ophthalmic optics files

6. THE DIFFERENT TYPES OF OPHTHALMIC LENSES
CHAPTER III

The Different Types 2/Multifocal Lenses

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These lenses are used mainly by presbyopes (emmetropes and ametropes) to give them both near and distance vision without having to change their spectacles.

The lens is divided into two distinct zones, so that the upper part offers clear distance vision and the lower, clear near vision.

These two zones are of different powers: Fd for distance vision and Fn for near vision, the difference between them (Fn - Fd) represents the reading addition (add), which compensates for a low accommodation.
Benjamin FRANKLIN in about 1760 mounted two half lenses of suitable power together to form the first bifocal. Since then, many lenses have been devised to satisfy the very varied needs of presbyopes. This booklet describes the bifocals in common use, together with their geometrical optical properties. The results of the eye/lens combination will be studied later.
The CEMENT bifocals

Any historical survey of lenses would not be complete without mentioning the cement bifocal, which is now an antique form of lens. It is the grandfather of lenses available today.

The manufacturing process involved cementing an extremely thin, small diameter lens with a razor sharp edge to the back surface of a lens that was intended for distance vision. The surfaces for cementing must, of course, have the same radius of curvature. The power of the small lens, know as the “wafer” corresponded to the reading addition. The components were joined with Canada balsam which softens at about 40°C. Canada balsam is still used in the manufacturing of instrument lenses.

The main manufacturing difficulty was to surface the segment without chipping the rather delicate edge.

The disadvantage experienced by patients was that, in the cold weather, the segment frequently came away from the main lens.
Lens Types

The method of bifocal manufacture depends on the type of material used, i.e., glass or plastic.

**Glass Bifocal Lenses**

There are two types of glass bifocal - solid and fused which have been available for many years. Each type has its own advantages.

Solid bifocal lenses were the natural progression of Benjamin FRANKLIN'S original idea. These days bifocal forms are gradually changing with the improvements in the manufacturing technology.

**Plastic Bifocal Lenses**

These are in a special category of their own, as they are produced from moulds which have had to be surfaced. The precision with which the moulds are made give the plastic lenses an excellent surface quality.

General Characteristics

The individual specifications can be found in the manufacturers catalogues. They include:
(a) the diameter of the uncut lens, e.g., Ø 65 mm
(b) the shape and measurements of the segment for near vision (Fig. 1). When the segment is shaped (e.g. flat or curved top), the description will be accompanied by the width (W) and height (H).

When the segment is round, the diameter alone gives sufficient information, eg. 22, 25, 28, 38.

- The position of the segment on an uncut lens is located in relation to the geometrical centre of the uncut. This position varies with the sources of manufacture.

To simplify the description, manufacturers often identify each lens by a name. For example, Omega bifocal - Ø 67 mm. This bifocal has an elliptical shaped segment, but it is stated as a 22 mm segment.
Method of manufacturing a solid visible bifocal

1. Selection of a suitably curved, glass blank.
2. Generating smoothing and polishing of:
   3. (a) the near vision area (N) and,
      (b) the distance area (D).
   (This process must produce a fine dividing line between distance and near portions.)
4. Surfacing of the front surface (spherical or toric).

Manufacture of the visible solid bifocal segment (Fig. 3)

The blanks are stuck to a concave tool at given angle of inclination, three at a time.
Tools can then be applied to the segment area of each lens independently.

Appearance of a solid visible bifocal lens (fig. 4)
solid bifocals (glass)
The name "Solid Bifocal" has been given to a lens made entirely from one type of material. The difference in power between the distance and near portions in obtained by surfacing two different curves on one side of the lens. This creates a dividing line between the distance and near portions of the lens, which must be well-defined.
To obtain the required geometric seg inset, and facilitate accurate blank sizing. The lenses are usually rotated by 10°, insetting the reading segment towards the nose. (Fig. 6)

Visible solid bifocals
These are an older form of lens which are not so cosmetically appealing, and are therefore rarely used. The diameter of the segment is usually 22 mm or 38 mm. The optical centre for distance is situated somewhere between 2 and 5 mm above the segment top and there is always a visible step at the junction between the distance and reading portions. The segment is characteristically on the back surface of the lens. If the back surface power of the distance portion is - 6.00 D and the back surface power of the segment is - 4.00 D, the addition is + 2.00 D.

