THE UNIVERSITY OF MINNESOTA

GRADUATE SCHOOL

Report

of

Committee on Examination

This is to certify that we the undersigned, as a committee of the Graduate School, have given Ellery Leslie Armstrong final oral examination for the degree of Master of Science. We recommend that the degree of Master of Science be conferred upon the candidate.

Minneapolis, Minnesota

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THE UNIVERSITY OF MINNESOTA

GRADUATE SCHOOL

Report

of

Committee on Thesis

The undersigned, acting as a Committee of the Graduate School, have read the accompanying thesis submitted by Ellery Leslie Armstrong for the degree of Master of Science. They approve it as a thesis meeting the requirements of the Graduate School of the University of Minnesota, and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science.

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The Development of the Human Eyeball and Optic Nerve in the Fetal Period, with Particular Reference to Their Changes in Size, Form and Position.

A thesis submitted to the
Faculty of the Graduate School of the
University of Minnesota

by

Ellery Leslie Armstrong

In partial fulfillment of the requirements
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By

Ellery Leslie Armstrong

CONTENTS

Introduction.

Although the gross and microscopic anatomy of the human eye has been the subject of a very large number of investigations, the growth of this sense organ in man has received comparatively little attention. Apparently the first collection of data on the postnatal growth of the eyeball as a whole was that of Engle ('50) who published a few observations on the length of the optical axis and on the transverse and longitudinal diameters of the bulbus oculi in childhood. The most extensive study is that of Weiss ('95),('97) who measured, weighed and made determinations of the volume of the eyeball in a series of 26 individuals whose ages ranged from birth to 15 years. Weiss also examined a number of adult eyes in order to establish an adult norm for comparison with the various measurements of the eyeball in childhood. Second in importance is the investigation of Halben ('00) who determined the sagittal diameter of the organ in 38 children less than 3 years of age and in one girl of 9 years. The only other systematic investigation of changes of the mass and dimensions of the eye in the postnatal developmental period seems to be the work of Baratz ('02) who made quantitative observations on "27 cases under 1 year of age". At present his work is available in this country only in the form of very brief and incomplete summaries. There are also a number of minor studies on the growth of certain dimensions or parts of the eye in postnatal life. Of these the more complete are Becker ('83), Grod ('10) and Collins ('05) on the lens; and Smith ('89) and von Reuss ('81) on the cornea.

A number of investigators besides those mentioned above have made quantitative studies of the eye of the newborn. Among these the more important are those of Dieckmann ('96), von Hipple ('97), von Pflugk ('09), and Merkel and Orr ('92). However these studies, almost without exception, are limited to the lengths of the several diameters of the eye and its axes and to the measurements of the several internal parts. They will be considered at greater length in a later part of this paper.

Even less is known regarding the growth of the eye in prenatal life. A few individual observations have been reported by Bishoff ('63), Welcher and Brandt ('03) and Jackson ('09) regarding the weight and volume of the eyeballs in the latter part of the fetal period, but no systematic observations have been made on the subject. The only extensive series of observations on the dimensions of the eye in fetal life is that of Konigstein ('84) who measured the diameters of the eyeball and the cornea in 16 specimens ranging from 4 fetal months to 10 fetal months in age.

The above summary of the literature indicates on what a small amount of observation our knowledge of the growth of the eye in man actually rests, and the need of further data on the subject for the interpretation of the anomalies and perversions of the size and position of the eyeballs in later life. The following study was undertaken for the purpose of filling a part of this gap in our knowledge through a systematic study of the growth of the eyeball in volume and dimensions in prenatal life, and of the changes of the organ in position during this period.

Material.

The material studied consisted of a series of 66 fetuses of which 30 were males and 36 were females. These ranged in total or crown heel from 85 mm. to 501 mm. They were distributed in 5 cm. intervals of crown heel length as follows:

Table I

Distribution of material according to total (crown-heel) body length:

Range of length	Number of cases
5 to 10 cm.	3
10 to 15 cm.	9
15 to 20 cm.	6
20 to 25 cm.	14
25 to 30 cm.	5
30 to 35 cm.	6
35 to 40 cm.	7
40 to 45 cm.	8
45 to 50 cm.	7
50 cm. and over	1

These fetuses were selected from a large collection as representative specimens for study, care being taken to take individuals in which the eyeballs showed no evidences of shrinkage or distortion. Most of the material was fixed in 10 per cent. formalin. A few had been fixed in 10 per cent. formalin containing 1 per cent. chromic acid as a hardener. All specimens were preserved for a considerable period in a 10 per cent. formalin solution before dissection. The only exceptions to this mode of preservation were 3 specimens which were first fixed in Zenker's fluid and which were later preserved in 70 per cent. alcohol.

TECHNICAL METHODS AND MEASUREMENTS.

In all 22 quantitative determinations were made on each specimen, a total of some 1400 observations. These determinations may be divided into three groups, namely, dimensional determinations and volumetric determinations and measurements of position. These will be considered separately.

1. Dimensional determinations.

These measurements were made on the organ in situ with a steel verinier caliper graduated to 1 mm. by the major and to 0.1 mm. by the minor scale. All readings were made to 0.1 mm. The several measurements were as follows:

a) The transverse diameter of the eyeball was measured by taking the greatest distance between the lateral and medial external surfaces. This measurement was made on both right and left eyeballs.

b) The antero-posterior or sagittal diameter of the eyeball was taken from the vertex of the cornea to the most distant point on the posterior surface of the globus oculi. The latter corresponds approximately to the position of the macula. This measurement was made on both right and left eyeballs.

c) The superior-inferior or vertical diameter of the eyeball was taken from the most superior point on the upper surface to the most inferior point on the lower surface of the eyeball. This measurement was made on both right and left eyeballs.

d) The transverse diameter or breadth of the cornea was taken from the lateral or temporal margin of the limbus cornea to the medial (or nasal) margin in a line at right angles to the vertical axis of the eyeball. This measurement was taken for both right and left eyes.

f) The <u>vertical diameter of the cornea</u> was measured from the superior to the inferior limbus corneae in the vertical axis of the eyeball. This measurement was made on both right and left eyes.

g) The <u>length of the optic nerve</u> was measured from the middle of the juncture of the optic nerve and the eyeball to the medial point on the anterior margin of the optic chiasma. This measurement was made on both right and left optic nerves.

h) The <u>diameter of the optic nerve</u> was measured from the lateral to the medial surface of the nerve just posterior to its entrance into the eyeball. This measurement was made for both right and left nerves.

2. Volumetric determinations.

The eyeball was first dissected from all muscle attachments, fatty tissue, etc., and the optic nerve was detached at its connection with the bulbus. The bulbus was then immersed in water, and then removed and dried on a gauze pad for about 10 seconds in each instance. The volume was then determined with the Jones apparatus, readings being taken to 0.01 cc. The volumes of both eyes were determined.

3. Determinations of position.

A number of measurements were made to determine the position of the eyeballs and optic nerves in relation to each other, to the optic chiasma and to the median sagittal plane of the head for the purpose of following the changes in position of the eyeballs during the fetal period. The several measurements taken are as follows:

a) The angle of the optic nerves was measured as the angle formed by two lines arising from the central point of the junction of the optic nerve with the posterior surface of the eyeball and meeting in the medial line of the head on the anterior margin of the optic chiasma.

b) The lateral distance of the eyeballs is a measurement taken between the two most distant points on the lateral (or temporal) surfaces of the right and left eyeballs in a line at right angles to the median plane of the head and in the transverse plane of the head.

c) The medial distance of the eyeballs is a measurement of the shortest distance between the medial (or nasal) surfaces of the eyeballs taken at right angles to the median plane of the head and in the transverse plane.

d) The medial distance of the optic nerves is a measurement of the distance between the medial (nasal) margins of the right and left optic nerves at the points of their entrance into the sclera.

e) The lateral distance of the optic nerves is the distance from the lateral margin of the optic nerve from a line projected posteriorly and parallel to the optic nerve from the most lateral point of the lateral or temporal surface of the eyeball.

METHODS OF TREATMENT OF DATA.

All measurements were made before any attempt was made to analyze the data. The measurements were then grouped by 5 cm. intervals of crown-heel or total body length and the averages of each dimension determined for these intervals. Where measurements were taken on the right and left sides of the same specimen, these two values were averaged before combined in the totals from which the final averages were determined. The results of these preliminary calculations were arranged in tabular form and constitute tables 2 to 14 inclusive of the present paper.

The data were also examined by some of the simpler methods of graphic analysis. A field graph was made of the measurements of each value, the value in question being used as the ordinate and the crown heel length of the body as the abscissa. These graphs form figures 1 to 12 inclusive of this paper. The average value for each 5 cm. interval of crown-heel or total body length were then indicated on these graphs by special symbols, their exact position in relation to the abscissae being determined by weighting for the average crown-heel length for the specimens in the interval. Curves representing the growth of each dimension were then established on the field graphs by inspection and by the use of the "three point rule". The conclusions regarding the general character of the growth of the general dimensions recorded in this paper are based upon the examination of the curves established in this manner, and the various statements regarding the ages of specimens are based upon these curves as translated into time in fetal months according to Mall's tables.

Observations.

1. The growth of the eyeball.

The growth of the eyeball may be traced by following the increase in its volume and the changes in the dimensions of its major axes (transverse, antero posterior or sagittal, and superio-inferior or vertical). The growth of the cornea is represented in part by the increase in the transverse or horizontal and superio-inferior vertical diameters of this structure. The values obtained for these various measures of growth are shown in tables 2 to 7 inclusive and graphically in figures 1 to 6 inclusive.

a) The growth of the eyeball in volume. The growth of the eyeballs in volume in fetal life is similar in its general character to the growth in volume of other organs and parts of the body in this period. It is characterized by a slow absolute increase from 5 to about 30 cm. of crown-heel length and a much more rapid increase thereafter. The volume of the eyeball at 10 cm. C H is approximately 0.13 cc. at 25 cm. C H approximately 0.8 cc., at 40 cm. C H approximately 2.0 cc., and at 50 cm. C H or birth it is 3.2 cc. Reduced to time in fetal months, according to Mall's convention, the volume of the eyeball at 3 fetal months is 0.12 cc., at 6 fetal months approximately 1.2 cc., and at birth (10 full fetal months or 51.5 cm. C H) about 3.4 cc. Thus the eyeball has acquired about one-thirtieth of its natal volume or a little more than 1 per cent. of its final adult volume at the close of the third fetal month, while by the close of the sixth fetal month the eyeball has about one-third of its average volume at birth or nearly one-tenth of its final volume. The values for the volume of the eye of the newborn as determined for the newborn in this study (3.2 cc. for the fetus of 50 cm. C H or 3.4 cc. for 10 full fetal months) are distinctly higher than those given by Weiss ('97) whose average for 14 newborn children was 2.185 cm. The reason for this difference is obvious if one examines the data regarding the body weight and length of the specimens in these two series of cases for the average weight of Weiss' specimens was but 2290 grams, the maximum being 2400 grams and the minimum 1900 grams. These weights indicate a body length of approximately 45 cm., which is the body length of fetuses of about 9 fetal months, and the specimens which Weiss considered as newborn cannot be properly regarded as representing full term children. Weiss found that the volume of the eyeball at three months after birth (in specimens of 3490 and 3480 grams body weight respectively) was 3.35 cc. These figures for children having about the average weight of the child at birth in this region are quite similar to the volume of the eye at birth in the material described in this study. It should be noted in this connection, however, that the eyeballs probably continue to increase in weight (or volume) after birth, even if the body weight as a whole does not increase so that the figures which are quoted here are not entirely comparable. If the figures for the volume of the eye at 50 cm. of total body length, as here determined, are accepted as the average for the newborn and Weiss' figure of 7.18 cc. be used as the adult norm, then the increase in the volume of the eyeball between birth and maturity is approximately 4 grams or about 125 per cent. These figures are considerably lower than those generally quoted for the postnatal growth of the eyeball because Weiss' figures on premature infants which are quoted above have been always used as the norm for the newborn.

