Ophthalmic Optics Files

Progressive Lenses

essilor

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Summary

Introduction

Since their introduction by Essilor in 1959, progressive lenses have gained world-wide acceptance as the most suitable correction for presbyopia. Because they provide clear, comfortable, natural vision at all distances, they have gradually replaced bifocal lenses and are becoming used more and more instead of single vision lenses for near.

Today, one in four of the world population is presbyopic, some 1.5 billion people. Less than half of these presbyopes are corrected, but where they are, about 25% are fitted with progressive lenses, less than 25% with bifocal lenses and around 50% with single vision lenses. Although the precise distribution varies from country to country, the use of progressive lenses is seen to be on the increase everywhere.

With the expected growth in the population, particularly amongst the elderly, presbyopes will become even more numerous in the years to come. The market for lenses to correct presbyopia will continue to grow and the replacement of bifocal and single vision lenses by progressive lenses is certain to follow. Progressive lenses still have a good future.

This volume of the Essilor Ophthalmic Optics Lens Files series reviews the basic physiological and technical concepts behind progressive lenses from their first appearance to the most recent developments.

Fig. 1 : Presbyopes : a growing population

1.Concept
of progressive lenses

A Basic design of Progressive lenses.

A progressive lens is a lens whose power increases continuously from top to bottom, between an upper zone designed for distance vision and a lower zone designed for near vision. The increase in power is obtained by a continuous change in curvature of one or both surfaces of the lens. We will consider how this occurs by comparing the design with a single vision and a bifocal lens.

The convex surface of a single vision reading lens consists of a single sphere of appropriate radius providing, in combination with the back surface, correction for near vision only (Figure 2a). Because the lens focuses the eye for near, when the wearer tries to look into the distance, vision is blurred. Furthermore, there is no specific correction for intermediate vision which the subject will only be able to enjoy whilst there is sufficient accommodation (Figure 3a).

In a bifocal lens, a distance vision sphere is placed above a near vision sphere and linked by a single step creating a visible dividing line (Figure 2b). Note in Figure 3b, which represents a subject whose amplitude of accommodation is 1.50 D and who has been given a near addition of 2.00 D, that there is a gap in the intermediate range of vision at arm's length between 50cm and 67cm.

In a progressive lens the curvature increases at a predetermined rate between the distance and near portions providing clear intermediate vision at all distances in between. This is obtained from a succession of uninterrupted horizontal curves between distance and near, with no visible separation, so that the lens power increases smoothly from the distance zone at the top of the lens through an intermediate zone in the middle, to the near zone at the bottom of the lens (Figure 2c). The wearer benefits from continuous clear vision from distance to near (Figure 3c).

Fig. 2a : Single vision

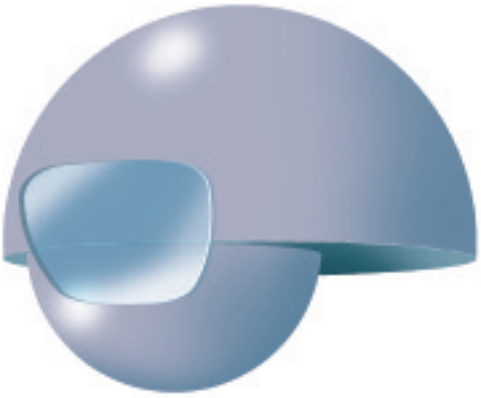


Fig. 2b : Bifocal.

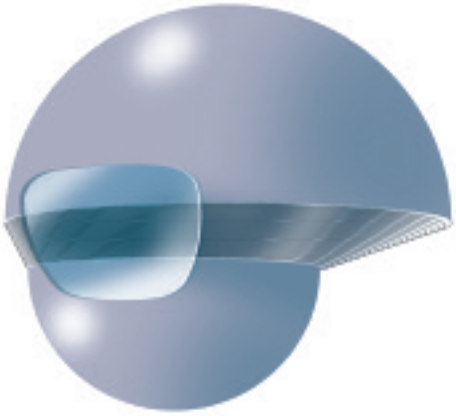


Fig. 2c : Progressive.

Fig. 2 : Design principles of single vision, bifocal and progressive lenses

Fig. 3 : Ranges of vision with

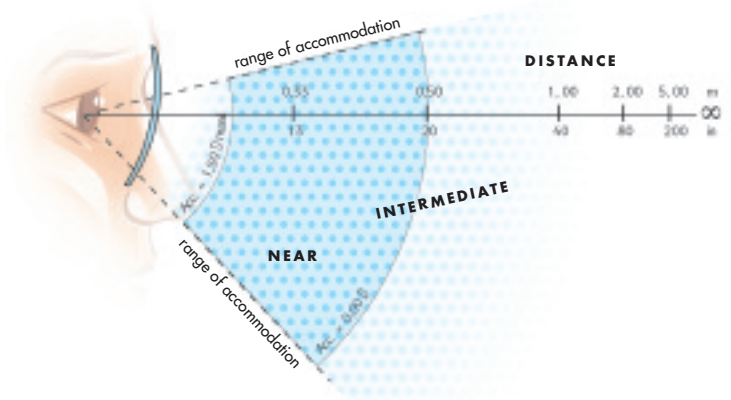


Fig. 3a : single vision lens of power +2.00

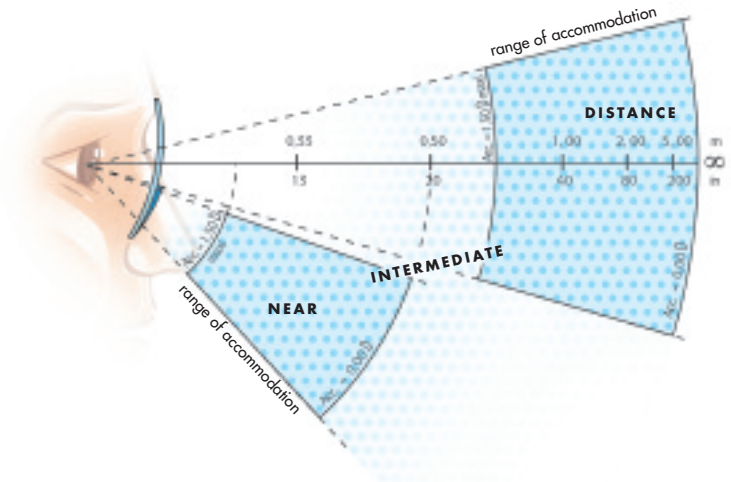


Fig. 3b : bifocal lens with 2.00D addition

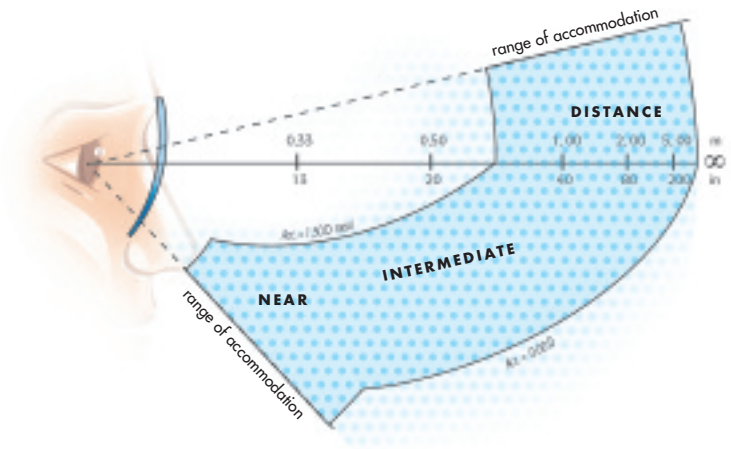


Fig. 3c : progressive lens with 2.00D addition

B Advantages of Progressive power lenses

Compared with single vision and bifocal lenses, progressive lenses offer the presbyope the following advantages :

Continuous vision from distance to near : single vision lenses offer a range of clear vision in the near area only whereas bifocal designs, with their abrupt change in power, create two ranges, one for distance and one for near vision.

Comfortable vision for all intermediate distances (50 cm to 1.5 m) since the progressive lens is the only design which has zones specifically designed for these distances. In the early stages of presbyopia (additions less than 1.50 D), the wearers of single vision and bifocal lenses may still obtain clear vision at these distances. A low reading addition, together with their remaining amplitude of accommodation, enables them to see clearly over this range. On the other hand, in later stages of presbyopia (additions over 2.00 D), clear intermediate vision is no longer possible since the remaining amplitude of accommodation is too little, and the reading addition too great, to provide clear vision at these distances. Only progressive lenses allow comfortable vision at all intermediate distances.

Continuous support for accommodation adapted for all distances : with a progressive lens the eye can find some region of the progression zone where the power is correct for the viewing distance. In the case of a single vision reading lens, vision is possible only for near vision. With a bifocal lens the eye must increase and then relax its accommodative effort as it passes through the intermediate range.

Continuous space perception is obtained from the gradual change in power across the lens. Single vision lenses do not provide real space perception since they limit vision only to the near range. Bifocal lenses divide the range into two while altering perception in the horizontal, and vertical lines appear broken and produce image jump at the dividing line between distance and near.

a) the distance zone of a bifocal lens.

b) the near zone of a bifocal lens.

c) the intermediate zone of a progressive lens.

Fig. 4 : Vision at intermediate distances

Limitations of progressive lenses :
Although progressive lenses possess many advantages they also have some limitations. In effect, due to the laws of physics, optical aberrations arise as a result of the necessary power variation across the surface. For this reason all progressive lenses have undesirable changes in spherical and cylindrical power in their lateral zones. The art of the designer is to manage and control these aberrations in every possible way taking into account the physiology of vision and using all available means for lens design and calculation.

