CONTACT GLASSES

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HISTORICAL.

THE possibility of correcting anomalies of refraction by means of lenses in actual contact with the eye seems to have occurred to several investigators during the past century or so. It is known that the younger Herschel, astronomer and physicist, attempted to make contact glasses about 1827. I have not been able to get exact details of his experiments, but apparently he adopted a method of casting from a gelatine negative and used the glass positive moulded therein along with a gelatine meniscus in contact with the cornea. In 1887 Dr. A. E. Fick* advocated contact glasses for keratoconus. His experiments were mostly concerned with blown glasses but it is on record that he approached Abbé with a view to having examples ground. Whether Abbé attempted to grind any is unknown, but he had specimens blown for him in the Forest of Thuringia. About the same date Kalts in Paris experimented with contact glasses but did not publish. Later, a few practical opticians actually ground some specimens—Strübin in Basle and Himmler in Berlin. In 1892 Sulzer had contact glasses ground for him by opticians in Paris and Geneva. Müller, of Wiesbaden, whose glasses will be referred to in more detail later, was associated with the experiments of Fick in 1887 and has produced blown glasses ever since. The firm of Carl Zeiss, of Jena, first produced ground contact glasses for experimental purposes in 1911 and for keratoconus in 1918.

So far, in spite of repeated attempts and isolated successes, there is little progress to record. The history is that of many other scientific conceptions; the idea had to await fulfilment until progress in other branches of science had sufficiently advanced to translate it into practice. The equipment of the optical manufacturer was manifestly unequal to the task. Before such technical excellence as that of the present Zeiss model became more than a mere possibility a whole series of new machines and processes had to be devised. The technique of grinding out of a single piece of glass a small, fragile bowl, complicated in form, mathematically exact in curvature, and polished so finely as to be tolerated by the eye, is obviously one of great precision and delicacy. The shape ultimately chosen is a difficult one to work to, being a section of

*I am happy to say that Dr. Fick is still alive. He now lives in retirement near Munich.

a double sphere, the respective radii of which are usually unequal. At the junction of the two spherical surfaces there is a projecting inner rim which, like the outer edge, must be carefully rounded off and polished. The curvatures of both surfaces must be optically exact and the thickness of the optical area uniform and accurate. The material, moreover, is very thin and very hard, qualities which add to the difficulty of working. The manner in which these difficult problems were finally solved by the firm of Zeiss should prove, when fully known, to be one of the romances of optical history.

During the past few years this firm has greatly extended the possibilities of this method of correction and now manufacture contact glasses and trial sets designed to cover practically the whole range of ametropia.* This remarkable result is in great measure due to one man, Geheimrat Prof. Leopold Heine, of Kiel University, whose energy, enthusiasm, and experiments, ably seconded by those of the scientific staff of Messrs. Zeiss, have placed the use of contact glasses in its present satisfactory position.

DESCRIPTION OF ZEISS GROUND GLASSES.

The Zeiss ground contact glass (Fig. 1) is a thin, transparent, hollowed bowl which fits on to the anterior part of the eyeball beneath the lids, in contact with the sclera but separated from the

FIG. 1.

Zeiss Ground Contact Glasses.

cornea by a fluid meniscus. It consists of a central, optically effective crown, which forms an arc of a sphere, surrounded by an optically ineffective peripheral brim, which is also spherical. The former may be called the corneal portion; the latter the sclerotic. The material is crown glass which has in sodium light a refractive

*Within the past month or two Messrs. Zeiss have succeeded in manufacturing contact glasses with a scleral radius which is less than the corneal radius.

index $\mu = 1.516$, and is chemically highly resistant in order to withstand the corroding action of tears.

The central or corneal part has a diameter of approximately 12 mm. and is about 0.5 mm. thick at the vertex. The diameter of the sclerotic zone (*i.e.*, of the whole glass) is about 20 mm. and the thickness of the edge about 0.3 mm. The total weight of a contact glass is only 0.5 gm. (grs. 7). It is thus easily carried by the eyeball in its movements around the centre of rotation.

For the examination of patients Messrs. Zeiss now supply two trial sets of test contact glasses, a larger and a smaller. In both sets the glasses are arranged in three series according to three standard scleral measurements. Each series has the same range of corneal radii—viz. from 5 to 11 mm.—representing the radius of curvature of the inner surface. In the smaller set the unit of corneal radius is 1 mm., *i.e.*, it contains test glasses corresponding to the whole numbers 5 to 11. The unit in the larger set is the half-millimetre, so that this set contains additional glasses corresponding to 5.5, 6.5, and so on up to 11 mm. of corneal radius. Professor Heine recommends still further sub-division, *i.e.*, a set with corneal radii progressing by 0.25 mm. The radii of the inner scleral curvatures in both sets usually measure 11, 12, and 13 mm. respectively, but half-millimetre sub-divisions are also available. These figures are etched on the rim of each glass in the trial case. The vertex thickness of each glass is also given though not indicated on the glass itself. Tinted glasses with a light absorption value of 25 per cent., 50 per cent. and 75 per cent. to protect the eye from glare can be added to the trial case, the tint being incorporated in the corneal portion.

Two important points should be noted. First, the radius of the inner surface of the corneal portion is taken as the standard. That of the outer surface may have to be modified by having a plus or minus sphere worked on it. This point will be apparent later when the details of prescribing are considered. Secondly, the trial test glass and often the actual glass made for the patient is afocal, that is, the corneal crown has no optical power in air. The dominant factor in the combination (afocal contact glass + fluid meniscus + ametropic ocular system) is the fluid meniscus lying between the cornea and the inner surface of the contact glass.