After the back surface has been finished the front surface is then worked to the required power. To centre the segment for near vision, the lenses are, as is usual, rotated by 10° towards the nose. If the lenses are spherical, this insetting is carried out when the lenses are glazed. When toric, the inset is applied at the surfacing stage. With this lens form accurate control can be applied to the prismatic effects for near vision. Cap. Fig. 6. 10° Insetting of the reading segments
Manufacture of a glass invisible solid bifocal

The invisible solid bifocal is manufactured using a moulded blank, which is about 120 mm diameter. Special tools are used to smooth and polish the central reading zone. After this zone has been finished, the distance area, surrounding the segment is surfaced. This distance curve, is steeper than that of the segment. The difference in power of these surfaces gives the required reading addition. After the rear surface has been produced, the semi finished "saucer blank", is cut so that more than one lens blank is produced. The front surface is then completed to give the finished lens the power required by the patient.

Fig. 7 shows how the semi-finished saucer blank is cut into the individual semi-finished blanks.
Solid straight top (executive) bifocal

The executive bifocal first appeared in the USA and later became popular everywhere in the world. It is often used because it offers a large reading field and also a good optical performance in the reading portion. The appearance of this lens is poor, as it has a pronounced step at the distance/near junction. The segment forms a step, usually on the front surface. This lens does not glaze well into metal or nylon supra frames due to the front surface shape. It is important that the segment dividing line is horizontal. Before this lens was introduced, it was possible to make a similar lens by cementing a segment on to the back surface of a single vision lens. This segment could also include both prismatic and astigmatic elements, making it possible to adjust the axis and power of the near cylinder.

Invisible solid bifocals (Fig. 9)

It is possible to surface a near vision segment so that there is a very fine dividing line between the distance and near portions. This lens looks cosmetically more attractive than the solid visible variety. In some respects, the optical features of this lens make it less desirable than a straight top bifocal. The image jump seen is an invisible bifocal when crossing the dividing line can be quite large and also, when the distance prescription is negative, they do not centre well for near vision.
Plastic bifocals

a) With round segments

These lenses, manufactured using moulding techniques, fit into the same category as the invisible glass bifocals. The segment diameters currently available are 22, 25, 28, 38 mm (Fig. 11).

The moulding technique can produce a semi-finished blank which is surfaced to a finished lens as required, or a finished lens ready for glazing. The moulds can be used many times.

The moulds

To produce the excellent surface quality required, the moulds must be made to a very high standard. The mould surface is produced using instrument lens polishing techniques. The precision of the curve is checked using interference. After manufacture, all moulds are heat toughened so they can withstand the strain of the polymerisation process.

A bifocal mould differs from a single vision mould, in that it has a segment curve. As the segment is usually on the front surface of the lens, a concave depression is cut into the concave half of the mould. This produces depression a convex surface for the distance portion, together with a steeper convex surface for the reading segment.

It is possible, by modifying the shape of the segment portion on the mould, to produce a finished lens that has a shaped segment, such as a curved top. (Fig. 10).
Fused glass bifocals

These lenses, invented by John BORSH in 1908, are commonly used today.

The method of manufacture

1. A crown glass blank is selected and a depression is hollowed out of the front surface, using a spherical tool. When polished to a high degree of accuracy, the surface is referred to as "the contact curve." The radius of curvature selected for this depression depends on the addition required.

2. In the finished lens, this depression curve will be filled with a glass of a higher refractive index. The next stage is to manufacture this high index component called the "button".

A piece of glass of the required refractive index (usually about 1.68) with a diameter larger than the depression, is selected. A curve is then worked on to one of the surfaces, so that it is 0.25 D steeper than the contact curve.

3. These two components are assembled on a refractory block so that the button is suspended over the depression curve.

One side is held open with a piece of copper wire that is bent in the shape of the Greek letter "alpha" (α) which is called the "feeler" and, when heated during fusing (600 °C) allows the button to sag gently into the depression curve. As the button has a slightly steeper curve, all the air is expelled and a good contact will result. After fusing, the blank is annealed by very slow cooling. After the blank has cooled, the button is brightened so that the contact curve can be checked for quality.