2.Physiology of vision
and progressive lenses

Progressive lenses must not only restore the ability to see clearly at all distances, but also, must not upset the physiological relationship between foveal, peripheral and binocular vision.

A Foveal vision

This relates to all zones of the lens which are used by the eyes for tasks which require discrimination of fine detail. These zones must provide images of high quality.

Accommodation, posture and movement of the eyes:
The wearer's natural body and head positions determine the vertical rotation of the eye for distance and near vision, and therefore, the optimal length power progression for the lens. Furthermore, the coordination of body, head and eye movements, in relation to object's location in the visual field, defines the power value needed at each point on the progression.

Eye and head movements:
Likewise, the natural coordination of horizontal eye and head movements determines the field of gaze in physiological conditions and defines the width of the lens zone normally used for foveal vision (usually less than 15°).

Visual acuity:
To maximize the wearer's visual acuity in the central area of the lens the unwanted aberrations must be kept to a minimum and pushed to the peripheral parts of the lens.

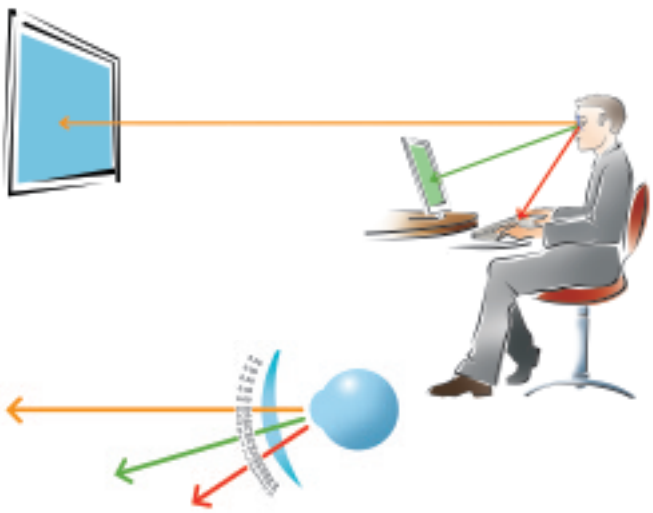


Fig. 5 : Progression of power in relation to viewing distance, head posture and eye movements.

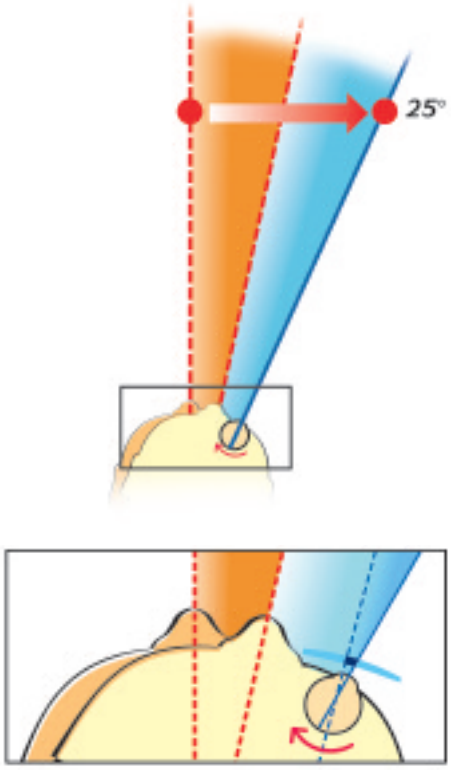


Fig. 6 : Coordination of horizontal eye/head movement and width of field.

B Peripheral vision

This refers to the visual perception provided by the periphery of the retina. In extra-foveal vision, wearers do not see objects sharply but locate them in space, perceive their form and detect their movement. It occurs principally through the peripheral zones of the lens.

Space and form perception:
Space and form perception is provided by the retina's periphery and is directly influenced by the distribution of prism on the progressive lens surface. Depending on the orientation and magnitude of these prismatic effects the power progression introduces slight deformations of horizontal and vertical lines thus altering the wearer's visual comfort.

Perception of movement :
Movement is perceived by the whole of the retina which is almost uniformly sensitive to motion. Here also, the variation in prismatic effects plays a role in the wearer's comfort where it must be slow and smooth across the whole lens to ensure comfortable dynamic vision.

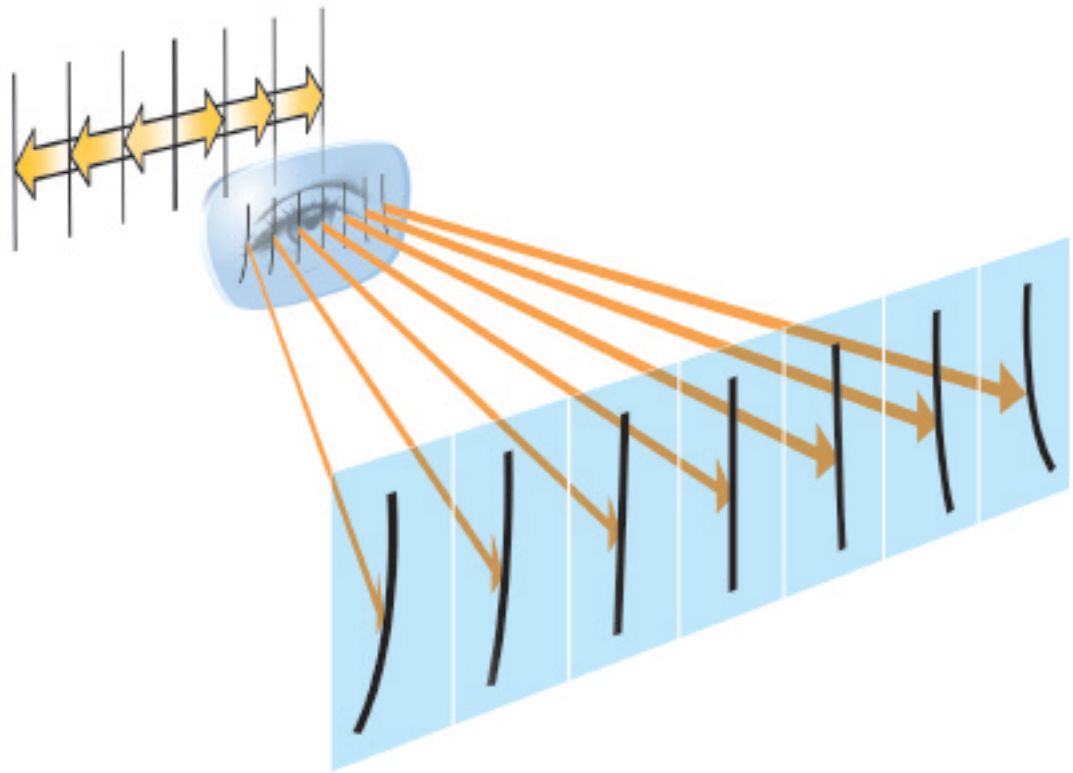


Fig. 7 : Perception of form and movement through a progressive lens.

C Binocular vision

Binocular vision includes simultaneous perception, fusion of the images and the stereoscopic sense. With a progressive lens the criterion for good binocular vision is to enable natural fusion and perception by the two eyes.

Motor fusion:
The eyes naturally converge when the gaze is lowered for near vision. The power progression must be positioned on the lens in order to follow the eye's path of convergence downwards in the nasal direction. For ease of motor fusion, in all directions of gaze both right and left lenses must exert approximately equal vertical prismatic effects on each side of the power progression path.

Sensorial fusion:
To ensure sensorial fusion the retinal images formed in each eye must be similar in all directions of gaze. To that end, the power and astigmatism encountered in corresponding areas of the right and left lenses must be approximately equal, for all directions of gaze. The concept of asymmetry of the progressive surface is for that purpose very important: the lens should be designed with a symmetry along horizontal lines, on each side of the oblique line of power progression, so as to keep approximately the same image for each eye during lateral rotation of the eyes around the intermediate and near fields.

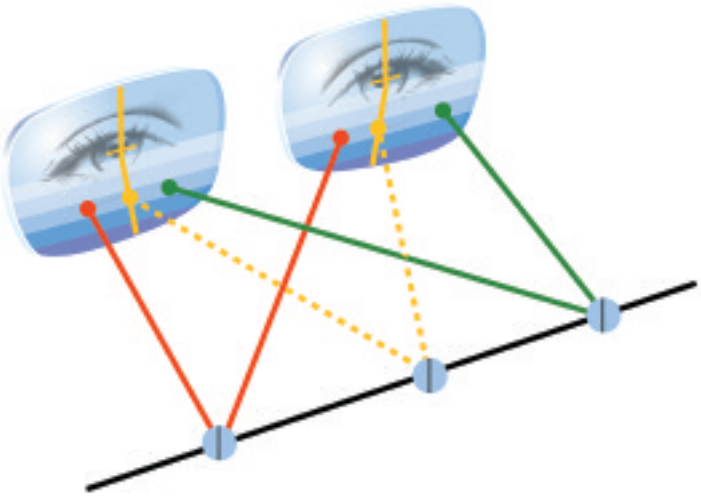


Fig. 8 : Binocular vision with progressive lenses.

The physiological criteria for progressive lenses can be defined using two different approaches:

- either by considering the average visual requirements of a large number ofpresbyopes in order to achieve a "universal" progressive design,
- or by attempting to highlight specific needs of the wearer in order to achieve a "personalized" design.

These opposite but complementary approaches are the origin of the two major categories of progressive designs which are available today, progressives for "universal use" and "personalized" progressives.

3.Design
of progressive lenses

A Principles of design of progressive lenses

1) The ophthalmic lens as an optical system

An ophthalmic lens is an optical system designed to form images of objects on the far point sphere of the eye. This imaginary sphere is conjugate with the retina of the unaccommodated eye as it rotates around the field. Instead of being sharp, the image of an object point formed on this sphere is usually blurred as a result of various aberrations of the lens.