MÜLLER'S BLOWN CONTACT GLASSES

The firm of Messrs. F. Ad. Müller Söhne, of Wiesbaden, directed by Dr. F. Müller, Sen., has manufactured blown contact glasses continuously since 1887. At least two other German firms make similar glasses at the present time. Müller's glasses were first designed for protective purposes, to prevent injury to the

cornea in cases of inadequate closure of the lids, absence of eyelids, dystichiasis or entropion, etc., but it soon became apparent that they were also able to correct defects of corneal refraction. The type of refractive defect for which blown glasses have been and are being used includes chiefly conditions such as leucomata, the result either of injury or disease, and conical cornea. They can be used equally well, however, for myopia or aphakia.

There are perhaps no finer examples of the glass-blower's art than these glasses. If we acknowledge the ground contact glass to be a triumph of mechanical achievement, we must equally admit the blown glass to be a triumph of human skill. The molten glass is endowed with the necessary form and curvature by blowing alone and undergoes no further manipulation to give it optical effectivity. That is to say, the size of the lens, its thickness, and

Fig. 2.

Müller's Blown Contact Glasses.

the radii of curvature of the outer and inner surfaces—both being important to the final result—are determined solely by the technique of the glass-blower. Few craftsmen even of the highest grade possess the necessary qualities of co-ordination, patience and skill. The delicate touch and judgment required make great and exhausting demands on the nervous energy of the workman. The act of successful blowing entails an exquisite co-ordination of hands, lips and eye—a combination of qualities essential to success but sufficiently rare to explain the somewhat restricted use to which blown glasses have hitherto been put.

In appearance Müller's blown contact glasses (Fig. 2) rather resemble artificial eyes of the "shell" type. They consist of a central, transparent, corneal portion and a surrounding opaque scleral brim. The latter is oval shaped, milky coloured and marked with representations of conjunctival vessels in order to make it inconspicuous. Its lower portion, which fits into the inferior fornix, is broader than the upper and right and left contact glasses are different.

The method of insertion is much the same as that of an artificial eye. The glass is moistened with plain water or, preferably, physiological salt solution. The patient is directed to look down. The surgeon then draws up and fixes the upper lid with his thumb, passes the upper brim of the glass under the eyelid, taking care not to abrade the cornea, and finally asks the patient to look up. At this point the lower eyelid is drawn down, the glass pressed into position over the cornea and the lower lid allowed to spring back into position over the glass. A finger can now be placed on the glass and the latter coaxed into the correct position by a light twisting movement. If the shape is correct the glass will work into position by itself, and it is well to give it a little time to do so before beginning the subjective tests. It is not necessary to instil an anaesthetic.

There is no fluid meniscus between the cornea and a blown contact glass, but there must be no air bubble between the two. Apparently, in satisfactory cases there is close contact between glass and cornea at any rate for a considerable area of the latter. The patient, however, should experience no sensation of pressure either on the cornea or conjunctiva and does not when the curvatures of the glass correspond exactly with those of the cornea and sclera. When pressure is felt on the cornea the glass is too flat. When there is conjunctival irritation the radius of curvature of the whole glass is too small. If the glass tends to change its position it is too flat and wide. If only the edge of the scleral brim appears in contact its radius of curvature is too short.

When there is conical cornea of both eyes it is better to get one eye thoroughly accustomed to the contact glass before fitting the other. At first the glass should be worn only for a few hours daily and the period gradually increased. It is taken out at night but when worn for protective purposes—lagophthalmos, spastic entropion, etc., it may be worn throughout the night so long as it is efficiently cleansed morning and evening. When not worn at night it must be cleaned, dried, and kept dry until morning.

To remove the glass the makers supply a short rod curved into a blunt hook at one end. The patient looks up, pushes the hook beneath the lower edge, looks down and by a slight movement of the rod drops the glass on to a towel.

The making of these glasses is purely empirical and, although it is possible to obtain a non-astigmatic optical zone corresponding to the natural cornea, their refractive power and correcting capacity cannot be definitely determined beforehand. This determination is made by means of tests after the glasses are finished. For this reason it is found inexpedient to manufacture a series of trial glasses for the use of surgeons, so that the personal attendance of the patient is necessary during the time the glasses are

being made. Only in this way can individual differences be taken into account, but this is a fact which undoubtedly restricts their usefulness.

Blown glasses can often be worn for years before the surface becomes roughened and with proper attention the transparency of the corneal portion can be depended upon for at least a year.

FITTING AND PRESCRIBING GROUND GLASSES

After examining the eyes in the ordinary way and determining the amount and character of the refraction, the process of selecting the best contact glass is begun. As several may have to be fitted and removed at each consultation, the conjunctiva must be anaesthetized. Holocaine (2 per cent.) is preferable to cocaine as it does not dilate the pupil. I have, however, sometimes used 2 per cent. cocaine. If more than one examination is necessary it will generally be found that a local anaesthetic need not be used except on the first occasion.

I am not sure that the most suitable solution for the fluid meniscus has yet been determined. The refractive index of the cornea is approximately $\mu = 1.376$ and that of tears approximately $\mu = 1.336$. Ringer's solution or normal saline (0.9 per cent.) is almost isotonic with tears, and my present practice is to use a 2 per cent. saline solution which at the time of examination is diluted with equal parts of hot water. This gives a warm solution approximately 1 per cent. in strength. Some patients find, however, that after 3-4 hours' wear this solution becomes turbid. Ridley has recently pointed out that tears have a relatively high protein content, and it is possible that the addition of a certain percentage of serum would be an improvement. I have tried this on some occasions but have not been able to satisfy myself that there was any advantage over the simpler solution.