The curve formed by the volume of the eyeball when plotted against body length (figure 1) is a typical curve of the growth in volume or weight of any fetal organ or part. It is, however, somewhat shallower than the majority of curves of this type and resembles closely the curves of the volume of the spinal cord, the mid brain and the medulla for this period (as determined by Dunn ('21) using methods similar to those employed in this study). This is a quite different relation than the one found in postnatal life when the eyeballs appear to grow more like the cerebrum than like the brain stem or the spinal cord.

b) The growth of the diameters of the eyeball. The growth of the diameters of the eyeball are shown in tables 3, 4, and 5, and graphically in figures 2, 3, 4, and 5. An examination of these figures and graphs shows that the general tendency of growth of all of these dimensions is much the same. This is shown particularly well by figure 5 in which the curves have been superimposed. All of these curves indicate that the growth of the diameters of the eye is distinctly more rapid between 3 and 5 fetal months than between five fetal months and birth, the curves formed from the averages for the 5 cm. intervals of body length being of the type known as logarithmic.

The antero-posterior or sagittal diameter of the eye is approximately 5 mm. at 10 cm. C H, 12 mm. at 30 cm. C H, and 17 mm. at 50 cm. C.H. Translated into time in fetal months it is 5 mm. at 3 months, 11 mm. at 5 months, and 17 mm. at birth. Thus about one-fifth of the final or adult dimension of this diameter is obtained by the close of the third fetal month, one-half of the adult diameter by the close of the sixth fetal month, and over two-thirds by birth. The dimensions which were found for the newborn are almost identical with those observed by Weiss ('97), Konigstein ('84), Halben ('00), and Merkel and Orr ('02). This finding is particularly interesting because, while these observations were made on preserved material, the observations of Halben, Konigstein and Weiss were made on fresh specimens. The close correspondence in these various sets of data indicates that fixation has but little effect on the dimensions of the eye in situ and that the results obtained from the examination of preserved material may be translated into terms of the fresh material without serious error.

The growth of the superio-inferior or vertical diameter of the eyeball is very similar to that of the sagittal or antero-posterior diameter and a detailed description of the findings regarding it is hardly necessary except to state that the vertical diameter of the eyeball in fetal life is generally about 0.4 mm. less than the sagittal.

The vertical diameter of the eyeball in the newborn as established by this set of observations is approximately 16.5 mm. (as determined by graphic exterpellation from the curve shown in figure 3). This measurement is somewhat smaller than the sagittal diameter. Weiss found the vertical diameter to have an average of 15.4 in the newborn and 16.0 in a child of 20 days. Following the figures of this author for the average vertical diameter in the adult the gain in this dimension in postnatal life is approximately 50 per cent.

The growth of the transverse diameter of the bulbus oculi is apparently slightly different from that of the vertical and sagittal diameters as it increases somewhat more proportionately during the fetal period (figure 4). At 10 cm. C H the average transverse diameter is 0.44 mm., at 30 cm. C H it is 11.6, and at 50 cm. C H it is approximately 17 mm. Thus this diameter at three months is somewhat less than either the vertical or the sagittal diameters and at birth it is slightly greater than the vertical diameter and is almost equal to the antero-posterior or sagittal. The relation of the transverse diameter of the eyeball to the sagittal diameter at birth has been the matter of considerable discussion. Weiss found it to be slightly less than the sagittal diameter (16.0 mm. as compared to 16.4 mm.), while Merkel and Orr ('92) and von Pflugk ('09) found it slightly greater. Using Weiss' data on the length of this dimension in the adult this dimension increases slightly less than 50 per cent. in postnatal life.

2. The growth of the cornea.

The growth of the cornea is illustrated by tables 6, and 7, and by figures 6 and 7.

a) The vertical diameter. The vertical diameter of the cornea at the end of the third fetal month, as determined by graphic interpellation, is 0.27 mm., at six fetal months is 0.6 mm., and at birth (50 cm. C H) is 0.9 mm. While individual measurements of the corneal height show some variation the general tendency of growth in the fetal period is very constant and regular. When plotted with vertical corneal diameter as the ordinate and body length as the abscissae the measures of central tendency are arranged in practically a straight line indicating that the rate of relative growth of the cornea is established by the close of the third months of prenatal life and remains constant throughout the remainder of the period. Since according to the observations of Priestley Smith ('89) the vertical diameter of the cornea is about 10.5 mm., the entire postnatal increase in this dimension is only about 1.5 mm. or approximately 17 per cent. In other words the entire postnatal growth in the vertical diameter of the cornea is only equal to the prenatal growth of the structure in the last two months of fetal life.

b) The breadth or transverse diameter. The general character of the growth of the cornea in breadth is similar to that of the growth in the vertical axis. Like the growth in height, the rate of growth of the breadth of the cornea is established by the close of the third fetal month and thereafter remains constant. However the rate of growth of the corneal breadth is slightly faster than that of corneal height. This difference in the rates of growth of these two dimensions is reflected in the form of the cornea at different times in fetal life. At the end of the third fetal month the outline of the base of the cornea is practically circular and the vertical and transverse diameters of this base practically equal; but after this time it becomes increasingly elliptical and at birth the transverse diameter is 9.7 mm. or about 8 per cent. greater than the vertical diameter.

The average transverse or horizontal diameter of the cornea in the adult is about 11.6 mm. (Merkel and Orr '92, Priestly Smith '89). Therefore the increase in this dimension during postnatal life is about 2 mm. or approximately 20 to 25 per cent. The observations of Konigstein ('84) and others show that the greater part of this increase takes place in the first year or two after birth.

The dimensions of the cornea as determined by the observations recorded here are in fair agreement with those of other investigators lying midway between those of von Reuss ('81) and those of Konigstein ('84).

3. The growth of the optic nerve.

Figures 8 and 9, and tables 8 and 9 illustrate the growth in length and thickness of the optic nerve in the fetal period.

a) The growth in length. The growth in length of the nervus opticus bears a simple constant relation to the growth of the body in length. Starting at 4 mm. at the close of the third fetal month (10 cm. C H) the structure grows at a constant rate as compared to the growth of the body and reaches a length of 9.2 mm. at 20 cm. C H, 14.2 mm. at 30 cm. C H, 19.4 mm. at 40 cm. C H, and 24.4 mm. at 50 cm. C H. Thus the structure has reached approximately one-sixth of its natal length at 3 fetal months, about two-fifths of its natal length at 6 fetal months and nearly nine-tenths of its natal length at 8 months.

According to Vierordt ('06) the average length of the optic nerve in the adult is about 33.5 mm. The nerve therefore increases about one-third in length between birth and maturity.

b) The growth in diameter. The growth of the optic nerve in diameter follows the same general course as its growth in length. Like the growth in length the data on the diameter of the nerve in fetal life when plotted against the body length forms a straight line. At 10 cm. C H the average diameter, as determined by graphic interpellation, is approximately 1 mm., at 20 cm. C H it is 1.44 mm., at 30 cm. C H it is 1.88 mm., at 40 cm. C H it is 2.32 mm., and at 50 cm. C H or birth it is 2.76 mm.

Findings on the diameter of the optic nerve in the adult are somewhat variable. The average of all figures available being about 12 mm. Therefore the increase in the diameter of the nerve between birth and maturity is over 4 fold.

It will be seen that there is a great difference in the relative growth of the optic nerve in length and diameter during prenatal and postnatal life. Between the end of the third and the end of the tenth fetal month the nerve increases about 6 times in length, but less than 3 times in thickness. Between birth and maturity, however, the nerve increases only one-third in length and about 4 fold in thickness. This change in the character of the growth of the optic nerve is probably due to the medullation of the fibers of the optic nerve during postnatal life. According to Bakitjko (quoted by Gundobin '08) the definite medullary sheaths of the optic nerve fibers first appear about the time of birth and at the end of the first year are completely established. This is supported by the observations of Baratz ('02) who found that the diameter of the optic nerve at the end of the first year was practically as great as in the adult.

4. Changes in the position of the eyeballs during the fetal period.

The fact that during development the eyeballs and the optic axes undergo marked changes in position and in their relation to the axes and planes of the head is well known. In embryos of the early part of the second month the eyes project from the lateral surfaces of the head while by the middle of the third month they face forward and appear externally to be parallel to one another. These changes are also reflected in modifications of the angle formed by the posterior ends of the optic nerves at the chiasma. In embryos of the latter part of the first and early part of the second month the optic stalks, which represent the optic nerves at this time, lie in line with one another almost exactly in the frontal plane of the body or may even project a little posteriorly from this plane. In the later fetal and in postnatal life, on the other hand, they form a more or less acute angle with one another. Apparently no effort has been made to determine quantitatively the time, rate or nature of this shift in the axes of the eyes although the process is often referred to in connection with discussions of the causes of strabismus.

Figure 10 and table 10 show some measurements of the changes of this relation of the optic nerves in the fetal period. In the last part of the third fetal month the angle formed by the optic nerves at the chiasma averages 102 degrees. During the middle part of fetal life the angle drops rather rapidly, being about 95 degrees at 4 months and about 88 at 5 months. This decline continues during the sixth and seventh months and at the end of the eighth month the average angle of divergence is about 75 degrees. This angle remains fairly constant, on the average, during the remainder of the fetal period, the average angle at birth, as determined by graphic interpellation from the curve in table 10 being about 76 degrees. The angle formed by the optic nerves at the chiasma in the adult usually ranges from 66 to 70 degrees, the average being about 68 degrees.

It is evident that the convergence of the optic nerves is a continuous process extending from the latter part of the first month of prenatal life until some time after birth. Three periods can be distinguished in this process as follows: 1) A period of extremely rapid convergence from the end of the first fetal month to the end of the third fetal month during which the angle decreases from about 180 degrees to about 100 degrees. 2) A period of continued but less rapid convergence extending from 3 fetal months to 8 fetal months during which the angle declines about 25 degrees (from about 100 degrees to about 75 or 76 degrees). 3) A terminal period of very slow convergence beginning about the ninth fetal month and continuing until some time after birth. During this last period there is a reduction of the angle of not more than 10 degrees. It may be stated that these conclusions are based on the averages of a number of cases and while the average change in any given period seems to be quite regular, there is considerable variation in the angle in individual specimens of the same age even in fetal life.

It has been generally assumed that the normal convergence of the eyeballs during the developmental period is dependent on the growth changes of the bony orbit. The observations just cited do not support this view. The most rapid and extensive changes in the angle of the optic nerve occur in the second and third fetal months. The ossification of the bones of the orbit does not begin until about the middle of this period and is still incomplete at the end of it. It is evident then that over two-thirds of the convergence of the optic nerves and eyeballs takes place before there is really any definite bony orbit present. And the greater part of the remaining convergence takes place in the middle part of the prenatal life while the bones are still delicate and plastic and are partly formed in cartilage only. It is probable that the convergence of the eyeballs depends on factors which are much more complicated than the simple mechanical pressure of the bony walls of the orbit. From what we know of the growth of other bony cavities and particularly of the growth of the cranial cavity it is much more probable that the form and position of the bony orbit is determined by the form and position of the eyeball than that the position of the eyeball is determined by the changes in the orbit.

The changes in the position of the eyes does not depend entirely on the changes in the position of the optic nerve, but also on the changes in the form of the eyeball particularly in relation to the optic nerve. Some of these changes in the position of the eyeballs are shown in tables 11 and 12 and in figures 11 and 12. Table 11 and figure 11 illustrate the changes in the distance between the lateral surfaces of the eyeballs in fetal life. These show that the lateral distance of the eyeballs increases rapidly up to the end of the fifth fetal month and then slightly more slowly until birth. The distance between the medial surfaces of the eyeball also show a period of more rapid increase in the first part of the fetal life than in the latter half, but the rate of increase in this distance is much slower than the rate of increase in the distance between the lateral surfaces of the eyeballs (figure 12). The explanation of this apparent discrepancy in growth probably lies in the difference in the growth of part of the eyeball lying medial (or nasal) to the optic nerve and the portion lying lateral (or temporal) to the nerve. These differences are shown in tables 13 and 14 and figures 13 and 14. During the period between 3 and 6 fetal months the distances between the entrance of the optic nerve and the lateral and medial surfaces of the eye grow at approximately the same rate, the absolute increase for the medial distance being 1.4 mm. and that for the lateral distance being 1.7 mm. But after the fifth month the lateral distance increases much more rapidly than the medial distance. Between the 5 fetal months and birth the distance between the optic nerve and the lateral surface of the eyeball increases about 7 mm. or about 200 per cent. while in the same period the distance between the optic nerve and the medial surface of the eyeball increases about 1.2 mm. or approximately 85 per cent. Thus the growth of the eyeball in the latter half of fetal life is characterized by a great increase in the temporal portion as compared with the nasal portion. It has long been known that the posterio-temporal segment of the eye of the newborn is relatively larger than in later life. This has been explained as due to a partial rotation of the eyeball on its axis and the readjustment of its parts along with this process of convergence. It has been argued that a part of the convergence of the eye is in the eyeball itself through growth of the nasal portion and the large size of the temporal portion of the eyeball in the newborn has been pointed out as evidence of a stage in this process. But the material here presented indicates that the expansion of the temporal segment of the eyeball in fetal life is a secondary process which takes place after the greater part of the convergence of the eyes has been accomplished.

