ULTRASOUND AND PHAKOMETRY MEASUREMENTS OF THE PRIMATE EYE

Francis A. Young, Ph. D.
George A. Leary, F.S.M.C.
Primate Research Center
Washington State University

Donald N. Farrer, Ph. D.

FOREWORD

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C.H. KRATOCHVIL, Lt Colonel, USAF, MC
Commander

ABSTRACT

Results obtained on 160 eyes of 53 male and 40 female chimpanzees ranging in age from 2 to 15 years, using ultrasonography and photographic ophthalmophakometry to measure anterior chamber depth, lens thickness, and axial length, are compared with the results obtained on 140 human eyes of a comparable sex grouping using the same methods. The intercorrelations between methods are not quite as high on the chimpanzees as on the humans, but the correlations between the measures of axial length and the vertical ocular refraction are virtually identical for the two groups. Either ultrasound or photographic ophthalmophakometry may be used successfully on primates and will yield results which compare favorably with those obtained on humans, but ultrasound is the method of choice since it does not require as much time to make the measurement or to calculate the result as does phakometry. Further, it does not require the rigid degree of control over the animal's behavior that phakometry requires and its flexibility allows measurement in situations in which it would be impossible to obtain phakometry measurements. Thus for both human and animal work, ultrasound is generally superior to phakometry.

I

INTRODUCTION

Since 1962 Young and Farrer (Ref. 1, 2, 3, 4, 5) have been carrying out a longitudinal study of the development of refractive characteristics of chimpanzees' eyes as effected by age and environmental conditions. In order to gain more information, this study has recently been expanded to include ultrasonography (USG) and ophthalmophakometry, as well as biomicroscopy, fundus photography, keratometry and ophthalmoscopy.

This paper presents a report of the methods and techniques used to obtain measures of the radius and power of the cornea, the depth of the anterior chamber, the radius and power of the lens surfaces, the equivalent power, the lens thickness, total power of the eye, and the axial length using ultrasound and phakometry. The results obtained are presented in a preliminary form since the speed of transmission of ultrasound in the aqueous, lens, and vitreous of the chimpanzee eye have not yet been determined. The measurements presented are based upon the rate of transmission of ultrasound through the aqueous, lens, and vitreous of the human eye as determined by Jansson (Ref. 6). The phakometric measurements were made with equipment which, though modified in design, maintained the same optical principles and measurements as used on the human eye (Ref. 7). Since this equipment was used without alteration on the chimpanzee, the results obtained are subject to correction.

The chimpanzee eye is slightly smaller than the human eye with a greater corneal curvature and a relatively deep anterior chamber. It must be stressed that the results presented here are based on instruments and principles developed for use on human eyes which may require modification for use on chimpanzee and monkey eyes. The results presented here will be corrected, if necessary, after the equipment has been more efficiently designed for use on the chimpanzee and monkey eye.

II

APPARATUS

The ultrasound apparatus consisted of a Kretz Technik Series 7000 which provides a frequency range of 3 to 20 megacycles and a rectified trace to remove random small echoes. The baseline of the Kretz oscilloscope is not linear and the degree of control over the signal and echoes is very limited. For this reason the ultrasound unit of the Kretz was modified to allow simultaneous presentation of both the rectified and the unrectified echo traces. These traces were fed to a Tektronix type 547 oscilloscope equipped with a type 1A1 dual-trace plug-in unit.

The type 547 oscilloscope features two identical time-base generators that can be used singly or electronically alternated for viewing a single signal or multiple signals at two sweep rates. The two time-base generators can also be used in "delaying" and "delayed" sweep operation for highly accurate time measurements. Sweep rates of 0.1 microsecond per cm. to 5 seconds per cm. in 24 calibrated steps with a displayed sweep-rate accuracy of ±2 percent for both sweeps are provided along with a sweep magnification feature which allows a 2X, 5X and 10X magnification of the display horizontally with an accuracy of ±5 percent in the magnified positions.

Since distance is measured by ultrasound in terms of the time required for a pulse to leave the crystal, strike an interference, and return to the crystal as an echo (the crystal serves as a transmitter and receiver), the accuracy of measurement will depend upon the rate of transmissions of sound through the medium and the accuracy with which the time intervals can be measured. The Kretz unit does not provide accurate measurement of time intervals nor does it provide an internal calibration whereas the Tektronix instrument provides both. Thus with the Kretz unit, it is necessary to use a piece of plastic which has been calibrated to provide an echo signal of a known distance interval on the screen of the scope. The probe is placed in contact with the desired surface of the piece of plastic and the instrument controls are

adjusted until an interval of the proper magnitude is obtained on the scope. With the Tektronix unit the sweep rate and delay controls are merely set to the desired values and provide much greater accuracy and reliability than the Kretz unit. We have recently substituted a Precision Sonics Company UTR-1 ultrasonic plug-in for the Kretz since the Precision Sonics plug-in is designed to replace the 1A1 plug-in in the Tektronix scope.