The glass may be inserted as follows:—A small rubber sucker is applied to the convex surface to pick up the glass, which is then held vertically by the attached bulb and filled quite full with saline. The patient leans forwards until his face is almost horizontal, and while he is in this posture the surgeon controls the eyelids with the fingers of his left hand and directs the patient to look at the glass. The contact glass containing saline must be kept level and gradually apposed to the cornea. The lower rim is first inserted into the inferior fornix and as the fluid touches the cornea both lids are swept over the glass by the left hand and the suction bulb removed. It is not always easy to control an involuntary movement of the lids or of the head. Every ophthalmic surgeon is familiar with the type of patient

known as a "squeezer," and it is squeezing rather than blinking that causes trouble. The following two precautions help—the fluid should be warm and the approach to the cornea gradual and gentle. When a movement of either kind occurs part of the fluid gets spilt and a bubble of air appears between the cornea and the glass. This necessitates the glass being removed, refilled, and reinserted. With practice, however, this accident should become comparatively infrequent. Once the important matter of the correct scleral fit has been decided there will rarely be difficulty with the bubble. Its presence usually means that the glass is too flat.

In a recent communication Mr. Affleck Greeves has described an alternative method; "the surgeon stands behind or beside the patient, who may either lie on a couch with his head on a low pillow, or may sit in a chair which supports the head with a head-rest . . . the patient is told to look slightly upwards and inwards, and the empty contact glass, held by means of the sucker in the surgeon's right hand, is inserted into the lower fornix, the surgeon depressing the lower lid slightly for that purpose with his left thumb. With his left hand the surgeon now steadies the patient's upper lid in order to prevent blinking, and while he holds the contact glass close to the globe, but not quite against it, with his right hand, an assistant allows saline to drip from an undine into the space between the contact glass and the globe. The space becomes quickly filled (the fluid remaining in it by capillary attraction), and when this is accomplished the surgeon gently applies the contact glass to the globe, at the same time allowing the upper lid to fall over the upper margin of the glass. Removal of the sucker concludes the operation."

During the examination the patient should be encouraged to insert the glass himself. It is surprising how quickly he learns to do so. I may add that after a little practice it is not difficult for either surgeon or patient to insert a contact glass without a sucker. The glass is removed by means of the sucker. The latter is pressed firmly on the centre of the cornea until it adheres. The patient moves the eye towards the nose and at the same time sweeps the glass towards the outer canthus, or *vice versa*. The surgeon as a rule can easily remove it by dislocating it from its position by means of manoeuvres of the lids.

Two separate and distinct determinations have to be made during the examination and of these the first is by far the more important:—(1) the exact fit of the scleral brim; (2) the refractive power. It will be seen in the section dealing with the optical theory of correction that the refractive power is a comparatively simple determination. Very great care, however, must be taken to ensure the accuracy of the scleral fit. It is probably fair to say

that the prescribing of contact glasses is not so much an optical problem as an orthopaedic one. Good vision depends entirely on corneal curvature, but comfort depends on scleral curvature, and in the last analysis it is comfort that determines whether a glass shall or shall not be worn. Every effort must be made to get the scleral fit as exact as possible and no glass should be prescribed until all doubt on this point is removed. The procedure is simple. The surgeon selects one of the three standard types of scleral measurement and, having placed the glass in position, makes a careful examination by the aid of a good light and condensing lens. An accurate fit is indicated by a complete zone of adhesion near the limbus. If contact is greater at the edge than at the limbus the rim will rub, irritate, and become intolerable. Examination by means of the slit-lamp and corneal microscope should be made in doubtful cases, but as a rule with good focal illumination and a loupe the correct scleral fit can be determined. It may happen that none of the three standard scleral curves fits the particular eye. For example, a 12 mm. glass may be too tight and a 13 mm. too wide. In such a case a 12.5 mm. radius will probably answer and should be prescribed.

Having settled the matter of scleral fitting the second problem, correction of the ametropia, remains to be considered. It is more convenient to discuss this in the section dealing with optical theory, but the general principle is to find the contact glass which gives the best distance vision and then add plus or minus spheres in a trial frame to see whether the vision can be still further improved. With a contact glass there is no corneal astigmatism. The effect of the fluid meniscus between the cornea and the glass is that the cornea as an optical entity disappears. Except in later life, when senile changes occur in the lens, astigmatism in otherwise normal eyes is practically always corneal.

Where spherical additions are necessary it is important to ascertain another measurement, the distance between the vertex of the contact glass *in situ* and the back of the sphere in the trial frame. This can be estimated with the Wessely keratometer. The following is a simpler method. The sphere is removed from the trial frame and a pin-hole diaphragm is substituted at exactly the same distance and accurately centred to the vertex of the contact glass. The measuring instrument* (Fig. 3) consists of a stainless steel ruler graduated along one side in millimetres, on the other in half-millimetres. A slot is cut in the scale to take a sleeve through which slides a fine metal rod. The rod can be made to project beyond the end of the rule and its other end is bifurcated

* This instrument can also be used for taking measurements for Gonin's operation for retinal detachment. It is made by Messrs. Weiss & Son, Ltd., 287, Oxford Street, W.

to form two pointers, one of which registers millimetres, the other half-millimetres. To take the measurement; the end of the ruler is placed against the diaphragm and the rod pushed through the pin-hole until it touches the contact glass. The degree of projection, recorded by the pointers, is read off the scale after the manner of a depth gauge. The accuracy of the method is not so great if plano-convex and plano-concave spheres are not available. This completes the data necessary for writing the prescription. They are:—(1) the scleral radius; (2) the corneal radius; (3) the amount (in dioptres) and sign of any additional correction; and (4) the distance in millimetres between the posterior spherical vertex and the contact glass vertex. With regard to (3) it is said that additional spheres ought not to be higher in power than about 4 D., otherwise the contact glass would become too heavy. It is often

FIG. 3.

advisable, however, for reasons which are discussed later, to employ much higher spherical additions. The increase in weight does not appear to cause much inconvenience.

After the prescription has been dispensed the patient attends again in order to practice putting in the glass and taking it out under the surgeon's supervision. He is advised to wear the glasses for a few hours only at first, gradually lengthening the period until he can wear them all day without discomfort. They must always be removed at night.

The presbyope will require either a separate pair of contact glasses for close work or a pair of spectacles embodying his presbyopic addition to be worn in conjunction with his contact glasses for distance. The latter is much more convenient.

