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THE MORE ACCURATE DETERMINATION OF THE
POSITION OF FOREIGN BODIES IN THEIR
RELATION TO THE EYEBALL AND ITS
COMPONENT STRUCTURES

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DURING the present war there have been introduced many new methods, or modifications and improvements of older ones, for the localization of bullets and other missiles within the tissues by means of the Röntgen rays. For the most part, these have been directed towards the simplification of the work and the economy of plates and of time.

The localization of foreign bodies within the eyeball, however, must be carried out with one central purpose—the securing of the utmost accuracy. The process should consist of two distinct parts, first the ascertainment of the relationship of the foreign body to a known point, and, secondly, the interpretation of this in terms of the various structures concerned.

I do not propose to describe in full detail any method of effecting the first part of the localization, for there is none better than some of those that are in general use; but I shall review the question of the choice of method and apparatus, and refer to certain

necessary precautions in their use. I shall take the opportunity of pointing out also some fallacies in current practice.

Localization in relation to a known point

In ophthalmic work screening has but little place, and in the finer parts of it none at all. Radiography in two planes is available, but to obtain accuracy much elaboration of apparatus would be required, and in any event the disadvantage of having to make one of the exposures through the dense cranium is a great one. We are therefore confined to radiography in one plane, that is, upon one plate, or upon two plates successively occupying the same position.

Of such means the oldest is that which was invented by Sir J. Mackenzie Davidson, the cross-thread system, and it embodies the principle of most of the best methods which have yet been devised. It may be taken as the type of the methods based on the comparison of similar triangles.

Regarding the apparatus to be employed in securing the correct positions for taking the radiographs required in these methods, the chief point, in addition to its permitting the requisite movements of the tube, is that it should maintain efficient head fixation. Personally, I think this can be better achieved with the patient lying than sitting, and better lying on his back than on his side. The apparatus invented by Major Higham Cooper meets the requirements very well and it is simple in construction and easy to use. It combines in one unit the plate-holder with cross-wires, the tube carrier, and the head fixation clamp, thus minimizing the possibility of relative movement. It has the merit also of fixing automatically the anode perpendicularly over one of the cross-wires and of permitting movement only in the correct line. The addition of a support to be gripped between the patient's teeth, is easily made and is, I consider, an essential.

Fixation of the eyeball also is absolutely necessary. The simplest plan is to have the patient keep his vision directed to a mark suitably arranged above him. Colonel Lister and Captain Gamlen have suggested the use of a small perforated mirror as a fixation object by means of which a spot of light could at the same time be thrown on to the patient's cornea. The perforation would allow of observation of the eye during the time of the exposures either directly or through a sort of periscope, and thus an objective check on the fixation could be made. If this idea is carried out in such a manner as to be convenient in practice it should be of great value.

Hardly less important than fixation of the eyeball is the adoption of the correct position in which to fix it. It is customary to make the line of vision parallel with the plate, but this is wrong; the geometric axis, which is almost identical to the optic axis, should be parallel with the plate. The difference is not an academic one

merely, but is important practically. Assuming an angle gamma of 5° and fixation of vision to be made parallel with the plate, a line taken directly backwards from the centre of the cornea will meet the posterior surface of the sclera about 2.1 mm. towards the outer side.

FIG. 1.—Horizontal axial section of the eyeball.

C D, optic axis; R F, fixation line; B N A, line of vision;
C E, line through centre of cornea parallel to B N A.

Lateral distances correlated with this line, C E in Fig. 1, instead of with the axis, C D, will be incorrectly determined to an extent varying from nothing at the cornea to 2.1 mm. at the posterior pole. An allowance should be made for the angle γ , and the fixation object placed 5° towards the nasal side. If considerable error of refraction is known or suspected to exist, the angle should be measured and the fixation object placed accordingly.

The effective securing of the correlating body, which is usually a piece of lead wire, is essential. The wire ought to be sufficiently long to ensure that its chief support is taken from the skin of the cheek far enough down to be beyond the area influenced by movements of the eyelid. As a rule 1 cm. below the centre of the cornea is chosen for the position of its upper extremity; but it is best to be content with an approximation to this and then measure accurately its relations in all three dimensions, for despite every care there will be found frequently in three, and almost always in two, an inexactitude of alignment for which allowance must be made. It is necessary that the line of fixation bear the same relation to the head when these measurements are made as when the radiographs are taken. This in practice means that they must be made while the patient is in position for radiography, either before or after the exposures; I prefer to do it afterwards. The antero-posterior measurement, however, can be made with accuracy and with more facility when the apparatus is removed.

Some workers keep the head parallel to the plate, while others allow it to come round until the temple is in contact. I have heard it stated that the result is fallacious in the latter case. It is not so if the correlation measurements are appropriately carried out, but maintenance of the correct line of vision is less restful and conceivably therefore less perfect than when the head is parallel or nearly parallel to this line.

