINICAL EXPERIMENT 5

APHAKIA REPEATABILITY

a. Refractive Data pages 370 - 379

b. Individual values computed for 13 mm BVD. pages 380-382

c. "Mean" values computed for 13 mm BVD. pages 383

(S = Subjective; R = Retinoscopy; O = Ophthalmetron).

Name	Age	Sex	R/l	Pract.		Refraction	Bvd.	VA
R.A.	57	M	L		S_1	+12.50 / -1.50 x 85	8	6/12
				A	R_1	+12.50 / -2.00 x 80	8	6/12
					O_1	+11.75 / -1.50 x 95	13	6/12-
					S_2	+10.50 / +2.00 x 175	10.	6/9-
				C	R_2	+11.00 / +2.00 x 180	10	6/12
					O_2	+11.75 / -1.25 x 100	13	6/12-
					S_3	+10.50 / +2.00 x 170	11	6/12+
				B	R_3	+ 9.50 / +2.00 x 180	11	6/24
					O_3	+11.50 / -1.25 x 105 or 110	13	6/18+
D.C.	52	M	R		S_1	+11.00 / +2.00 x 140	11	6/9
				B	R_1	+ 9.50 / +2.50 x 140	11	6/18-
					O_1	+12.00 / -1.50 x 45	13	6/7.5
					S_2	+13.00 / -1.50 x 40	9	6/7.5 -1
				A	R_2	+13.50 / -1.50 x 45	9	6/7.5 -1
					O_2	+11.50 / -1.00 x 50	13	6/12
					S_3	+10.50 / +2.00 x 150	9	6/6-
				C	R_3	+11.00 / +1.50 x 160	9	6/9-
					O_3	+12.00 / -1.25 x 55	13	6/9
M.C.	80	M	L		S_1	+12.50 / +1.50 x 180	9	6/6 -1
				B	R_1	+12.00 / +2.00 x 10	9	6/12
					O_1	No obtainable reading		
					S_2	+16.00 / -2.50 x 100	5	6/6
				A	R_2	+16.00 / -2.50 x 105	5	6/9 +4
					O_2	No obtainable reading		
					S_3	+13.00 / +2.25 x 10	7	6/6
				C	R_3	+13.00 / +2.00 x 15	7	6/6 -2
					O_3	No obtainable reading		

Name	Age	Sex	R/L	Pract.		Refraction	BvD	VA
V.C.	53	M	R		S_1	+ 9.00 / +3.50 x 70	12	6/9
				C	R_1	+ 8.00 / +3.50 x 65	12	6/12
					O_1	+11.50 / -2.25 x 150	13	6/12 -2
					S_2	+ 9.00 / +2.75 x 70	11	6/9 +4
				B	R_2	+ 8.50 / +3.00 x 70	11	6/9 -1
					O_2	+12.25 / -3.50 x 165	13	6/12 +2
					S_3	+12.00 / -2.50 x 165	10	6/9 +4
				A	R_3	+13.00 / -2.50 x 180	10	6/18?
					O_3	+12.00 / -3.00 x 165	13	6/12 +1
			L		S_1	+10.50 / +3.00 x 20	10	6/9
				C	R_1	+ 9.50 / +3.00 x 25	10	6/12
					O_1	+12.00 / -2.50 x 110	13	6/6
					S_2	+ 9.50 / +3.25 x 32½	11	6/9 +1
				B	R_2	+ 9.50 / + 3.00 x 30	11	6/9
					O_2	+12.25 / -2.75 x 115	13	6/6 -2
					S_3	+12.75 / -3.50 x 130	8	6/9
				A	R_3	+12.00 / -2.50 x 105	8	6/18
					O_3	+12.25 / -2.50 x 125	13	6/9-
H.D.	44	M	L		S_1	+16.75 / -2.00 x 65	8	6/6 -3
				A	R_1	+16.50 / -3.00 x 60	8	6/9 +3
					O_1	+15.00 / -1.00 x 70	13	6/12 +2
					S_2	+13.00 / +1.75 x 145	14	6/9+
				B	R_2	+11.00 / +2.00 x 150	14	6/24
					O_2	+15.12 / -1.12 x 70	13	6/12 +2
					S_3	+13.50 / +2.00 x 150	9	6/6
				C	R_3	+13.50 / +2.50 x 150	9	6/12
					O_3	+15.25 / -1.25 x 75	13	6/12

Name	Age	Sex	R/L	Pract		Refraction	BvD	VA
D.	51	M	R		S_1	+11.75 / -0.50 x 85	8	6/4
				A	R_1	+11.75 / -0.75 x 90	8	6/4
					O_1	+10.75 / -0.25 x 80	13	6/4-
					S_2	+10.50 / +0.50 x 160	10	6/5
				B	R_2	+9.50 / +0.50 x 160	10	6/18
					O_1	+10.75 / -0.25 x10	13	6/4-
					S_3	+10.75 / +0.75 x 180	10	6/5+
				C	R_3	+10.50 / +1.00 x 10	10	6/5-
D.E.	56	F	R		S_1	+13.50 / +0.50 x 90	10	6/9
				B	R_1	+13.00 / +0.50 x 90	10	6/12
					O_1	+14.62 / -0.62 x 145	13	6/12-
					S_2	+14.50 / +0.50 x 10	11	6/9
				C	R_2	+14.00 / +1.00 x 10	11	6/9-
					O_2	+14.25 / -0.50 x 125	13	6/12 +2
					S_3	+16.00 / -1.00 x 100	8	6/9 -1 +2
				A	R_3	+16.00 / -1.00 x 100	8	6/9 - +2
					O_3	+14.50 / -0.62 x 130	13	6/12 +2
E.H.	52	M	R		S_1	+11.00 / +1.50 x 5	10	6/6+
				B	R_1	+11.00 / +1.50 x 180	10	6/6 -1
					O_1	+11.50 / -0.75 x 85	13	6/9
					S_2	+11.50 / +2.00 x 175	6	6/6+
				C	R_2	+11.00 / +2.00 x 180	6	6/6-
					O_2	+11.00 / -0.50 x 85	13	6/6 +2
					S_3	+12.75 / -1.25 x 70	6	6/5 -2
				A	R_3	+12.50 / -1.50 x 75	6	6/6+
					O_3	+11.375 / -0.75 x 105	13	6/6

Name	Age	Sex	R/L	Pract		Refraction	BvD	VA
E.H.	52	M	L		S_1	+10.75 / +2.00 x 10	10	6/5 -3
				B	R_1	+10.50 / +2.25 x 20	10	6/9+
					O_1	+12.25 / -1.00 x 120	13	6/9+
					S_2	+11.50 / +2.50 x 10	6	6/5
				C	R_2	+11.50 / +2.00 x 10	6	6/5-
					O_2	+12.00 / -1.00 x 120	13	6/9 -1 +3
					S_3	+13.75 / -2.00 x 102½	6	6/5 - +
				A	R_3	+14.00 / -2.00 x 105	6	6/5 -1 +2
					O_3	+12.12 / -1.12 x 120	13	6/6 +2
A.L.	66	M	R		S_1	+12.75 / -2.00 x 80	8	6/5
				A	R_1	+13.50 / -2.00 x 90	8	6/9
					O_1	No reading		
					S_2	+10.25 / +2.00 x 180	14	6/5 -2
				B	R_2	+10.00 / +2.00 x 180	14	6/18
					O_2	No reading		
					S_3	+10.00 / +2.75 x 175	10	6/5 -1
				C	R_3	+10.50 / +2.50 x 175	10	6/5
					O_3	No reading		
T.L.	59	F	L		S_1	+13.75 / -1.75 x 97½	6	6/6
				A	R_1	+14.00 / -2.00 x 90	6	6/6
					O_1	+12.75 / -2.75 x 90	13	6/6 -2
					S_2	+12.00 / +3.00 x 180	5	6/5 -1
				C	R_2	+11.50 / +2.50 x 180	5	6/6-
					O_2	+12.75 / -2.25 x 80	13	6/9 -2
					S_3	+11.25 / +1.75 x 180	7	6/9
				B	R_3	+ 9.50 / +2.00 x 180	7	6/36
					O_3	+13.25 / -2.50 x 75	13	6/60