4. At this stage in the production, the front surface of the lens is produced in the usual way. As the surfacing process proceeds, (Figures 13 - 4 - 5 - 6,) the segment will reduce in diameter. This reduction must be controlled during the surfacing process. When the contact curve is steep, this effect is fairly small, but when the addition is low and the contact curve shallow, this effect is very marked, indeed, almost hazardous.

5. The semi-finished blank is now ready. The front surface is finished and the addition fixed. Finally the concave side of the semi-finished blank is surfaced. If there is a cylinder present in the prescription, it will be applied using a toric curve for this surface.

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Fig. 12

1 - 2 - 3 Production of a fused blank.

4 - 5 - 6 Surfacing sequence to produce a finished fused bifocal.
**Calculating the addition of a fused bifocal**

The power of the crown lens is removed to form the depression.

\[ F_{\text{Crown}} = \left( \frac{1}{R_1} + \frac{1}{r} \right) (n_{\text{Crown}} - 1) \]

The power of the same lens in Flint, which will replace the crown lens is:

\[ F_{\text{Flint}} = \left( \frac{1}{R_1} + \frac{1}{r} \right) (n_{\text{Flint}} - 1) \]

as the thickness is negligible.

The addition is \( F_{\text{Flint}} - F_{\text{Crown}} \), therefore

\[ \text{Add} = \left( \frac{1}{R_1} + \frac{1}{r} \right) (n_{\text{Flint}} - n_{\text{Crown}}) \]

e.g. what is the radius of the curvature of the contact curve to be worked on a blank with a front power 
\( F_1 = +6.00 \) D (\( R_1 = 88 \) mm or 0.088 m, \( n_c = 1.528 \))
to obtain an addition of 2.00 D (\( n_f = 1.680 \))

It follows from the above formula that:

\[ 2 = \left( \frac{1}{0.088} + \frac{1}{r} \right) (1.680 - 1.528) \]

\[ r = 0.557 \text{ m} \]

In practice, the difference in thickness of the two lenses are taken into account to obtain the required precision.

\( F_1 = +6.00 \) R₁ = 88 mm R₂ = 88 mm F₂ = −6.00

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**Fig. 14**
Fused bifocals are usually mass-produced and stocked in the semi-finished form. In this way, both spherical and astigmatic correction can be produced easily when required.

To get the best quality lenses, great care must be exercised at the different stages of manufacture:
1 – The raw materials have to be carefully chosen. In addition to the refractive index and the dispersive

power required, the crown and flint glass must also have very similar coefficients of expansion to ensure a perfect bond.
2 – There must be surgical cleanliness during the assembly stage and prior to fusing.
3 – During the heating and cooling cycle the temperature must be perfectly regulated.
4 – The quality control must be rigorous at each stage.
Manufacturer of the shaped segment fused bifocal

The initial stages of manufacture consist of two separate parts. The production of the blank into which the segment is fused. The manufacture of the composite button which controls the shape and dimensions of the finished segment.

After these two components have been made they are assembled using the fusing technique. A crown glass blank is selected and a depression is ground into it to accept the segment. The radius of the curve required is calculated using the equation found in the supplement (14) on page 12. A diagram of the blank with the depression can be seen in the supplement fig. 17. The "button" the construction of fused bifocals is always done using the same technique regardless of the segment shape. The method of producing a shaped segment differs from the production of the traditional round fused bifocal in that the button is made up of several pieces of glass of different refractive indices. Supplement fig. 16 shows how the proportion of each of the components is altered to produce the variety of segments available. The diagram shows how, the part needed for the finished segment is made of a high index glass whereas the unwanted part is made of crown glass. The crown glass of the button will fuse to the crown glass blank and vanish to become part of the distance portion.
The traditional fused bifocal shape

The round segment
This is the oldest type of fused bifocal which was relatively easy to construct. However, the optical qualities can be rather poor as the reading portion can suffer from rather obvious amounts of chromatic aberration and the patient may experience difficulties when reading as the print may be fringed with colour. As this bifocal has a circular segment there is also some image jump on entering the segment, which will increase as the reading add gets higher. This jump however is reasonable as these segments are usually only 25 mm diameter.