Finally, the points from which the two radiographs are taken must be definitely known in their relationships to each other, to the plate, and to the cross-wires. They should for convenience be vertically over one of the wires and equidistant from the other or, alternatively, one of them may be over the actual crossing. A total displacement of 6 cm. has a special suitability in that it gives stereoscopic results. The points of preference are therefore those at 3 cm. on each side of the crossing and in what follows I shall assume that they are employed. The distance of the anode from the plate should be from 40 to 50 cm.; if a greater distance is chosen a greater tube movement also should be used, as the shadow displacement otherwise would become unduly small.

Having, with due regard to the foregoing precautions, obtained the two radiographs, we may interpret them by means of the cross-thread instrument or may use geometrical construction, which in most hands will give more accurate results. Still better, however, is arithmetical calculation which permits of no error additional to that which is common to all methods, and which results from imperfection in the fixation of the head and eye, in the correlation of the guide-body with the centre of the cornea, and in the practical measurement of the plates. The measurements of the shadow distances on the plates can be made, with a maximum error not exceeding a tenth of a millimetre, by means of a gauge fitted with a vernier. In the case of small foreign bodies the measurements should be taken from the centre of the shadows, or from corresponding points near the centre. Such points are obtained by drawing two fine lines across each shadow, either cross diameters, if the shadows are circular, or lines connecting identifiable points of the periphery, if there are irregularities. In the case of larger bodies it may be useful to have a complete localization of the two extremities in which case corresponding points of the outline should be chosen. As any inaccuracy in these measurements—or in the setting of the cross-threads, if used—is magnified many times in the estimation of depth, an average of about eight in eye work, the advantage of being able to use a vernier and immediately translate the measurement into figures is obvious.

If the plates have been exposed as stated, the construction for the geometrical method is as follows: On one of the plates mark the

position of the foreign body as its shadow appears on the other, and similarly the position of the guide-body ; a sheet of paper may be used instead of drawing on the plate, in which case cross lines to represent the shadow of the wires are first drawn, and relatively to them the positions of the shadows on both plates are marked. Each of the shadows is now joined to one of the three cm. points on the transverse line, the right hand shadows to the left side and the shadows towards the left to the point on the right.

FIG. 2.—Geometrical construction for finding the co-ordinates in the two directions parallel with the plane of the plate.

A and B, points at 3 cm. from the crossing of the wires; C and D, positions of the shadows of the foreign body; G and H, positions of the shadows of the marker.

It will be seen that the construction corresponds to a projection vertically on to the plate of the rays casting the respective shadows,* or similarly it may be regarded as a projection of the threads of the Mackenzie Davidson apparatus. Perpendiculars let fall from the points of crossing of the connecting lines upon each of the wire shadows, as O E and O F, K L and K M, will therefore give the distances of the foreign body and marker from the planes of the respective wires. One special case may occur, the two shadows of one of the objects may fall on the transverse line as in Figure 3.

In this event draw a line parallel to the transverse wire as CD, join the two shadows to the three cm. points on this line, and let fall a perpendicular from the crossing O back on to the line AB. G will be the point required, giving the actual position of the object as regards both dimensions in question. (The proof of this is apparent if the method of calculation which follows be applied to it.)

*Although strictly it is the obstructing body which casts a shadow, it is convenient to refer to the direction of a ray together with the dark line which continues it on to a shadow point, as "the ray which casts the shadow."

To obtain the depth of the foreign body from the plate, draw on a sheet of paper two parallel lines, separated by a distance equal to that of the anode from the plate; or, to make the diagram smaller, the distance may be a half, third, or other fraction of this length (fig. 4)

FIG. 3.—E and F, shadows of foreign body; C D, line drawn parallel to A B; L and M, the 3 cm. points; G, the true position of the foreign body.

FIG. 4.—Construction to find depth of foreign body.
A B, tube displacement; C D, shadow displacement;
O E, depth of foreign body.

On one of these lines mark off 6 cm., and on the other the amount of the shadow displacement; cross connect the points. From the crossing drop a perpendicular on to the line representing the shadow displacement (OE). The length of this, multiplied by the appropriate factor, if the total length was reduced, is the depth required. Similar construction is used to ascertain the distance of the marker from the plate. There are various other ways in which the same results may be obtained geometrically, but those I have given are perhaps the simplest, although not quite the shortest.

Those who wish the quickest methods, however, will rely entirely on calculation. For this purpose the following formulæ may be used :--

$$1. \quad Z = \frac{z \times s}{s + 6}$$

$$2. \quad X = \frac{x \times 6}{s + 6}$$

$$3. \quad Y = \frac{y \times 6}{s + 6}$$

where Z is the required depth,
 X is the required distance from the wire parallel with the displacement of the tube,
 Y is the required distance from the wire at right angles to this,
 z is the distance of the anode from the plate,
 x is the distance of the shadows from the parallel wire,
 y is the mean of the distances of the two shadows from the perpendicular wire,
 and s is the distance between the two shadows.

In these formulae the 6 represents the displacement of the anode in cm.; all the other measurements should therefore be used in the same form. If, however, it is preferred to minimize the use of decimal points 60 may be substituted and all the measurements given in mm.

The calculation in each case can be done in less than a minute to an accuracy of 1/100 cm. by means of a slide rule or by one of the many varieties of pocket calculators, such as Fowler's or Halden's. These instruments are somewhat uninviting to many, but their use for an elementary form of calculation like this is extremely simple and can be learned very easily without the aid of mathematical knowledge.