This unit and the 547 scope provide a single package, highly versatile and accurate ultrasound unit which will display either a rectified or an unrectified trace with magnification of any portion of the trace or both the rectified and unrectified traces at the same time without magnification. The complete unit weighs 31.8 kg. and is 33 cm. wide × 71 cm. long × 41 cm. high.

In the present study a six megacycle Kretz probe was used. The probe was fitted with a perspex tube made of acrylic plastic with an internal diameter of 6 mm. and external diameter of 8.5 mm. The end of the tube was covered with a polyethylene film 0.03 mm. (30 microns) in thickness. When filled with water and attached to the probe, the tube provides a water column 31 mm. long. Recently, Saran plastic 0.005 mm. (5 microns) thick has been substituted for the polyethylene as a membrane. Since the limits of resolution of most ultrasound units in use today is 0.2 to 0.3 mm. or 200-300 microns, either of these membranes may be ignored as far as measurement is concerned and the front surface of the membrane may be taken as the front surface of the cornea.

The phakometer, while based upon the one used by Sorsby, et al. (Ref. 7) as far as dimensions are concerned, used two 32-candlepower, 12-volt automobile bulbs (GE 1073) as light sources instead of the electronic flash unit and mirror arrangement used by Sorsby. These lights were operated at 6 volts for focusing and were "flashed" by a short pulse from a 16,000 microfarad capacitor which provided a peak of 28 volts. The phakometer was mounted on the outer arm of a Poser slit lamp base while the camera was mounted on the inner arm. The base was modified to provide a locking device to hold the arms at angles of 40 and 60 degrees while allowing the arms to rotate as a unit. For photography of the right eye the camera was to the left of the light sources and reversed for the left eye. The pulse, which "flashed" the lights was controlled by the flash

synchronizer of the camera and provided an intensity of approximately 200 joules. A Miranda model F reflex camera fitted with an F 2 lens and extension tube to provide a magnification of 1: 1 was used on a rack and pinion focusing mount.

A Poser slit lamp with a Miranda camera equipped and mounted in the same manner as on the phakometer was used to photograph the slit lamp section. The slit lamp and the phakometer were mounted on a sliding board which permitted alternate use without moving the subject. Corneal curvature was determined through the use of a Bausch & Lomb keratometer with its range extended by supplementary lenses. The keratometer was calibrated against ball bearings throughout its normal and extended range.

III

METHOD

Postmortem eyes were used initially to determine the control panel settings most suitable to provide adequate traces. These settings, which were maintained throughout the study are as follows:

The Kretz 7000

Reject - was left in "off" position (its use in an earlier study resulted in modification of the magnitude of the intervals between echo peaks (Ref. 8)).

Filter - "on" position.

Gain - position "2" of the arbitrary scale provided.

Trace expansion - when filled with water the probe extension tube repeated the membrane signal every 31 mm. Since the chimpanzee axial length is less than this, all data were contained between the membrane signals. Setting at a maximum spread of the screen (Scale 6).

Calibrator - Set at zero and not used.

The Tektronix 547

Only time base A was used on the scope and the settings for this time base were: Mode, auto stability; slope, positive; coupling, AC; and source, plug-in. A horizontal display setting of "A" was combined with a time/cm. of 10 and sweep magnification of 5X. The calibrator was set at "Calib."

Dual trace 1A1 plug-in

The mode was set at the alternating position in order to display the rectified trace on channel one and the unrectified trace on channel two at the same time. Both channels had settings of "2" on volts/cm., variable volts/cm. at maximum and input selector at "AC."

These settings gave a good amplitude to the lens surface peaks without evidence of "infolding" of the peaks when maximum amplitude signals were obtained. The Kretz instrument was used as a monitor from which observations of the form of the trace could be obtained. All measurements were taken from the film negatives obtained by photographing the traces displayed on the Tektronix scope.

Two calibrations were necessary, (a) the camera reduction ratio, screen size: film size, and (b) the screen magnification ratio, screen time interval: actual time interval or the ratio of the time interval represented by the length portrayed on the screen to the time interval in the eye.

(a) Camera reduction - The interval between the two extreme graduations on the face of the oscilloscope screen is 100 mm. By measuring this interspace on the film negative the camera reduction could be calculated from

$$100/C = R \text{ (camera reduction ratio)}$$

where C = the microscope vernier reading in mm. for the measured interspace. The equivalent screen distances (S) between echo peaks could then be determined by measuring the distance between the peaks on the film and multiplying by the camera reduction ratio (R).

The camera reduction was reassessed for each trace used. This ensured that so long as the camera was refocussed after removal for reloading, correct positioning was not a variable.