CONCLUSIONS.

The results of this study may be summarized as follows:

a) <u>The growth of the eyeball.</u>

The growth of the eyeball in the fetal period follows the general course of growth of the other organs and parts of the body during this period, being characterized by a slow rate of absolute increase in the first part of the period and a rapid rate of increase in the latter part. The growth of the eyeballs in volume in fetal life resembles more closely the growth of the spinal cord and the brain stem than that of any other part of the body.

The volume of the eyeball at birth is approximately 3.2 cc. and the organ increases about 135 per cent. in postnatal life. The figures generally quoted for the volume of the eyeballs at birth are distinctly too low, due to the inclusion of premature children. Consequently previous conclusions regarding the amount of growth of these structures in childhood are distinctly too high.

The general course of the growth of the major axes of the eyeball in prenatal life is the same. It is characterized by a fairly rapid growth up to the sixth fetal month and a slower growth thereafter. This type of growth is also characteristic of the dimensions of the brain stem and spinal cord whose growth in volume is comparable with that of the eyeballs. The transverse diameter of the eye grows a little more rapidly in prenatal life than does the sagittal or the vertical diameter.

The growth of the cornea differs distinctly from the growth of the remainder of the eye in fetal life. The rate of growth of its diameters bears a direct ratio to the rate of growth of the body as a whole from the third month to birth. In other words, the cornea grows like the other external dimensions of the body rather than like the other parts of the eye.

The growth of the vertical and transverse diameters of cornea show the same general characteristics but the transverse diameter grows more rapidly than the vertical during the middle and latter part of the fetal period. Consequently the outline of the base of the cornea, which is circular in the early part of the fetal period, becomes elliptical by the time of birth.

b) The growth of the optic nerve.

The growth of the optic nerve in length and thickness in the fetal period is directly proportional to the lineal growth of the body as a whole. The length of the nerve increases 6 fold between the third fetal month and birth while the thickness of the nerve increases nearly 3 fold in the same period. After birth the nerve increases comparatively little in length (about 35 per cent.) but grows about 400 per cent. in thickness. The differences in the rates of growth of the nerve in length and thickness in prenatal and postnatal life can be explained on the time of medullation of the optic fibers.

c) The changes in position of the optic nerves and eyeballs.

During fetal, and probably early postnatal life, the eyeballs undergo great changes in position. Three epochs can be recognized in these changes. In the first period, from the end of the first to the end of the third fetal month, the eyeballs converge toward one another through an angle of 80 degrees. In the middle period, from the end of the third to the end of the eighth fetal month, the convergence is continued at a slower rate and the angle of the optic nerves is reduced by 25 degrees. In the third period, extending from the eighth fetal month to an unknown time in childhood, the angle is very slowly reduced; the entire reduction in this epoch being not over 10 degrees.

During the last half of fetal life the temporal or lateral segment of the eyeball grows more rapidly than the medial or nasal segment.

The data here presented indicate that the changes in the axes of the eyeballs and optic nerve are not dependent primarily on the changes in the bony orbit. Most of the convergence of these structures takes place before the ossification of the orbit is well under way and even before this cavity is completely outlined in bone or cartilage.

The process of the convergence of the eyeballs seems to be quite variable in individual cases and it is possible that certain cases of strabismus may be explained on the basis of this variation. Thus an arrested convergence might account for a divergent strabismus and an excessive convergence might account for a convergent strabismus.

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10-20 5M

TABLE NO. 2

VOLUME OF THE EYEBALLS (AVERAGE OF RIGHT AND LEFT)
Volume (cc).

	Av. Body Length	Max.	Min.	Av.	No. of Cases.
5-10	8.5	.2	.1	.17	2
10-15	13.5	.3	.1	.21	5
15-20	17.4	.4	.3	.36	5
20-25	22.3	.8	.3	.65	13
25-30	27.2	1.1	.7	.89	5
30-35	32.2	1.6	1.0	1.27	6
35-40	37.6	1.8	1.5	1.69	6
40-45	41.9	2.5	1.8	2.0	8
45-50	47.6	3.3	1.5	2.87	7
50-55	50.1	3.4	3.4	3.4	1

TABLE NO. 3

ANTERO-POSTERIOR DIAMETER OF THE EYEBALL.

Total body length (cm.)		Antero-posterior Diameter of the Eyeball (mm)			Number of
Range	Mean	Max.	Min.	Mean	Cases
5 to 10	8.5	6.	4	4.7	3
10 to 15	13.5	6.8	5	5.9	6
15 to 20	17.4	8	6.9	7.5	5
20 to 25	22.3	11.6	7.5	9.1	14
25 to 30	27.2	12.	10.9	11.3	5
30 to 35	32.2	13.4	11.6	12.7	6
35 to 40	37.6	15	12	13.8	2
40 t0 45	41.9	16.4	13.9	15.4	8
45 to 50	47.6	18.0	11.0	16.3	8
50 to 55	50.1	18.	18.	18.	1

TABLE NO. 4

SUPERIOR-INFERIOR DIAMETER OF THE EYEBALL

Total body length (cm.)		Superior-inferior Diameter of the Eyeball (mm).			Number of
Range	Mean	Max.	Min.	Mean	Cases
5 to 10	8.5	5.9	3.9	4.6	3
10 to 15	13.5	6.6	4.6	5.55	6
15 to 20	17.4	7.7	6.5	7.1	5
20 to 25	22.3	10.2	7.2	8.76	14
25 to 30	27.2	11.8	10.3	10.9	5
30 to 35	32.2	13.0	10.5	12.05	6
35 to 40	37.6	14.0	11.9	13.2	7
40 to 45	41.9	15.8	13.7	14.6	8
45 to 50	47.6	17.4	10.6	15.1	8
50 to 55	50.1	17.4	17.4	17.4	1

TABLE NO. 5

TRANSVERSE DIAMETER OF THE EYEBALL.
(63 cases).

Total body length (cm.)		Transverse Diameter of Eyeball (mm).			Number Of
Range	Mean	Max.	Min.	Mean	Cases.
5 to 10	8.5	5.6	4.0	4.4	3
10 to 15	13.5	6.1	4.8	5.6	6
15 to 20	17.4	7.6	7.0	7.2	5
20 to 25	22.3	11.3	7.4	8.8	14
25 to 30	27.2	11.7	10.2	10.9	5
30 to 35	32.2	13.1	11.4	12.2	6
35 to 40	37/6	13.9	11.8	13.3	7
40 to 45	41.9	16.0	13.5	14.8	8
45 to 50	47.6	17.7	10.9	15.6	8
50 to 55	50.1	17.6	17.6	17.6	1

TABLE NO. 6

HEIGHT OF THE CORNEA.
(63 cases).

Total body length (cm.)		Height of the cornea of Eyeball (mm).			Number of
Range	Mean	Max.	Min.	Mean	Cases
5 to 10	8.5	2.8	2.2	2.5	3
10 to 15	13.5	3.6	2.5	2.9	8
15 to 20	17.4	4.2	3.6	3.8	6
20 to 25	22.3	5.2	3.8	4.6	14
25 to 30	27.2	5.8	5.3	5.5	5
30 to 35	32.2	6.2	5.7	5.98	6
35 to 40	37.6	7.9	6	6.9	7
40 to 45	41.9	8.8	6.5	7.7	8
45 to 50	47.6	9.1	8.0	8.5	8
50 to 55	50.1	9.5	9.5	9.5	1

10-20 5M

TABLE NO. 7

BREADTH OF THE CORNEA.
(63 cases)

Total body length (cm.)		Breadth of the cornea (mm).			Number of
Range	Mean	Max	Min.	Mean	Cases
5 to 10	8.5	2.9	2.5	2.7	3
10 to 15	13.5	3.7	2.8	3.1	8
15 to 20	17.4	4.4	3.6	3.9	6
20 to 25	22.3	5.9	4.1	4.9	14
25 to 30	27.2	6.4	5.5	6	5
30 to 35	32.2	6.8	6	6.6	6
35 to 40	37.6	8.5	6.3	7.2	7
40 to 45	41.9	10.4	7.4	8.3	8
45 to 50	47.6	9.7	8.7	9.2	8
50 to 55	50.1	10	10	10	1

TABLE NO. 8

LENGTH OF THE OPTIC NERVE.

Total body length (cm).		Length of the Optic nerve (mm)			Number of Cases
Range	Mean	Max.	Minn.	Mean	
5-10	8.5	6.	2.4	4.0	3
10-15	13.5	6.3	4.2	5.4	6
15-20	17.4	9.6	6.7	7.8	5
20-25	22.3	13.1	9.4	10.9	14
25-30	27.2	15.6	13.4	14.6	5
30-35	32.2	20.3	15.8	17.3	6
35-40	37.6	20.3	15.4	17.5	7
40-45	41.9	22.4	17.3	20.0	8
45-50	47.6	25.9	13.4	22.4	8
50-55	50.1	23.8	23.8	23.8	1

TABLE NO.9

DIAMETER OF THE OPTIC NERVE.

Total body length (cm.)		Diameter of the Optic Nerve (mm).			Number of
Range	Mean	Max....	Min.	Mean	Cases
5 to 10	8.5	1.2	.8	.9	3
10 to 15	13.5	1.6	.8	1.16	6
15 to 20	17.4	1.8	1.4	1.66	5
20 to 25	22.3	1.6	1.2	1.6	14
25 to 30	27.2	2.	1.6	1.8	5
30 to 35	32.2	2.1	1.7	1.9	6
35 to 40	37.6	2.3	1.7	2.0	2
40 to 45	41.9	2.8	2.1	2.4	8
45 to 50	47.6	3.0	2.0	2.6	8
50 to 55	50.1	2.7	2.7	2.7	1

TABLE NO.10

ANGLE FORMED BY THE OPTIC NERVES.

Total body length (cm.)		Angle formed by the optic nerve			Number of
Range	Mean	Max	Min.	Mean	Cases
5 to 10	8.5	110	90	102	3
10 to 15	13.5	109	92	99	9
15 to 20	17.4	100	94	96	6
20 to 25	22.3	97	82	91	14
25 to 30	27.2	96	80	86	5
30 to 35	32.2	82	72	77	6
35 to 40	37.6	90	73	80	2
40 to 45	41.9	83	72	76	8
45 to 50	47.6	90	72	78	8
50 to 55	50.1	76	76	76	1

TABLE NO.11

DISTANCE BETWEEN THE LATERAL SURFACES OF THE EYEBALL.

Total body length (cm)		Distance between the lateral surfaces of the eyeball			Number of
Range:	Mean	Max.	Min.	Mean	Cases
5-10	8.5	20.	10.5	14,3	3
10-15	13.5	20.3	15.5	17.3	7
15-20	17.4	25.	22.5	22.1	5
20-25	22.3	35.5	22.9	28.	14
25-30	27.2	43.	31.9	35.9	5
30-35	32.2	42.7	37.2	39.3	6
35-40	37.6	45.8	38.	42.	7
40-45	41.9	50.0	43.0	46.3	8
45-50	47.6	56.0	33.6	49.9	8
50-55	50.1	54.	54.	54.0	1

TABLE NO. 12

DISTANCE BETWEEN THE MEDIAL SURFACES OF THE EYEBALL.

Total body length (cm.)		Distance, medial, Eyeball (mm).			Number of
Range	Mean	Max.	Min.	Mean	Cases
5 to 10	8.5	8.	3.5	5.3	3
10 to 15	13.5	7.8	5.8	6.3	6
15 to 20	17.4	10.	7.3	8.4	5
20 to 25	22.3	13.	8.7	10.6	14
25 to 30	27.2	15.	11.3	12.7	5
30 to 35	32.2	16.	13.	15.0	6
35 to 40	37.6	19.5	12.7	16.5	7
40 to 45	41.9	20.5	16.0	17.8	8
45 to 50	47.6	23.5	13.5	19.5	8
50 to 55	50.1	20.	20.	20.	1

TABLE NO. 13.