OPTICAL THEORY.

In contrasting contact glass correction of ametropia with ordinary spectacle correction the optical problems that call for consideration are very numerous. In order to avoid the somewhat unprofitable discussion of purely theoretical aspects, it seems best to select for consideration a single relevant problem and study that under both conditions. Among the phenomena that occur

when an optical instrument is associated with the eye, that of size of retinal image and the factors which influence its variation are points of practical interest:

A factor of importance in this connection is that of displacement, by measures of optical correction, of the cardinal points of the eye. If it can be shown that contact glass correction of the several varieties of ametropia involves a minimum displacement of cardinal points, in other words, a minimum departure from the optical conditions of the normal eye, then its superiority, from the purely optical point of view, over other methods of correction, *i.e.*, spectacle correction, may be regarded as established.

In this discussion I propose to accept the values and attempt to follow the methods advocated by the late Prof. Gullstrand, although I am aware that neither one nor the other has received full acceptance in this country or America. Mr. A. S. Percival, who is our greatest English authority, has criticized both in the last edition of his admirable "Prescribing of Spectacles." The general conclusions, however, remain unaffected irrespective of the method used.

THE SIZE OF THE RETINAL IMAGE.

The apparent size of an object is measured by the visual angle which it subtends at the eye. Variations in the size of this angle and consequently of the retinal image, give rise, among other effects, to certain disturbances of monocular appreciation of perspective which are of practical importance. The point in the eye at which the visual angle is measured must be defined. It may be referred, for example, to the first principal point or to the first nodal point, but in discussing perspective it is customary to refer it to the centre of rotation of the eye, since through this point in the moving eye all the principal rays necessarily pass.

The diagrams (Fig. 4) show this angle in eyes corrected by plus and minus lenses. In the case of a myopic eye the angle W formed by the principal ray with the optic axis in the object space is larger than the angle W' in the image space, whereas in hypermetropic eyes with lens correction W is smaller than W' . A myope, therefore, sees with his correction objects subtending an angle W' at the centre of rotation which is smaller than the corresponding angle W in the same space. A hypermetrope, on the other hand, sees them subtending an angle W' which is larger than the object angle W . In order to view an object subtending a certain angle the myopic eye has to rotate less and the hypermetropic eye more than the emmetropic eye. These facts have an important bearing upon the interpretation of space relations. Objects present themselves to the myopic eye so as to

subtend a comparatively small angle with a similar result as if perspective representations are viewed from too great a distance. In the case of hypermetropic eyes the effect is similar to that produced when a perspective representation is viewed at a lesser distance. Supposing the object be a cube, the fact that the near and far faces are known to be of equal height will give an

FIG. 4.

impression of excessive depth to a myopic eye while a hypermetrope will underestimate it.

In spite of the fact that myopes nearly always maintain that glasses cause them to see objects reduced in size, the corrected myopic eye actually receives a somewhat larger image on the retina than a normal eye does. The size of the distinct image is related to the size of the image in the emmetropic eye in the inverse ratio of the refractive powers, *i.e.*, in the case of a myope corrected by -10.0 D. as $58.63 : 56.44$.*

It will be shown later that correction by contact glasses is not associated with these defects and that its superiority is particularly manifest in such cases as anisometropia, especially unilateral aphakia, where binocular vision would require differing amounts

* The value 56.44 of the total refraction is a consequence of assuming the position of the principal point of the correcting lens (-10.0 D) to be 12 mm. in front of the corneal vertex.

of deviation for the two eyes. It hardly seems necessary to assert that, although the ordinary user of spectacles soon becomes accustomed to disturbances such as those just described, there are occasions when a swift and accurate judgment of distance is of grave moment and even a slight miscalculation may be fraught with serious consequences. Driving a car at high speed or landing an aeroplane are examples.

THE CARDINAL POINTS.

From the standpoint of geometrical optics the eye is a system of spherical refracting surfaces of different indices of refraction centred more or less accurately upon an optic axis. To trace the path of a given incident ray through such a system and to find the position and size of the image of an object produced by paraxial rays incident upon it, there is available the method introduced by Gauss. This method consists of replacing the series of surfaces and media by a system of six cardinal points and planes, by means of which graphic determinations become relatively simple. The refraction of the eye is estimated by the convergence of paraxial rays incident upon it when the image is sharply focussed at the retina, and this measurement may be taken at any cardinal point. Owing, however, to the simpler form of the equations involved it is convenient to refer the measurement to the first principal point of the eye. Further, as the two principal points are so close together in the eye, no great error is introduced if we sometimes regard them as co-incident and speak only of one principal point. It is well also to remember that principal point refraction, as it is called, is different from and always algebraically more than spectacle refraction, a value which is estimated at the principal point of the correcting lens. The latter, following Hess, is often called the corrective value of the refraction.

AXIAL AMETROPIA.

In considering the case of pure axial ametropia corrected by a non-refractive contact glass and a fluid meniscus of certain thickness, we shall assume that the individual optical parts of the system are surrounded by air, *i.e.*, an infinitely thin layer of air separates the contact glass from the fluid lens and the latter from the cornea. This assumption enables us to ignore the non-refractive contact glass entirely in order to ascertain the power of refraction and the position of the principal points, and to take account only of the fluid meniscus.