(b) Screen magnification - The time/cm and sweep magnification settings were recorded for each subject. For the purpose of the present investigation these settings were kept constant. Relative to the screen length, the number of microseconds of travel represented by the screen to the actual number of microseconds in the media of the eye is obtained from the proportion

$$TS/2M = \mu \text{ (microseconds of travel)}$$

where T is time/cm. setting on scope, S is the screen measurement or the product on the camera reduction ratio and the measurement on the film, and M is the sweep magnification setting on the scope. Since the screen interval represents the time for the pulse to reach a surface and the echo to reach the crystal, it must be halved.

Pending further investigation the following velocities were used in all calculations: aqueous and vitreous, 1534.5 meters per second; the lens, 1642.2 meters per second. These values are based on Jansson's values for human subjects of 1532 meters per second for the aqueous and vitreous and 1641 meters per second for the lens at 37° centigrade. Since the rectal temperature of the chimpanzee is approximately 38.4° centigrade, a temperature correction was made using Jansson's values for the aqueous and vitreous of 1.8 meters per second per degree centigrade and of 1.0 meters per second per degree centigrade for the lens.

Calculation of the true distances - The camera reduction (R), the screen measurement (S) and the number of microseconds of travel (U) in the respective tissues were calculated. To obtain the true depth of the anterior chamber and the thickness of the lens, the number of microseconds of travel in the respective tissues is multiplied by the velocity of the ultrasound within the tissues, i.e.,

VU = true distance within the eye.

For the axial length, the posterior chamber depth from the rear lens peak to the retinal lens peak is calculated and added to the true anterior chamber depth and the true lens thickness with 0.5 mm. being added to account for the retinal thickness (Ref. 9).

Calculation of the lens power - The lens power referred to the corneal vertex was calculated from a predetermined knowledge of the vertical ocular refraction under cycloplegia and the vertical corneal power, where

k' = dioptric equivalent of the axial length ($n = 1.3333$)

K = vertical ocular refraction (from tables, Ref. 7)

F_1 = vertical corneal power (from keratometer or tables)

F_e = total power of the eye

F_v = power of the lens at the corneal vertex

$$F_e = k' - K$$

$$F_v = F_e - F_1$$

The vertical ocular refraction is algebraically subtracted from the dioptric equivalent of the axial length taking into account the sign of the refraction (k' is always positive).

Photographic ophthalmophakometry combined with a photographic slit lamp technique was used to obtain the following data on the components of ocular refraction: the depth of the anterior chamber, the radius and power of the front and back surfaces of the lens, the equivalent power of the lens, the total power of the eye and the axial length. The method is that used by Sorsby, et al. (Ref. 7) and requires mydriasis and complete cycloplegia.

Comparison ophthalmophakometry utilizes three of the Purkinje images: the first image from the anterior surface of the cornea, and the third and fourth images from the front and back surfaces of the lens respectively. If each of these images could be duplicated by using two vertically-aligned light sources, the separation of each individual pair will be proportional to the radius of curvature of the parent surface when compared with the predetermined radius of curvature of the cornea.

In the present investigation each pair of images was photographed separately since they do not form in the same plane. The first and fourth images were photographed at 40° to the visual axis and the third image at 60° to avoid obscuration by the bright corneal images (Ref. 9). A photograph of the slit lamp section was obtained at 40° to provide data for the apparent depth of the anterior chamber and apparent lens thickness from which the true depth and true lens thickness could be calculated.

The separation of the Purkinje images and the components of the slit lamp section were measured on the film negative under a Pye two-dimensional microscope. Computation of the results from a knowledge of the cycloplegic ocular refraction, the corneal data and observations on the depths and curvatures of the lens is by conjugate foci relationships employing the paraxial equations of optics.

A. Subjects

The animals used in this study comprised of 93 available chimpanzees (53 males and 40 females) from the total population of 119 animals at the colony of the 6571st Aeromedical Research Laboratory, Holloman Air Force Base, New Mexico. The subjects were divided according to age, based on dental eruptions, and sex as shown in Table 1.

B. Procedure

On the day of the study the chimpanzees were not fed until the examination had been completed. Small animals (less than 22.5 kg.) were brought into the preparation room and strapped to a portable operating table. One drop of 1 percent cyclopentolate hydrochloride (Cyclogyl) was placed in each conjunctival sac followed by a second drop ten minutes later. Following the second drop the chimpanzees were given 1.65 mg. phencyclidine hydrochloride (Sernylan) per kilogram of body weight, intramuscularly. Twenty minutes later, a third drop of Cyclogyl was placed in each conjunctival sac. For the animals over 22.5 kg.; Sernylan was given before the first drop of Cyclogyl was placed in the sac.