Name	Age	Sex	R/L	Pract		Refraction	BvD	VA
M.M.	38	F	R		S_1	+11.50 / +1.25 x 180	12	6/5-
				C	R_1	+11.50 / +1.00 x 180	12	6/6+
					O_1	Cycle did not start		
					S_2	+11.00 / +0.50 x 160	13	6/5 -3
				B	R_2	+10.50 / +0.50 x 170	13	6/9+
					O_2	Cycle did not start		
					S_3	+12.75 / -1.00 x 82½	8	6/5-
				A	R_3	+12.50 / -0.75 x 75	8	6/5 -4
					O_3	Cycle did not start		
			L		S_1	+13.00 / +0.50 x 45	12	6/6
				C	R_1	+13.00	12	6/6-
					O_1	+12.25 / -0.50 x 145	13	6/6-
					S_2	+11.50 DS	13	6/6
				B	R_2	+11.00 DS	13	6/6 -2
					O_2	+11.75 DS	13	6/6 -2
					S_3	+13.75 / -0.50 x 160	7	6/5
				A	R_3	+13.75 / -0.25 x 180	7	6/5-
					O_3	+12.25 / -0.50 x 165	13	6/5
W.M.	63	M	L		S_1	+18.00 / -3.00 x 100	4	6/6 -2
				A	R_1	+17.50 / -3.00 x 95	4	6/9-
					O_1	+16.50 / -1.75 x 110	13	6/60
					S_2	+13.00 / +2.00 x 10	14	6/6
				B	R_2	+11.50 / +2.00 x 10	14	6/24
					O_2	+16.37 / -1.87 x 115	13	6/9+
					S_3	+14.00 / +1.50 x 5	9	6/6 -2
				C	R_3	+14.50 / +1.50 x 10	9	6/6-
					O_3	+16.50 / -2.00 x 105	13	6/6-

Name	Age	Sex	R/L	Pract		Refraction	BvD	VA
McC	67	M	R		S_1	+13.50 / -1.75 x 107½	10	6/6 -3
				A	R_1	+14.00 / -2.00 x 100	10	6/9
					O_1	+12.25 / -1.00 x 130	13	
					S_2	+11.00 / +2.00 x 20	11	6/4-
				C	R_2	+11.00 / +2.50 x 25	11	6/9-
					O_2	+11.75 / -0.75 x 125	13	
					S_3	+10.00 / +1.50 x 35	14	6/9 +1
				B	R_3	+ 9.00 / +1.50 x 10	14	6/24
					O_3	+11.75 / -1.00 x 125	13	
U.S.	47	M	R		S_1	+11.50 / -2.00 x 45	10	6/4 -1
				A	R_1	+11.50 / -2.00 x 45	10	6/4 -1
					O_1	+ 9.75 / -1.27 x 75	13	6/5
					S_2	+ 9.50 / +1.25 x 155	10	6/4
				C	R_2	+ 9.00 / +1.00 x 165	10	6/9
					O_2	+10.25 / -3.00 x 60	13	6/5
					S_3	+ 9.50 / +1.00 x 155	11	6/5
				B	R_3	+ 8.50 / +1.00 x 160	11	6/24
					O_3	+ 9.25 / -1.75 x 70	13	6/9
K.T.	49	F	R		S_1	+12.00 / +2.00 x 20	13	6/9
				B	R_1	+12.50 / +1.50 x 20	13	
					O_1	+14.25 / -2.50 x 120 or 110	13	6/9-
					S_2	+13.00 / +2.50 x 10	10	6/6
				C	R_2	+12.50 / +2.50 x 10	10	6/9+
					O_2	+14.75 / -2.50 x 120 or 115	13	6/9
					S_3	+15.50 / -2.50 x 100	8	6/6 -1
				A	R_3	+15.50 / -2.50 x 90	8	6/9?
					O_3	+14.50 / -2.25 x 125	13	6/9 -2

Name	Age	Sex	R/L	Pract		Refraction	BvD	VA
L.V.	65	M	R		S_1	+12.00 / +1.50 x 85	12	6/6+
				B	R_1	+11.50 / +1.50 x 90	12	6/9 +1
					O_1	No reading - Cycle did not start		
					S_2	+13.00 / -1.25 x 25	10	6/6 -3
				A	R_2	+13.50 / -1.25 x 30	10	6/6 -3
					O_2	No reading - Cycle did not start		
					S_3	+12.00 / +1.50 x 85	10	6/5
				C	R_3	+11.50 / +1.50 x 80	10	6/6+
					O_3	No reading - Cycle did not start		
L.V.	65	M	L		S_1	+12.50 DS	12	6/5-
				B	R_1	+12.50 Ds	12	6/6
					O_1	+10.75 DS	13	6/6 -4
					S_2	+14.00 / -1.00 x 165	10	6/5
				A	R_2	+13.50 / -1.00 x 20	10	6/12
					O_2	+11.25 DS	13	6/5
					S_3	+12.50 / +0.50 x 40	10	6/5
				C	R_3	+12.00 / +0.50 x 30	10	6/5
					O_3	+11.25 / -1.00 x 170	13	6/9 -1
J.W.	71	M	L		S_1	+11.50 / +2.00 x 170	7	6/5
				C	R_1	+11.50 / +1.50 x 170	7	6/6
					O_1	+11.75 / -1.00 x 100	13	6/5-
					S_2	+10.50 / +2.50 x 175	10	6/6+
				B	R_2	+ 9.50 / +2.00 x 180	10	6/12
					O_2	+11.50 / -1.00 x 90	13	
					S_3	+13.75 / -1.75 x 85	6	6/5 -2
				A	R_3	+14.00 / -1.75 x 70	6	6/9
					O_3	+12.00 / -1.25 x 95	13	

Name	Age	Sex	R/L	Pract		Refraction	BvD	VA
A.C.	49	M	L		S_1	+10.00 / +0.50 x 170	11	6/4 -2
				C	R_1	+ 9.50 / +0.75 x 180	11	6/6 +2
					O_1	+10.25 / -0.75 x 90	13	6/6
					S_2	+10.75 / -0.50 x 85	11	6/9 +3
				G	R_2	+11.00 / -0.50 x 90	11	6/9
					O_2	+10.25 / -0.50 x 90	13	6/6
					S_3	+10.75 / -0.50 x 77½	11	6/6 -2
				A	R_3	+11.25 / -0.50 x 80	11	6/9 -4
					O_3	+10.12 / -0.62 x 90	13	6/6
M.D.	68	F	R		S_1	+12.25 / -1.50 x 80	11	6/7.5
				A	R_1	+11.75 / -2.00 x 80	11	6/7.5 -2
					O_1	+11.25 / -0.75 x 97½	13	L 6/18
					S_2	+12.00 / -2.00 x 82½	12	6/9
				E	R_2	+12.00 / -1.75 x 90	12	
					O_2	+10.75 / -0.50 x 105	13	6/24
					S_3	+11.75 / -2.00 x 90	13	6/5
				H	R_3	+12.00 / -2.00 x 90	13	
					O_3	+11.50 / -1.00 x 100	13	6/8
A.D.	26	M	R		S_1	+ 9.25 / -1.00 x 180	13	6/5
				H	R_1	+ 9.00 / -1.00 x 180	13	6/6
					O_1	+ 8.62 / -0.62 x 90	13	
					S_2	+ 9.25 / -1.00 x 180	13	6/4
				A	R_2	+ 9.00 / -0.50 x 180	13	6/5 -2
					O_2	+ 8.87 / -0.62 x 20	13	
					S_3	+ 8.00 / +1.00 x 95	13	6/5
				B	R_3	+ 7.50 / +1.00 x 90	13	6/9
					O_3	+ 9.00 / -0.50 x 20	13	