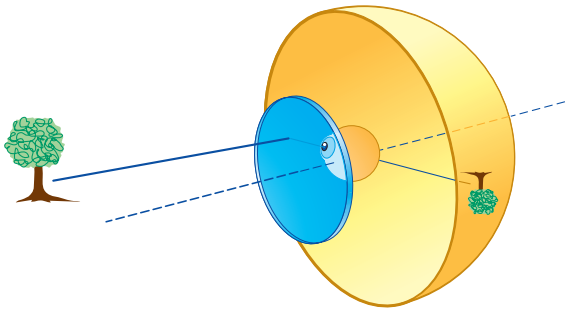


Fig. 9 : Formation of the image on the far point sphere.

To measure the quality of the image of any object point, the designer traces a bundle of selected light rays which enter the eye's pupil after passing through the lens, and calculates their intersections with the eye's far point sphere. The image quality is determined by the diameter of the blur spot formed on this sphere. Lens designers strive to improve the quality of this image by controlling the optical aberrations of the lens in the best possible way.

Next, the designers consider the quality of the image formed on the retina. To do this they must produce an optical model whose characteristics closely simulate the spectacle lens plus the eye. Although the parameters of the lens may be exactly known, those of the eye are more difficult to determine. It becomes necessary to know the powers of the cornea and the crystalline lens, their relative positions (depth of the chambers, length of the eye) and the refractive indices of the different transparent media possessed by the human eye. Average data is employed to obtain the details for an average model eye. The position and inclination of the lens in front of the eye must also be included in the calculation, information such as the vertex distance, and the pantoscopic and dihedral angles of the front (dihedral angle is the angle formed by two intersecting planes) When all the information is known, the optical system comprising both the spectacle lens and the eye can be analyzed to obtain its optical characteristics.

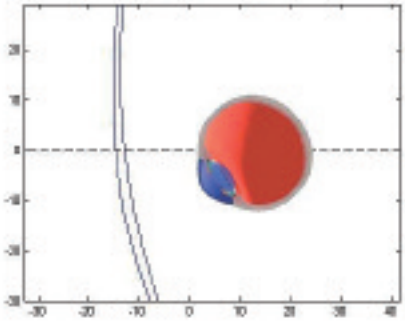
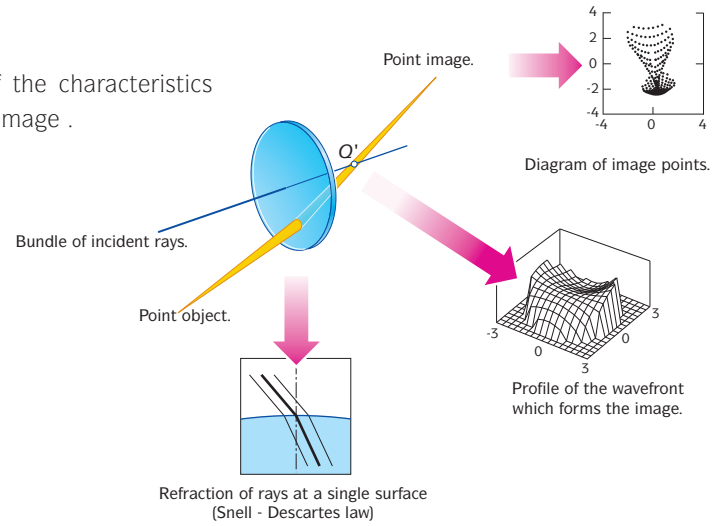


Fig. 11 : Model of the eye + lens.

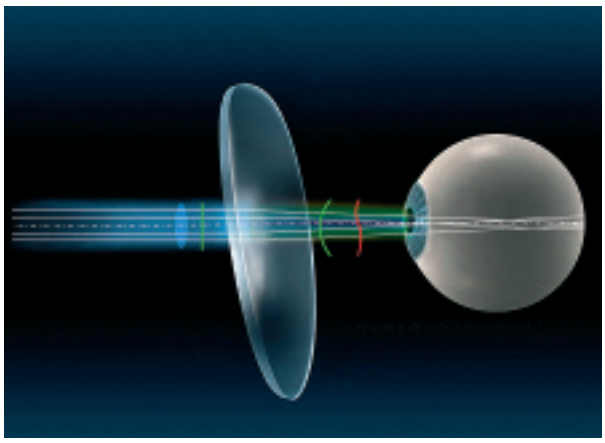
Fig. 10 : Calculation of the characteristics of the retinal image .



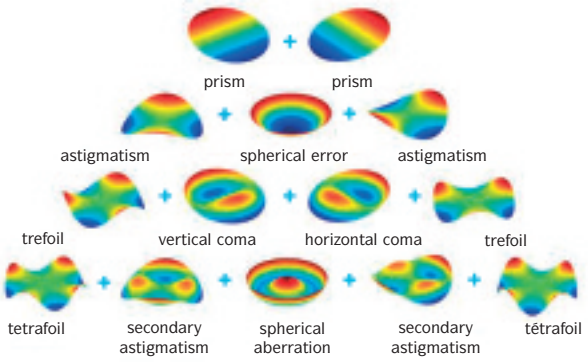
2) Wavefront technology:

This technique analyzes the wavefronts of the light passing through the lens. The principle is, for each direction of gaze, to obtain the most regular wave form possible before the beam enters the pupil of the eye. In practice, the wavefront is decomposed into the sum of elementary waves, the first element of which is the wearer's prescription and the following terms represent the optical aberrations (see Figure 12). The form of the lens surfaces are then modified to control and minimize the aberrations according to the visual requirements of the wearer. This technology has been applied for the first time in the design of the Varilux Physio" (see later).

Fig. 12 : Wavefront technology.



a) Wavefront.



b) Decomposition of the wavefront .

3) Optimization software and Merit Function

Lens designers cannot create optimized optical systems in a single step. Instead, most designers employ an iterative process using optimization software. In this process, the designer defines an initial optical system and a "Merit Function" which is used to rate the overall performance of the optical system. After rating the initial optical system, the optimization software recomputes the parameters of an upgraded system. This process is repeated until a final optimized optical system is obtained.
The Merit Function evaluates numerous points on the lens. For each point, a target value and a specific weight are assigned to each optical characteristic, power, astigmatism, prismatic components and their gradients. The Merit Function calculated at each point is the weighted sum of the quadratic differences between the set optical characteristics, Tj and actual characteristics, Aj of the system.
The overall performance of the lens is then evaluated by the weighted sum of the found Merit Function values according to the following formula:

$$\text{Merit Function} = \sum_{i=1}^{i=m} P_i \cdot \sum_{j=1}^{j=n} W_j \cdot (T_j - A_j)^2$$

where :
Pi weight for the point i
Wj weight for the optical characteristic j
Tj target for the optical characteristic j
Aj current value of the optical characteristic j

The concept of Merit Function is a classical method used for managing large numbers of partially conflicting constraints. Merit function applied to ophthalmic lenses links physiological requirements and lens calculations.

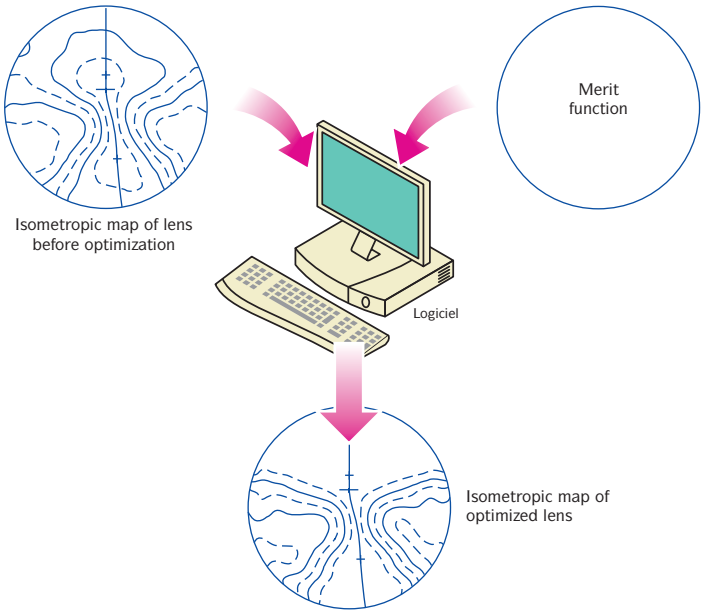


Fig. 13 : Optimization software.

B Design of progressive lenses

1) Specific optical requirements of a progressive lens

The optical characteristics of a progressive lens are defined by the visual physiology and postural behaviour of the wearer, as determined by clinical experiments. They can be divided into two categories:
- characteristics that must respect strictly determined values,
- characteristics that should be kept below given thresholds.

a) Power progression requirements

The primary function of a progressive lens is to restore near and intermediate vision while maintaining clear distance vision. Lens designers must respect distance and near vision powers but avail themselves of more freedom in defining the progression, especially:

- Vertical location of the near vision area : physiological considerations such as strain of the extra-ocular muscles, or, limited range of binocular fusion with downward gaze, require a high position of the near vision area of the lens. This is achieved by using a short power progression which, unfortunately, usually results in rapidly varying peripheral aberrations. A good compromise is to locate the near vision zone at a downward gaze angle of about 25°.

- Profile of power progression : a suitable power progression along the meridian line of the lens enables the wearer to explore the object field without tiresome vertical head movement. This is achieved by associating the shape of the power progression to the orientation of the vertical horopter (horopter is the sum of all points in space whose images form at corresponding points on the plane of the retina). linked to the natural tilting of near material.