It is convenient to tabulate the following expressions :—

Vertex of cornea	- - - - -	S
Vertex of fluid meniscus	- - - - -	V
Radius of curvature of inner surface of contact glass	- - - - -	r_H
Radius of curvature of outer surface of contact glass	- - - - -	r_K
Radius of curvature of outer surface of cornea	-	r_C
Thickness of fluid meniscus (assumed = 0.5 mm.)	-	d_T
Refractive index of fluid meniscus	- - -	n_T
Refractive power of fluid meniscus	- - -	D_T
Principal points of fluid meniscus relative to air	- - -	$H_T H'_T$
Principal points of Ametropic eye	- - -	$H_A H'_A$

The refractive power D_T of the fluid meniscus is as follows :—

$$D_T = \frac{(n_T - 1) [r_C - r_H + \left(1 - \frac{1}{n_T}\right) d_T]}{r_H r_C} \quad (1)$$

If the refractive power of the outer and inner surfaces of the fluid meniscus be represented by

D_{TH} D_{TC} , then

$$D_{TH} = \frac{(n_T - 1)}{r_H} \text{ and } D_{TC} = \frac{(1 - n_T)}{r_C} \quad (2)$$

Thus, it is possible to indicate the positions of the principal points H_T and H'_T .

$$VH_T = \frac{d_T D_{TC}}{n_T D_T} \text{ and } SH'_T = \frac{-d_T D_{TH}}{n_T D_T} \quad (3)$$

If the refractive power of the ametropic eye be assumed to be $D_A = 58.64$ Dioptres and the positions of its principal points $SH_A = 1.348$ mm. (in air) and $SH'_A = 1.602$ mm. (in the vitreous), by ascertaining the distance (in air) between the principal points H'_T and H_A as

$$\delta = SH_A - SH'_T = 0.001348 \text{ mm.} + \frac{D_T D_{TH}}{n_T D_T} \quad (4)$$

then the refractive power $D_{TA} = D_{HTA}$ of the whole system and the positions of its principal points H_{TA} , H'_{TA} can be calculated. Thus

$$D_{TA} = D_T + D_A - \delta D_T D_A \quad (5)$$

$$\text{and } H_T H_{TA} = \frac{\delta D_A}{D_{TA}} \text{ and } H'_A H'_{TA} = \frac{-n \delta D_T}{D_{TA}} \quad (6)$$

n being the refractive index of the vitreous.

This determines the distance of the first principal point H_{TA} of the system from the first principal point of the fluid meniscus T and the distance (in the vitreous) of the second principal point H'_{TA} of the system from the second principal point H'_A of the eye. The distance of the principal points H_{TA} , H'_{TA} of the system from the corneal vertex is as follows :—

$$SH_{TA} = VH_T + H_TH_{TA} - d_T \text{ and } SH'_{TA} = SH'_A + H'_AH'_{TA} \quad (7)$$

As indicated in the table the thickness of the fluid meniscus T has been assumed as $d_T = 0.5$ mm. but even in the case of other

FIG. 5.

values, e.g., from 1.0 to 0.0 mm. there would be only a negligible change in the image.

These results are easily followed in von Rohr's graphic representation (Fig. 5). The corneal vertex is represented by the vertical line S and the anterior and posterior focal planes F_{TA} and F'_{TA} are drawn to scale representing a series of contact glass radii from 6 to 18 mm. and a range of ametropic refraction values of from + 12.5 D. to - 25.0 D. The scale used is shown on the emmetropic line ($A = 0$) corresponding to a cornea of radial curvature 7.7 mm.

When the positions of the principal points H_{TA} , H'_{TA} are plotted out for the entire series it is seen that the resulting curves deviate very little from the perpendicular throughout. Compared with the schematic normal eye there is found a slight anterior shift in hypermetropia and a slight posterior shift in myopia. If the curves of the anterior and posterior foci are compared it is seen that this shift practically corresponds with the antero-posterior differences in length of the corrected eye, so that it is legitimate to conclude that contact glasses, unlike spectacles, correct ametropia, not by shifting the principal points but by altering the refractive power.

The comparison in this respect between spectacle correction and contact glass correction is strikingly demonstrated in the diagram, where the dotted lines F, F', H, H' represent the anterior and posterior foci and the two principal points of a spectacle corrected system. The spectacle lens is assumed to be infinitely thin and placed at the anterior focal plane, viz., 12 mm. in front of the corneal vertex. The dotted line F' is superimposed upon F_{TA} because of necessity the posterior focal plane in both methods of correction must be at the fovea. The relatively considerable change in position of the principal points in the spectacle corrected eye is apparent if one compares the dotted curves H and H' with those of H_{TA} and H'_{TA} . In accordance with this difference of principle between contact glass correction and spectacle lens correction, there follows that dissimilarity in the sizes of the retinal images, produced by the two methods, which underlies the faulty appreciation of perspective and judgment of distance associated with the latter.*

MAGNIFICATION OF THE RETINAL IMAGE.

In contact glass correction magnification of the retinal image is a result of two factors:—

- (a) That of the afocal contact glass,
- (b) That of the fluid meniscus in conjunction with axial length.

(a) In the case of an afocal contact glass, whose refractive index is $n_H = 1.516$ and thickness $d_H = 0.5$ mm. by applying formula (1), viz.

$$D_H = \frac{(n_H - 1) [r_H - r_K + \left(1 - \frac{1}{n_H}\right) d_H]}{r_H r_K} \quad (8)$$

we get

$$r_K = \frac{r_H - (n_H - 1) d_H}{n_H} = r_H + 0.170 \text{ mm.} \quad (9)$$

The magnification V_H is equal to the ratio between the two radii of curvature of the contact glass r_K and r_H .

$$\text{Thus, } V_H = \frac{r_K}{r_H} = \frac{1 + (n_H - 1) d_H}{n_H r_H} = \frac{1 + 0.170}{r_H} \quad (10)$$

Therefore, the magnification V_H increases with the refractive index n_H and thickness d_H and decreases with an increasing radius

*Strictly speaking, the disturbance of perspective is due to the dissimilarity in size of the angles W and W' (Fig. 4). The angle W' however, may be taken as a measure of the size of the retinal image.

of curvature of the inner surface. Within the ordinary limits of these factors the magnifying effect of the afocal contact glass on the retinal image varies between approximately 1 per cent. and 3 per cent. over the whole range of ametropia from myopia to aphakic hypermetropia.