TABLE II. Age and Sex Determination of the Chimpanzee

Age (years)	Number of males	Number of females	Total
2	4	2	6
3	10	7	17
4	6	3	9
5	12	8	20
6	9	7	16
7	8	4	12
8	2	2	4
9	1	2	3
10	1	2	3
11	0	1	1
13	0	1	1
15	0	1	1
Total	53	40	93

After the administration of the third drop of Cyclogyl the animals were strapped into chairs which consisted of the base and back parts of an Armed Forces medical field examination chair mounted on a hydraulic bumper jack. The head of the animal was taped to the headrest of the chair which was then rolled into the first examination room. A biomicroscopic examination with a Thorpe slit lamp was usually performed first, followed by an ophthalmoscopic examination and fundus photography with a Nikon fundus camera. The position of the animal's head and of the chair were adjusted by the examiner and an assistant to permit these examinations. Following these examinations the animal was moved to a Bausch and Lomb keratometer for determination of corneal curvature. Phakometry followed keratometry. In a few cases keratometry preceded the biomicroscopic and ophthalmoscopic examinations.

After phakometry the animal was moved to a second examination room where it was refracted in a sitting position while still in the chair. At this point the animal was removed from the chair and returned to a table in the supine position. The chimpanzee was then moved to a third examination room for a second refraction by a different refractionist and for ultrasound measurements and Schiotz tonometry. All refractions were made with Copeland streak retinoscopes and trial case lens using a procedure described in detail in Reference 10. At this point the animal was removed from the table and if small, taken to a recovery room or, if large, to his cage. Using this procedure, between 10 and 17 animals were examined each day.

IV

RESULTS

The measures of anterior chamber depth, lens thickness, and axial length as determined on 160 eyes by ultrasonography and photographic ophthalmophakometry are presented in Table II along with the differences between paired measures and the vertical ocular refraction.

TABLE II. Data on 160 Eyes Obtained by Ultrasonography and Photographic-Ophthalmophakometry

Male Chimpanzees				Anterior Chamber Depth (mm)			Lens Thickness (mm)			Axial Length (mm)		
Animal No.	Age (yrs)	Eye	Vertical ocular refraction	USG	Phakometry	Difference	USG	Phakometry	Difference	USG	Phakometry	Difference
60-234	2	OD	2.06	3.4	3.2	0.2	3.5	3.7	-0.2	20.5	20.7	-0.2
		OS	1.53	3.6	3.6	0.0	3.5	3.9	-0.4	20.6	21.3	-0.7
93-245		OD	0.50	3.0	3.1	-0.1	3.8	3.5	0.3	19.8	21.2	-1.4
		OS	1.00	3.0	2.9	0.1	4.0	4.0	0.0	19.7	20.7	-1.0
78-239		OD	0.25	3.7	3.6	0.1	3.6	3.7	0.1	20.6	22.1	-1.5
		OS	0.25	3.5	3.6	0.1	3.8	3.7	0.1	20.7	22.0	-1.3
96-255		OD	-0.93		3.9			4.3			23.6	
		OS	-0.50	3.6	3.8	-0.2	3.6	4.2	-0.6	20.8	23.1	-2.1
61-256	3	OD	1.27	3.9	3.4	0.5	3.5	3.9	-0.4	21.5	22.5	-1.0
		OS	1.27	3.9	3.5	0.4	3.5	3.4	0.1	21.6	22.1	-0.5
91-263		OD	1.27	4.3			3.5			21.4		
		OS	1.01	3.9			3.6			20.8		
87-199		OD	1.01	4.0			3.5			21.5		
		OS	1.01	3.9			3.4			21.1		
15-252		OD	0.76	3.9	3.5	0.4	3.6	3.6	0.0	20.5	21.0	-0.5
		OS	1.01	4.0			3.4			20.5		

TABLE II Continued

Male Chimpanzees				Anterior Chamber Depth (mm)			Lens Thickness (mm)			Axial Length (mm)		
No.	Age	Eye	VOR	U	P	D	U	P	D	U	P	D
50-194	3	OD	0.76	3.8	3.6	0.2	3.7	4.4	-0.7	20.7	21.2	-0.5
		OS	1.01	3.6	3.6	0.0	3.7	3.7	0.0	20.5	20.3	0.2
2-183		OD	0.25		3.7			3.5			21.3	
		OS	0.76		3.8			3.6			21.7	
11-243		OD	0.00		3.6			4.0			22.5	
		OS	0.00		3.6			3.9			23.4	
72-184		OD	0.00	4.2	3.8	0.3	3.3	3.6	-0.3	21.9	24.4	-2.5
		OS	-0.00									
16-253		OD	0.00	3.8	3.7	0.1	3.4	3.8	-0.4	21.2	21.5	-0.4
		OS	-0.25									
77-238		OD	-0.25	3.6	3.7	-0.1	3.7	3.8	-0.1	20.7	22.3	-1.6
		OS	0.25	3.5	3.6	-0.1	3.7	3.8	-0.1	20.7	21.7	-1.0
79-218	4	OD	1.27		3.6			3.2			21.0	
		OS	0.50	3.3	3.4	-0.1	3.2	3.2	0.0	19.7	21.6	-1.9
58-192		OD	1.01		3.8			3.5			21.2	
		OS	0.76	3.9	3.6	0.3	3.4	3.5	-0.1	20.7	21.5	-0.8
73-211		OD	0.50	4.3	3.7	0.6	3.4	3.8	-0.4	22.2	21.8	0.4
		OS	1.01	3.8	3.5	0.3	3.5	3.8	-0.3	21.4	20.7	0.7
1-170		OD	-0.74	4.1	3.9	0.2	3.7	3.7	0.0	22.5	22.1	0.4
		OS	-0.99		3.8			3.6			22.1	