- Horizontal (lateral) location of the near vision area : once the power profile has been defined, its positioning on the lens must be adapted to the natural convergence of the eyes, the power of the distance portion and the value of the reading addition. The natural convergence of the visual axes when the head is lowered for an average reading distance defines the inward decentration of the near vision zone. Also, visual acuity diminishes with age and as presbyopia increases, subjects tend to hold reading material closer to the eyes than they did in early presbyopia, in order to obtain some magnification of the retinal image. As a consequence, the near vision zone must be decentred further inwards with increasing near addition. Finally, the prismatic effects of the distance portion alter the position of the near visual point such that less inward decentration is required for myopes and more for hypermetropes, than when the distance prescription is negligible.

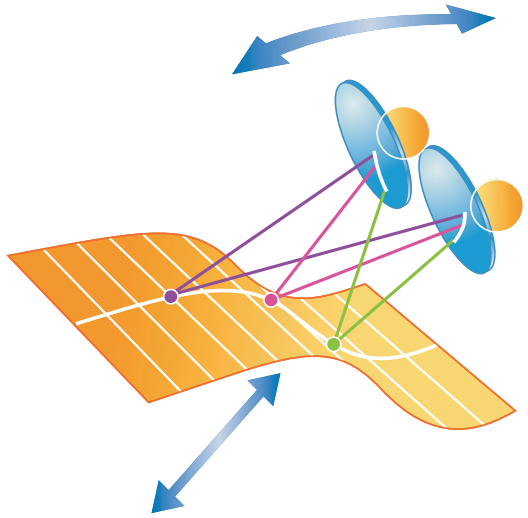


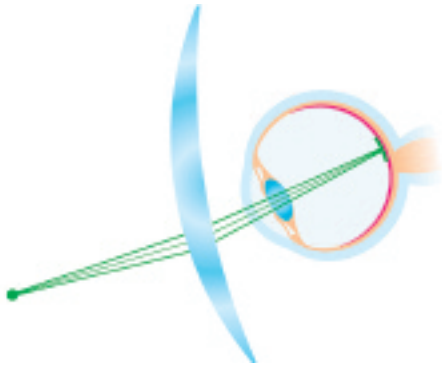
Fig. 14 : Power progression.

b) Visual perception requirements

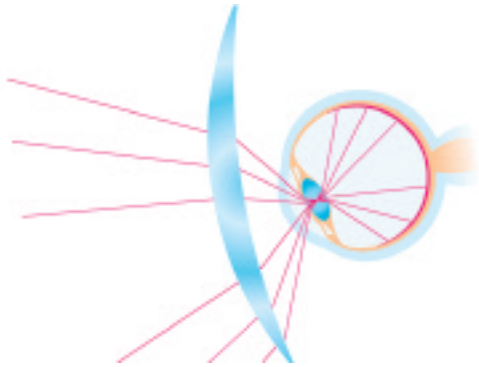
To ensure optimal performance in foveal vision, aberrations of the image must be kept to the lowest possible level on the lens surface and in particular in the region of the meridian line.
In the central lens area, great care must be taken to balance the power, astigmatism and vertical prismatic effect between the right and left eyes to ensure comfortable binocular vision. This is achieved by the asymmetric design of the progressive surface coupled with proper positioning of the meridian line.
In the lens periphery, used primarily in extra-foveal vision, aberrations cannot be totally eliminated. In this region, image quality constraints are less demanding whilst the control of prismatic effects is of utmost importance. Motion perception is a key factor when considering the lens periphery, where the gradient of variation of the residual aberrations is more important than their absolute value. To consider the effects of ophthalmic lenses in peripheral vision, it is necessary to use a different model of the eye to that used to depict foveal vision. The eye is assumed to lie in a fixed position and looking at the intersection points of lines on a grid, from each point of which, rays are traced through the two surfaces of the lens and the centre of the eye's pupil to the retina. The positions of the images of each intersection point on the retina are considered. This provides information about what happens when the subject moves the head, i.e., the performance of the lens in dynamic vision.

All of the above optical requirements introduced in the Merit Function, are then integrated into the lens design optimization software.

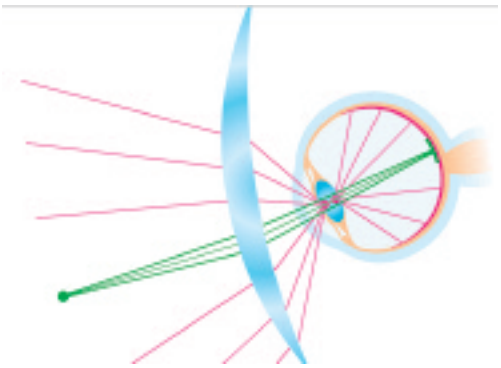
Fig. 15 : Modelling the lens-eye system.



a) Model used for central vision : the rays emanate from a fixed point and focus on the retina.



b) Model used for peripheral vision : the rays emanate from each point in object space. Their position on the retina is studied, rather than their quality.



c) Combination of the two models for central and peripheral vision : the designer must manage the two effects simultaneously.

Personalized progressive lenses :
Recent developments in lens surfacing enable progressive lenses to be designed and produced individually for each wearer. It is thus possible to incorporate characteristics which are individual to the behaviour of each wearer. For example, the specific relationship between the eye and head movements of an individual when using the intermediate and near fields, for which the dimension of the central area of the lens and the softness of the periphery can be incorporated in the design for each individual wearer. (See a more detailed explanation of this feature in the section on the Varilux Ipseo). Furthermore, it is possible to integrate features relating to the prescription, centration and fitting in the calculation of a progressive lens.

2) Clinical studies and the "dioptric loop"

Following the lens optimization and calculation process, the design team – composed of physiologists and engineers – propose several tentative designs. These prototypes are manufactured and tested by means of rigorous clinical trials undertaken on a "double-blind" basis (neither the wearer nor the practitioner knowing the exact nature of the lens under test). The protocol followed during these trials is designed to ensure that no bias can be introduced during clinical evaluation of each design. The controls built into the trial include : ensuring that a representative cross-section of spectacle wearers is chosen, the type of spectacles previously worn is known, the order and length of time for which the trial spectacles are worn, the lens material, lens coatings and the accuracy of the centration of the lenses are all verified. A comparative evaluation of the lenses is undertaken by detailed analysis of the comments and remarks made by the wearers. A statistical analysis is also undertaken. The results determine the best progressive surface.It is important to stress that it is difficult, if not impossible, to establish a formal relationship between the calculated characteristics of the lenses and wearer satisfaction. It is for this reason that all innovation must be systematically validated through the process described as the "dioptric loop" (Figure 16). This consists of translating the physiological requirements into a calculated design for the surface from which a series of prototype lenses can be made. The manufactured surfaces are carefully measured to verify that they conform with the design specification and then submitted for clinical trial by a group of wearers. If the trial indicates that a superior design has emerged (better visual performance, increased wearer satisfaction), then a new design could emerge. If the trial does not indicate a superior design then the information gained can be used to enrich the knowledge of the design team and the iterative process can recommence with new information being added to the "dioptric loop".

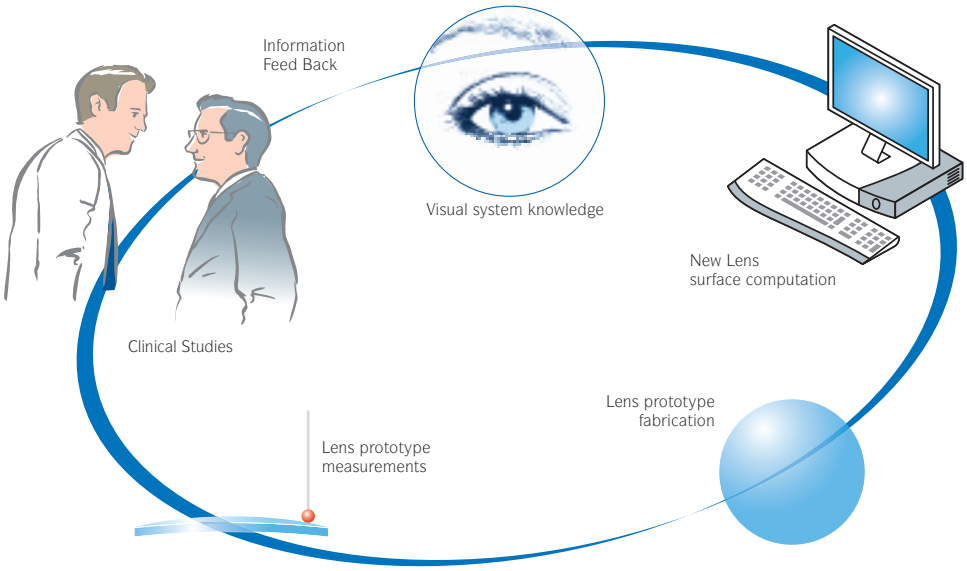


Fig. 16 : The "Dioptric Loop" "the only real innovation is that perceived by the wearer"

4.Description and Control
of progressive lenses

A Graphical representation of progressive lenses

Lens designers often use graphical methods to represent the optical characteristics of progressive lenses. Those most often seen depict the "optical" characteristics of the lenses, that is to say, those relative to the optical system comprising the lens plus the eye, as opposed to those which describe the "geometrical" characteristics of the progressive surface itself. The characteristics most frequently described are as follows:

1) Power profile

The curve represents the power progression of the lens along the meridian line from the distance zone to the near zone. The curve results from the continuous variation in surface curvature from the upper zone to the lower zone of the lens. The power profile describes the power variation of the lens and enables the length of the progression to be determined.