The proofs of the above formulae are as follows :

$$1. \quad Z = \frac{z \times s}{s + 6}$$

Let A and B, fig. 5, be the anode positions at 6 cm. apart, C the site of the foreign body, D and E its two shadows, and FCG the vertical height of the anode from the plate.

The $\triangle$ AFC and CGE are similar, being between parallels and between the same straight lines AE and FG.

$$\therefore AF : FC :: GE : GC, \text{ similarly } BF : FC :: DG : GC.$$

$$\therefore AB : FC :: DE : GC \therefore, \text{ adding proportionate terms :}$$

$$AB + DE : FG :: DE : GC, \text{ i.e., } 6 + s : z :: s : Z, \text{ or}$$

$$\frac{z \times s}{s + 6} = Z.$$

FIG. 5.

FIG. 6.

$$2. X = \frac{x \times 6}{s + 6}$$

Again, let A and B, Fig. 6, be the anode positions, D and E the shadow points, GF a vertical through the crossing C.

As in the former case:

$$AB + DE : FG :: AB : FC$$

which is

$$6 + s : x :: 6 : X$$

$$\text{i.e., } \frac{x \times 6}{s + 6} = X.$$

$$3. Y = \frac{y \times 6}{s + 6}$$

Let A, B, D, and E, Fig. 7, have the same significance as before. Join O C and produce to M. Produce E D to T and draw C P parallel. Again, as the vertically opposite triangles are similar and as $A O = O B \therefore D M = M E$ and T M is the mean distance of D and E from T, that is T M is y.

Δs T M O and P C O are also similar $\therefore T M : M O :: P C : C O$ but $M O : C O :: A B + D E : A B$, therefore $T M : P C :: A B + D E : A B$ which is $y : Y :: 6 + s : 6$, i.e. $\frac{y \times 6}{s + 6} = Y$.

FIG. 7.

Having in one of the foregoing ways obtained the relationship of the foreign body and of the marker to the point of crossing of the guide-wires, one has merely to add the distances if they are on opposite sides of the lines, or to subtract them if on the same side, in order to find their relationship to each other. A comparison with the relations of the marker to the centre of the cornea will give the localization of the foreign body from that point.

The degree of accuracy ought to preclude a total error from all causes exceeding half a millimetre.

The only methods based on totally different principles that I shall mention are two most ingenious ones that have been introduced by Dr. W. M. Sweet, who charts the planes of the rays associated with the shadows of the foreign body and of one, or, in the older method, two markers. For his later method Dr. Sweet has invented an apparatus which, although it appears somewhat complicated at first sight, is in use probably one of the simplest and most convenient available. It possesses several distinctive

features which make for increased precision. Particularly to be mentioned in this connexion are a reflector and telescope for the setting of the marker in one plane, and a perforated mirror for the dual purpose of setting the marker in the other planes, and of fixing the line of vision. I have not had an opportunity of using this instrument, but a study of its description* assures one of the validity of the principles on which the method is founded, and of the possibilities it affords for rapid and very accurate work.

It makes no provision for the error due to the angle γ but a very slight addition to or alteration of the fixation object would achieve this purpose. The chart employed is an essential part of the system of obtaining the relations to the marker. It does not, however, give a full interpretation of these relations, and belongs in this respect to the same category as the chart shown in fig. 13, the shortcomings of which will be discussed later.

In general it may be said that the requirements for a good system are satisfactory fixation and correct mathematical principles. The former requisite is not easy to obtain, but the latter is readily accessible, and any departure from exactitude is unjustifiable. Yet methods based on unsound principles are in frequent use. No system should be employed until one is satisfied on this point. Methods which dispense with a predetermined knowledge of the distance from anode to plate and of the tube displacement, are especially to be regarded with suspicion. The defect of such methods is incidental to the unknown degree of the divergence of the rays. The earlier of the methods invented by Dr. Sweet is subject to fallacy from this cause, and as it is still much practised, and as the results obtained by it are liable to be very inaccurate, I shall discuss its principles in some detail.

The apparatus consists of mechanism for head fixation and a special marker. The plate carrier may be a separate piece which is to be strapped to the head, or, more usually, it is made integral with the fixation clamp. The marker, which is the characteristic of the instrument, has two small metal knobs carried on the arm of a device by means of which one of the two knobs may be held, in so far as it is possible to place it accurately, at a known distance, say, 1 cm., in front of the centre of the cornea; while the other is fixed immovably to it, usually at 15 mm. distance, in a direction vertically towards the plate, that is to the temporal side. Two radiographs are made with the side of the head corresponding to the injured eye directed towards the plate-holder and lying parallel to it. The first exposure is made from a point vertically over the two knobs of the marker, thus the central ray crosses the face at 1 cm. in front of each cornea.

* Article by Dr. Sweet in "Diseases of the Eye," eighth edition, by G. E. de Schweinitz, M.D., LL.D.

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For the second exposure the tube is displaced towards the patient's chin in a direction parallel to the face, and it is tilted so that the centre of the diaphragm is still directed towards the first knob of the marker. Neither linear nor angular displacement is measured, however, nor is the distance from tube to plate in either instance.