Name	Age	Sex	R/L	Pract		Refraction	BvD	VA
W.O.	60	M	R		S_1	+13.00 / -0.50 x 115	10	6/5-
				D	R_1	+14.00 / -0.75 x 120	10	
					O_1	+12.75 / -1.00 x 123	13	
					S_2	+13.00 / -0.75 x 125	10	6/4 -2
				A	R_2	+13.00 / -0.75 x 110	10	6/5
					O_2	+12.375/ -1.125 x 130	13	
					S_3	+13.00 / 1.00 x 120	10	6/6 -2 +1
				F	R_3	+12.50 / -2.00 x 140	10	6/18 +1
					O_3	+12.25 / -0.75 x 130	13	
S.	69	F	L		S_1	+15.00 / -0.75 x 80	13	6/6-
				H	R_1	+15.00 / -1.25 x 80	13	6/6-
					O_1	+15.50 / -0.75 x 85	13	6/9
					S_2	+17.50 / -1.00 x 120	10	6/6-
				E	R_2	+16.50 / -1.00 x 95	10	
					O_2	+15.50 / -0.75 x 90	13	6/9 -1 +3
					S_3	+13.00 / +1.00 x 60	13	6/9?
				B	R_3	+13.00 / +1.00 x 60	13	6/12
					O_3	+15.50 / -0.75 x 75	13	6/9-
J.T.	58	M	R		S_1	+ 6.50 / -1.25 x 80	15	6/5
				A	R_1	+ 6.00 / -1.00 x 90	15	6/5
					O_1	+ 6.25 / -0.87 x 95	13	
					S_2	+ 6.50 / -0.75 x 60	10	6/6-
				D	R_2	+ 6.50 DS	10	6/9
					O_2	+ 6.125/ -0.75 x 102½	13	
					S_3	+ 5.50 / +1.50 x 180	11	6/9 pt
				C	R_3	+ 5.00 / +1.50 x 10	11	6/7.5 pt
					O_3	+ 6.25 / -0.75 x 100	13	

Name	Age	Sex	R/L	Pract		Refraction	BvD	VA
P.V.	49	F	R		S_1	+13.25 / -1.50 x 35	11	6/5 +5
				A	R_1	+13.00 / -1.50 x 40	11	6/6
					O_1	+12.75 / -0.50 x 70	13	6/6+
					S_2	+12.00 / +1.00 x 135	11	6/6
				C	R_2	+11.50 / +1.00 x 135	11	6/6
					O_2	+12.75 / -0.50 x 60	13	6/6+
					S_3	+13.50 / -0.50 x 65	10	6/4
				C	R_3	+13.50 DS	10	6/5-
					O_3	+12.25 DS	13	6/9
W.	60	M	R		S_1	+ 6.75 / -1.00 x 90	8	6/18+
				I	R_1	+ 6.50 / -1.00 x 105	8	
					O_1	+ 9.50 / -0.50 x 105	13	
					S_2	+ 7.00 / 1.00 x 90	6	6/18 +3
				A	R_2	+ 7.00 / -1.00 x 110	6	6/18 +1
					O_2	+ 9.50 / -0.50 x 95	13	
					S_3	+ 5.50 / +1.00 x 175	10	6/18 +2
				F	R_3	+ 6.50 / +0.75 x 10	10	6/18
					O_3	+ 9.625 / -0.625 x 95	13	

Name	S_A	S_B	S_C	R_A	R_B	R_C	O_A	O_B	O_C
R.A.	+11.76	+12.30	+12.20	+11.76	+11.34	+12.67	+11.75	11.50	11.75
D.C.	+12.36	+12.78	+12.10	+12.81	+11.85	+12.05	11.50	12.00	+12.00
M.C.	+14.18	+13.40	+14.32	+14.18	+13.46	+14.07			
V.C.	+11.58	+11.62	+12.52	+12.51	+11.40	+11.54	+12.00	+12.25	+11.50
	+11.99	+12.61	+13.23	+11.32	+12.36	+12.29	+12.25	+12.25	+12.00
H.D.	+15.46	+14.14	+14.83	+15.24	+13.15	+15.34	+15.00	+15.125	+15.25
D.	+11.10	+10.68	+11.26	+11.10	+9.74	+11.19	+10.75	+10.75	+10.875
D.E.	+14.81	+13.47	+14.59	+14.81	+13.01	+13.63	+14.50	+14.625	+14.25
E.H.	+11.71	+12.15	+12.65	+11.49	+12.21	+12.22	+11.375	+11.50	+11.00
	+13.82	+12.42	+13.25	+12.75	+12.45	+12.65	+12.125	+12.25	+12.00
A.L.	+11.99	+12.39	+12.51	+12.65	+12.13	+12.72			
T.L.	+12.54	+12.29	+13.91	+12.75	+10.99	+13.04	+12.75	+12.75	+13.25
M.M.	+11.99	+11.50	+12.50	+11.76	+11.00	+12.38			
	+12.70	+11.50	+13.33	+12.70	+11.00	+12.83	+12.25	+11.75	+12.25
W.M.	+15.49	+15.20	+14.77	+15.12	+13.66	+15.22	+16.50	+16.375	+16.50
T.McC.	+12.97	+11.62	+12.79	+13.44	+10.60	+13.30	+12.25	+11.75	+11.75
W.S.	+11.12	+10.32	+10.50	+11.12	+9.36	+9.75	+9.75	+9.25	+10.25
K.T.	+14.39	+14.22	+15.05	+14.39	+14.01	+14.59	+14.50	+14.25	+14.75
L.V.	+12.51	+13.37	+13.37	+12.97	+12.88	+12.68			
	+13.44	+12.35	+12.55	+12.97	+12.35	+12.08	+11.25	+10.75	+11.25
J.W.	+12.54	+12.70	+12.77	+12.75	+11.25	+12.27	+12.00	+11.50	+11.75

Name	S_1	S_2	S_3	R_1	R_2	R_3	O_1	O_2	O_3
A.C.	+10.30	+10.52	+10.52	+10.07	+10.76	+11.00	10.25	10.25	10.125
A.D.	+9.25	+9.25	+9.01	+9.00	+9.00	+8.51	8.625	8.875	9.00
M.D.	+11.96	+11.86	+11.75	+11.48	+11.86	+12.00	11.25	10.75	11.50
W.O.	+12.51	+12.51	+12.51	+13.44	+12.51	+12.05	12.75	12.375	12.25
S.	+15.00	+16.63	+14.01	+15.00	+15.72	+14.01	15.50	15.50	15.50
J.T.	+6.59	+6.38	+6.95	+6.07	+6.38	+6.46	6.25	6.125	6.25
P.V.	+12.91	+12.73	+12.97	+12.67	+12.25	+12.97	12.75	12.75	12.25
W.	+6.53	+6.67	+6.41	+6.30	+6.72	+7.13	9.50	9.625	9.625

Name	S_A	S_B	S_C	R_A	R_B	R_C	O_A	O_B	O_C
R.A.	+11.015	+11.29	+11.19	+10.77	+10.33	+11.66	11.00	+10.875	+11.125
D.C.	+11.615	+11.77	+11.09	+12.065	+10.585	+11.295	11.00	11.25	11.375
M.C.	+12.935	+12.65	+13.19	+12.94	+12.455	+13.065			
V.C.	+10.35	+10.23	+10.72	+11.28	+ 9.88	+ 9.74	10.75	10.50	10.375
	+10.27	+10.965	+11.705	+10.085	+10.84	+10.765	10.875	10.875	10.75
H.D.	+14.47	+14.055	+13.82	+13.76	+12.135	+14.075	14.50	14.56	14.625
D.	+10.85	+10.43	+10.785	+10.725	+ 9.49	+10.685	10.635	10.625	10.685
D.E.	+14.31	+13.22	+14.34	+14.31	+12.76	+14.125	14.19	14.34	14.25
E.H.	+11.085	+11.395	+11.645	+10.745	+11.515	+11.215	11.00	11.125	10.75
	+12.825	+11.415	+11.895	+11.755	+11.315	+11.645	11.56	11.75	11.50
A.L.	+11.00	+11.375	+11.11	+11.66	+11.155	+11.45			
T.L.	+11.67	+12.455	+11.415	+11.755	+ 9.99	+11.785	+11.375	+12.00	+11.625
M.M,	+11.49	+11.25	+11.87	+11.385	+10.75	+11.875			
	+12.45	+11.50	+13.08	+12.575	+11.00	+12.83	12.00	11.75	12.00
W.M.	+13.995	+14.185	+14.015	+13.625	+12.645	+14.46	+15.625	+15.44	+15.50
T.McC.	+12.11	+10.86	+11.775	+12.455	+ 9.84	+12.03	11.75	11.25	11.375
W.S.	+10.135	+ 9.82	+ 9.87	+10.135	+ 8.86	+ 9.255	9.125	8.375	8.75
K.T.	+13.155	+13.01	+13.78	+13.155	+13.255	+13.32	13.375	13.00	13.50
L.V.	+11.89	+12.615	+12.615	+12.35	+12.125	+11.925			
	+12.945	+12.35	+12.30	+12.475	+12.35	+11.83	11.25	10.75	10.75
J.W.	+11.67	+11.44	+11.765	+11.88	+10.245	+11.515	11.375	11.00	11.25