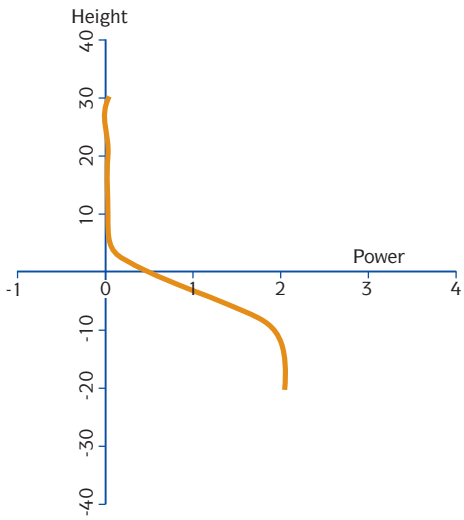
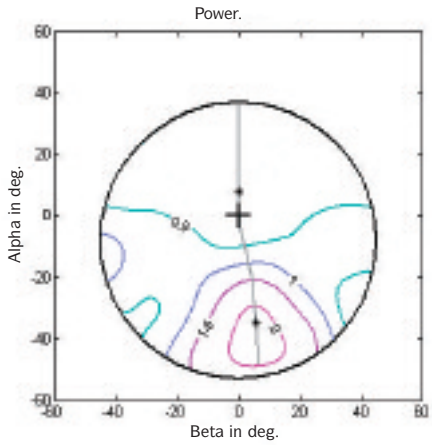


Fig. 17 : Power profile for a progressive lens.

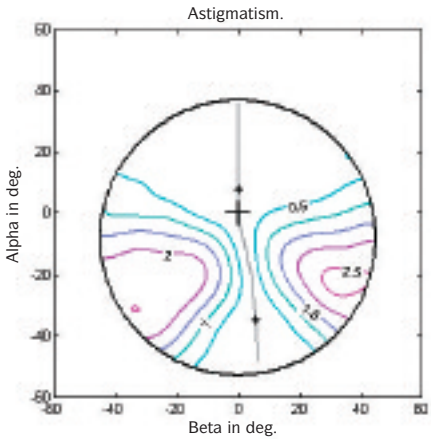
2) Contour plots

This is a two-dimensional map of the lens representing either the distribution of power or of the astigmatism. The map also shows lines of equal dioptric power (iso-power or iso-astigmatism). Between two consecutive lines the power varies by a constant amount, 0.50 D in these examples. Note that since these two types of plots are interdependent, they should never be presented singly without the other.

Fig. 18 : Contour plots of progressive lens charasteristics.



a) Power.



b) Astigmatism.

3) Grid plots :

This type of graph highlights the distribution of prismatic effects of the lens by showing how they alter the shape of a regular rectangular grid.

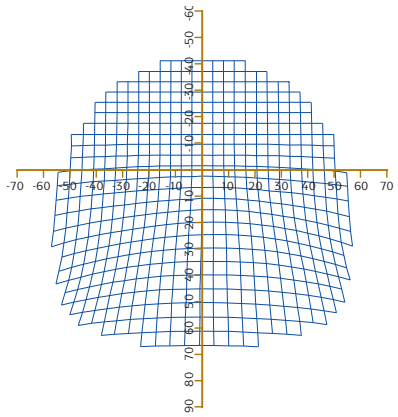


Fig. 19 : Grid plot for a progressive lens.

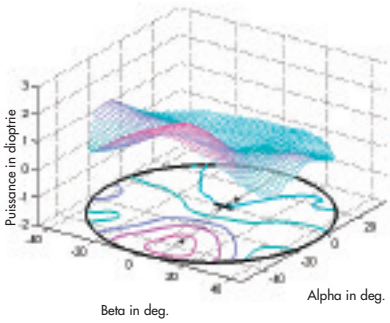
4) Three-dimensional plots :

A three-dimensional representation, which plots vertically, the value of a given optical characteristic at each point of the lens, in relation to a reference plane. It may be used to show the distribution of mean power, astigmatism, prismatic effects or the gradients of any one of these characteristics. These three-dimensional plots are more demonstrative of lens characteristics than contour plots.

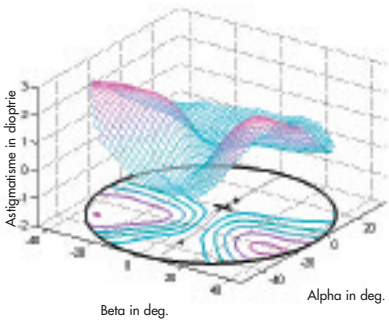
Plot interpretation :

Though useful in the lens design process all these plots are mere representations of the characteristics of progressive lenses and do not really correlate with wearers' acceptance. As such, plots cannot be used to make significant comparisons between progressive lens designs or predict patient's visual comfort. The only trustworthy method for assessing or comparing lenses consists of conducting properly monitored clinical trials amongst a representative group of presbyopes.

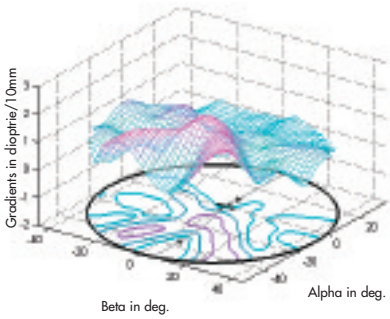
Fig. 20 : Three-dimensional plots of the characteristics of a progressive lens.



a) Mean power.



b) Astigmatism.



c) Gradients of mean power.

B Measurement and control of progressive surfaces:

Control of the conformity of progressive surfaces is critical to both the lens designer and the manufacturer of progressive lenses. It can be achieved by three-dimensional mechanical measurement or by deflectometric methods (analysis of the deviation of light rays produced by the surface). The accuracy of the surface can be verified from a comparison of the measured values with the results obtained from theoretical equations to the surface. An indirect method may also be used in which the optical characteristics of the lens are simulated under conditions of use when the wearer's eye is behind the lens.

During mass production the conformity of the lens to its technical specifications can also be verified by means of traditional focimetry to check power, astigmatism and prism at selected points on the lens.

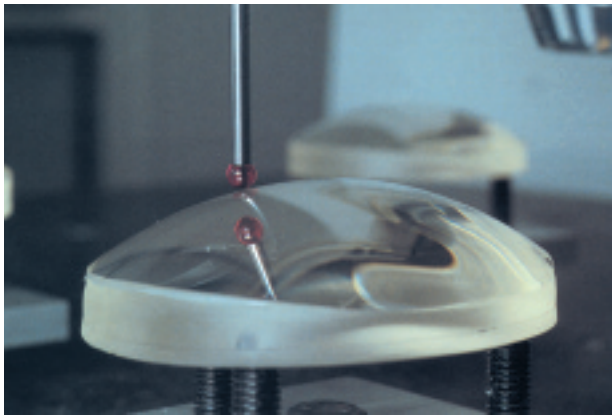


Fig. 21 : Measurement and control of a progressive surface.

Supplement

Mathematical description of progressive surfaces

A Local mathematical description of surfaces :

Any surface defined by a z = f(x,y) equation can be mathematically expressed in a 3D coordinate reference system Oxyz – xOy being the tangential plane to the surface at point O – by a quadratic equation plus terms of higher degrees. This quadratic surface is osculatory with the surface at point O (i.e. its curvatures are identical to those of the real surface) and is defined by the equation :

$$z = rx^2 + 2\,sxy + ty^2$$

Were r,s,t are local derivatives of the surface :

$r = d^2z/dx^2$, $s = d^2z/dxdy$, $t = d^2z/dy^2$

This quadric surface defines the local axis and main curvatures of the surface at O. Furthermore, since any surface can be assimilated locally to a toric surface, characterized by its orthogonal main curvatures C_1 and C_2 and by its axis derived from the following equations:

$$C_1.C_2 = \frac{r.t - s^2}{(1 + p^2 + q^2)^2} \quad \text{(total curvature)}$$

$$\frac{C_1 + C_2}{2} = \frac{t.(1+p^2) + r.(1+q^2) - 2.p.q.s}{2.(1 + p^2 + q^2)^{2/3}} \quad \text{(mean curvature)}$$

where p = dx/dz et q = dz/dy

Axis = Arctg (m) with m solution of the quadratic equation :

$$[t.p.q - s(1+q^2)].m^2 + [t.(1+p^2) - r.(1+q^2)].m + s.(1+p^2) - r.p.q = 0$$

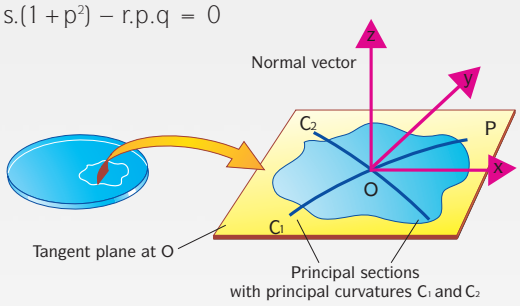


Fig. A : local description of a surface.

B Mathematical characterization of surfaces in a circular domain

Any portion of a complex surface can be defined by using the reference system known as Zernike polynomials. This system is used to mathematically express the surface by a sum of a series of specific polynomials. The first ten Zernike polynomials give rise to a remarkable mathematical and physical applications: the 5th gives access to the mean curvature, the 4th and the 6th to its cylinder and axis, the 7th and 1Oth to its slope of curvature variation. Zernike polynomials are also used in the determination of the local power, astigmatism, coma and spherical aberration of the lens by means of the wavefront analysis. The lens surface is mathematically expressed by:

$$f(y, z) = \sum_{i=0}^{i=9} Z_i . P_i$$

P_i : Zernike polynomials
où Z_i : Coefficients
y,z : reduced v

Piston	1	Z_0
Tilt in y	y	Z_1
Tilt in z	z	Z_2
Asti +- 45°	2y.z	Z_3
Defocus	$-1 + 2y^2 + 2.z^2$	Z_4
Asti 0,90°	$z^2 - y^2$	Z_5
Coma tr y	$3y.z^2 - y^3$	Z_6
Coma y	$-2y + 3y.z^2 + 3y^3$	Z_7
Coma z	$-2z + 3z.y^2 + 3.z^3$	Z_8
Coma tr z	$z^3 - 3zy^2$	Z_9

Expansion of a surface into the first 10 Zernike polynomials.