By such means two radiographs are obtained, the first of which shows a single shadow representing the two markers, while in the second the shadows are separated. The relative positions of a possible case are represented diagrammatically in Figures 8 and 9.

FIG. 8 and 9.—M, shadow of markers superimposed; E, shadow of foreign body; M', shadow of axial marker; M'', shadow of temporal marker; B, shadow of foreign body.

The subsequent procedure is to ascertain the distances between perpendiculars from the shadows of the markers to those of the foreign body. To this end, lines are drawn, as shown in the Figures, horizontally through each marker—in Figure 8 the two are superimposed—and vertically through the shadows of the foreign body. The distances thus obtained are marked on a special localizing chart. The measurements taken from Figure 8 are charted directly as in Figure 10, which represents a vertical median section of the eye. They become, without modification, the

ultimate estimates for the backward and vertical correlation of the foreign body and the principal knob of the marker.

But it is obvious that in both cases these measurements are excessive, for the central ray, associated with the shadow of the

FIG. 10.—Vertical section through the axis.
M, marker; 'O, charted position of foreign body.

FIG. 11.—Equatorial section.
M' and M'', the markers, are fixed points of the chart from which the measurements are made.

marker was vertical; while that associated with the foreign body was divergent, in a direction upward and backward, corresponding to the two elements of separation of the objects.

The measurements from Figure 9 are transferred to a chart which represents an equatorial section of the eye with the markers projected backwards upon it.

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From M' , Fig. 11, the distance $M'S'$ is marked vertically and equal to AB , Fig. 9; and from M'' , $M''S''$ equal to CB , Fig. 9. The points $S'S''$ are joined, and are assumed to indicate the line of the ray associated with the shadow of the foreign body. A horizontal line, HK , at the same distance above or below the optic axis as the site of the foreign body, O , Fig. 10, would, if the measurements were correct, indicate by its point of intersection, B , the excentricity of the object towards the temporal or nasal side.

But if the ray $S'S''$ which passes through the foreign body should be distant from the markers by amounts equal to the shadow distances on the plate, then the rays passing respectively through the foreign body and the markers must be parallel. For, as the plate TE , Fig. 12, and the constructed lines $M'S'$ and $M'S''$ are verticals and therefore parallel, and as $M'S' = P'P$ the rays $S'S'P$, $M'P'$, and $M''P''$ are also parallel.

FIG. 12.—Represents the points shown in fig. 11, together with the position of the photographic plate. The heavy lines show the rays (parallel) and plate when $M'S'$ and $M'S''$ equal the shadow distances. The dotted lines show the positions when the rays are divergent.

The reconstruction of the ray as carried out in Fig. 11 is therefore correct only for a source of the X-rays situated at infinite distance. The true line of the ray $S'S''$ should be a lower one such as NQ which would thus indicate the foreign body at O , Fig. 11, and not at B . It will be observed that the plate TE , Fig. 12, must, if the reconstruction is to be correct, come down to such a position as $T'E'$, for only thus would the divergent rays passing through M' and M'' which are fixed points meet the plate at the distance $P'P''$. The points P, P', P'' , therefore come to X, X', X'' . As the ray $A'X$ is divergent from $A''X$, $M'L'$ is less than $X'X$, but $M'S' = P'P = X'X$, therefore $M'L'$ is less than $M'S'$, therefore the ray $A'X$ lies below the ray $S'P$ throughout its course: this position is indicated by the line NQ , Fig. 11.

With an anodal distance of 22 inches the error of this system (which is variable in amount according to the situation of the foreign body) is liable to be as much as 3.5 mm. in a backward direction; 1.5 mm. in a vertical plane, in a direction away from the optic axis; and a variable amount and direction (according to the anodal displacement used) in the remaining dimension.

It is not actually impossible to localize correctly without measuring the distance of the anode, for if one had a sufficiently elaborate marker, for example, four knobs arranged in a square of known size, the plates would give sufficient data from which to calculate the divergence of the rays. But the process would be of the nature of a mathematical problem, interesting chiefly for its intricacy.

The interpretation of the figures correlating positions in the vicinity of the eye with the centre of the front of the cornea

The means of interpreting the figures relating to the cornea in determining the relation of a foreign body to the periphery of the eyeball, and to the structures within it, is a subject which has been remarkably neglected and very generally misunderstood.*

A common type of chart which is used for this purpose consists of three sections of the eye: (1) vertical axial, (2) horizontal axial, and (3) equatorial. Such a chart serves as a record of the figures, but as an interpreter of them it is not only useless, but is liable to carry a conviction which may be quite incorrect, and may readily lead to the most disastrous consequences. In Fig. 13, for example, a point is marked on a chart of this kind at 20 mm. behind the centre of the cornea, 7 mm. towards the nasal side, and 6 mm. above the optic axis. In all three sections this point is well within the outline of the eyeball, yet in this position it is in reality situated outside the sclerotic, as I shall demonstrate later. Relations shown to the ciliary body and lens would be equally fallacious. A chart of a section can show exact positions only of points lying actually in the plane of the section; all other points have to be projected into it, and no index is available of the boundaries of the plane in which the point may happen to lie.