Name	S_1	S_2	S_3	R_1	R_2	R_3	O_1	O_2	O_3
A.C.	10.05	10.27	10.27	9.695	+10.51	+10.75	9.875	10.00	9.81
A.D.	8.755	8.755	8.505	+ 8.505	8.75	8.005	8.31	8.56	8.75
M.D.	11.22	10.865	10.765	10.495	10.995	11.015	10.875	10.50	11.00
W.O.	12.26	12.135	12.01	13.065	12.135	11.06	12.25	11.81	11.875
S.	14.625	16.13	13.505	14.38	15.22	13.505	15.125	15.125	15.125
J.T.	5.975	6.005	6.195	5.575	6.38	5.705	5.815	5.745	5.875
P.V.	12.17	12.225	12.72	11.93	11.745	12.97	12.50	12.50	12.25
W.	6.03	6.17	5.91	5.80	6.22	6.755	9.25	9.31	9.31

Name	S_A	S_B	S_C	R_A	R_B	R_C	O_A	O_B	O_C
R.A.	1.49	2.02	2.02	1.98	2.02	2.02	-1.50	-1.25	-1.25
D.C.	1.49	2.02	2.02	1.49	2.53	1.51	-1.00	-1.50	-1.25
M.C.	2.49	1.50	2.26	2.48	2.01	2.01			
V.C.	2.46	2.78	3.60	2.46	3.04	3.60	-3.00	-3.50	-2.25
	3.44	3.29	3.05	2.47	3.04	3.05	-2.50	-2.75	-2.50
H.D.	1.98	1.77	2.02	2.96	2.03	2.53	-1.00	-1.125	-1.25
D.	0.50	0.50	0.75	0.75	0.50	1.01	-0.25	-0.25	-0.375
D.E.	1.00	0.50	0.50	-1.00	0.50	1.01	-0.625	-0.625	-0.50
E.H.	1.25	1.51	2.01	1.49	1.51	2.01	-0.75	-0.75	-0.50
	1.99	2.01	2.51	1.99	2.27	2.01	-1.125	-1.00	-1.00
A.L.	-1.98	2.03	2.80	1.98	2.03	2.54			
T.L.	1.74	1.75	3.01	1.99	2.00	2.51	-2.75	-2.50	-2.25
M.M.	1.00	0.50	1.26	0.75	0.50	1.01			
	0.50	0.00	0.50	0.25	0.00	0.00	-0.50	0.00	-0.50
W.M.	2.99	2.03	1.51	2.99	2.03	1.51	-1.75	-1.875	-2.00
T.McC	1.72	1.52	2.03	1.97	1.52	2.54	-1.00	-1.00	-0.75
W.S.	1.97	1.00	1.26	1.97	1.00	0.99	-1.25	-1.75	-3.00
K.T.	2.47	2.02	2.54	2.47	1.51	2.54	-2.25	-2.50	-2.50
L.V.	1.24	1.51	1.51	1.24	1.51	1.51			
	0.99	0.00	0.50	0.99	0.00	0.50	0.00	0.00	-1.00
J.W.	1.74	2.52	2.01	1.74	2.01	1.51	-1.25	-1.00	-1.00
A.C.	0.50	0.50	0.50	0.75	0.50	0.50	0.75	0.50	0.625
A.D.	0.99	0.99	1.01	0.99	0.50	1.01	0.625	0.625	0.50
M.D.	1.48	1.99	1.97	-1.97	1.73	1.97	0.75	0.50	1.00
W.O.	0.50	0.75	1.00	0.75	0.75	1.98	1.00	1.125	0.75
S.	0.75	1.00	1.01	1.24	1.00	1.01	0.75	0.75	0.75
J.T.	1.23	0.75	1.51	0.99	0.00	1.51	0.875	0.75	0.75
P.V.	1.48	1.01	0.50	1.48	1.01	0.00	0.50	0.50	0.00
W.	1.00	1.00	1.00	1.00	1.00	0.75	0.50	0.625	0.625

Name	Mid Sphere S_M	R_M	O_M	Name	Cylinder Power S_M	R_M	O_M
R.A.	11.165	10.92	11.00	R.A.	1.84	2.01	1.33
D.C.	11.49	11.315	11.21	D.C.	1.84	1.84	1.25
M.C.	12.925	12.82		M.C.	2.08	2.17	
V.C.	10.43	10.30	10.54	V.C.	2.95	3.03	2.92
	10.98	10.56	10.83		3.26	2.85	2.58
H.D.	14.115	13.32	14.56	H.D.	1.92	2.51	1.125
D.	10.69	10.30	10.64	D.	0.58	0.75	0.29
D.E.	13.96	13.73	14.26	D.E.	0.67	0.84	0.58
E.H.	11.375	11.16	10.96	E.H.	1.59	1.67	0.67
	12.045	11.57	11.60		2.17	2.09	1.04
A.L.	11.16	11.42		A.L.	2.27	2.18	
T.L.	11.85	11.18	11.67	T.L.	2.17	2.17	2.50
M.M.	11.54	11.34		M.M.	0.92	0.75	
	12.34	12.135	11.92		0.33	0.08	0.33
W.M.	14.065	13.58	15.52	W.M.	2.18	2.18	1.875
T.McC	11.58	11.44	11.46	T.McC	1.76	2.01	0.92
W.S.	9.94	9.42	8.75	W.S.	1.41	1.32	2.00
K.T.	13.315	13.24	13.29	K.T.	2.34	2.17	2.08
L.V.	12.37	12.13		L.V.	1.42	1.42	
	12.53	12.22	10.92		0.50	0.50	0.33
J.W.	11.625	11.21	11.21	J.W.	2.09	1.75	1.08

APPENDIX 14 : CLINICAL EXPERIMENT 5

APHAKIA REPEATABILITY

Pair Analysis Results

Mid Equivalent Sphere	pages	385 - 388
Cylinder Power	pages	388 - 391
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Maximum Positive Sphere	pages	396 - 399

Mid Equivalent Sphere (1)

GROUP	$\bar{X}_1$	$\bar{X}_2$	$\bar{D}=\bar{X}_1-\bar{X}_2$	S/D	t	n	b	a	R
S_A v R_A	12.011	11.995	0.017	0.455	0.168	21	0.845	1.841	0.937
S_A v R_A	12.054	11.974	0.081	0.459	0.723	17	0.858	1.636	0.945
S_B v R_B	11.823	11.12	0.703	0.694	4.644	21	0.857	0.991	0.831
S_B v R_B	11.788	11.002	0.786	0.747	4.337	17	0.834	1.116	0.827
S_C v R_C	12.094	11.931	0.163	0.439	1.704	21	1.049	-0.751	0.946
S_C v R_C	12.07	11.896	0.174	0.454	1.582	17	1.081	-1.155	0.954
S_A v O_A	12.054	11.846	0.209	0.748	1.150	17	1.050	-0.814	0.892
S_B v O_B	11.788	11.733	0.054	0.752	0.298	17	1.261	-3.133	0.921
S_C v O_C	12.07	11.776	0.294	0.743	1.663	17	1.220	-2.949	0.918
R_A v O_A	11.974	11.846	0.128	0.802	0.658	17	1.142	-1.829	0.880
R_B v O_B	11.002	11.733	-0.731	1.115	-2.705	17	1.404	0.286	0.766
R_C v O_C	11.896	11.776	0.120	0.545	0.910	17	1.119	-1.540	0.954
S_A v S_B	12.011	11.823	0.188	0.629	1.371	21	0.793	2.298	0.874
S_A v S_B	12.054	11.788	0.266	0.645	1.704	17	0.804	2.095	0.887
S_C v S_C	12.011	12.094	-0.083	0.556	-0.684	21	0.849	1.891	0.904
S_A v S_C	12.054	12.07	-0.016	0.590	-0.111	17	0.844	1.900	0.907
S_B v S_C	11.823	12.094	-0.271	0.606	-2.052	21	0.903	1.416	0.872
S_B v S_C	11.788	12.07	-0.282	0.651	-1.788	17	0.895	1.525	0.871
R_A v R_B	11.995	11.12	0.875	0.862	4.648	21	0.764	1.956	0.737
R_A v R_B	11.974	11.002	0.971	0.934	4.291	17	0.736	2.190	0.730
R_A v R_C	11.995	11.931	0.064	0.603	0.485	21	1.032	-0.452	0.894
R_A v R_C	11.976	11.896	0.078	0.651	0.492	17	1.043	-0.597	0.898