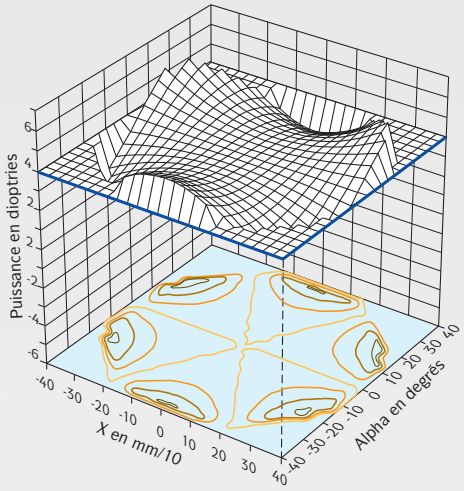


Fig. B : Graphic representation of the 8th Zernike polynomial

C Mathematical modelization of surfaces with B. splines polynomial functions :

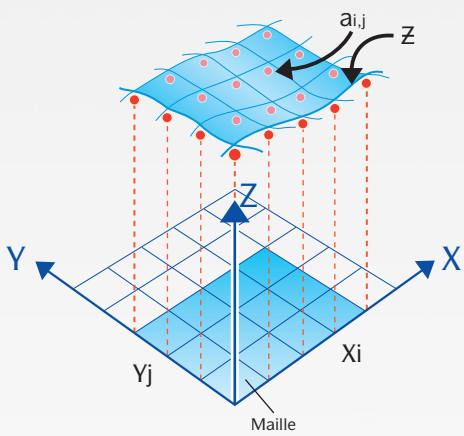


Fig. C : Modelization of a surface with B. splines functions

Any bi-regular surface can be represented by a set of numerous ordinates evenly distributed on the surface according to a regular reference grid. The local characteristics of the surface at an x, y coordinate point, z = f(x,y), p, q, r, s, t are deduced from the values of the discrete ordinates in the vicinity of this point by their linear combination on a squared matrix. These characteristics are calculated according to the following formula :

$$z = \sum_{i,j} \lambda_{i,j} . a_{i,j}$$

$$p = \frac{df}{dx} = \sum_{i,j} w^{x}_{i,j} . (a_{i+1,j} - a_{i,j})$$

$$q = \frac{df}{dy} = \sum_{i,j} w^{y}_{i,j} . (a_{i,j+1} - a_{i,j})$$

$$r = \frac{d^2 f}{dx^2} = \sum_{i,j} w^{xx}_{i,j} . (a_{i+2,j} - 2.a_{i+1,j} + a_{i,j})$$

$$s = \frac{d^2 f}{dxdy} = \sum_{i,j} w^{xy}_{i,j} . (a_{i+1,j+1} - a_{i+1,j} + a_{i,j} - a_{i,j+1})$$

$$t = \frac{d^2 f}{dy^2} = \sum_{i,j} w^{yy}_{i,j} . (a_{i,j+2} - 2.a_{i,j+1} + a_{i,j})$$

with $\lambda_{i,j}, w^{x}_{i,j}, w^{y}_{i,j}, w^{xx}_{i,j}, w^{xy}_{i,j}, w^{yy}_{i,j}$,

being tabulated coefficients..

5.Manufacture
of progressive power lenses

A Manufacture of progressive power lenses

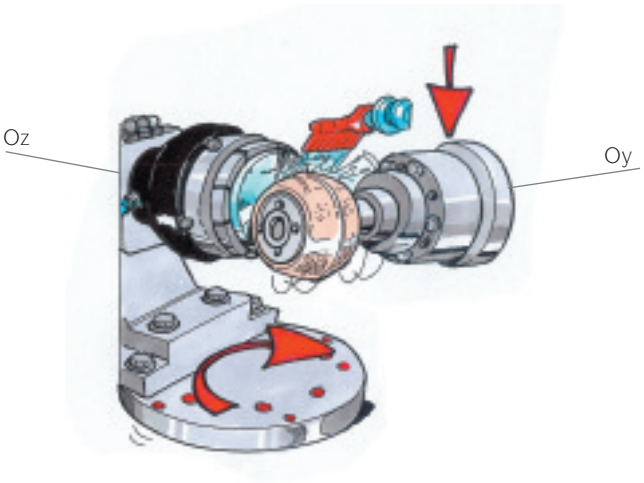


Fig. 22 : Principle of generating a progressive lens.

Not least of the challenges in the production of progressive lenses is to be able to produce, and accurately reproduce, non-rotationally symmetrical progressive power surfaces. The first progressive lens surfaces were ground by means of a cam-following process followed by soft polishing where the polisher simply followed the form of the surface. Today, such surfaces may be directly generated by means of computer numerically controlled (CNC) machining of either the surface itself, or, of the mold from which the surface is to be cast.

The important stages in the production process for a progressive power surface are:

1) Surface design and numeric description

Surface design and computation of the surface topography is translated into numeric data in the form of (x,y,z) co-ordinates that can be fed directly into the CNC generator. Several thousand numeric data points may be required for an individual surface and this information must be stored for all combinations of base curves, reading additions and for right and left lenses. The basic reference for the progressive surface is usually taken to be an aspherical surface whose curvature is similar to the base curve that will finally be obtained.

2) Generating the progressive surface :

The principle of CNC generating is illustrated in Figure 22. The blocked lens is attached to a spindle that rotates slowly about the z-axis of the surface and the workpiece can move in the x, y and z meridians as directed by the CNC grinding program. The diamond impregnated milling wheel rotates about the y-axis and makes single-point contact with the surface during the grinding operation. The cutter moves in a spiral pathway over the face of the workpiece.

3) Polishing the progressive surface :

The surface that is obtained at the end of the generating process is most of the time so finely ground that it is ready for polishing without any intermediate smoothing being necessary. Polishing methods include polishing with the aid of a floating, soft foam, polishing pad or direct CNC polishing of the surface.

4) Laser marking of the surface:

After polishing, the progressive surface is marked to aid accurate location of the progression zone and with other identifying information. Two circles are normally inscribed, 34mm apart, along the horizontal center line of the blank, the near addition inscribed under the temporal circle and a logo together with other information about the lens design and/or material inscribed beneath the nasal circle. The engravings may be marked on the lens itself or on the mold from which the lens will be cast in which case they will appear in relief on the cast surface.

5) Inspection :

To ensure that the polished face faithfully follows the design characteristics of the surface, it is inspected at each stage of the manufacturing process by one of the methods described above.

B Enhancing the characteristics of finished progressive lenses

1) Equithin Progressive Lenses

As a result of the increase in curvature of the progressive surface in the near portion a progressive lens is thinner at its bottom edge than at the top edge (Figure 23). To produce thinner lenses an equithin technique (prism thinning) is normally employed to equalise the thickness at the top and bottom edges of the lens. The process induces a base down prism; its value in prism dioptres (cm/m) is generally 2/3 of the value of the addition and can be measured at the geometrical center of the lens. For example, in the case of a progressive lens with a 3.00 D addition, the thinning prism would be 2Δ base down and if there is no further prescribed prism, this value would be read at the prism reference point of the lens. The thinning prism must be the same for the right and left eyes to avoid the introduction of vertical differential prism between the two lenses.
The effect of the equithin prism is a slight upward shift of the whole visual field. It has been clinically proven to have no significant effect on the visual comfort of the wearer. Since it offers dramatically thinner, lighter and more comfortable lenses, the use of equithin prism is highly recommended for progressive lenses of any distance power and addition.

2) Pre-decentred uncut progressive lenses

In markets where round uncut lenses are distributed (like Europe), pre-decentration and pre-shaping of the progressive lens uncut is a method used by manufacturers to produce thinner plus-power lenses. To obtain a thinner lens, the lens diameter is reduced but, so as not to lose temporal capacity, the progressive surface is decentred nasally. Pre-decentred finished lenses are produced, for example, in 65/70 mm diameters which means that the lens has a 65mm geometric diameter but a 70mm effective diameter, i.e., the surface is shifted nasally by 2.5mm. In the same way, reducing the uncut lens to an elliptical shape by reducing its vertical diameter also results in a thinner lens.

Lens pre-decentration is also used with semi-finished lenses for increasing the effective diameter of the blank.

Fig. 23 : Prism thinning applied to a progressive lens

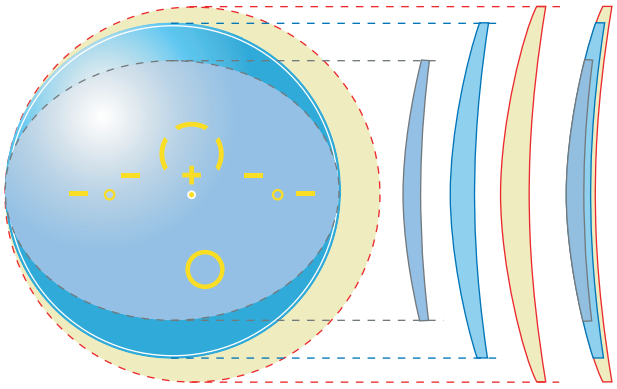


Fig. 24 : Pre-decentred finished progressive lens

3) Precalibration

The most effective way of reducing the center thickness of plus lenses is to produce them in precalibrated form. This involves calculating first, the position on the edge of the shaped lens where the thickness is a minimum and then surfacing them to the minimum center thickness which the prescription specification will allow to provide the minimum thickness at this point on the edge. Wearer monocular PDs (RPD and LPD), fitting heights (RH and LH) and the frame shape and size are all taken into account in the calculation to obtain the thinnest, lightest lens (Figure 25).