The axial and equatorial sections of the eyeball are the most extensive possible in their respective directions; hence if a point should appear outside any of those sections it is certainly outside the globe, but the converse is not true. All points on the outer surface of the sclera and cornea will in fact fall within the charts in

* An article by Mr. J. Herbert Fisher, showing the correct mode of marking and of interpreting charts of two sectional planes of the eye, appeared in the closing number of the *Ophthalmic Review*, December, 1916. The present paper had at that time received its general form, and it has seemed best, in the interests of arrangement and of continuity of demonstration, to retain its completeness, although on certain points this involves the retraversing of ground covered by Mr. Fisher.

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every case excepting points on the three circumferential lines represented by the peripheries of the sections: these points alone are in the plane of one or other section and they alone are truly exhibited.

In order correctly to determine whether a foreign body is within the eyeball it is necessary to have either its distance from the centre of the scleral sphere for comparison with the radius; or, alternatively, the data necessary for comparing its position with the limits of the

FIG. 13.—Chart consisting of three sections: (1) vertical axial; (2) equatorial; (3) horizontal axial. A point is charted at 20 mm. behind the centre of the cornea, 6 mm. above the axis, and 7 mm. to the nasal side. Its true position is outside of the eyeball. (Each square equals 2 mm.)

plane in which it lies. The simplest data satisfying this purpose are its distance from the geometric axis together with the radius of a section of the eyeball parallel to the equator at the particular distance behind the cornea at which the foreign body is situated.

If A be the centre of curvature of the outline of the eyeball as

FIG. 14.—Vertical axial section; FIG. 15.—Horizontal axial section.

A point seen at O, Fig. 14, may occupy any position on the line $O'O'''$, Fig. 15.

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the vertical excentricity over the lateral excentricity, that is $C O$ over $C A$ Fig. 16. This angle $C A O$ can be read directly from a slide rule if it is not more than 45° ; if over that amount the reciprocal, $C A$ over $C O$, will give its complement, $O A E$.

FIG. 17.—Vertical axial section.

The point O is seen in projection. The angle $C B O$ is the angle formed at the transverse diameter B , at a point having the same lateral excentricity as the point O .

FIG. 18.—Axial section in the plane of the meridian $B D$ of Fig. 16.

$L O$ is the same line as $A O$ of Fig. 16, but seen in the direction of the arrow marked on that figure.

The angular relationship to the horizontal plane in backward or forward directions from the transverse diameter can be found in a similar way; for this one uses the vertical measurement over the

distance, behind or in front of the centre, as the tangent :
 $\left(\frac{OC}{CB} = \tan. C B O, \text{ Fig. 17} \right).$

The tangent of the angular relationship to the axis, measured from the centre of curvature, is obtained by dividing the square root of the sum of the squares of the lateral and vertical dimensions by the distance behind or in front of the centre : thus $\tan. O K L$ Fig. 18 is $\frac{OL}{LK}$ but as the section is in the meridian of the point O, L O is A O of Fig. 16, which is $\sqrt{A C^2 + C O^2}$, therefore $\tan. O K L$ is $\frac{\sqrt{A C^2 + C O^2}}{L.K.}$

This is the line (K O of Fig. 18) along which the distance from the centre ought to be measured in finding the relationships to individual structures, for in this plane K O is the true distance of O from K, and if taken in conjunction with the meridian ascertained as above (Fig. 16) a complete localization will be established. A table of angular relationships is necessary if this method is applied to the parts which are not concentric with the sclera : it will be found later in the form of a chart (chart A, Fig. 23).

The alternative method is in many respects more convenient. If in an equatorial section of the eyeball the projection of a foreign body be found at O Fig. 19, that is if its height above the axis be A B and its lateral excentricity A C then its distance from the axis is $\sqrt{A B^2 + A C^2} = A O$. (Fig. 19.) If now its distance behind

FIG. 19.—Equatorial section.

O, a foreign body at distance A O from the axis.

the centre of the cornea be D E Fig. 20, and if the length E F is known, then E F — A O will determine, according as it is a plus or

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minus quantity, whether the foreign body is inside or outside the eye, and similarly if the distance from the axis of any of the radially symmetrical contained structures is known, the relationship to such structure will be indicated. It will be noted, however, that the distances from spherical surfaces given by this formula are not the shortest except in the plane of the equator; thus if the object is at O, O G is the value and not O F, and if at O' it is O' G' not O' F'.

FIG. 20.—Axial section in the plane of the meridian A O of Fig. 19.

Parallel lines are drawn at right angles to the axis at every 2 mm. from the cornea. E O equals A O of Fig. 19.

The general rule for the radial method is:—From the radial distance (in the appropriate plane) of the surface to which the relationship is required, subtract the distance of the foreign body from the axis, E F — E O Fig. 20 (E O Fig. 20 being A O of Fig. 19).

The significance of positive and negative resultants is obvious. The comparative relationship to two successive surfaces will show that to the body delimited by them. The meridian is found in the manner already described.