Mid Equivalent Sphere (2)

GROUP	$\overline{X}_1$	$\overline{X}_2$	$\overline{D}=\overline{X}_1-\overline{X}_2$	S/D	t	n	b	a	R
R_B v R_C	11.12	11.931	-0.811	0.843	-4.406	21	0.876	2.183	0.787
R_B v R_c	11.002	11.896	-0.894	0.890	-4.141	17	0.922	1.749	0.799
O_A v O_B	11.846	11.733	0.112	0.339	1.368	17	1.034	-0.517	0.981
O_A v O_C	11.846	11.776	0.07	0.245	1.179	17	1.040	-0.549	0.991
O_B v O_C	11.733	11.776	-0.042	0.247	-0.708	17	0.986	0.201	0.990

Mid Equivalent Sphere (Correct Order) (1)

S_1 v R_1	11.514	11.290	0.223	0.442	2.722	29	1.003	-0.255	0.976
S_1 v R_1	11.430	11.172	0.258	0.435	2.972	25	1.008	-0.350	0.980
S_1 v R_1	11.040	11.756	0.284	0.443	2.637	17	0.971	0.062	0.933
S_2 v R_2	11.492	11.190	0.302	0.592	2.746	29	0.884	1.026	0.962
S_2 v R_2	11.433	11.093	0.340	0.615	2.767	25	0.876	1.083	0.965
S_2 v R_2	11.957	11.518	0.439	0.671	2.697	17	0.823	1.676	0.880
S_3 v R_3	11.408	11.217	0.191	0.694	1.482	29	0.953	0.350	0.941
S_3 v R_3	11.297	11.099	0.198	0.734	1.351	25	0.956	0.298	0.941
S_3 v R_3	11.915	11.597	0.318	0.791	1.657	17	1.056	-0.983	0.880
S_1 v O_1	11.430	11.401	0.029	0.948	0.154	25	0.902	1.090	0.900
S_1 v O_1	12.040	11.799	0.240	0.778	1.272	17	1.281	-3.625	0.906
S_2 v O_2	11.433	11.380	0.054	0.952	0.282	25	0.840	1.778	0.909
S_2 v O_2	11.957	11.735	0.222	0.712	1.286	17	1.144	-1.939	0.920
S_3 v O_3	11.297	11.275	-0.078	1.037	-0.374	25	0.888	1.344	0.882

Mid Equivalent Sphere (Correct Order) (2)

GROUP	$\bar{X}_1$	$\bar{X}_2$	$\bar{D}=\bar{X}_1-\bar{X}_2$	S/D	t	n	b	a	R
S_3 v O_3	11.915	11.820	0.095	0.765	0.512	17	1.094	-1.220	0.895
R_1 v O_1	11.172	11.401	-0.229	1.036	-1.106	25	0.862	1.775	0.885
R_1 v O_1	11.756	11.799	-0.043	0.912	-0.195	17	1.146	-1.673	0.844
R_2 v O_2	11.093	11.380	-0.287	1.170	-1.224	25	0.859	1.852	0.844
R_2 v O_2	11.518	11.735	-0.217	1.121	-0.798	17	1.018	0.005	0.767
R_3 v O_3	11.099	11.375	-0.276	0.963	-1.433	25	0.892	1.475	0.900
R_3 v O_3	11.597	11.820	-0.223	0.779	1.179	17	0.909	1.275	0.892
S_1 v S_2	11.514	11.492	0.021	0.603	0.190	29	1.030	-0.361	0.960
S_1 v S_2	11.430	11.433	-0.003	0.614	-0.023	25	1.039	-0.439	0.964
S_1 v S_2	12.040	11.957	0.082	0.635	0.535	17	1.064	-0.857	0.894
S_1 v S_3	11.514	11.408	0.106	0.634	0.896	29	0.961	0.344	0.950
S_1 v S_3	11.430	11.297	0.133	0.668	0.998	25	0.953	0.399	0.951
S_1 v S_3	12.040	11.915	0.125	0.745	0.692	17	0.988	0.021	0.843
S_2 v S_3	11.492	11.408	0.084	0.699	0.649	29	0.891	1.166	0.945
S_2 v S_3	11.433	11.297	0.136	0.728	0.934	25	0.882	1.208	0.948
S_2 v S_3	11.957	11.915	0.043	0.603	0.291	17	0.892	1.246	0.907
R_1 v R_2	11.290	11.190	0.100	0.867	0.620	29	0.872	1.350	0.907
R_1 v R_2	11.172	11.093	0.079	0.898	0.440	25	0.867	1.406	0.912
R_1 v R_2	11.756	11.518	0.238	0.974	1.007	17	0.758	2.606	0.709
R_1 v R_3	11.290	11.217	0.073	1.005	0.392	29	0.876	1.327	0.879
R_1 v R_3	11.172	11.099	0.073	1.073	0.341	25	0.869	1.386	0.878
R_1 v R_3	11.756	11.597	0.159	1.094	0.600	17	1.015	-0.341	0.752

Mid Equivalent Sphere (Correct Order) (3)

GROUP	$\bar{X}_1$	$\bar{X}_2$	$\bar{D}=\bar{X}_1-\bar{X}_2$	S/D	t	n	b	a	R
R_2v R_3	11.190	11.217	-0.027	1.111	-0.130	29	3.862	4.159	0.847
R_2 v R_3	11.093	11.099	-0.006	1.188	-0.024	25	0.879	1.353	0.843
R_2 v R_3	11.518	11.597	-0.079	1.306	-0.249	17	0.803	2.351	0.636
O_1 v O_2	11.401	11.380	0.022	0.390	0.277	25	0.976	0.247	0.983
O_1 v O_2	11.799	11.735	0.064	0.324	0.816	17	1.029	-0.409	0.983
O_1 v O_2	11.401	11.375	0.026	0.308	0.429	25	0.997	0.005	0.990
O_1 v O_3	11.799	11.820	-0.020	0.277	-0.302	17	1.000	0.017	0.987
O_2 v O_3	11.380	11.375	0.005	0.379	0.063	25	0.998	0.013	0.984
O_2 v O_3	11.735	11.820	-0.084	0.249	-1.398	17	0.959	0.568	0.990

Cylinder Power (1)

S_A v R_A	1.735	1.781	-0.047	0.351	-0.609	21	0.873	0.267	0.892
S_A v R_A	1.748	1.821	-0.073	0.384	-0.783	17	0.837	0.358	0.880
S_B v R_B	1.561	1.598	-0.037	0.259	-0.658	21	0.973	0.080	0.957
S_B v R_B	1.602	1.618	-0.016	0.262	-0.249	17	0.972	0.062	0.961
S_C v R_C	1.889	1.806	0.083	0.334	1.144	21	0.925	0.059	0.928
S_C v R_C	1.873	1.815	0.058	0.364	0.659	17	0.928	0.077	0.925
S_A v O_A	1.748	1.324	0.425	0.580	3.022	17	0.087	-0.122	0.762
S_B v O_B	1.602	1.375	0.227	0.654	1.433	17	0.823	0.057	0.772
S_C v O_C	1.873	1.404	0.469	0.852	2.266	17	0.486	0.494	0.544
R_A v O_A	1.821	1.324	0.498	0.661	3.105	17	0.775	-0.087	0.678

Cylinder Power (2)