Although not specific to progressive lenses, the results obtained with precalibration are more spectacular for this type of lens and is an additional benefit to the equi-thin process. This technique is systematically used in laboratories which both surface and edge the lenses.

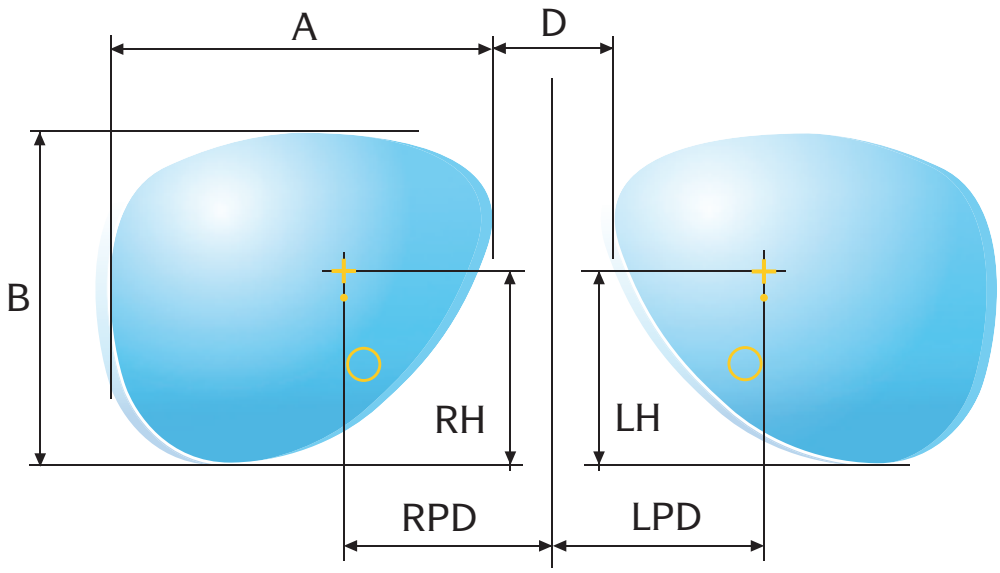


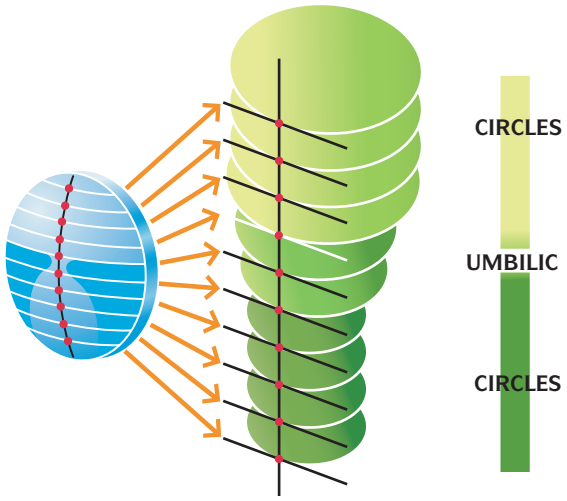
Fig. 25 : Principle of precalibration.

6.Evolution
of progressive lenses

1st generation : the “first” progressive lens

After several, tentative but unfruitful attempts during the first half of the 20th Century, the first successful progressive lens appeared in France in 1959. After a several years of personal work, Mr Bernard Maitenaz developed the 1st progressive lens in the Société de Lunetiers (or S.L., which later became Essel, which company merged in 1973 with Silor, to form Essilor).
Progressive lenses have a power which varies along a characteristic umbilic line, called the “meridian line”, where, at each point along the meridian line, the principal radii of curvature are equal. In the very first progressive lenses which were studied, the meridian line ran vertically down the lens, that is to say that the power varied continuously from the top to the bottom of the lens. The law controlling the power variation was then modified to introduce a stabilization of power in the upper and lower zones of the lens in order to enlarge the distance field and to enable the focimeter to measure the power of the lens for near.
In the first commercially available progressive lenses, marketed in 1959 under the name of Varilux, the distance zone had been chosen to be entirely spherical and the zone for near vision was sufficiently stabilized to provide a structure resembling a bifocal which progressives were destined to replace (figure 26). The lower lateral zones of the lens, although controlled, were composed for this reason significant lateral aberrations which necessitated some effort of adaptation on the part of the wearer.

Concerning binocular vision, it was in 1964 that the first asymmetric progressive lenses were introduced (where the construction of the right and left lenses differed) to provide improved lateral vision thanks to specifically computed zones to provide this effect. Before that date progressive lenses were symmetrical in construction, each lens being rotated 10° inwards nasally to produce right and left lenses.
Although optical considerations were essential, the challenge at the time was equally in mechanical engineering: how to design machinery to produce, for the first time, non-rotationally symmetrical optical surfaces. At the time most lenses were made in glass, both difficult to surface and polish. It was only by adopting the principle of point-by-point calculation, making use of the technique of reproduction from a model surface and soft polishing that Varilux could be actually manufactured.
To introduce a lens having such lateral aberration was, at the time, attempting the impossible. In addition to the technical challenges, it was necessary to overcome the scepticism of the optical profession. However, the perseverance of the designers showed that it was possible to produce progressive lenses and pointed the way to later improvements: a better understanding of peripheral vision through ophthalmic lenses and how to take it into account in the design of progressive surfaces.
Varilux 1, although the first creation, bore all the basic principles of progressive lenses. It was the precursor to an enormous revolution which was to take place in the world of optics.



a) Surface design of the Varilux® 1.

b) Bernard Maitenaz: inventor of the progressive lens.

Fig. 26 : First generation progressive lens (Varilux® 1).

2nd generation : the progressive lens with "optical modulation"

After the new concept of a progressive surface had been accepted by the profession, Bernard Maitenaz and his team could move away from the "spherical" structure of Varilux 1 and design a progressive surface with improved peripheral zones. They succeeded in 1972 with the launch of the second generation progressive lens, under the name of Varilux 2. The object was not just to reduce the level of peripheral aberrations but also to control the image deformations which they produced.

- The reduction in aberration was obtained by horizontal "optical modulation" achieved by producing a slight increase in power in the lateral portions of the distance zone and a slight decrease in power in the lateral portions of the near zone. The slight difference in radius of curvature which existed in the peripheral regions of the distance and near zones produced a significant reduction in the level of aberration. Such a surface can be represented by a series of conic sections, such as those shown in Figure 27.
- Furthermore, in order to reduce the considerable swimming effect shown by Varilux 1, the concept of "orthoscopy" was introduced, the aim being to ensure that straight lines in space, and in particular, vertical and horizontal lines, appeared straight when viewed through the periphery of the lens. To accomplish this, it was necessary to calculate a surface whose characteristic was to have, on one hand, horizontal prismatic effects which hardly varied along two vertical lines (one nasal and one temporal) and on the other, vertical prismatic effects which hardly varied along two horizontal lines, one in the upper portion and one in the lower portion of the lens. It was for this characteristic that patents were obtained for Varilux 2 which protected the design for a number of years. Although originally stated in this form, the principle of orthoscopy has been retained for all subsequent generations of Varilux.
- Of course, from the point of view of binocular vision, the Varilux 2 design was designed from the start with different surface geometries for the right and left lens with special attention being paid to the areas of the lens which were in use simultaneously by the eyes.

With the second generation of progressive lenses, real progress had been accomplished and it was from this time that progressive lenses became recognised and accepted as a standard method for correcting presbyopia.

During the decade which followed the launch of Varilux 2, (also called Varilux Plus in the USA) several variations derived from the Varilux 2 design were developed by other manufacturers, focusing upon specific optical characteristics. Some emphasised large distance and near vision zones, concentrating the inevitable astigmatism in the lens periphery (American Optical Ultravue, Rodenstock Progressiv R, Silor Super NoLine / BBGR Visa, Sola VIP/Graduate). Others took the opposite approach, reducing the amount of unwanted astigmatism in the periphery by spreading it more widely in the lens (American Optical Truvision Omni). Still others placed special emphasis on the concept of lens asymmetry and comfortable binocular vision (Zeiss Gradal HS). Thus, it was by a joint effort on the part of both practitioners and manufacturers that a rapid expansion in the correction of presbyopia by progressive lenses was brought about.

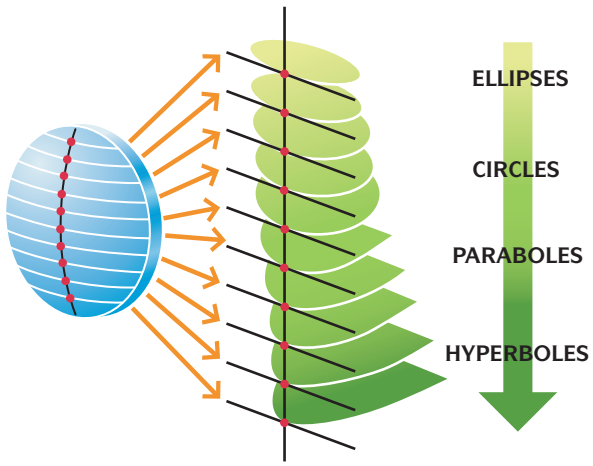


Fig. 27 : 2nd generation progressive lens design : the Varilux® 2 surface.

3rd generation : the “multi-design” progressive lens

A further step in the enhancement of progressive lens performance was made with the third generation, multi-design concept. It was realized that if the same power law was used for each different near addition, it did not result in the optimum progressive surface for each stage of presbyopia. By freeing the design from this constraint, the optimum surface could be designed for the needs of wearers in all stages of presbyopia. Early presbyopes require a soft progressive surface to enable them to adapt quickly to progressive lenses whereas late presbyopes prefer a harder design to provide large fields of vision.