For the conducting of calculations on the foregoing principles a preliminary essential is an accurate knowledge of the form and dimensions of the eye. To this end I have constructed a series of figures based chiefly on measurements of specimens and of the scale photographs in Professor A. Thomson's stereoscopic atlas, and checked by comparison with the optical measurements of Listing and von Helmholtz. From these sources averages have been struck and finally a compromise of vertical and horizontal measurements made in order to give exact radial symmetry. As the difference in the two principal diameters of the equatorial plane is about 0.4 mm,

it follows that the mean is only 0·2 mm. from either. Other modifications of the actual measurements have been made for the same purpose, but all are of a smaller value than 0·2 mm.; the cornea, for example, has been made spherical, while the surfaces of the retina, choroid, and the inner aspect of the sclerotic have been assumed parallel. It is true that the vertical and horizontal diameters of the cornea differ by about 1 mm., but if the line at which opaque structure gives places to clear be ignored the asymmetry is less than 0·2 mm.

The construction of the eye so calculated is as follows:—

TABLE 1.

	Distance of centre of curva- ture behind centre of front of cornea,	Radius.
Cornea, anterior surface	8·0 mm.	8·0 mm.
„ posterior „	7·6 „	6·7 „
Sclerotic (from plane 2.5 to plane 7.5)—		
External surface	13·25 „	12·2 „
Internal „	13·55 „	11·9 „
Sclerotic (behind plane 7.5)—		
„ external surface	12·25 „	11·75 „
„ internal „	11·85 „	11·15 „
Choroid, internal surface	11·85 „	10·85 „
Retina „ „	11·85 „	10·65 „
Lens, anterior surface	14·0 „	10·0 „
„ posterior „	2·0 „	6·0 „
„ equatorial border	5·5 „	4·5 „

The ciliary body lies between planes 3·5 and 7·5, the iris between 3·5 and 4. The depth of the anterior chamber is, of course, variable and therefore the position of the iris and lens not constant; the positions given leave a chamber of 3·1.

The radii of sections of this eye made parallel to the equator at each half millimetre from the cornea are as follows (the measurements are corrected to the nearest 1/10th mm.):

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TABLE 2.

	Distance behind front of cornea	Radius of section.		Distance behind front of cornea.	Radius of section.
	0.0 mm.	0.0 mm.		12.0 mm.	11.7 mm.
	0.5 "	2.8 "		12.5 "	11.7 "
Cornea (radius 8 mm., centre 8 mm. back)	1.0 "	3.9 "		13.0 "	11.7 "
	1.5 "	4.7 "		13.5 "	11.7 "
	2.0 "	5.3 "		14.0 "	11.6 "
	2.5 "	5.8 "		14.5 "	11.5 "
	3.0 "	6.6 "		15.0 "	11.4 "
Ciliary part of sclerotic (radius 12.2 mm., centre 13.25 mm. back)	3.5 "	7.3 "		15.5 "	11.3 "
	4.0 "	8.0 "		16.0 "	11.1 "
	4.5 "	8.5 "		16.5 "	10.9 "
	5.0 "	9.0 "		17.0 "	10.7 "
	5.5 "	9.4 "		17.5 "	10.5 "
	6.0 "	9.8 "	Sclerotic— <i>continued.</i>	18.0 "	10.2 "
	6.5 "	10.2 "		18.5 "	9.9 "
	7.0 "	10.5 "		19.0 "	9.6 "
	7.5 "	10.7 "		19.5 "	9.2 "
	8.0 "	10.9 "		20.0 "	8.8 "
	8.5 "	11.1 "		20.5 "	8.4 "
	9.0 "	11.3 "		21.0 "	7.8 "
	9.5 "	11.4 "		21.5 "	7.2 "
	10.0 "	11.5 "		22.0 "	6.6 "
	10.5 "	11.6 "		22.5 "	5.7 "
Sclerotic behind ora serrata (radius 11.75 mm., centre back, 12.25 mm.)	11.0 "	11.7 "		23.0 "	4.7 "
	11.5 "	11.7 "		23.5 "	3.4 "
				24.0 "	0.0 "

The cornea has a thickness of 1.1 mm. at the limbus and 0.9 mm. at the centre; the plane of the limbus is 2.5 mm. behind that of the centre. The sclerotic is 1 mm. thick at the posterior pole, 0.6 at the equator, 0.4 at the ora serrata, and 0.6 at the junction with the cornea.

The radial distances of the surfaces of the ciliary body and the lens to the nearest half millimetre are;

TABLE 3.

Distance behind cornea.	Ciliary body.	Lens.
3.5 mm.	6.0 mm.	—
4.0 „	5.5 „	0.0 mm.
4.5 „	5.0 „	3.0 „
5.0 „	5.0 „	4.0 „
5.5 „	5.5 „	4.5 „
6.0 „	8.5 „	4.5 „
6.5 „	9.0 „	4.0 „
7.0 „	9.5 „	3.5 „
7.5 „	10.0 „	2.5 „
8.0 „	—	0.0 „

The ciliary body is variable: maximum dimensions have been chosen. As the radial distances of the inner surfaces of the sclerotic, the choroid, and the retina can be gauged with sufficient accuracy by comparison with the radii of the periphery, they have not been tabulated.