DISTANCE OF THE ENTRANCE OF THE OPTIC NERVE FROM THE GREATEST CIRCUMFERENCE OF THE EYE-BALL.

Total body Length (cm.)		Distance of the entrance of the optic nerve from the greatest circum. of the Eyeball (mm).			Number of Cases
Range	Mean	Max.	Min.	Mean	
5 to 10	8.5	1.7	.8	1.3	3
10 to 15	13.5	3.	1	1.9	6
15 to 20	17.4	3.	2	2.5	5
20 to 25	27.3	4.5	2.1	3.0	14
25 to 30	27.2	4.2	3.3	3.8	5
30 to 35	32.2	5.2	4.2	5.0	6
35 to 40	37.6	5.5	4.3	5.1	7
40 to 45	41.9	7.0	4.9	5.7	8
45 to 50	47.6	7.9	4.3	6.6	8
50 to 55	50.1	5.5	5.5	5.5	1

TABLE NO. 14.

DISTANCE BETWEEN OPTIC NERVES AT ENTRANCE INTO EYEBALL.

Total body length (cm.)		Distance between optic nerves at entrance into Eyeball.			Number of
Range	Mean	Max.	Min.	Mean	Cases
5 to 10	8.5	9.4	3.8	5.9	3
10 to 15	13.5	8.9	6.7	7.6	7
15 to 20	17.4	11.	7.9	9.7	5
20 to 25	22.3	17.4	11.9	13.7	14
25 to 30	27.2	18.1	15.4	16.5	5
30 to 35	32.2	20.5	17.5	18.7	6
35 to 40	37.6	22.9	18.8	20.7	7
40 to 45	41.9	25.7	19.2	21.6	8
45 to 50	47.6	28.5	16.4	24.4	8
50 to 55	50.1	24.6	24.6	24.6	1

Figure 1.

A field graph and curve illustrating the growth in volume of the eyeball in fetal life. Individual cases indicated by dots. Abscissae: total body length in cm. Ordinates: volume of eyeball in cc.

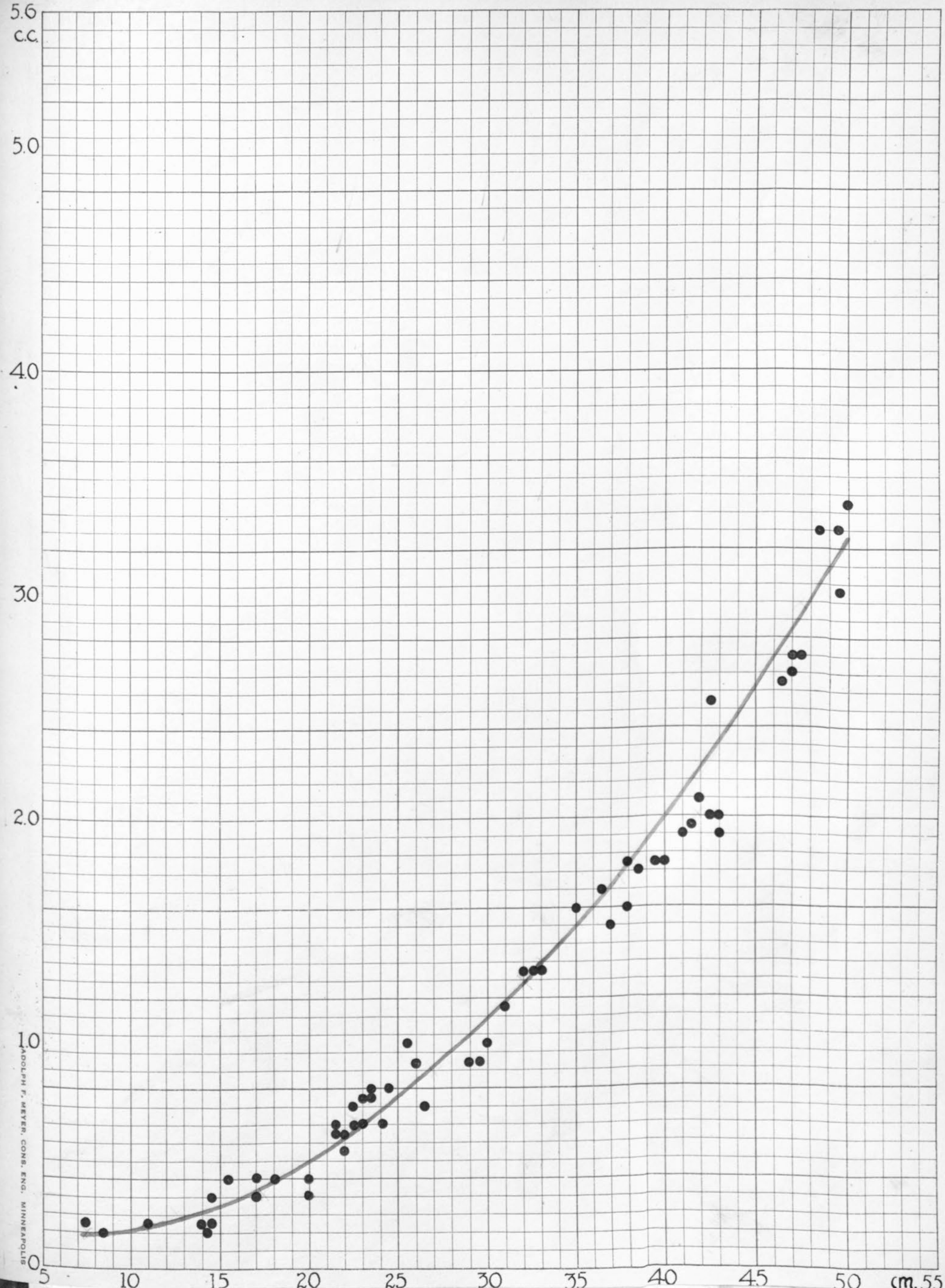

5.6
c.c.
5.0
4.0
3.0
2.0
1.0
0
5
10
15
20
25
30
35
40
45
50
cm. 55
ADOLPH F. MEYER, CONS. ENG. MINNEAPOLIS

Figure 2.

A field graph and curve illustrating the growth of the antero-posterior diameter (sagittal) of the eyeball in fetal life. Individual cases indicated by dots. Abscissae: total body length in cm. Ordinates: antero-posterior diameter of eyeball in mm.

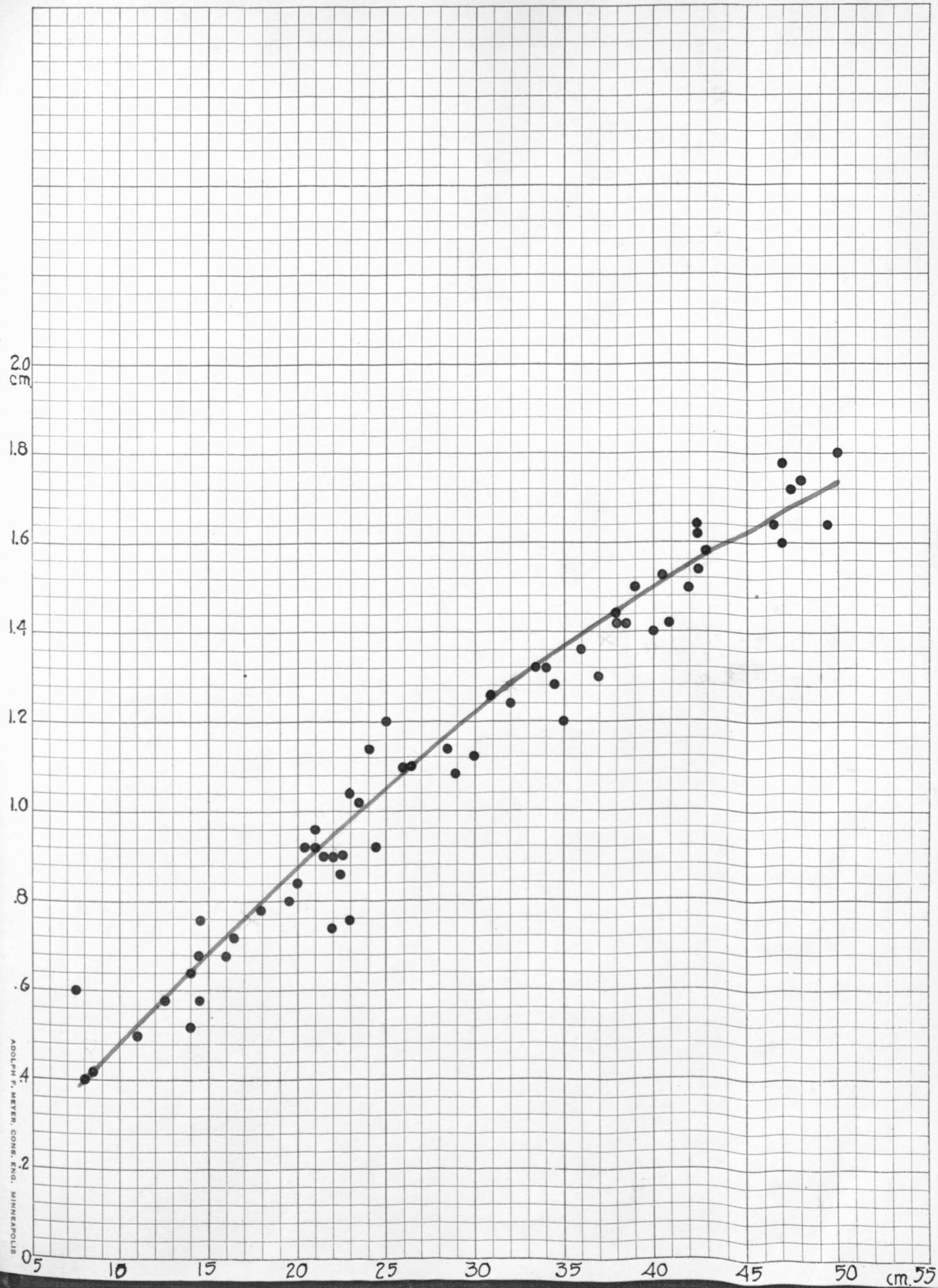

2.0
cm.
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
5
10
15
20
25
30
35
40
45
50
cm. 55
ADOLPH F. MEYER, CONS. ENG. MINNEAPOLIS

Figure 3.

A field graph and curve illustrating the growth of the superio-inferior (vertical) diameter of the eyeball in fetal life. Individual cases indicated by dots. Abscissae: total body length in cm. Ordinates: superio-inferior diameter of eyeball in mm.