The "flat top" segment
In this case the upper part of the round segment which gave rise to the unpleasant chromatic aberration on the dividing line has been reduced.
This segment type is defined by its width W and height H e.g. 22 x 16.5. The dividing line between the near vision and distant vision areas is at distance h from the geometric centre of the DV portion. This distance is chosen by the manufacturer and may vary between 2 and 5 mm. The segment is displaced towards the nasal side of the blank by a distance d which is usually between 2 and 3.5 mm. As the dividing lines must always be horizontal when lenses are edged, left and right lenses have to be made. As there is only a small distance between the segment centre and the dividing line, the jump experienced is very small.

The "curved" segment
This is a recent bifocal design which is quite difficult to manufacture. It is very popular as the dividing line is less obvious than that of a flat top. This lens also has all the qualities of a Flat Top design.
Optical centre of solid bifocals

Visible solid bifocals (Fig. 21)

$C_1$ and $C_2$ are the centres of the curves for the front and back surfaces of the distance portion $O_N$ the centre of the near vision segment is on the axis connecting the two centres $C_1$ and $C_2$. Their position depends on the angle of the segment, and also on the radius of curvature on the inside curve of the segment, and the addition. In particular $O_N$, can be on the dividing line, when the lens is called a “no jump” bifocal.

Solid invisible bifocals (Fig. 22)

The centre $O_N$ is located on the $C_1$, $C'_2$ axis.
"Rectangular" segment (B seg.)

This is another version of the Flat Top bifocal, made by removing the rounded bottom part of the Flat Top segment. As can be imagined, this extends the production and slightly increases the cost price. Some opticians use this lens as it gives area of distance vision below the segment, which is quite useful when walking up and down stairs. There is obviously a slight reduction in the reading field.

Blended bifocals

The main criticism that patients have against the common types of bifocal is that, the segment is very conspicuous and betrays the wearer’s age. This has greatly hindered bifocal development, and as early as 1946, principally in the U.S.A., manufacturers have tried to solve this criticism. Their solution is called a "blended bifocal".

The manufacturers removed the dividing line by surfacing over a small area on either side of the line thereby "blending out" this region. Removing the line creates an area of poor optical quality which is accepted by some patients. A more elegant solution to this cosmetic problem is the progressive lens which is discussed in book 7.
General characteristics of bifocals

In practice the distance prescription of bifocals rarely exceed ± 6.00 D. except in some special cases, like aphakics where the prescription may be as high as +18.00 D. These powers may be combined with cylinders from 0.25 to 4.00 D. The additions usually go in steps of 0.25 D. between 0.50 and 4.50 D. Manufacturers keep finished spherical lenses and will surface the toric prescriptions using semi-finished blanks.

Whilst fused bifocals can be obtained with solid tints, it is not ideal as the button is always made of clear glass. This reduces the tint present in the segment and in this respect a vacuum may have an advantage. It should be remembered however, that some vacuum tints, notably blue, have a very short guarantee period. The most common lens spherical powers are stocked.

Experience has shown that a patient uses a near vision area in a bifocal which is about 1 to 3 mm in and 6 to 10 below the optical centres for distances (Fig. 26). The position of this area is somewhat variable and will depend on such things as: the inter-pupillary distance, the patient’s height, the nature and distance of the work, the body position and the normal head posture...

- **Near vision point**

In this, the area used for near vision is considered as a single point located 2 mm inset and 8 mm below the distance optical centre. When a patient uses a point away from the optical centre, a reduction in the optical quality is experienced. It is useful to remember that a bifocal design forces a patient to use an off axis point for near vision.

- **The near optical centre**

It is possible to design the solid visible type of bifocal so that there is an optical centre at the N.V.P. or so that prism is applied to the segment producing a lens that lighter centres well or reduces the jump.

- **Plastic bifocals**

Fig. 27 shows the N.V.O.C. is on the axis C1, C’2, C1 being centre of curvature of the front surface and C’2 the centre of curvature of the segment. The position of the near optical centre will depend on the prescription of the lens. If the concave side of the lens is −6.00 D (Fig. 27) and the reading addition is +2.00.
As the power of the front distance surface increases, $C_1$ moves towards the lens. At the same time, the near optical centre moves upwards. As the distance power of the lens increases the back surface power is reduced. The aphakic lens is an example. This causes $C_2$ and $C_2'$ to move backwards, away from the lens, whilst $C_1$ moves closer. The consequence of this is that the near optical centre can move even further up to the point when it lies outside the segment and can even coincide with the optical centre for distance.