(b) The magnification produced by the altered refractive power V_{TA} resulting from the fluid meniscus in conjunction with axial length.

$$V_{TA} = \frac{D_A}{D_{TA}} = \frac{D_A}{(D_T + D_A - \delta D_T D_A)} \quad (11)$$

The dependence of the magnification value V_{TA} on the relationship between the contact glass radius of curvature r_H and the refraction A becomes clear in the diagram (Fig. 6) where curves are drawn to show the effect of an afocal contact glass; of a system comprising fluid lens and eye; and of thin spectacles worn 12 mm. from the corneal vertex.

These curves demonstrate that the value V_{HTA} , that is, the product of the value of the afocal contact glass magnification and of that due to the altered refractive power, increases in the case of $A = -20.0$ D. to 1.5 and decreases in that of $A = +9.0$ D. to 0.9. Highly myopic eyes would gain, therefore, a magnification of the retinal image equivalent to 50 per cent. as compared with normal

FIG. 6.

vision and highly hypermetropic eyes a reduction of up to 10 per cent. In other words, compared with spectacle correction myopic eyes would gain much greater acuity of vision from contact glasses, while hypermetropic eyes would suffer a slight reduction. This result is achieved without any disturbance of perspective. In eyes corrected by contact glasses the angle W (Fig. 4) remains unaltered ($W = W'$ for myopic, hypermetropic and emmetropic eyes).

In the event of a contact glass not being afocal but possessing a definite refractive power as a consequence of its outer surface being ground to have the properties of a plus or minus lens, the problem resolves itself into that of an afocal meniscus plus a positive or negative thin lens. The close apposition of this thin lens to the fluid meniscus prevents any great displacement of the principal points of the system, and the results arrived at above are still correct.

INDEX AMETROPIA.

The same fact, viz., negligible displacement of the principal points, applies also in the case of curvature or index ametropia, so that the degree of magnification of the retinal image defined in formula (11) differs but little from the unit value. In the particular instance of corneal astigmatism neutralization by the fluid meniscus results in equalization of the curvature deviation of the two principal sections. Both assume the same refractive power and exact the same positions for the principal points, thus ensuring a practically undistorted image such as is unattainable with spectacle correction. A problem of clinical importance, which has been exhaustively studied by Erggelet, arises in connection with corneal astigmatism corrected for near vision, viz., the relationship between the internal effort of accommodation and its external result. The disparity between the two reaches its highest degree in cases of mixed astigmatism but, as it is present in all varieties of ametropia, it will be considered in the next section.

ACCOMMODATION.

It is known that the act of accommodation causes very little displacement of the principal points of the eye. In Gullstrand's schematic eye the effect of accommodating 10.0 D. causes about 0.45 mm. backward displacement, and a difference of 0.5 mm. may be regarded as within the normal limits of error. The increase in refractive power of the crystalline lens of the eye during accommodation displaces to a negligible degree the principal

points of the system (contact glass + fluid meniscus + ametropic eye).

Early in 1925 Percival drew attention to a curious point which had often been suspected clinically but never fully understood. It is well known that convex spectacles worn for distance correction in the usual position, *i.e.*, 12 mm. in front of the corneal vertex, have the same effect as stronger lenses in contact with the cornea, while the reverse is true of concave lenses. Percival proceeds to show that for near correction this is no longer true. The spectacle lens, convex or concave, worn 12 mm. from the cornea, has greater power in every case than that of the same lens in contact with the cornea. The position is as follows. When the same correction is used for all purposes, the spectacle lens at 12 mm. has higher effectivity than a correcting lens when used for reading. To be effective for near work the power of the lens must be increased. This applies to plus and minus lenses.

In simple astigmatism, therefore, a stronger cylinder will be necessary for reading, especially in the case of high cylinders. This applies, however, only to simple astigmatism; it does not apply when sphero-cylindrical combinations or presbyopic additions are necessary. If +3.0 D. is the presbyopic correction, the + 3.0 D. "merely forms an image at a distance of the object (at 1/3 m. distance). Hence, no modification in the cylinder will be necessary, for the cylinder already found by trial that corrects the astigmatism for distance will still correct the error for reading." When no presbyopic addition is made, *i.e.*, when the same spherical correction is used for near work, the cylinder must be increased. Alteration of the spherical component may be neglected because for practically all purposes any spherical addition can be found by trial. When no spherical addition is required, approximately about 9 per cent. of the power of the lens required for distance must be added to produce the same effectivity when used for close work.

Later, in the same year, Erggelet drew attention to a discrepancy between the internal effort of accommodation and its external result in eyes corrected for ametropia. The following experiments should make the position clear.

A reduced schematic eye is set for emmetropia and a lens of + 4.0 D. added to it. This imitates an internal accommodative effort of 4 dioptries which would produce on the retina a sharp image of an axial object situated at a distance of 25 cm. The reduced eye is now lengthened so as to make it myopic and its ametropia corrected by placing a thin correcting lens at the usual distance of 12 mm. in front of the refracting surface. When the + 4.0 lens is again added, the eye is found to be focussed not for the same point as before but for a nearer one; in other words the

act of accommodating 4.0 D. (the internal effort) has produced a greater effect (the external result). A similar experiment with a shortened axis, simulating hypermetropia, produces a contrary effect. The practical importance of this is obvious in a condition such as mixed astigmatism corrected by a sphero-cylindrical combination placed 12 mm. from the corneal vertex, for whatever the internal effort the eye may make, it will be focussed in the primary section for a shorter distance and in the secondary section for a greater, or *vice versa*. In other words, in an eye whose astigmatism is fully corrected for distance, the astigmatism inevitable reappears during accommodation for near objects.

The experiment may be carried further by placing a thin correcting lens apposed to the refracting surface of the ametropic reduced eye so as to reproduce roughly the condition of a contact glass. The eye will now be found to focus with a + 4 D. lens in every case for the same near point as when adjusted for emmetropia.