The only divergencies that it seems feasible or necessary to take account of by a fixed rule are those for errors of refraction. In the case of young children the equatorial diameter of the eye can be measured with a pair of ball-tipped callipers and all measurements reduced in proportion to the factor found.

The form of the myopic eye of moderate degree may be assumed to be that of the normal eye with a cylindrical band let in at the equator, while the hypermetropic eye is as though a band had been removed immediately behind the equator (Figs. 21 and 22).

I have been unable to obtain material for the measurement of markedly ametropic eyes, and apart from the length, which of course is definite, the shapes chosen are from personal judgment of probability in moderate cases. It is true that no part of an eye can ever be absolutely parallel sided as in my myopic model; but for 2 mm. on each side of the equator of an emmetropic eye the diameter alters by only one-tenth of a millimetre; for practical purposes therefore

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this area is cylindrical. The central part of an elongated eye is likely to be still flatter. In the hypermetropic model the removal from the normal contour of a band at A B, C D, Fig. 22, would theoretically make the points C and D an imperfect counterpart of A and B, but again it is a matter of less than 0.1 mm.

FIG. 21.—Myopic eye of six dioptries
A cylindrical band A B C D is added to the normal contour, increasing the length by one twelfth.

FIG. 22.—Hypermetropic eye of six dioptries.
A band has been removed at A C B D, reducing the eye to eleven-twelfths of the normal length.

These hypotheses have been assumed in order to preserve the spherical shape for all curves, together with an accuracy which in the case of errors of not more than 5 or 6 dioptries is probably little short of that obtainable in averaging the meridians of the normal

eyeball. It will be observed that for all points in front of the equator (that is, the 12·25 mm. plane) both myopic and hypermetropic models are of normal shape and therefore no allowance will be required in dealing with the anterior hemisphere.

The allowances on account of these modifications of form as applicable to points behind the 12·25 mm. plane are to be made thus:

1. *Spherical method*.—In estimating the distance of the foreign body behind the centre of curvature the deduction of 12·25 mm. from its distance behind the cornea is to be increased by 1 mm. for every three dioptries of myopia; that is, 13·25 mm. would be subtracted if 3 D. were the amount of the refractive error. But if the foreign body lie between the plane 12·25 and the new centre obtained by the above addition, then the latter point is to be regarded as in the same plane as the foreign body, the reason being that within the cylindrical part the centre must be taken as that point on the axis which lies in the same plane as the point which has to be brought into relation to it.

For every three dioptries of hypermetropia the deduction is to be reduced by 1 mm. In all other respects the procedure in both cases is the same as for the normal eye.

2. *Radial method*.—The effect is similar in this case, but as one is not taking account of the spherical centre, the modifications are made upon the assumed position of the foreign body.

For each three dioptries of myopia the foreign body is to be regarded as being 1 mm. further forward than its ascertained position; but it is never to be brought across the equator, only up to it if the full allowance would carry it past this plane. For three dioptries of hypermetropia the position is taken backward 1 mm.

Let me repeat that none of these allowances has any bearing upon points in the anterior hemisphere. In estimating relationships to the iris, posterior chamber, and lens, however, an appropriate allowance for marked variation in the depth of the anterior chamber must be made. The necessary modification of Table 3 for that purpose hardly requires explanation.

In the higher degrees of errors of refraction, the matter is more difficult. In pathological myopia the elongation concerns only an area considerably behind the equator, and a single curve for the posterior hemisphere is obviously impossible, while in some cases of high hypermetropia the eyeball as a whole is reduced in size. In hypermetropia of over 5 or 6 D. the equatorial diameter should be measured, as in the case of children. For high myopia, a definite rule is probably impossible for the diameter of the staphyloma is variable. It is to be remembered, too, that a moderate degree of myopia may be of the pathological type, but the error due to failure to make this differentiation would be a small one. In the absence

FIG. 23.—Charts for the application graphically of the methods of determining the exact relations of foreign bodies. "A," section through the axis. The meridional plane represented by the section is that in which the point that may be charted actually lies. "B," Equatorial section. The squares and concentric circles indicate 1 mm. distances. The design of the charts is according to the measurements given in table 1.

of data founded on measurements of a large number of myopic eyes I would suggest that the normal shape be assumed to the 18th parallel, and that the staphyloma be sketched on to chart A, to give the required extension; it should be of a fuller shape than a spherical curve, and will be better formed by hand than with compasses.

For the purpose of rapidly finding the value of radii from the amounts of measurements in two or three planes, as required in the foregoing methods, I have constructed a table of the square roots of the sums of the squares of the numbers from 0 to 15 in steps of halves. The values were obtained geometrically and checked where necessary with the slide rule. They are corrected to 0.25 mm.

If it be required, for example, to find the distance from the axis of the point charted in Figure 13, one proceeds thus:

On the top line of the Table take the lateral excentricity, namely, 7 mm., and on the left-hand line take the vertical excentricity, 6.5 mm.; opposite these two numbers will be found the distance from the axis, which is 9.5 mm. To determine if this point is within the eyeball, it remains only to subtract this length from the radius of a section at the plane 20. From Table 2 it is seen that the radius at this plane is 8.8 mm., therefore the point is outside the globe by a distance which (measured radially from the axis) amounts to 0.7 mm. By the spherical method the process is equally simple. Having found that the distance from the axis is 9.5 mm., one combines this measurement with the distance behind the centre of curvature which is 7.75 mm.