GROUP	$\overline{X}_1$	$\overline{X}_2$	$\overline{D}=\overline{X}_1-\overline{X}_2$	S/D	t	n	n	a	R
R_B v O_B	1.618	1.375	0.243	0.668	1.501	17	0.805	0.072	0.764
R_C v O_C	1.815	1.404	0.410	0.930	1.819	17	0.408	0.664	0.458
S_A v S_B	1.735	1.561	0.174	0.532	1.497	21	0.915	-0.026	0.798
S_A v S_B	1.748	1.602	0.146	0.538	1.118	17	0.955	-0.068	0.818
S_A v S_C	1.735	1.889	-0.154	0.643	-1.100	21	0.814	0.477	0.704
S_A v S_C	1.748	1.873	-0.125	0.691	-0.744	17	0.814	0.449	0.694
S_B v S_C	1.561	1.889	-0.328	0.450	-3.338	21	0.876	0.522	0.869
S_B v S_C	1.602	1.873	-0.271	0.456	-2.447	17	0.885	0.455	0.881
R_A v R_B	1.781	1.598	0.183	0.581	1.446	21	0.907	-0.017	0.761
R_A v R_B	1.821	1.618	0.203	0.633	1.323	17	0.924	-0.065	0.745
R_A v R_C	1.781	1.806	-0.024	0.589	-0.189	21	0.882	0.234	0.749
R_A v R_C	1.821	1.815	6.471	0.626	0.043	17	0.926	0.127	0.749
R_B v R_C	1.598	1.806	-0.207	0.509	-1.868	21	0.824	0.488	0.834
R_B v R_C	1.618	1.815	-0.196	0.554	-1.461	17	0.824	0.481	0.827
O_A v O_B	1.324	1.375	-0.051	0.287	-0.740	17	1.102	-0.084	0.962
O_A v O_C	1.324	1.404	-0.081	0.576	-0.579	17	0.746	0.418	0.773
O_B v O_C	1.375	1.404	-0.029	0.544	-0.223	17	0.705	0.435	0.837

Cylinder Power (Correct Order) (1)

GROUP	$\bar{X}_1$	$\bar{X}_2$	$\bar{D}=\bar{X}_1-\bar{X}_2$	S/D	t	n	b	a	R
S_1 v R_1	1.51	1.613	-0.103	0.336	-1.649	29	0.996	0.109	0.927
S_1 v R_1	1.502	1.610	-0.109	0.344	-1.581	25	0.994	0.117	0.932
S_1 v R_1	1.742	1.829	-0.087	0.383	-0.937	17	1.023	0.046	0.933
S_2 v R_2	1.569	1.5	0.069	0.286	1.301	29	0.945	0.017	0.947
S_2 v R_2	1.570	1.49	0.080	0.307	1.296	25	0.939	0.016	0.941
S_2 v R_2	1.838	1.809	0.029	0.310	0.383	17	0.870	0.211	0.944
S_3 v R_3	1.518	1.483	0.034	0.335	0.554	29	0.867	0.167	0.897
S_3 v R_3	1.458	1.448	0.010	0.352	0.136	25	0.870	0.180	0.884
S_3 v R_3	1.644	1.616	0.028	0.326	0.350	17	0.816	0.274	0.907
S_1 v O_1	1.502	1.115	0.387	0.594	3.257	25	0.613	0.194	0.749
S_1 v O_1	1.742	1.301	0.440	0.641	2.831	17	0.639	0.189	0.753
S_2 v O_2	1.570	1.105	0.465	0.837	2.775	25	0.660	0.069	0.604
S_2 v O_2	1.838	1.309	0.529	0.952	2.293	17	0.713	-0.001	0.590
S_3 v O_3	1.458	1.17	0.288	0.536	2.685	25	0.761	0.061	0.743
S_3 v O_3	1.644	1.426	0.217	0.604	1.482	17	0.698	0.279	0.696
R_1 v O_1	1.610	1.115	0.495	0.701	3.534	25	0.523	0.273	0.681
R_1 v O_1	1.829	1.301	0.527	0.793	2.743	17	0.519	0.353	0.671
R_2 v O_2	1.49	1.105	0.385	0.840	2.393	25	0.659	0.124	0.601
R_2 v O_2	1.809	1.309	0.501	0.942	2.233	17	0.785	-0.112	0.599
R_3 v O_3	1.448	1.17	0.278	0.579	2.401	25	0.724	0.122	0.696
R_3 v O_3	1.616	1.426	0.189	0.611	1.278	17	0.735	0.238	0.660
S_1 v S_2	1.51	1.569	-0.059	0.570	-0.557	29	0.822	0.328	0.779

Cylinder Power (Correct Order) (2)

GROUP	$\overline{X}_1$	$\overline{X}_2$	$\overline{D}=\overline{X}_1-\overline{X}_2$	S/D	t	n	b	a	R
S_1 v S_2	1.502	1.570	-0.068	0.557	-0.610	25	0.809	0.354	0.805
S_1 v S_2	1.742	1.838	-0.096	0.641	-0.621	17	0.751	0.530	0.773
S_1 v S_3	1.51	1.518	-0.008	0.558	-0.073	29	0.679	0.493	0.755
S_1 v S_3	1.502	1.458	0.044	0.554	0.397	25	0.650	0.481	0.785
S_1 v S_3	1.742	1.644	0.098	0.594	0.682	17	0.632	0.543	0.788
S_2 v S_3	1.569	1.518	0.051	0.490	0.565	29	0.707	0.408	0.830
S_2 v S_3	1.570	1.458	0.112	0.479	1.169	25	0.697	0.364	0.845
S_2 v S_3	1.838	1.644	0.195	0.517	1.553	17	0.689	0.378	0.834
R_1 v R_2	1.613	1.5	0.113	0.582	1.044	29	0.768	0.261	0.784
R_1 v R_2	1.610	1.49	0.120	0.610	0.987	25	0.736	0.305	0.783
R_1 v R_2	1.829	1.809	0.019	0.692	0.116	17	0.619	0.678	0.759
R_1 v R_3	1.613	1.483	0.130	0.653	1.070	29	0.560	0.579	0.693
R_1 v R_3	1.610	1.448	0.162	0.688	1.180	25	0.530	0.595	0.693
R_1 v R_3	1.829	1.616	0.213	0.667	1.317	17	0.518	0.668	0.788
R_2 v R_3	1.5	1.483	0.017	0.573	0.159	29	0.626	0.543	0.759
R_2 v R_3	1.49	1.448	0.042	0.597	0.352	25	0.608	0.543	0.747
R_2 v R_3	1.809	1.616	0.194	0.415	1.922	17	0.710	0.332	0.880
O_1 v O_2	1.115	1.105	0.01	0.534	0.094	25	1.132	-0.157	0.844
O_1 v O_2	1.301	1.309	-0.007	0.646	-0.047	17	1.144	-0.180	0.828
O_1 v O_3	1.115	1.17	-0.055	0.331	-0.831	25	0.934	0.129	0.901
O_1 v O_3	1.301	1.426	-0.125	0.354	-1.458	17	0.856	0.313	0.903
O_2 v O_3	1.105	1.17	-0.065	0.462	-0.703	25	0.687	0.411	0.889
O_2 v O_3	1.309	1.426	-0.118	0.520	-0.933	17	0.629	0.603	0.918

Cylinder Axis (1)