TABLE II Continued

Male Chimpanzees				Anterior Chamber Depth (mm)			Lens Thickness (mm)			Axial Length (mm)		
No.	Age	Eye	VOR	U	P	D	U	P	D	U	P	D
51-196	4	OD	-1.25	4.7	3.3	1.4	3.7	3.8	-0.1	22.4	21.7	0.7
		OS	0.00	4.2	3.5	0.6	3.4	3.6	-0.2	21.4	22.1	-0.1
54-169		OD	-3.79	3.9	4.1	-0.2	3.5	3.6	-0.1	23.4	24.2	-0.9
		OS	-3.79	3.8	4.0	-0.2	3.6	3.4	0.2	22.9	23.3	-0.4
46-158	5	OD	1.01		3.9			3.5			21.4	
		OS	0.76	3.5	4.0	-0.5	3.5	3.8	-0.3	21.1	21.9	-0.8
9-213		OD	0.76		3.4			3.6			20.6	
		OS	0.76		3.3			3.3			20.8	
37-157	5	OD	0.25	3.5	4.1	-0.9	3.5	3.5	0.0	21.3	22.2	-0.9
		OS	0.00	3.7	4.2	0.5	3.6	3.9	-0.3	21.3	22.9	-1.6
66-251		OD	0.25	4.1			3.4			21.1		
		OS	0.00	3.9			3.4			20.6		
5-259		OD	0.00	3.8	3.5	0.3	3.6	3.9	-0.3	21.3	22.6	-1.3
		OS	0.00	3.9	3.6	0.3	3.3	4.0	-0.6	21.1	21.5	-0.4
82-168		OD	-0.25	3.8	3.8	0.0	3.4	3.8	-0.4	21.0	22.4	-1.4
		OS	-0.99	3.6	3.6	0.0	3.6	4.1	-0.5	20.8	21.6	-0.8
92-197		OD	-0.50	4.0	3.6	0.4	3.4	3.5	-0.1	21.7	23.0	-1.4
		OS	-0.25	3.8	3.6	0.2	3.3	3.5	-0.2	21.4	23.2	-1.8
17-246		OD	-0.67	3.6			3.6			22.0		
		OS	0.00	3.6			3.6			21.9		

TABLE II Continued

Male Chimpanzees				Anterior Chamber Depth (mm)			Lens Thickness (mm)			Axial Length (mm)		
No.	Age	Eye	VOR	U	P	D	U	P	D	U	P	D
42-149	5	OD	-0.99		3.4			3.5			23.7	
		OS	-0.99		3.5			3.4			23.1	
65-174		OD	-1.23	3.7			3.4			21.9		
		OS	-1.71	3.7			3.4			21.9		
47-172		OD	-1.47	3.6			3.4			21.8		
		OS	-1.47	3.9			3.4			22.3		
74-171		OD	-4.89	4.8	3.9	0.9	3.3	3.5	0.2	23.2	22.9	0.3
		OS	-4.89	3.8	3.9	-0.1	3.6	3.4	0.2	22.0	23.1	-1.1
4-209	6	OD	1.27		3.7			3.7			22.0	
		OS	2.32		3.7			3.8			22.4	
27-128		OD	0.25		3.7			4.0			22.9	
		OS	-2.65		3.5			3.8			23.9	
84-178		OD	0.00	3.6	3.5	0.1	3.9	3.4	0.5	22.9	23.6	-0.7
		OS	-0.25	4.0	3.4	0.6	3.5	3.5	0.0	22.7	23.6	-0.9
69-109		OD	0.00	3.5			3.4			21.1		
		OS	-0.50	3.4			3.4			21.1		
18-64		OD	-0.25	4.0	3.9	0.1	3.6	3.9	-0.3	21.8	21.8	0.0
		OS	-0.25									
98-250		OD	-0.99	3.2			3.6			20.7		
		OS	-0.74	3.3			3.6			21.0		