When the distance Rx is minus the near optical centre will not lie within the segment. Indeed it lies in the distance position and as the power increases the near optical centre elevates even more.

It is impossible to consider the near optical centre in isolation as its position depends on the interaction between the distance and add components. Features which are important are the power of both the distance and add components and the relative position of their optical centre.
- **Fused bifocals**

The prismatic effect experienced by a patient at the N.V.P. is the sum of the prism from the distance and add components at that point. The prism from the distance to the optical centre (OD). The prism offered by the add is due to the power of the add and the distance from the N.V.P. to the centre of the add component (G).

- **Image jump**

The jump experienced by a patient is due to the sudden change in prism found when crossing the dividing line between the distance and near. Fig. 29.

A first time bifocal wearer may experience a slight difficulty but with some training most wearers will adjust readily. It might be advantageous to instruct a patient to avoid the dividing line in the early stages as this will speed up the way in which they learn new head and eye positions.

Chromatic aberration, which can be quite obvious in the round segment bifocals with high additions, can cause difficulties. This problem is much reduced at the dividing line when curved or flat top segments are used. The amount of chromatic aberration present relates to the "V" value.

- **Segment size and the field of view**

The field of view depends on the segment size. A patient wearing a small segment bifocal will, however, have a very acceptable field as they are able to move their head.

When considering the appropriate size for a round segment a useful rule directs that large segments should be used for the hyperope whereas small ones may be desirable for the myope as this gives better centration within the segment. However, it must be remembered that large round segments produce more jump than small ones. This rule does not apply to the shaped segments where the optical centre of the add component usually lies just below the dividing line. The shaped segment centres quite well.
Value of image jump

This depends on the distance between the dividing line and the segment centre together with the power of the addition. It is defined as the sudden change of the prism effect at the dividing line.

$$\text{JUMP} = \left( H - \frac{W}{2} \right) \text{ cm x add}$$

The following table gives a few examples:

<table>
<thead>
<tr>
<th>Add</th>
<th>ORMA/22 ROUND</th>
<th>FLAT TOP SEGMENT 22 x 16.5</th>
<th>CURVED TOP SEGMENT 25 x 18</th>
<th>FLAT TOP BIFOCAL WITH NO JUMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>1.1</td>
<td>0.55</td>
<td>0.5</td>
<td>nil</td>
</tr>
<tr>
<td>2.00</td>
<td>2.2</td>
<td>1.1</td>
<td>1.0</td>
<td>nil</td>
</tr>
<tr>
<td>3.00</td>
<td>3.3</td>
<td>1.5</td>
<td>1.5</td>
<td>nil</td>
</tr>
</tbody>
</table>

No jump lens (Fig.31)

If the dividing line passes through the geometrical centre of the segment G, there is no jump. Fig. 31.

$$\left( H - \frac{W}{2} = 0 \right)$$

Caption Fig. 31
Flat top bifocal without image jump.
Edging bifocals

General guidelines

1. Lenses need to be well centred for distance vision
2. **Account must be taken of the near centration**
3. Segments need to be set at the right height. (usually the lower margin)
Vocational multifocals

Certain professions have special visual requirements:

this is true for dentists, librarians, musicians... They may require, for example, a near vision area in the upper part of the lens, or two near vision areas, and so on.

The possibilities are numerous and manufacturer can provide several designs.

The 2 types below are quite popular.

Areas 1,2,3, can be for near vision or intermediate vision as desired, but area 1 is generally for distance vision.

Fig. 34

The upcurve bifocals Fig. 35 is manufactured by fusing 2 buttons.

Fig. 35
Depth of field of a bifocal wearer when the addition he needs exceeds his amplitude of accommodation.

For example, a bifocal wearer with an addition of +2.25 D can use comfortably 0.75 D of this total accommodation i.e. 1.50 D.