GROUP	$\overline{X}_1$	$\overline{X}_2$	$\overline{D}=\overline{X}_1-\overline{X}_2$	S/D	t	n	b	a	R
S_A v R_A	86.944	84.444	2.5	9.354	1.134	18	0.978	-0.611	0.964
S_A v R_A	92.321	88.571	3.75	9.695	1.447	14	0.986	-2.495	0.957
S_B v R_B	92.361	93.889	-1.528	8.096	-0.801	18	0.929	8.008	0.981
S_B v R_B	101.25	101.429	-0.179	8.462	-0.079	14	0.925	7.808	0.974
S_C v R_C	87.222	89.444	-2.222	4.278	-2.204	18	0.995	2.662	0.991
S_C v R_C	92.857	95.714	-2.857	4.258	-2.511	14	0.901	12.041	0.989
S_A v O_A	92.321	106.071	-13.75	13.364	-3.850	14	0.837	28.826	0.910
S_B v O_B	101.25	103.036	-1.786	15.915	-0.420	14	0.792	22.797	0.903
S_C v O_C	92.857	100.536	-7.679	12.187	-2.357	14	0.943	12.955	0.894
R_A v O_A	88.571	106.071	-17.5	14.108	-4.641	14	0.808	34.543	0.906
R_B v O_B	101.429	103.036	-1.607	14.923	-0.403	14	0.837	18.164	0.905
R_C v O_C	95.714	100.536	-4.821	13.814	-1.306	14	0.995	5.307	0.859
S_A v S_B	86.944	92.361	-5.417	22.034	-1.043	18	1.010	4.508	0.845
S_A v S_B	92.321	101.25	-8.929	23.343	-1.431	14	0.892	18.940	0.780
S_A v S_C	86.944	87.222	-0.277	10.568	-0.112	18	0.890	9.821	0.952
S_A v S_C	92.321	92.857	-0.536	11.058	-0.181	14	0.754	23.236	0.954
S_B v S_C	92.361	87.222	5.139	20.624	1.057	18	0.680	24.400	0.870
S_B v S_C	101.25	92.857	8.393	21.830	1.439	14	0.565	35.684	0.816
R_A v R_B	84.444	93.889	-9.444	20.856	-1.921	18	0.944	14.148	0.846
R_A v R_B	88.571	101.429	-12.857	22.422	-2.146	14	0.827	28.167	0.786
R_A v R_C	84.444	89.444	-5	13.827	-1.534	18	0.849	17.721	0.918
R_A v R_C	88.571	95.714	-7.143	13.404	-1.994	14	0.663	36.974	0.949

Cylinder Axis (2)

GROUP	$\overline{X}_1$	$\overline{X}_2$	$\overline{D}=\overline{X}_1-\overline{X}_2$	S/D	t	n	b	a	R
R_B v R_C	93.888	89.444	4.444	20.714	0.910	18	0.702	23.506	0.847
R_B v R_C	101.429	95.714	5.714	23.110	0.925	14	0.503	44.682	0.758
O_A v O_B	106.071	103.036	3.036	9.617	1.181	14	1.043	-7.623	0.956
O_A v O_C	106.071	100.536	5.536	8.670	2.389	14	0.870	8.275	0.958
O_B v O_C	103.036	100.536	2.5	9.094	1.029	14	0.807	17.406	0.970

Cylinder Axis (Correct Order) (1)

S_1 v R_1	86.875	88.125	-1.25	6.255	-0.979	24	0.980	2.957	0.988
S_1 v R_1	91.111	91.111	0	5.879	0	18	0.970	2.738	0.989
S_1 v R_1	98.929	97.143	1.786	4.945	1.351	14	0.998	-1.565	0.991
S_2 v R_2	86.875	88.958	-2.083	8.427	-1.211	24	0.907	10.130	0.969
S_2 v R_2	87.917	91.111	-3.194	3.618	-3.746	18	0.931	9.229	0.995
S_2 v R_2	92.679	95.357	-2.679	3.462	-2.895	14	0.925	9.635	0.995
S_3 v R_3	88.229	83.333	-0.104	11.119	-0.046	24	1.005	-0.328	0.960
S_3 v R_3	88.333	86.667	1.667	11.213	0.631	18	0.961	1.761	0.950
S_3 v R_3	94.821	93.214	1.607	12.543	0.479	14	0.892	8.617	0.909
S_1 v O_1	91.5	97.775	-6.275	14.636	-1.917	20	0.791	25.407	0.927
S_1 v O_1	98.929	103.214	-4.286	17.053	-0.940	14	0.710	33.007	0.892

Cylinder Axis correct order (2)

GROUP	$\overline{X}_1$	$\overline{X}_2$	$\overline{D}=\overline{X}_1-\overline{X}_2$	S/D	t	n	b	a	R
S_2 v O_2	90	97.5	-7.5	13.402	-2.503	20	0.883	18.024	0.918
S_2 v O_2	92.679	101.429	-8.75	11.040	-2.966	14	0.989	9.769	0.934
S_3 v O_3	92.75	99.25	-6.5	22.789	-1.276	20	0.709	33.474	0.775
S_3 v O_3	94.821	105.357	-10.536	14.812	-2.661	14	0.868	23.096	0.875
R_1 v O_1	91.75	97.775	-6.025	14.490	-1.860	20	0.790	25.288	0.929
R_1 v O_1	97.143	103.214	-6.071	17.004	-1.336	14	0.707	34.489	0.895
R_2 v O_2	91.5	97.5	-6	12.418	-2.161	20	0.949	10.634	0.925
R_2 v O_2	95.357	101.429	06.071	11.958	-1.900	14	1.052	1.144	0.923
R_3 v O_3	93.25	99.25	-6	24.794	-1.082	20	0.658	37.857	0.747
R_3 v O_3	93.214	105.357	-12.143	17.510	-2.595	14	0.830	27.958	0.821
S_1 v S_2	86.875	86.875	0	21.544	0	24	0.709	25.314	0.842
S_1 v S_2	91.111	87.917	3.194	22.700	0.597	18	0.627	30.806	0.832
S_1 v S_2	98.929	92.679	6.25	23.033	1.015	14	0.619	31.486	0.781
S_1 v S_3	86.875	88.229	-1.354	24.439	-0.271	24	0.760	22.194	0.804
S_1 v S_3	91.111	88.333	2.778	22.441	0.525	18	0.722	22.544	0.833
S_1 v S_3	98.929	94.821	4.107	25.241	0.609	14	0.590	36.462	0.732
S_2 v S_3	86.875	88.229	-1.354	11.679	-0.568	24	1.071	-4.838	0.953
S_2 v S_3	87.917	88.333	-0.417	11.090	-0.159	18	1.095	-7.967	0.952
S_2 v S_3	92.679	94.821	-2.143	8.540	-0.939	14	0.974	4.540	0.958
R_1 v R_2	88.125	88.958	-0.833	20.306	-0.201	24	0.684	28.661	0.861
R_1 v R_2	91.111	91.111	0	23.073	0	18	0.590	37.342	0.820
R_1 v R_2	97.143	95.357	1.786	24.776	0.270	14	0.545	42.460	0.744

Cylinder Axis correct order (3)

GROUP	$\overline{X}_1$	$\overline{X}_2$	$\overline{D}=\overline{X}_1-\overline{X}_2$	S/D	t	n	b	a	R
R_1 v R_3	88.125	88.333	-0.208	25.473	-0.040	24	0.791	18.595	0.793
R_1 v R_3	91.111	86.667	4.444	23.066	0.817	18	0.732	20.006	0.817
R_1 v R_3	97.143	93.214	3.929	26.031	0.565	14	0.562	38.610	0.716
R_2 v R_3	88.958	88.333	-0.625	18.668	0.164	24	1.113	-10.709	0.886
R_2 v R_3	91.111	86.667	4.444	14.439	1.306	18	1.145	-17.666	0.921
R_2 v R_3	95.357	93.214	2.143	12.967	0.618	14	0.962	1.486	0.896
O_1 v O_2	97.775	97.5	0.275	8.896	0.138	20	0.954	4.176	0.963
O_1 v O_2	103.214	101.429	1.786	9.325	0.717	14	1.005	-2.297	0.953
O_1 v O_3	97.775	99.25	-1.475	10.161	-0.649	20	0.939	7.423	0.951
O_1 v O_3	103.214	105.357	-2.143	11.044	-0.726	14	0.933	9.034	0.929
O_2 v O_3	97.5	99.25	-1.75	7.482	-1.046	20	0.969	4.755	0.973
O_2 v O_3	101.429	105.357	-3.929	7.119	-2.065	14	0.927	11.307	0.973

Maximum positive sphere (1)