If the relationship between the power of accommodation and its external result be

$$\mathfrak{A}_k = A_k \mathfrak{R};$$

in contact glass correction this becomes

$$\mathfrak{A}_k \approx A_k; \mathfrak{R} \approx 1,$$

That is, the external accommodative result becomes almost equal to the internal accommodative effort and the factor of accommodation assumes values in the neighbourhood of 1. In comparison with spectacle correction this assists the hypermetrope on whom the discrepancy between effort and result has a disturbing effect, and to some extent handicaps the myope. The effect on the astigmatic is even more favourable.

APHAKIA.

This important variety of curvature ametropia may now be considered. Taking Gullstrand's values for the average radii of the corneal surfaces, viz., 7.7 and 6.8 mm. respectively and the refractive power D_A of the aphakic eye as that of the cornea, i.e., 43.05 D., the principal points will lie about 0.05 to 0.0505 mm. in front of the corneal vertex. The focal distance on the image side corresponds to the axial length l . The magnification of the retinal

image $V_{HT\bar{A}}$ in comparison with that of the normal eye is approximately $58.64 \times l \times V_H$. The comparison in regard to size of image between contact glass correction of aphakia and spectacle lens correction is shown graphically in Fig. 7. The curve $V_{HT\bar{A}}$ shows that for values over $+17.5$ D. there is actually a diminution in size of the retinal image under contact glass correction. With diminishing amounts of aphakic hypermetropia there is a gradual increase. The curve $V_{B\bar{A}}$ for spectacle correction remains relatively

FIG. 7.

level throughout and roughly represents a 25 per cent. enlargement.

Practically this means that in unilateral aphakia where the other eye has useful vision binocular fusion becomes possible. The difference in size of the retinal images of the two eyes in aphakic anisometropia is not, however, the principal cause of diplopia. Where the power of fusion is normal the eye can fuse at least 10 to 20 per cent. of difference. The chief difficulty arises from displacement of the image by the prismatic effect of spectacle lenses of high positive value. The eye can fuse differences in size, but one eye cannot deviate, say 10° and the other 30° . With contact glasses the necessity to do so does not exist, so that diplopia cannot occur either from incongruity of size of image or from disturbances of the turning angle (*Blickwendewinkel*.)

THEORY OF CORRECTION.

The data required for theoretical correction are as follows:—

- r_H = radius of curvature of inner surface of contact glass,
- A = refractive error of the eye,
- n_T = refractive index of the lacrimal fluid, viz., 1.336,
- r_C = radius of curvature of the outer surface of the cornea.

Of these, the radius of curvature of the contact glass is known, being engraved on each trial glass. The amount of refractive error is estimated beforehand, by retinoscopy, ophthalmometry, etc. The refractive index of the lacrimal fluid is also known. With regard to the radius of curvature of the cornea, practically all authorities—Donders, Tscherning, Gullstrand—give much the same average figure, viz., 7.7 mm. Fig. 8 showing the distribution of a series of measurements, is from Tscherning.

If we assume an afocal contact glass and an infinitely thin fluid meniscus with refractive power D_T equal to the principal point

FIG. 8.

Distribution of corneal measurements (Tscherning).

refraction A of the ametropic eye, *i.e.*, $D_T = A$ and $d_T = 0$, by applying equation (1) we obtain the following relation for r_H .

$$\frac{1}{r_H} = A (n_T - 1) + \frac{1}{r_C} \quad (12)$$

For every value of r_H it is now possible to determine a curve in the co-ordinate system r_C, A (Fig. 9). By means of this diagram it is possible to ascertain the best correcting test contact glass and also any additional refractive power that may be required.

As examples, take firstly a hypermetropic eye where $A = 8.0$ D. The horizontal line responding to $+ 8.0$ D. meets the vertical line representing a corneal radius of 7.7 mm. exactly on the curve 6.5. In this example, therefore, the eye is fully corrected by a test afocal contact glass $r_H = 6.5$ mm.

Again in the case of a myopic eye $A = - 3.0$ D. and r_C , determined by the ophthalmometer, = 8.1 mm., the point of intersection is 1.0 dioptré distant from both the 8.5 and the 9.0 curves. This eye, obviously, can be fully corrected by an 8.5 test glass plus

FIG. 9.

an additional refractive power of -1.0 D. or by a 9.0 glass with a $+1.0$ D. addition.

With the higher degrees of myopia and to a lesser extent with the higher degrees of aphakia a wider range of contact glasses is available as a basis on which a full correction can be prescribed by appropriate refractive corrections.

This is a great advantage. It is not always wise to prescribe the

contact glass that most closely approximates full correction. The larger the radius of curvature of the corneal portion of the glass, *i.e.*, the flatter the glass, the more likely it is to come in contact with the cornea. Numbers 10 and 11 often touch the cornea. When this occurs the cornea becomes deformed to assume the shape of the inner surface of the contact glass, and thus a correction is made. Contact glasses, both blown and ground, often press keratoconus flat, and no harm appears to be done. I have examined a patient who has worn blown contact glasses for conical cornea for 15 years, and although examination with the slit-lamp showed definite pressure on the apex of the cone, no sign of damage could be detected. It is just as well, however, to avoid contact with the cornea, and the aim in prescribing should be to utilise a contact glass with a corneal radius as nearly as possible that of the cornea itself. The residue of error can be corrected by super-imposing a lens of sufficient power on its outer surface. Failure to observe this principle explains the inability of many patients to become accustomed to their glasses.

The method here described can also be applied to astigmatism. The ametropia is estimated for one of the principal corneal sections, whether the primary or secondary is theoretically unimportant, and the appropriate contact glass determined in a similar manner. In the case of irregular astigmatism due to conical cornea or corneal nebulae it is best to fit a trial glass at random and test subjectively with convex and concave spheres until the maximum visual acuity is reached. The number of dioptres added is traced on the chart and the test glass whose curve most nearly corresponds is substituted. Plus or minus spheres are again added until a satisfactory correction is obtained. Occasionally a practical difficulty presents itself during subjective tests. Certain cases of both regular and irregular astigmatism, especially those of high degree, and even cases of axial ametropia, particularly hypermetropia, have defective form vision even when accurately corrected. It requires a good deal of experience to decide in those cases the best contact glass correction.