TABLE II Continued

Male Chimpanzees				Anterior Chamber Depth (mm)			Lens Thickness (mm)			Axial Length (mm)		
No.	Age	Eye	VOR	U	P	D	U	P	D	U	P	D
39-139	6	OD	-0.99	4.2	3.8	0.4	3.3	3.3	0.0	23.4	23.6	-0.2
		OS	-1.23	3.8	3.8	0.0	3.3	3.3	0.0	23.0	22.6	0.4
70-130		OD	-2.88	4.8			3.4			24.2		
		OS	-1.23	3.9			3.5			24.2		
23-105		OD	-3.79	4.1	4.0	0.1	3.6	3.2	0.4	24.1	24.5	-0.3
		OS	-3.79	4.2			3.6			24.2		
94-248	7	OD	0.00	4.2	3.7	0.5	3.5	3.8	-0.3	22.2	23.2	-1.0
		OS	-0.25									
24-82		OD	0.00	3.5			3.2			22.1		
		OS	-0.99	3.5			3.2			22.2		
8-84		OD	-0.50	4.4	4.4	0.0	4.5	4.5	0.0	22.8	22.7	0.1
		OS	-0.74									
7-110		OD	-0.99		4.1			3.5			21.4	
		OS	-1.23		3.7			4.0			22.9	
6-62		OD	-1.23									
		OS	-1.71	3.6			3.4			21.2		
22-85		OD	-1.71	3.9			3.5			21.5		
		OS	-0.99		4.2			4.0			23.4	
13-101		OD	-1.95									
		OS	-1.71	4.0	3.5	0.5	3.5	3.4	0.1	22.0	22.9	-0.9

TABLE II Continued

Male Chimpanzees				Anterior Chamber Depth (mm)			Lens Thickness (mm)			Axial Length (mm)		
No.	Age	Eye	VOR	U	P	D	U	P	D	U	P	D
26-120	7	OD	-7.19	4.6	3.9	0.7	3.4	3.8	-0.4	25.5	25.4	0.1
		OS	-7.40	4.2	4.0	0.2	3.4	3.7	-0.3	25.2	25.4	-0.2
44-129	8	OD	-0.50	4.0	3.7	0.3	3.4	3.8	-0.4	22.5	22.6	-0.1
		OS	0.00	3.5	3.8	-0.3	3.5	3.8	-0.3	21.9	21.2	0.7
95-249		OD	-0.50	3.4	3.7	-0.3	3.7	3.4	0.3	22.1	23.5	-1.4
		OS	-0.74									
21-80	9	OD	-2.42		3.3			3.7			22.4	
		OS	-1.95		3.8			3.2			22.6	
25-223	10	OD	0.50	3.7	4.0	-0.3	3.4	3.7	-0.3	21.2	21.2	-0.1
		OS	-0.74	3.8			3.2			21.4		

TABLE II Continued

Female Chimpanzees				Anterior Chamber Depth (mm)			Lens Thickness (mm)			Axial Length (mm)		
No.	Age	Eye	VOR	U	P	D	U	P	D	U	P	D
90-262	2	OD	1.79	3.7	3.2	0.5	3.7	3.4	0.3	20.3	20.9	-0.6
		OS	1.01	3.7	3.1	0.6	3.6	3.3	0.3	20.0	20.9	-0.9
88-264		OD	1.01	3.8	3.7	-0.1	3.5	3.7	-0.2	20.4	21.5	-1.4
		OS	0.25	3.5	3.4	0.1	3.5	3.7	-0.2	20.2	21.9	-1.7
55-257	3	OD	0.76	3.3	3.7	-0.4	3.8	3.9	-0.1	19.5	19.2	0.1
		OS	1.01		3.7			3.3			20.1	
56-254		OD	0.76		3.3			4.2			23.0	
		OS	0.76		3.4			4.0			23.6	
19-260		OD	0.50		3.9			3.9			23.5	
		OS	0.50	3.8	3.9	-0.1	3.7	3.9	-0.2	21.1	23.2	-2.1
52-203		OD	0.25	3.7			3.5			20.4		
		OS	0.50	3.5			3.4			20.3		
89-258		OD	0.00	3.6	3.8	-0.2	3.5	3.9	-0.4	20.5	22.2	-1.7
		OS	-0.76									
76-261		OD	-0.25	3.1			3.4			20.1		
		OS	-1.23	3.4			3.5			20.4		
53-202		OD	-0.99	3.6			3.6			22.2		
		OS	-0.99									
75-190	4	OD	1.79		3.8			4.2			20.9	
		OS	1.79		3.6			4.1			20.8	