GROUP	$\bar{X}_1$	$\bar{X}_2$	$\bar{D}=\bar{X}_1-\bar{X}_2$	S/D	t	n	b	a	R
S_A v R_A	12.879	12.885	-0.007	0.454	-0.067	21	0.888	1.454	0.941
S_A v R_A	12.928	12.884	0.044	0.460	0.395	17	0.894	1.329	0.946
S_B v R_B	12.554	11.914	0.640	0.572	5.121	21	0.905	0.533	0.892
S_B v R_B	12.528	11.808	0.72	0.600	4.946	17	0.877	0.827	0.893
S_C v R_C	13.095	12.786	0.309	0.505	2.803	21	1.016	-0.513	0.921
S_C v R_C	13.076	12.745	0.332	0.539	2.540	17	1.034	-0.780	0.925
S_A v O_A	12.928	12.499	0.429	0.793	2.230	17	1.055	-1.138	0.886
S_B v O_B	12.528	12.389	0.138	0.796	0.716	17	1.236	-3.097	0.911
S_C v O_C	13.076	12.493	0.584	0.801	3.007	17	1.224	-3.518	0.900
R_A v O_A	12.884	12.499	0.385	0.788	2.012	17	1.124	-1.983	0.891
R_B v O_B	11.808	12.389	-0.582	1.065	-2.253	17	1.113	-0.755	0.805
R_Cv O_C	12.745	12.493	0.252	0.703	1.478	17	1.116	-1.731	0.917
S_A v S_B	12.879	12.554	0.325	0.714	2.086	21	0.775	2.571	0.849
S_A v S_B	12.928	12.528	0.401	0.704	2.347	17	0.800	2.182	0.871
S_A v S_C	12.879	13.095	-0.217	0.677	-1.468	21	0.759	3.316	0.864
S_A v S_C	12.928	12.076	-0.148	0.728	-0.840	17	0.762	3.222	0.860
S_B v S_C	12.554	13.095	-0.541	0.655	-3.788	21	0.821	2.791	0.852
S_B v S_C	12.528	13.076	-0.549	0.696	-3.251	17	0.824	2.754	0.854
R_A v R_B	12.885	11.914	0.971	0.925	4.810	21	0.714	2.710	0.728
R_A v R_B	12.884	11.808	1.076	0.995	4.461	17	0.683	3.011	0.715
R_A v R_C	12.885	12.786	0.099	0.655	0.693	21	0.893	1.274	0.870
R_A v R_C	12.884	12.745	0.139	0.706	0.814	17	0.913	0.985	0.870

Maximum Positive Sphere (2)

GROUP	$\overline{X}_1$	$\overline{X}_2$	$\overline{D}=\overline{X}_1-\overline{X}_2$	S/D	t	n	b	a	R
R_B v R_C	11.914	12.786	-0.872	0.858	-4.655	21	0.809	3.147	0.773
R_B v R_C	11.808	12.745	-0.937	0.905	04.629	17	0.856	2.637	0.779
O_A v O_B	12.499	12.389	0.11	0.312	1.452	17	1.031	-0.494	0.985
O_A v O_C	12.499	12.493	0.007	0.329	0.085	17	0.993	0.079	0.982
O_B v O_C	12.389	12.493	-0.103	0.438	-0.973	17	0.937	0.883	0.969

Maximum Positive Sphere (Correct Order) (1)

S_1 v R_1	12.269	12.094	0.174	0.434	2.159	29	1.004	-0.228	0.979
S_1 v R_1	12.181	11.975	0.206	0.428	2.410	25	1.006	-0.285	0.982
S_1 v R_1	12.911	12.667	0.244	0.423	2.372	17	0.925	0.731	0.940
S_2 v R_2	12.314	11.920	0.395	0.598	3.555	29	0.890	0.962	0.965
S_2 v R_2	12.262	11.816	0.446	0.613	3.635	25	0.879	1.040	0.969
S_2 v R_2	12.941	12.364	0.576	0.670	3.549	17	0.820	1.749	0.888
S_3 v R_3	12.134	11.940	0.195	0.563	1.865	29	0.999	-0.189	0.964
S_3 v R_3	11.988	11.801	0.188	0.593	1.581	25	1.005	-0.246	0.964
S_3 v R_3	12.681	12.405	0.276	0.638	1.782	17	1.163	-2.344	0.936
S_1 v O_1	12.181	11.940	0.241	0.963	1.253	25	0.910	0.858	0.906
S_1 v O_1	12.911	12.448	0.462	0.787	2.422	17	1.271	-3.967	0.910
S_2 v O_2	12.262	11.92	C.342	0.997	1.712	25	0.837	1.661	0.910
S_2 v O_2	12.941	12.456	0.485	0.839	2.382	17	1.025	-0811	0.871
S_3 v O_3	11.988	11.945	0.044	1.014	0.216	25	0.920	0.910	0.892

Maximum Positive Sphere (Correct Order) (2)

GROUP	$\overline{X_1}$	$\overline{X_2}$	$\overline{D}=\overline{X}_1-\overline{X}_2$	S/D	t	n	b	a	R
S_3 v O_3	12.681	12.477	0.204	0.798	1.054	17	1.173	-2.400	0.903
R_1 v O_1	11.975	11.940	0.035	0.980	0.179	25	0.887	1.320	0.905
R_1 v O_1	12.667	12.448	0.219	0.830	1.087	17	1.274	-3.685	0.897
R_2 v O_2	11.816	11.92	-0.104	1.195	-0.437	25	0.864	1.712	0.852
R_2 v O_2	12.364	12.456	-0.092	1.226	-0.309	17	0.892	1.424	0.700
R_3 v O_3	11.801	11.945	-0.144	0.892	-0.806	25	0.910	1.201	0.920
R_3 v O_3	12.405	12.477	-0.072	0.759	-0.391	17	0.946	0.741	0.905
S_1 v S_2	12.269	12.314	-0.046	0.789	-0.313	29	1.024	-0.244	0.937
S_1 v S_2	12.181	12.262	-0.080	0.786	-0.511	25	1.029	-0.275	0.945
S_1 v S_2	12.911	12.941	-0.03	0.872	-0.142	17	0.942	0.779	0.800
S_1 v S_3	12.269	12.134	0.134	0.690	1.046	29	0.935	0.662	0.944
S_1 v S_3	12.181	11.988	0.193	0.694	1.389	25	0.923	0.742	0.950
S_1 v S_3	12.911	12.581	0.229	0.803	1.178	17	0.901	1.052	0.813
S_2 v S_3	12.314	12.134	0.18	0.766	1.265	29	0.854	1.617	0.942
S_2 v S_3	12.262	11.988	0.273	0.777	1.758	25	0.847	1.606	0.948
S_2 v S_3	12.941	12.681	0.259	0.700	1.529	17	0.826	1.989	0.878
R_1 v R_2	12.094	11.920	0.175	0.885	1.064	29	0.895	1.100	0.912
R_1 v R_2	11.975	11.816	0.159	0.900	0.884	25	0.885	1.219	0.919
R_1 v R_2	12.667	12.364	0.303	1.002	1.246	17	0.769	1.622	0.695
R_1 v R_3	12.094	11.940	0.154	0.964	0.865	29	0.898	1.082	0.897
R_1 v R_3	11.975	11.801	0.174	1.024	0.850	25	0.886	1.186	0.897
R_1 v R_3	12.667	12.405	0.262	1.105	0.977	17	1.064	-1.071	0.760

Maximum Positive Sphere (Correct Order) (3)

GROUP	$\overline{X}_1$	$\overline{X}_2$	$\overline{D}=\overline{X}_1-\overline{X}_2$	S/D	t	n	b	a	R
R_2 v R_3	11.920	11.904	-0.02	1.176	-0.092	29	0.861	1.675	0.844
R_2 v R_3	11.816	11.801	0.015	1.253	0.059	25	0.862	1.619	0.840
R_2 v R_3	12.364	12.405	-0.041	1.447	-0.117	17	0.717	3.537	0.567
O_1 v O_2	11.940	11.92	0.020	0.376	0.263	25	0.982	0.198	0.986
O_1 v O_2	12.448	12.456	-0.008	0.427	-0.074	17	0.961	0.492	0.969
O_1 v O_s	11.940	11.945	0.005	0.297	-0.081	25	0.989	0.135	0.991
O_1 v O_s	12.448	12.477	-0.029	0.292	-0.411	17	1.016	-0.175	0.986
O_2 v O_s	11.92	11.945	-0.025	0.371	-0.331	25	0.988	0.170	0.986
O_2 v O_s	12.456	12.477	-0.021	0.391	-0.227	17	1.013	-0.144	0.975