Taking 9.5 on the left hand column of the Table and 7.5 on the top line, one finds the resultant 12; if 8 is used instead of 7.5 the resultant is 12.5; so that for 7.75 it will be approximately 12.25 mm., which is the distance from the centre of curvature. Subtracting this from the radius of curvature, namely 11.75, one gets (*minus*) 0.5 mm., which is the true distance of the foreign body, in this case, outside of the globe. Referring again to Fig. 20, the distance, 0.7 mm., found by the radial method corresponds to $O'F'$, and the distance, 0.5 mm., shown by the spherical method, corresponds to $O'G'$.

It is in some respects more convenient, especially to those who prefer a minimal use of figures, to interpret the relationships of a foreign body by means of charts rather than by means of tables.

With this in view, and also to summarize the methods that have just been described, I have constructed the following charts, which represent graphically the measurements of the eyeball and the table of roots.

The spherical method has relatively less value when charts are used, for its chief advantage is the elimination of the necessity of having any prepared data regarding the eye other than merely its radius (that is, so far as concerns the posterior two-thirds). On the

other hand, it gives the same information, but at the cost of somewhat more trouble.

Yet, to illustrate the principle, it may be applied thus: Three factors are required—(1) The distance of the foreign body behind or in front of the centre of curvature, that is, its distance behind the cornea minus 12.25 mm. (2) Its lateral excentricity. (3) Its vertical excentricity. On chart B mark downwards (or upwards as the case may be) from the centre, the amount of factor three; and outwards from the point so found the amount of factor two. This second point indicates the meridian. With the aid of the concentric ruling observe the distance of this point from the centre, and chart it vertically below or above the latter. Horizontally outwards from this, mark off the amount of the first factor. The distance of this point from the centre is the distance of the foreign body from the centre of curvature of the sclera, and the angle it makes with the horizontal plane is its angular relationship to the axis. There remains only to chart the distance thus found along the appropriate radial line on chart A to find the exact relationships of the foreign body. (Concentric circles on chart A would facilitate this last measurement, but for the sake of simplifying the diagram they have been omitted.)

The easier way of marking the charts, however, based on the radial principle, will be as follows: (the radial lines and markings of degrees on chart A are unnecessary for this method and would, therefore, on a chart for routine use, generally be omitted.)

On chart B mark, first, on the horizontal diameter the distance of the foreign body to the nasal or temporal side and, secondly, vertically below or above this the distance of the foreign body below or above the centre of the cornea. Note the distance of this second mark from the centre of the chart as determinable by the concentric circles.

On chart A mark on the axial diameter the distance of the foreign body behind the anterior pole of the eyeball. Vertically below or above this mark—according as the foreign body is below or above the centre—and at a distance equal to that between the second mark on B and the centre of chart B, make a second mark on A.

Intermediate positions giving half millimetre markings should be used if fractions occur.

The second mark on A indicates the position of the foreign body relatively to the various structures of the eye.

The second mark on B denotes the meridian and quadrant in which the foreign body lies.

Chart A now represents an antero-posterior (axial) section of the eyeball in the plane of this meridian, and passing through the foreign body.

The allowances for errors of refraction are made in exactly the

same way as already described. In case of myopia the marks on A should be brought forward 1 mm. for every three dioptries, and in case of hypermetropia correspondingly displaced backwards. Again, these allowances are to be made only for points behind the equator, and if in a myopic eye they should bring the marks across this plane, the part which brings them up to this ordinate is alone to be allowed.

The modified markings, of course, do not give the relationship to the anterior hemisphere; if this is wanted, the original positions will show it.

The allowance for variations of depth of the anterior chamber also is made by placing the marks correspondingly forwards or backwards in establishing the relationship to the iris, posterior chamber, and lens.

The following information can at once be read from the charts:

1. The distance of the foreign body from the periphery.
2. Its relation to any of the structures within the eyeball.
3. The meridian in which it lies.
4. Its distance behind any particular point, such as the limbus.

In addition, the three measurements originally supplied are recorded.

The value of an exact localization of a foreign body, beyond the ascertainment whether it is within the globe, is, I believe, often underrated. But for magnetic extraction by the anterior route also I am convinced that it is often of great service. For extraction through a scleral wound it is obvious that it is a guide to the direction in which magnetic traction will act to greatest advantage in disentangling from adhesions, and to the direction which will, if possible, avoid entanglement in the ciliary region, or undue injury to the lens and its supporting ligaments.

Before concluding this paper I wish to express my thanks to Colonel W. T. Lister, C.M.G., consulting ophthalmic surgeon to the British Expeditionary Force, for his kind interest and advice, particularly with regard to the preparation of the two final charts.

NOTES

A NOTE ON CATARACT EXTRACTION, WITH A SUGGESTION

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FOR the extraction of cataract it is my practice to do the combined operation with iridectomy, usually at a single sitting, and I only quite rarely perform a simple extraction.