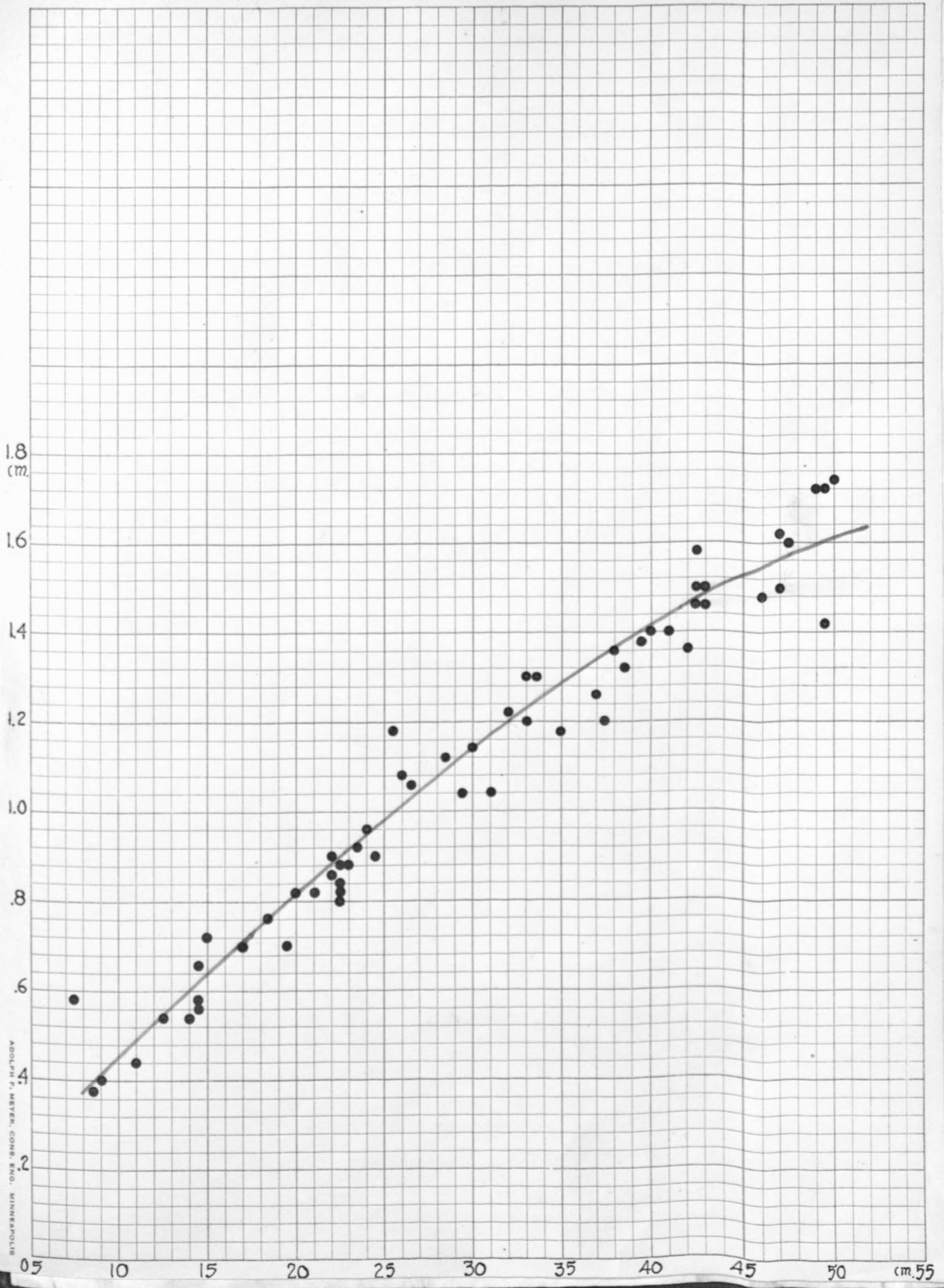

1.8
cm.
1.6
1.4
1.2
1.0
.8
.6
.4
.2
05
10
15
20
25
30
35
40
45
50
cm.55
ADOLPH F. MEYER, CONS. ENG. MINNEAPOLIS

Figure 4.

A field graph and curve illustrating the growth of the transverse (horizontal) diameter of the eyeball in fetal life. Individual cases indicated by dots. Abscissae: total body length in cm. Ordinates: transverse diameter of eyeball in mm.

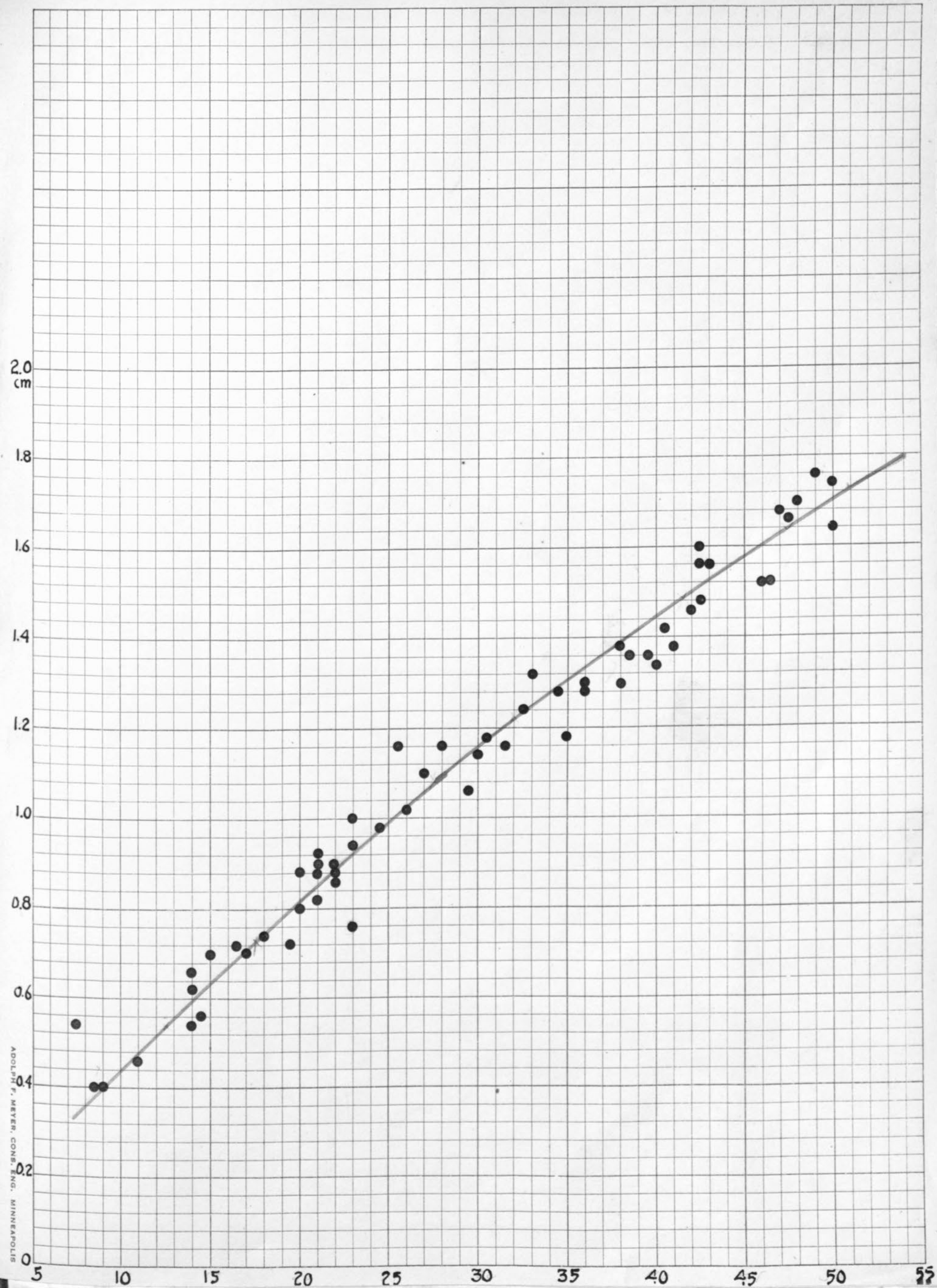

2.0
cm
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
5
10
15
20
25
30
35
40
45
50
55
ADOLPH F. MEYER, CONS. ENG. MINNEAPOLIS

Figure 5.

Three superimposed curves (figures 2, 3, and 4) illustrating the growth of the different diameters of the eyeball. Curve 1, antero-posterior diameter. Curve 2, transverse diameter. Curve 3, supero-inferior diameter.

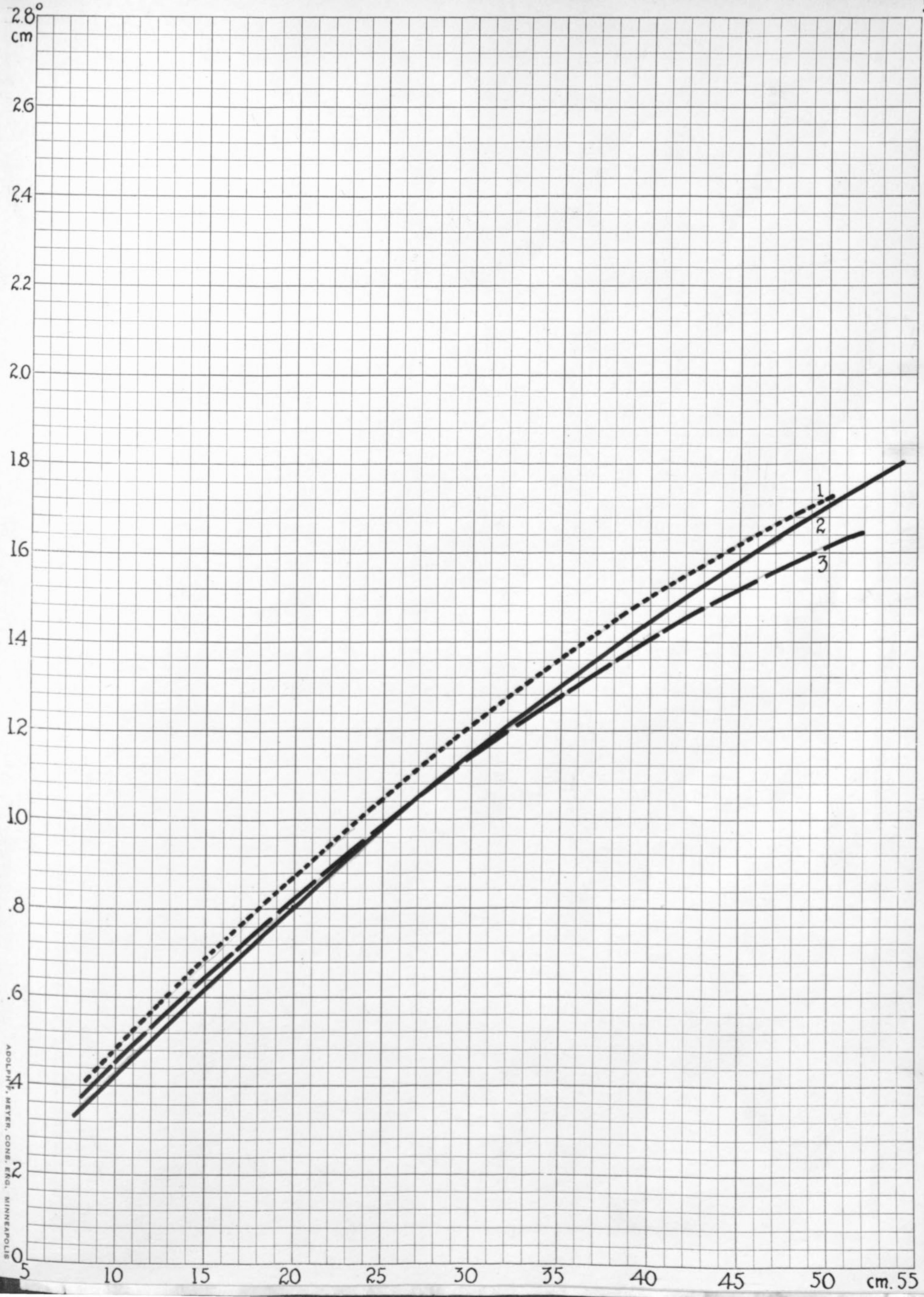

2.8°
cm
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
5
10
15
20
25
30
35
40
45
50
cm. 55
1
2
3
ADOLPH F. MEYER, CONS. ENG. MINNEAPOLIS

Figure 6.

A field graph and curve illustrating the growth of the height of cornea of eyeball in fetal life. Individual cases indicated by dots. Abscissae: total body length in cm. Ordinates: height of cornea of eyeball in mm.