In the construction of the chart (Fig. 9) an infinitely thin fluid meniscus, $d_T = 0$ has been assumed. This assumption introduces a small possibility of error, which, however, is afterwards neutralized by the subjective test.

USES.

I propose to review the subject matter of this section briefly and inadequately. I do this deliberately because, although it is certain that contact glasses have great possibilities, my own experience is not sufficiently wide to enable me to foresee where

exactly their future lies, and I doubt if that of anyone else is. Various factors complicate the issue, among others the psychological one. It may happen that the psychology of the British people will prove to be on the whole unfavourable. At present contact glasses are a novelty. This fact attracts some and repels others. When the novelty has worn off and their use has become more common it may be that many who are now repelled will be willing to wear them. A good many at present undoubtedly find something rather repulsive in the idea of inserting a glass in the eye. There is the fear of discomfort and the fear that it is not safe. The latter I believe to be unjustified. A contact glass, owing to its position in the orbit, is well protected from injury, much better than a spectacle lens. Should one be broken *in situ*, the risk of penetrating the cornea is small. An illustration will make this clear. If a thin cover glass, such as is used for microscope slides, be placed on the back of the hand and shattered by a blow, the skin will probably escape injury. If, however, a cover glass is fixed an inch away and then broken by a blow that tends to drive the particles along the direction of force towards the hand, the chances are that some of the fragments will be driven into the latter. The former example is analogous to the contact glass; the latter to the spectacle lens.

It will require a much more extended use of contact glasses than obtains to-day before we know what percentage can wear them all day without discomfort. Undoubtedly many people do. On the other hand, a fair percentage appears to be unable to tolerate them for more than 3-6 hours daily even after prolonged trial. I do not think this is always the fault of the contact glass. I suspect the solution has something to do with it, or the state of the conjunctiva. The presence of even a low grade chronic conjunctivitis will often after a few hours wear render the fluid turbid and induce discomfort and lacrimation. With greater experience these and similar questions will doubtless be solved.

In the foregoing remarks certain indications for the use of contact glasses for refractive errors have either been expressly stated or are tacitly implied. Stress has been laid on the fact that their use confers on an ametrope appreciation of perspective and judgment of distance comparable to that of an emmetrope. This is true of monocular and still more so of binocular vision. By securing uniformity of size of the retinal images in anisometropia, by neutralizing corneal astigmatism, and by permitting a full range of movement of the eyes, they completely satisfy practically all the ocular conditions of binocular vision. In addition to these advantages there is the increased field of vision, which is so striking to patients, particularly high myopes, that they hardly ever fail to remark on it. I feel sure that the gain in these three

directions—monocular perspective, binocular fusion, and increased field of vision—should ensure for these glasses an extended use in certain occupations and pursuits, for example, speed-racing on land, sea and air, and many others not quite so sensational. Contact glasses so used, being maintained at the body temperature, have the additional advantage that neither fog nor rain can condense on them. Further they protect the cornea from wind and the eye from glare. The protection from the latter is enhanced by the tinted varieties.

I feel sure also that they will enter largely into sport. Even when they are tolerated only for a few hours they should prove of value in tennis, shooting, swimming, etc. Their extreme inconspicuousness, amounting almost to invisibility, should prove an attraction in other activities. The actress, for example, may wear them on the stage and the Society hostess at her receptions.

The use of contact glasses as an aid in the treatment of certain diseases of the eye is a field still largely unexplored. Prof. Heine's unrivalled experience in this connection has led him to certain conclusions which may be briefly summarized. Contact glasses, especially when tinted, are of great value in relieving certain symptoms of albinism, such as defective vision, photophobia, and even nystagmus. They may be used with advantage, for similar reasons, in cases of phlyctenular conjunctivitis associated with blepharospasm and photophobia in children. They are indicated in many varieties of keratitis, inflammatory, neuroparalytic and degenerative, and in plastic operations of the cornea they are valuable for maintaining the grafts in position. When used for the treatment of corneal ulcers continuous application of an anti-septic ointment can be secured by smearing the preparation on the inner surface of the glass. They have also been used in iritis.

In no class is the value of contact glasses more manifest than in the group of visual defects due to irregular corneal astigmatism. Examples with diffuse interstitial haze, with scattered nebulae, even cases with definite keratinization are improved, often considerably. In one case, a man with double conical cornea, vision in the better eye improved under contact glass correction from 2/60ths to 6/9ths partly. Conical cornea appears to be specially suitable for this form of correction. My own experience is confined to this one case. The condition is one that appears to be becoming rarer.

I have so far not used contact glasses for squint. I am told that there is no theoretical reason why a contact glass should not be made with a prism worked on its outer surface to neutralize convergence, and so maintain, before amblyopia develops, simultaneous vision in the two eyes. Practically, however, it would not be possible to keep the prism in its correct position.

For the stage after the onset of amblyopia an appropriate contact glass should make the perfect occluder. Its outer surface could be mottled like Chavasse glass sufficiently to cut down vision in the better eye to the necessary degree without altering its appearance. This suggestion is quite practicable, and it may prove to be of great value in the treatment of this troublesome by-product of squint.

In conclusion, I should like to record my great indebtedness to Dr. H. Hartinger and Prof. M. von Rohr, of Jena for valuable information acquired during conversations with them and from their published writings. The optical formulae in this paper are all derived from Dr. Hartinger's publications,* and have been revised by him. Prof. Erggelet, of the University of Jena, has also very kindly placed at my disposal the results of his considerable experience.

*See Zur optischen Theorie der Haftgläser. *Zeitschr. f. Ophthal. Optik*, Vol. XVIII, Heft 5 and 6, 1930.

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