TABLE II Continued

Female Chimpanzees				Anterior Chamber Depth (mm)			Lens Thickness (mm)			Axial Length (mm)		
No.	Age	Eye	VOR	U	P	D	U	P	D	U	P	D
85-187	4	OD	1.53	3.8	3.8	0.0	3.5	4.0	-0.5	21.4	22.5	-1.1
		OS	1.27		3.4			3.8			22.0	
59-204		OD	-0.03	3.7	3.3	0.4	3.8	3.7	0.1	20.2	20.2	0.0
		OS	0.50	3.4	3.6	-0.2	3.9	3.5	0.4	20.1	20.4	-0.3
71-217	5	OD	1.27	3.7	3.4	0.3	3.4	3.5	0.1	21.0	21.6	-0.6
		OS	0.76	3.5	3.4	0.1	3.4	3.6	0.2	20.9	21.7	-0.8
30-122		OD	1.01	3.8	3.7	0.1	3.4	3.6	-0.2	21.8	22.0	-0.2
		OS	0.50	4.0	3.7	0.3	3.4	3.6	-0.2	22.0	21.1	0.9
57-167		OD	0.76	3.9	3.5	0.4	3.4	3.3	0.1	21.1	22.7	1.6
		OS	1.27	3.4			3.4			20.8		
83-191		OD	0.76	4.3	3.7	0.6	3.4	4.8	-1.4	21.7	22.3	-0.6
		OS	2.06	3.7	3.5	0.2	3.4	4.7	-1.3	20.8	21.7	-0.9
36-155		OD	-0.50	4.1	3.8	0.3	3.3	3.4	-0.1	21.3	21.8	-0.5
		OS	-0.50	3.7	3.8	-0.1	3.5	3.5	0.0	21.6	22.4	-0.8
40-177		OD	-1.47	3.7	3.6	0.1	3.5	3.5	0.0	22.6	23.2	-0.6
		OS	-1.71		3.7			3.5			23.8	
49-148		OD	-2.42	3.5			3.4			22.6		
		OS	-2.65	4.3			3.6			23.6		
12-154		OD	-4.01		3.9			3.8			23.4	
		OS	-4.45		3.8			3.8			23.6	

TABLE II Continued

Female Chimpanzees				Anterior Chamber Depth (mm)			Lens Thickness (mm)			Axial Length (mm)		
No.	Age	Eye	VOR	U	P	D	U	P	D	U	P	D
67-208	6	OD	1.01	4.0	3.5	0.5	3.2	4.1	-0.9	21.8	22.0	-0.2
		OS	0.25	3.8	3.5	0.3	3.2	4.0	-0.8	21.4	22.2	-0.8
45-145		OD	0.76		3.2			3.9			21.6	
		OS	1.27		3.5			3.7			20.5	
68-232		OD	0.76	4.2	3.6	0.6	3.4	4.0	-0.6	20.0	21.6	-1.6
		OS	0.50	3.3	3.8	-0.5	3.4	3.8	-0.4	19.0	21.6	-2.6
86-205		OD	0.55		3.7			3.1			21.3	
		OS	-0.99	4.3	3.7	0.7	3.3	3.4	-0.1	21.3	22.4	-1.2
29-126		OD	-0.50		3.3			3.4			22.6	
		OS	-0.25		3.4			3.5			22.9	
31-116		OD	-1.47	3.9	3.7	0.2	3.5	3.5	0.0	21.2	21.7	-0.5
		OS	-1.71		3.6			3.5			21.8	
43-143		OD	-1.71	4.7	4.5	0.2	3.4	4.1	-0.7	22.9	23.4	-0.5
		OS	-1.47									
97-247	7	OD	0.00	3.4	3.3	0.1	3.7	3.5	0.2	21.1	21.2	-0.1
		OS	0.00									
32-161		OD	-0.99	3.7			3.6			22.1		
		OS	0.25									
41-136		OD	-0.99		3.7			3.6			21.5	
		OS	-0.99		3.5			3.5			21.9	

TABLE II Continued

Female Chimpanzees				Anterior Chamber Depth (mm)			Lens Thickness (mm)			Axial Length (mm)		
No.	Age	Eye	VOR	U	P	D	U	P	D	U	P	D
34-123	7	OD	-1.71	3.9			3.7			21.6		
		OS	-1.71	3.7			3.5			21.4		
63-214	8	OD	-0.50	3.9	3.7	0.2	3.3	3.9	-0.6	22.2	22.8	-0.6
		OS	0.50		3.6			3.4			21.9	
20-46		OD	-1.47	3.8	3.7	0.1	3.6	3.5	0.1	22.8	22.5	0.3
		OS	-1.95	4.0	3.7	0.3	3.5	3.5	0.0	22.7	22.8	-0.1
28-222	9	OD	-1.23	3.5			3.7			21.3		
		OS	-1.23									
33-52		OD	-2.65		3.6			3.9			22.8	
		OS	-2.18		3.6			3.7			22.3	
81-241	10	OD	0.00	4.1			3.4			21.4		
		OS	0.25	4.0			3.3			21.4		
38-240		OD	-7.79	4.2	4.2	0.0	3.0	3.0	0.0	25.5	26.1	-0.6
		OS	-9.34	4.3	4.4	-0.1	3.0	3.4	-0.4	25.4	25.3	0.1
64-162	11	OD	-8.77	3.8			3.0			23.6		
		OS	-8.77	4.2			3.0			24.2		
48-242	12	OD	-2.42	3.8			3.2			22.5		
		OS	-2.18	4.3			3.4			23.2		
80-215	15	OD	-0.74	4.1	3.8	0.3	3.5	3.6	0.1	21.5	22.3	-0.8
		OS	-0.25	4.0	3.7	0.3	3.6	3.7	-0.1	21.5	22.7	01.2

Table III presents a comparison of the results obtained on the chimpanzees with those obtained on human subjects by Leary, Sorsby, Richards and Chaston (Ref. 8). The comparisons are made in terms of correlation coefficients between comparable measures on the two groups of subjects. The chimpanzee group is somewhat younger than the human group since the youngest human is seven years of age compared with two years of age for the chimpanzees. In the human population 18 of the 140 eyes were from children aged 7 to 11 and the remainder were 25 or less except for one sugject 34 and one 47 years old. The results obtained on the younger subjects are virtually the same as those obtained on the older subjects. The sex breakdown -- males, human 59 percent, chimpanzees 57 percent and females, human 41 percent, chimpanzees 43 percent -- is virtually the same in both groups.