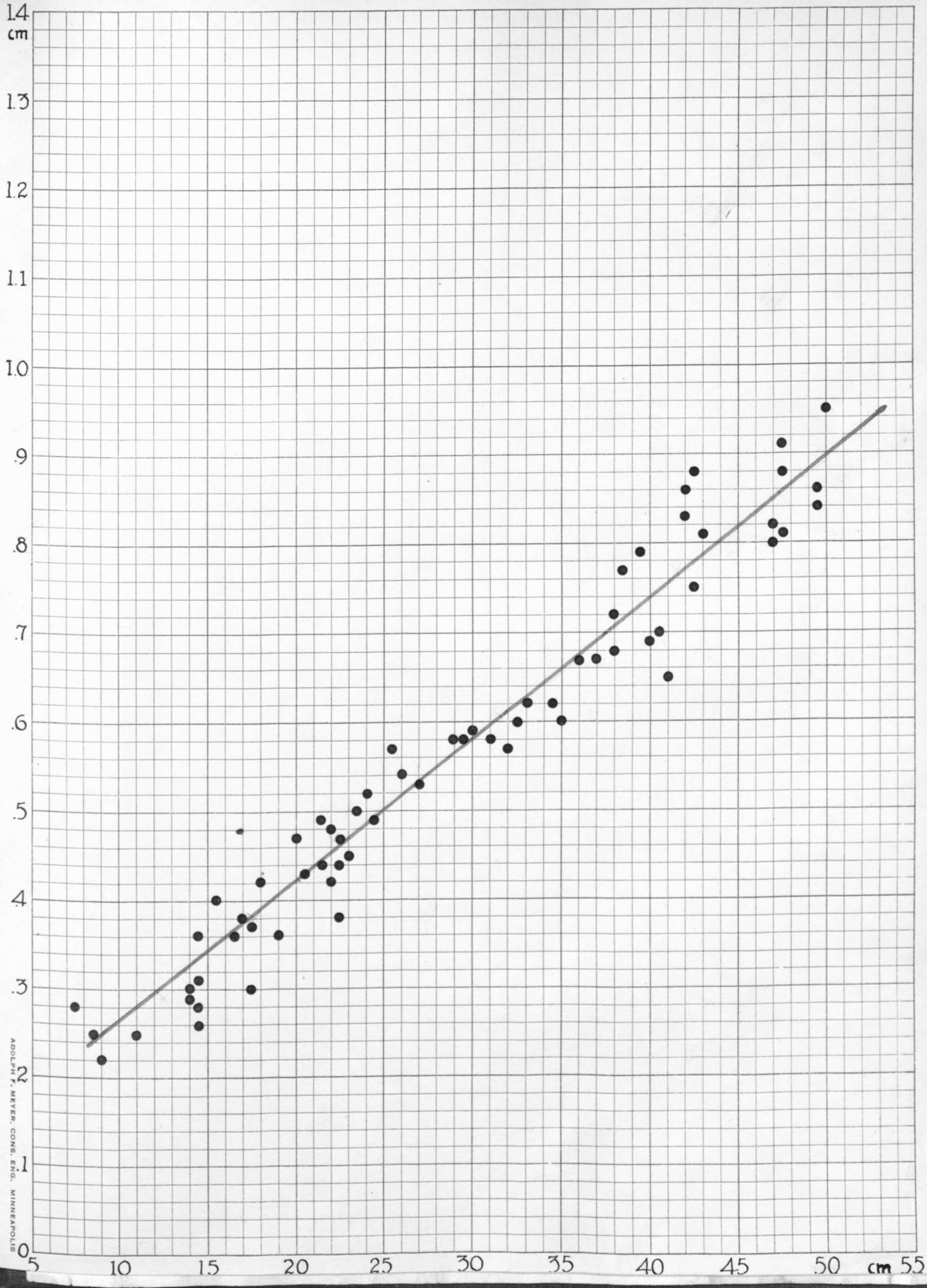

1.4
cm
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
5
10
15
20
25
30
35
40
45
50
cm 55
ADOLPH F. MEYER, CONS. ENG. MINNEAPOLIS

Figure 7.

A field graph and curve illustrating the growth in breadth of cornea of the eyeball in fetal life. Individual cases indicated by dots. Abscissae: total body length in cm. Ordinates: breadth of cornea of eyeball in mm.

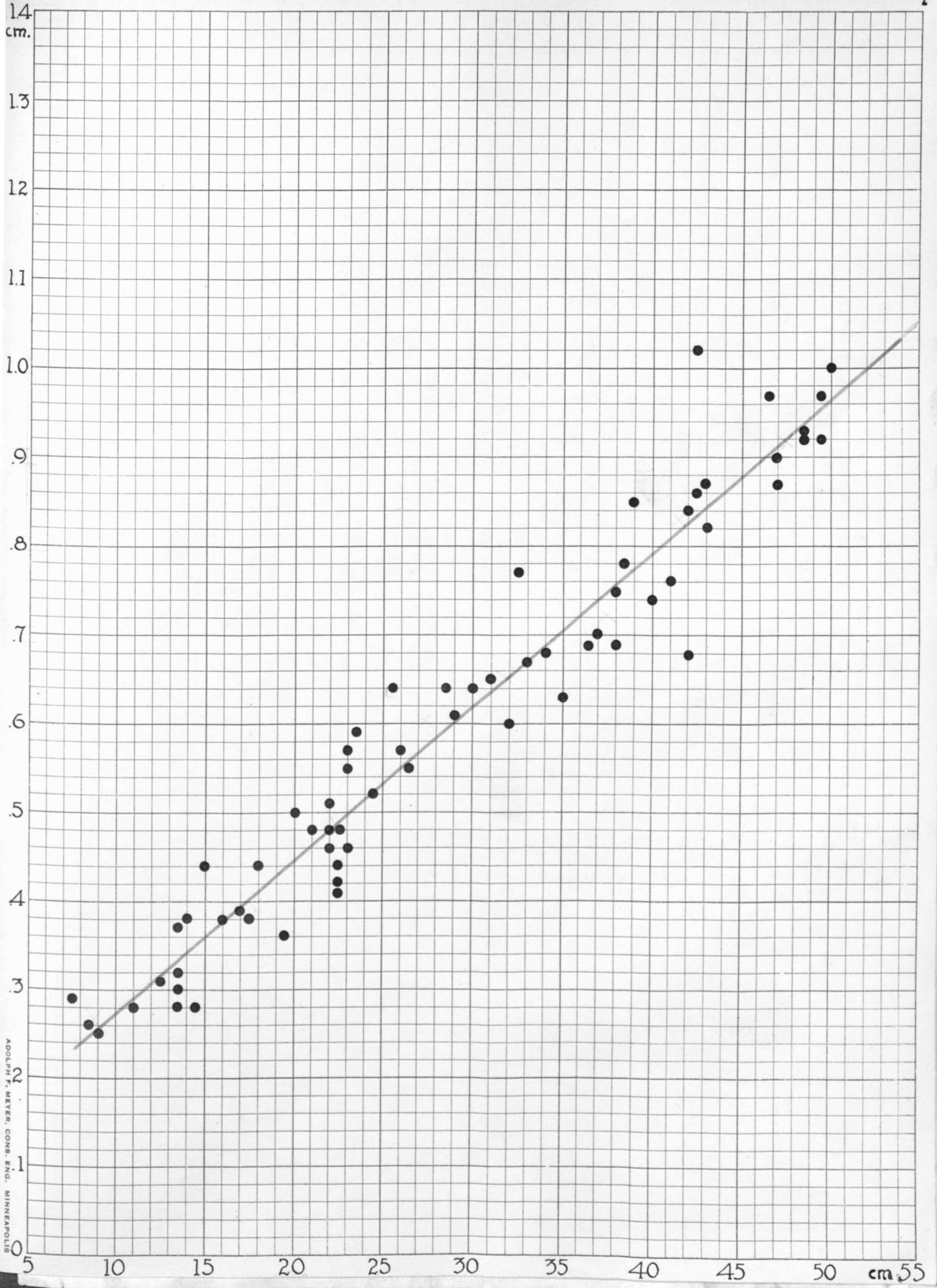

1.4
cm.
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
5
10
15
20
25
30
35
40
45
50
cm. 55
ADOLPH F. MEYER, CONS. ENG. MINNEAPOLIS

Figure 8.

A field graph and curve illustrating the growth in length of the optic nerve in fetal life. Individual cases indicated by dots. Abscissae: total body length in cm. Ordinates: length of optic nerve in mm.

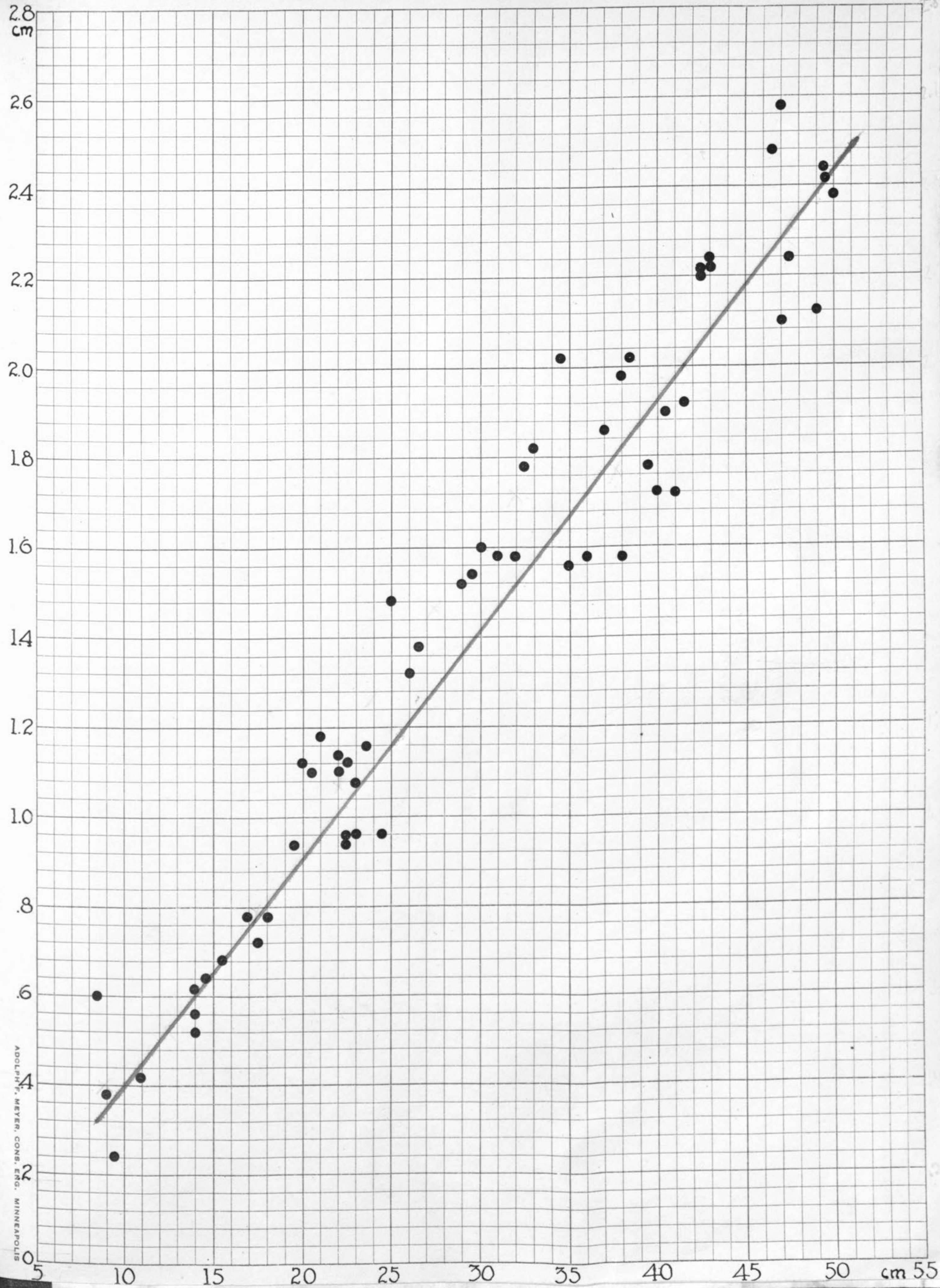

2.8
cm
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
5
10
15
20
25
30
35
40
45
50
cm 55
ADOLPH F. MEYER, CONS. ENG. MINNEAPOLIS

Figure 9.

A field graph and curve illustrating the growth in diameter of the optic nerve in fetal life. Individual cases indicated by dots. Abscissae: total body length in cm. Ordinates: the diameter of optic nerve in cm.