(2) The depth of clear vision through DV area extends from infinity to 1.33 m the depth of clear vision through NV area extends from 0.44 m to 0.33 m. The area laying between 1.33 and 0.44 m can not be perceived clearly through any of the optical lens areas.
Trifocal lenses

General principles

When the value of the addition required to correct a bifocal wearer, is greater than his remaining amplitude of accommodation, a zone laying between the two zones covered by the distant and near portions of the lens remains uncorrected. This uncorrected zone corresponds to our mid vision i.e., a zone laying approximately between 1 m on the reading distance.

By introducing a segment of intermediate power between the two parts of a bifocal, such a segment, offering intermediate vision (IV), must possess suitable optical characteristics so that it can be used without difficulty.

The different types and shapes of bifocal have been extended to the trifocal lens forms for general and professional use.

Contrary to common belief, the trifocal is not just used by the elderly. In fact, theorists who maintain that prolonged close work ought to keep at least half the accommodation in reserve say that wearing trifocals can be justified as from age 53, when the unused accommodation is about 1.50 D. For a presbyope needing 3.00 D. of power to see comfortably at 33 cm, an addition of 2.25 D must be used if the available accommodation is 0.75.
The different types

- **Solid trifocals** (glass)
  
  One of the most popular types, especially in the U.S.A., have dividing lines straight across the lens on the convex side of the lens. (Fig. 37)

  There are other types available but they can be more difficult to make and hence are more expensive.

- **Plastic trifocals**
  
  As with bifocals, the segments are on the front surface and obtained by moulding. The intermediate area of mould is the first to be surfaced, with a diameter, for example, of 36 mm then a concentric NV segment of 22 mm diameter is added in the centre of it. Finally the rest or the mould surface is worked after the two already polished areas have been given a protective coating (Fig. 38).

  This part of the mould will be used in conjunction with a concave spherical, or toric component to obtain the correct prescription. The lenses obtained in this way are of the invisible solid bifocal type.
Distance prescriptions range from plano to about ± 7.00 with a cylindrical correction up to 4.00 in 0.25 D. steps, with additions ranging from 1.50 and 4.00; this would be true, for example, of an ORMA round seg. trifocal.

The lens is edged with a 10° rotation of the segment towards the nasal side. This 10° rotation is taken into account, during surfacing so as not to alter the cylinder axis of toric prescriptions. The IV addition is rarely specified, by the prescriber, as this entails a special lens having to be made. If we consider, for example the following prescription is usually half of the reading addition for a trifocal lens.

RE + 1.50  add + 2.00
LE + 0.50

The IV area will have an addition of + 1.00.

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**Fused trifocals (glass)**

These differ from bifocals in that the button made of at least three different parts before being fused to the carrier.

The front surface of the blank is then surfaced to blend the various optical zones in one continuous curve.

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I. Preparation of the 3 parts of the button
II. Assembly and fusion of the button
III. Fusion of the button in the depression of the blank
IV. Surfacing the convex side to obtain semi-finished lenses

1 - is made of crown glass identical to the carrier
2 - is made of low density flint glass
3 - is made of dense flint glass
A trifocal lens has then to be completed by surfacing the concave side of the lens to the required prescription. The respective refractive indices $n_i$ and $n_v$ will determine the additions of the IV and NV areas. A fused trifocal lens can be made with curved or flat dividing lines. (Fig. 41)
Optical characteristics

These are similar to bifocals bearing in mind however, that there are now two dividing lines. As moving from distance vision now takes place via an intermediate area, the unpleasant jump at the dividing lines are somewhat less in amplitude but occur more often. Such considerations are particularly important to new wearers.

Edging
General guide

**Horizontal centring:** this is the same as for bifocals. The optical centres of the segments should correspond to the NV inter-pupillary distance. Vertical centring techniques may vary, depending on the conditions in which the trifocal lenses are to be used. Generally speaking, the top edge of the upper segment must be positioned higher than the upper edge of a near vision segment of a bifocal lens. It may be fitted at the centre of the pupil, or even be 1 mm higher. (Fig. 42). This high fitting position favours the near and intermediate vision areas, but can slightly obstruct the distance vision of the wearer if he does not drop his head. It can be recommended for prolonged close work. If the wearer uses his near and middle vision only occasionally, a lower fitting position is preferable for him to adjust to the lens rapidly, e.g. $h = 1$ mm below pupils.