V

DISCUSSION

The results presented in Table II do not show as close an agreement between the measurements made by photographic ophthalmophakometry and ultrasonography on the chimpanzee eye as the agreement found on human eyes by Sorsby, Benjamin, and Sheridan (Ref. 7). This might be expected since the human subjects were able to cooperate and did so by maintaining fixation during the measurement process. While the chimpanzees were under Sernylan anesthesia, some still showed slow eye movements and occasional body movements which made it difficult to hold the eye in the proper position for photographic phakometry. A further complication arose from the necessity of having to adjust the position of the body of the animal in order to bring the eye into proper position for photography. For these reasons photographic ophthalmophakometry proved to be much more time consuming and difficult to use on the chimpanzees than on humans, and the validity of the results decrease in proportion to the increase in difficulties encountered.

TABLE III. Correlations Between Comparable Measurements Obtained with Phakometry and Ultrasonography in Humans and Chimpanzees

	Vertical ocular refraction	Anterior chamber USG[1]	Anterior chamber phak.[2]	Lens thickness USG	Lens thickness phak.	Axial length USG
Anterior chamber USG[1]	-0.20 (-0.33)[3]					
Anterior chamber phak.[2]	-0.23 (-0.31)	+0.72 (+0.45)				
Lens thickness USG	+0.08 (+0.30)	-0.35 (-0.23)				
Lens thickness phak.	+0.03 (+0.25)		-0.44 (+0.06)	+0.71 (+0.24)		
Axial length USG	-0.73 (-0.77)	+0.49 (+0.61)		-0.17 (-0.29)		
Axial length phak.	-0.76 (-0.70)				-0.17 (-0.06)	+0.97 (+0.83)

(All values 0.17 and higher for humans and 0.18 and higher for chimpanzees are significant at the 5 percent level of confidence.)

---

1 Ultrasonography
2 Phakometry
3 Chimpanzee values shown in parenthesis

On the other hand ultrasonography on chimpanzees does not require as fixed a position of the animal since only the tip of the probe need be brought in contact with the cornea. This can be done while the animal is in the supine position and strapped to a table so that gross body movements are few and movements of the head can be controlled to a great degree by holding with the hands or a chin holder. Since the probe is light and flexible, it is possible to follow movements of the eye to some extent and still obtain measures on the visual axis.

While the correlations between the paired measures of the same element such as the anterior chamber are all higher in the human subjects as would be expected if the measures are more valid and reliable, the axial length correlation between the two methods is quite high in the chimpanzee. In fact, the correlation between the vertical ocular refraction and the two measures of axial length is approximately the same as that found in the human. The largest discrepancies between the human and chimpanzee correlations occur in correlations involving the anterior chamber depth and the lens thickness. In the human subjects the lens thickness is unrelated to the vertical ocular refraction whereas it is significantly related in the chimpanzee. The relationship suggests that the hypermetropic animals have thicker lens than the myopic animals and this relationship holds with either ultrasound or phakometry.

In general, the correlations between the two types of measurements on the chimpanzees are high enough to suggest that either method can be used but that ultrasound appears to have a slight edge in validity and reliability over phakometry as far as the animal is concerned. Ultrasound has a large edge over phakometry in terms of flexibility and in terms of time required for its use. Thus it would appear that ultrasound offers the greater promise for research on the development of refractive characteristics in animals and in humans.

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13 ABSTRACT

Results obtained on 160 eyes of 53 male and 40 female chimpanzees ranging in age from 2 to 15 years, using ultrasonography and photographic ophthalmophakometry to measure anterior chamber depth, lens thickness, and axial length, are compared with the results obtained on 140 human eyes of a comparable sex grouping using the same methods. The intercorrelations between methods are not quite as high on the chimpanzees as on the humans, but the correlations between the measures of axial length and the vertical ocular refraction are virtually identical for the two groups. Either ultrasound or photographic ophthalmophakometry may be used successfully on primates and will yield results which compare favorably with those obtained on humans, but ultrasound is the method of choice since it does not require as much time to make the measurement or to calculate the result as does phakometry. Further, it does not require the rigid degree of control over the animal's behavior that phakometry requires and its flexibility allows measurement in situations in which it would be impossible to obtain phakometry measurements. Thus for both human and animal work, ultrasound is generally superior to phakometry.

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