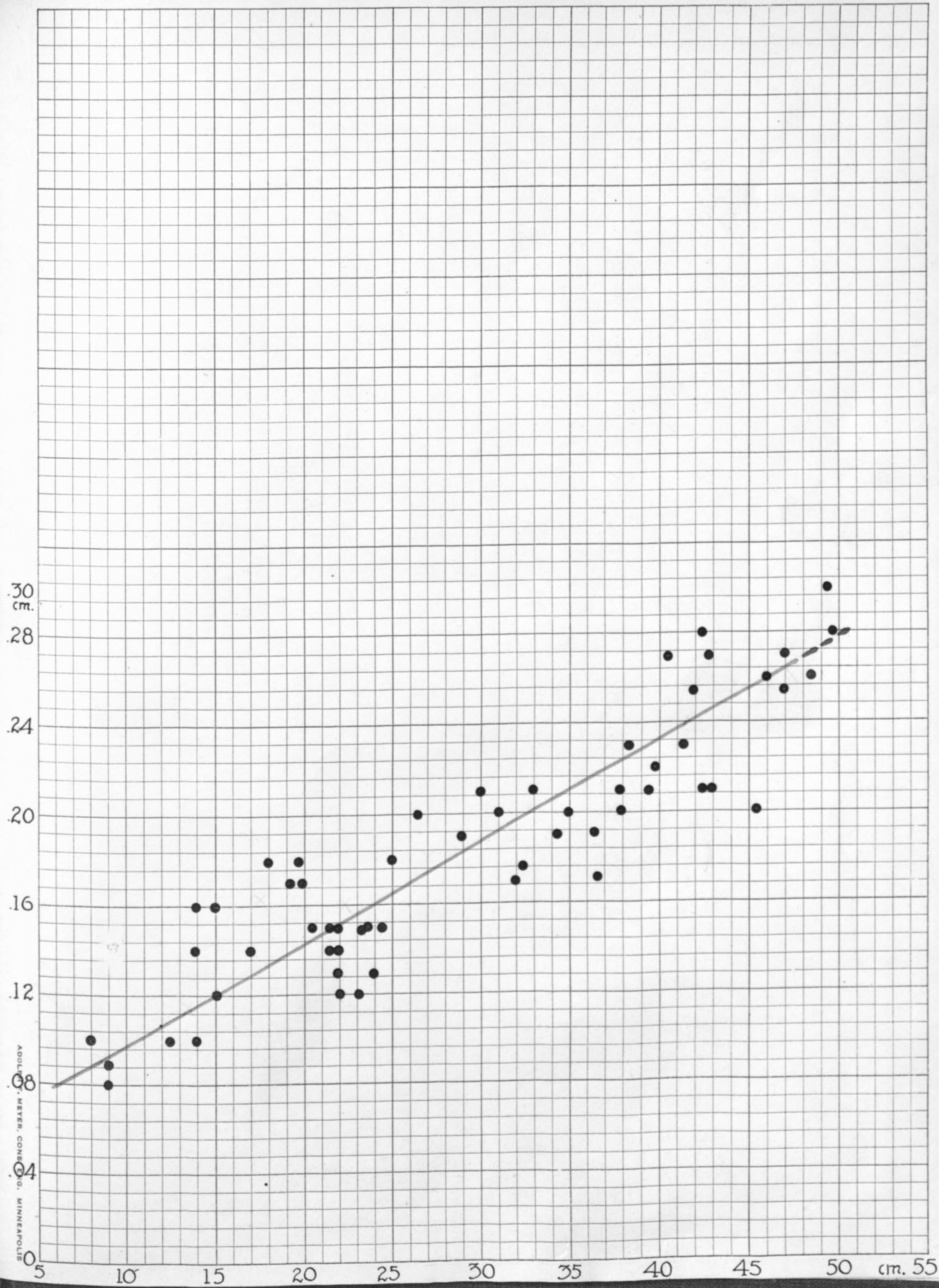
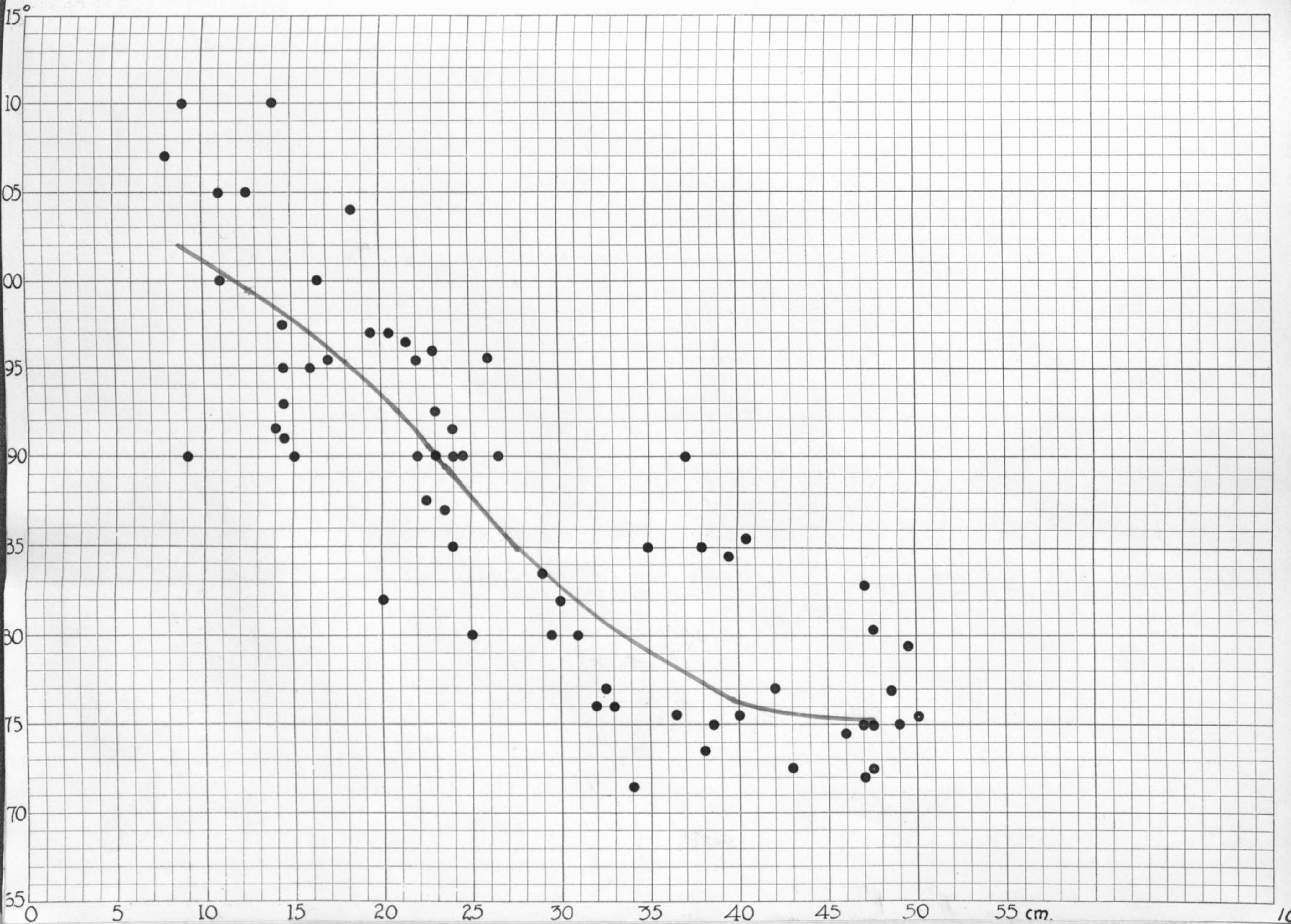

.30
cm.
.28
.24
.20
.16
.12
.08
.04
0
5
10
15
20
25
30
35
40
45
50
cm. 55

Figure 10.

A field graph and curve illustrating the angle formed at the chiasma by the optic nerves. Individual cases indicated by dots. Abscissae: total body length in cm. Ordinates: the angle formed at the chiasma by the optic nerves in degrees.



15°
10
05
00
95
90
85
80
75
70
65
0
5
10
15
20
25
30
35
40
45
50
55 cm.
10

Figure 11.

A field graph and curve illustrating the distance between the lateral surfaces of the eyeballs. Individual cases indicated by dots. Abscissae: total body length in cm. Ordinates: by the distance between the lateral surfaces of the eyeballs in mm.

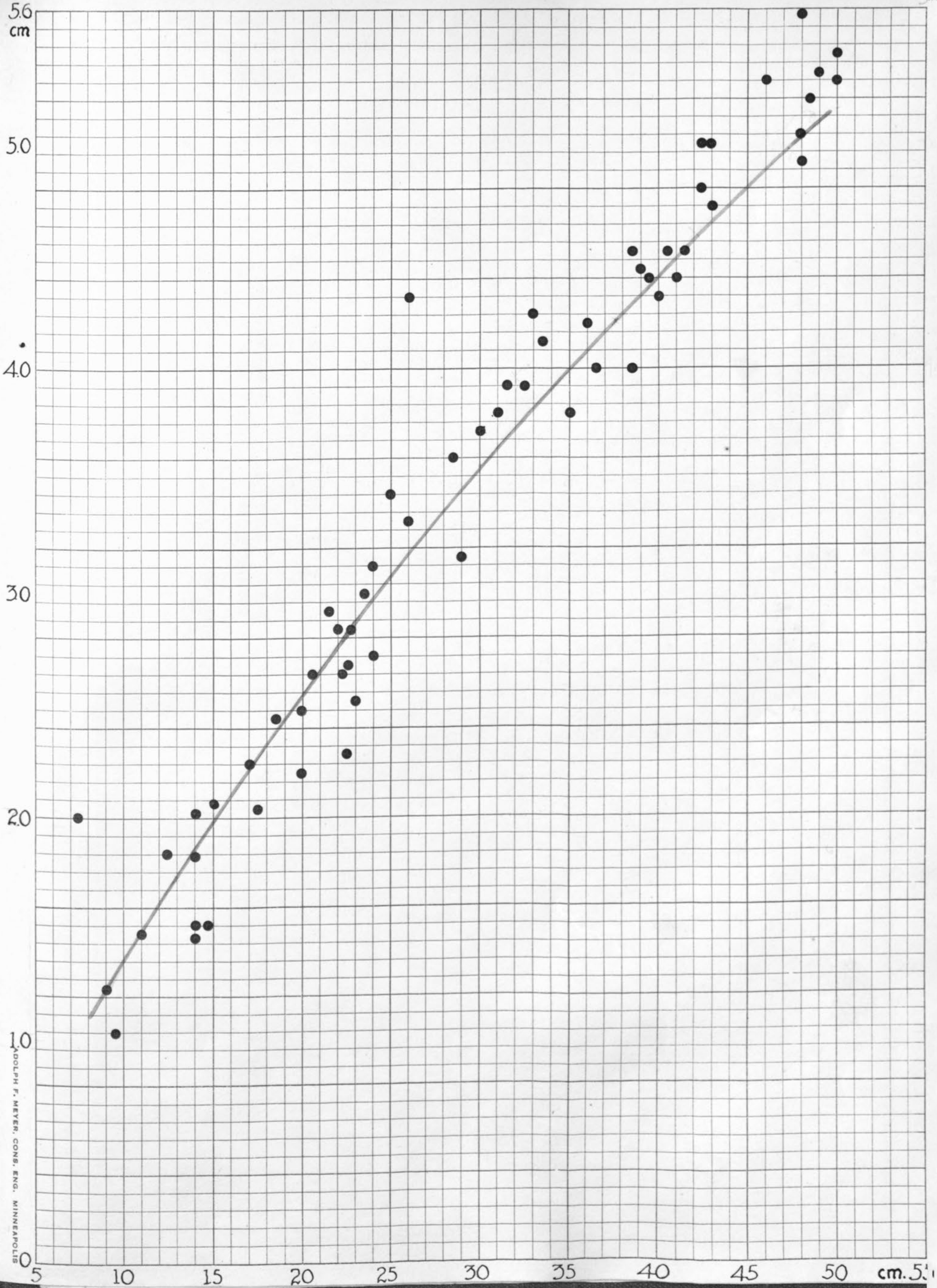

5.6
cm
5.0
4.0
3.0
2.0
1.0
0
5
10
15
20
25
30
35
40
45
50
cm. 55
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Figure 12.

A field graph and curve illustrating the distance between the medial surfaces of the eyeballs. Individual cases indicated by dots. Abscissae: total body length in cm. Ordinates: the distance between the medial surfaces of eyeballs in mm.

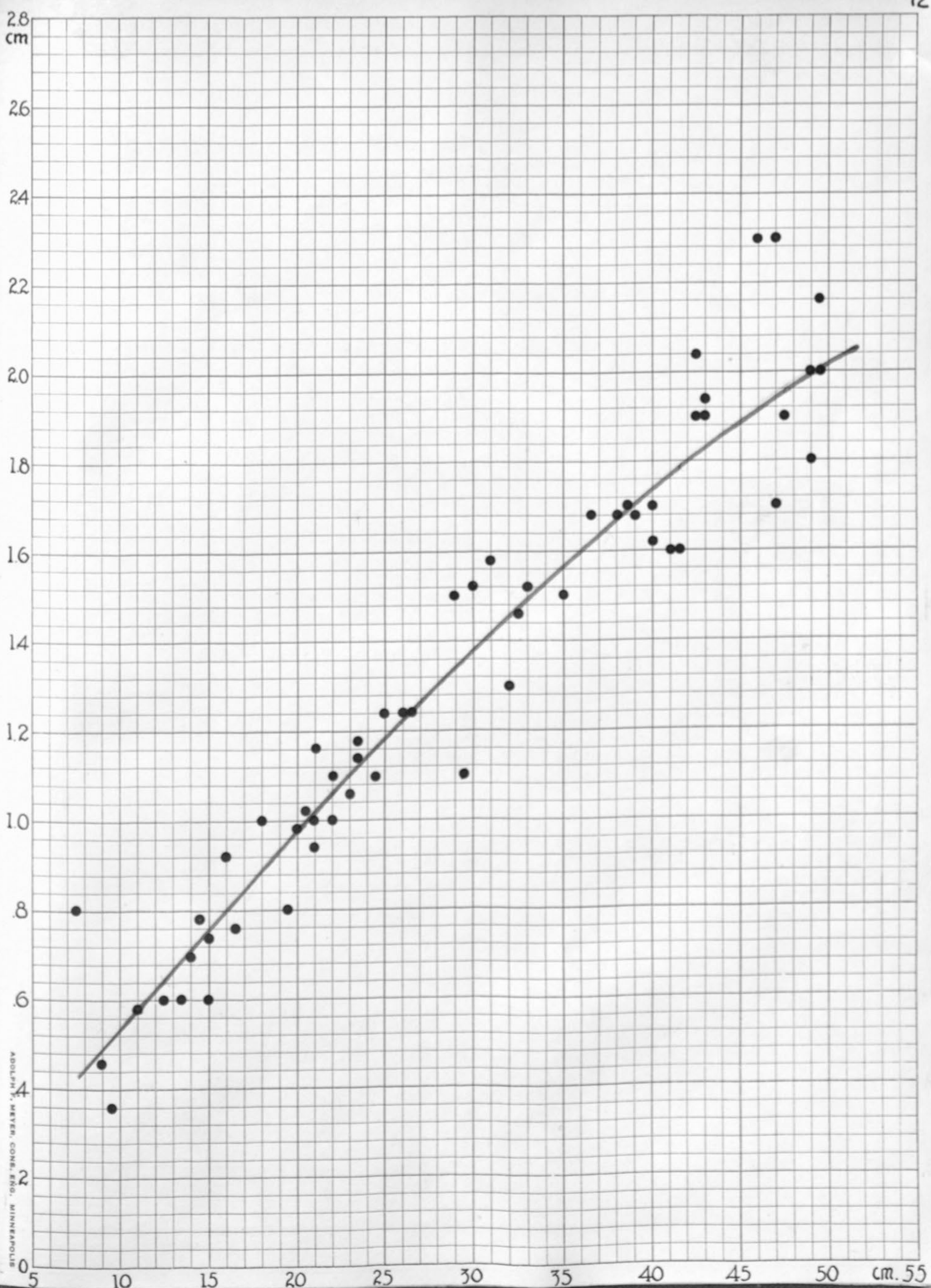
2.8 cm
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
5
10
15
20
25
30
35
40
45
50
cm. 55
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Figure 13.

A field graph and curve illustrating the distance of the entrance of the optic nerve from the greatest circumference of the eyeball. Individual cases indicated by dots. Abscissae: total body length in cm. Ordinates: the distance of the entrance of the optic nerve from the greatest circumference of the eyeball in mm.

Figure 14.

A field graph and curve illustrating the distance between the optic nerves at entrance into eyeballs. Individual cases indicated by dots. Abscissae: total body length in cm. Ordinates: the distance between the optic nerves at entrance into eyeballs in mm.

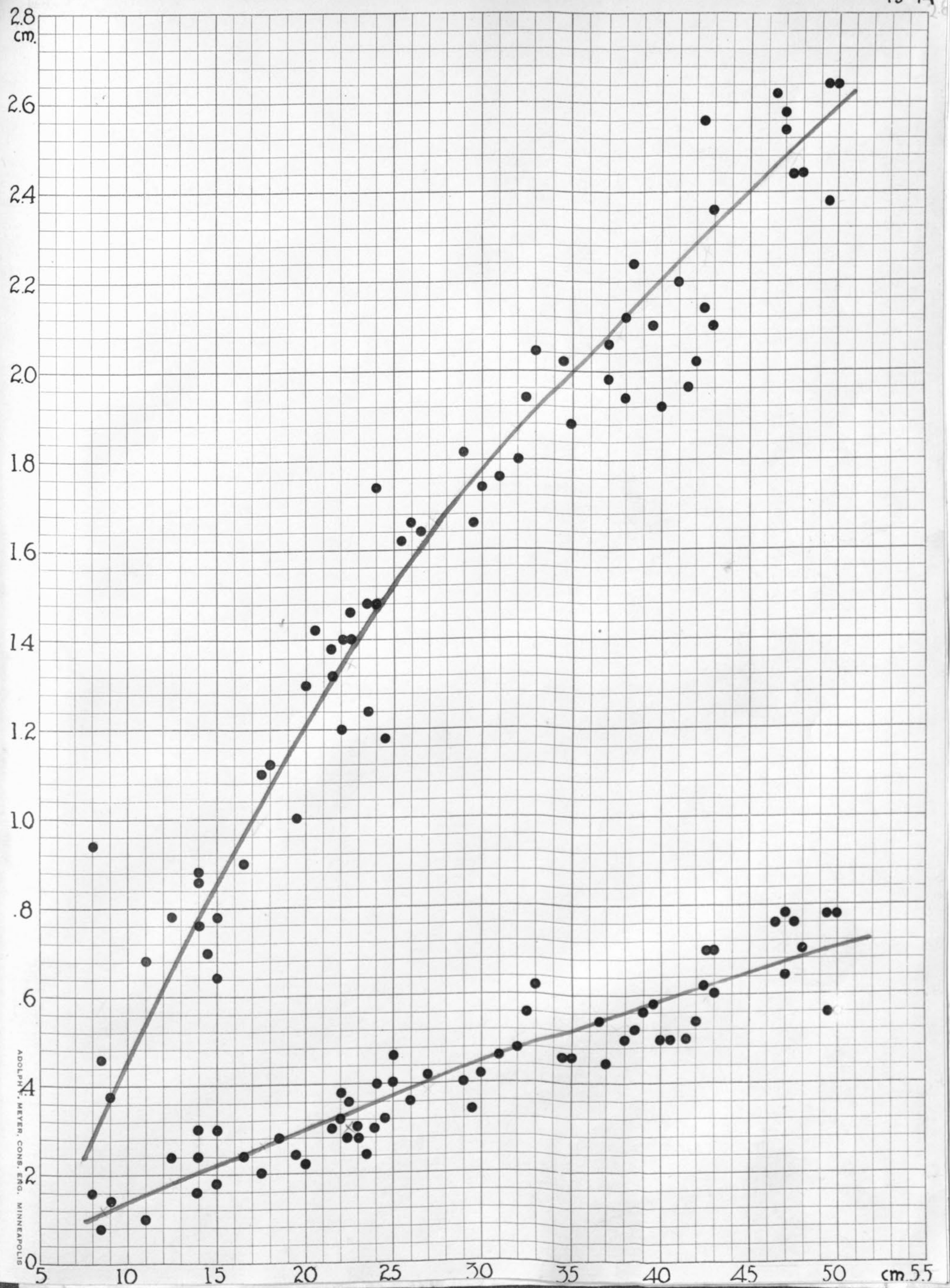
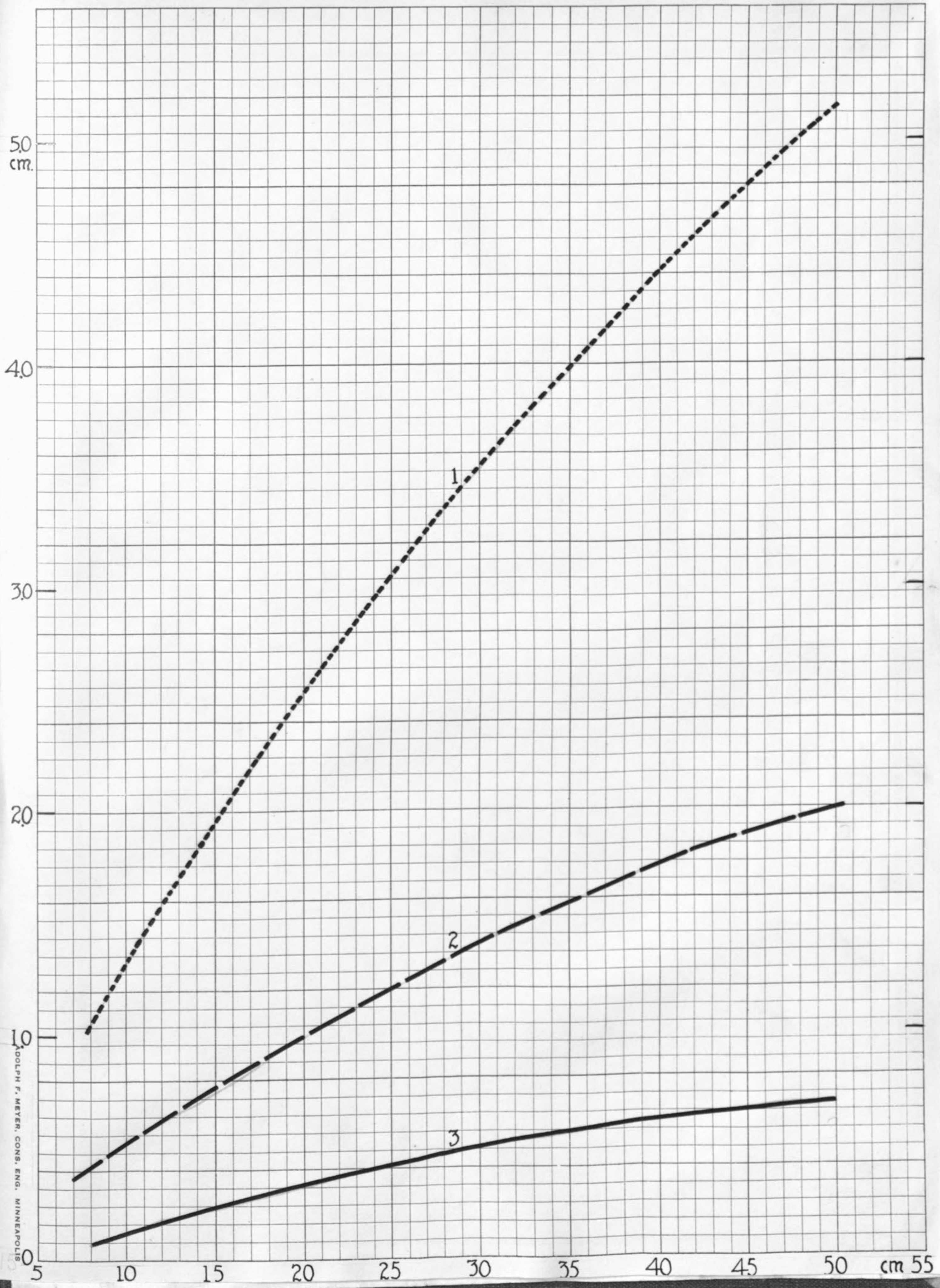

2.8
cm.
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
5
10
15
20
25
30
35
40
45
50
cm.55
ADOLPH F. MEYER, CONS. ENG. MINNEAPOLIS

Figure 15.

Three curves illustrating the changes in the distance between the eyeballs in fetal life. Curve 1, distance between the lateral surfaces of the eyeballs. Curve 2, distance between the medial surfaces of the eyeballs. Curve 3, distance between the optic nerve and the lateral surface of the eyeball.


5.0 cm.
4.0
3.0
2.0
1.0
0
1
2
3
5
10
15
20
25
30
35
40
45
50
cm 55
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