With a mono-design progressive lens series the designers were faced with a single alternative:

- to use a “soft” progressive surface, that is a long progression length with low levels of aberration spread over the entire surface of the lens, which had proved to be preferred by the early presbyope, but which offered only small fields of vision to the late presbyope,
- to use a “hard” progressive surface, that is a short progression length with rapidly increasing aberration levels concentrated in smaller areas of the lens, which had proved to be preferred by late presbyopes, but which were found to be difficult to adapt to by early presbyopes.

The solution was to offer softer surfaces for low additions and harder surfaces for high additions, which would maintain the near vision field despite the increase in near addition (Figure 28).

The Varilux Infinity / Varilux Multi-Design lens was introduced by Essilor in 1988 and each of the 12 near additions (+0.75 to +3.50 D in 0.25 steps) had a distinct design developed for the specific addition. Similar design philosophies were introduced with the American Optical Omni Pro, Silor Adaptar / BBGR Visa 3S and Hoya Hoyalux, etc. Although the Varilux Multi-Design is no longer available, having been replaced by newer generations, it was the forerunner of the great majority of the progressive lens designs on the world market today, the great majority of which employ the “multi-design” concept.

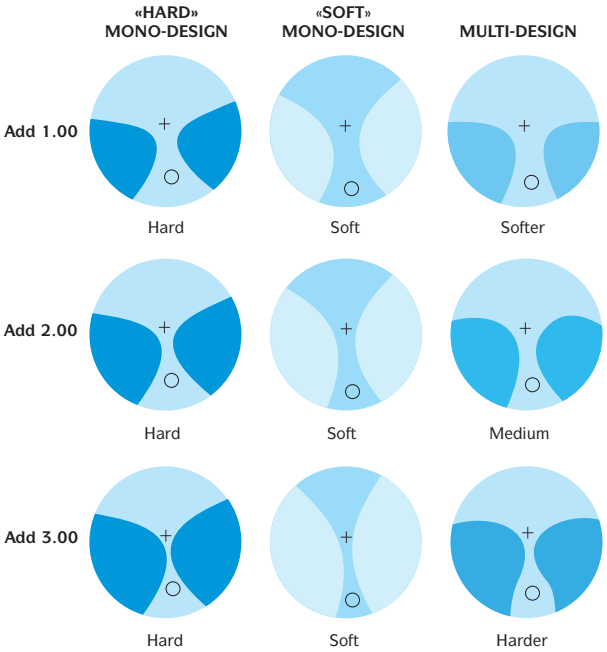


Fig. 28 : Principle of “multi-design” progressive lens compared with mono-design.

4th generation : the progressive lens for "natural vision"

The fourth generation of progressive lenses was introduced under the name of Varilux Comfort in 1993. Its design arose from observation of the wearing habits of users of progressive lenses and its manufacture was made possible by the evolution of manufacturing methods for progressive surfaces. The basic concept was to shorten the length of the progression zone of the lens, in order to offer wearers more comfortable posture for near vision, and at the same time to control deformation in the lens periphery. Put simply, before the advent of the fourth generation, the progressive lens designer had two options, designing a lens with a "short" progression and "hard" periphery or designing a lens with a "soft" periphery but a "long" progression. The first offered wearers a comfortable reading position but least comfort in peripheral vision. The second offered wearers comfortable dynamic vision but an uncomfortable reading posture. The requirement was to try to combine in a single design the two characteristics of a "short" progression and a "soft" periphery in order to offer wearers the double benefit of comfortable posture in near vision together with real comfort in peripheral vision (Figure 29). This was achieved in the design of the Varilux Comfort.

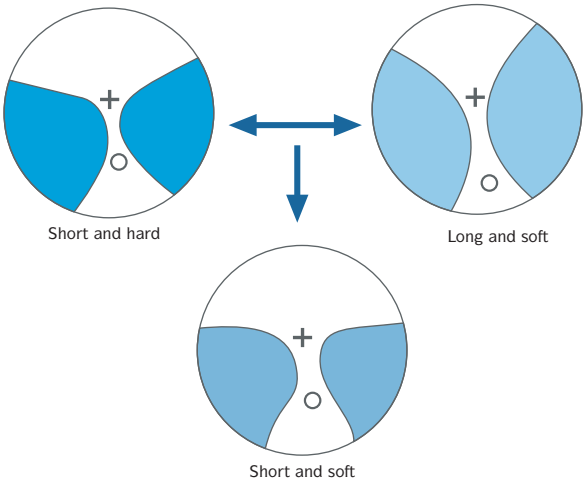


Fig. 29 : Principle of the design of Varilux Comfort®

Details of the characteristics of the lens :
To offer a more comfortable posture for near vision the near zone is located high in the lens so that the wearer can reach it easily and naturally on downward gaze of some 25°, which is 5° less than previous generations of progressive lens. As a consequence, the wearer can lower the head by some 35° (instead of 30°) which is nearer to the usual value employed for near vision before the onset of presbyopia (Figure 30). Moreover, he/she can explore the near vision field more comfortably because the necessary movement of the head and eyes is smaller (Figure 31).

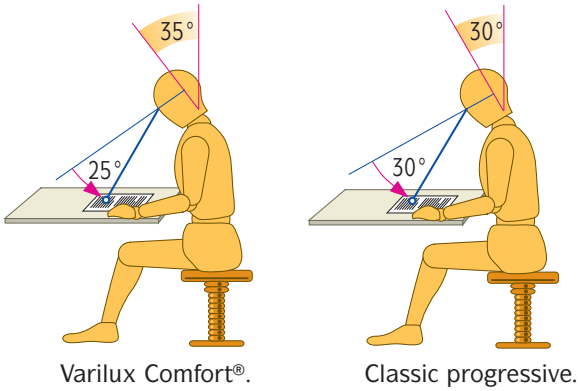


Fig. 30 : Comparison of head and eye positions between Varilux Comfort® and a classic progressive design.

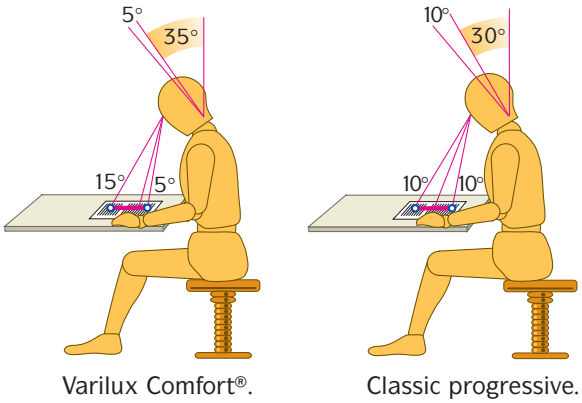


Fig. 31 : Comparison of head movement with Varilux Comfort® and a classic progressive design.

These advantages result from Varilux Comfort's power profile between distance and near vision. For an addition of 2.00 D, 85% of the full addition (considered to be the start of the near vision area) is obtained just 12mm below the fitting cross, compared with 14 or 15mm found in the previous generation of progressive lenses Figure 32).

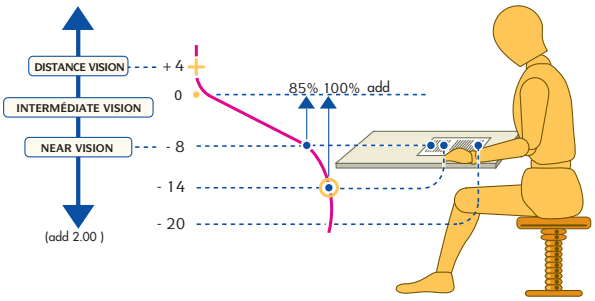
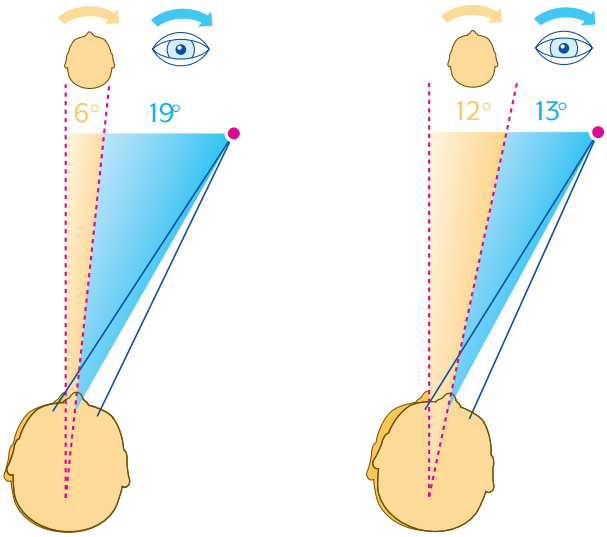


Fig. 32 : Power profile of Varilux Comfort® with 2.00 D add.

In order to obtain comfortable peripheral vision the progressive surface had been softened by strict control of the optical characteristics in the periphery. It had been observed that in peripheral vision, wearers were more conscious of the speed of variation in surface power and astigmatism – in fact, to the variation in prismatic effects which are attached to the power variations - rather than their absolute values. Hence, the variation in power on the progressive surface of Varilux Comfort was only rapid where it needed to be, along the meridian line of the progression, in order to provide a short progression length, and slower elsewhere on the surface. This characteristic formed one of the patents for Varilux Comfort. Furthermore, the peripheral softness of the surface offered wearers larger fields of clear vision and, consequently, the necessary horizontal head movement required to explore the full width of the field was greatly reduced (Figure 33).



Varilux Comfort®. Classic progressive.

Fig. 33 : Comparative head and eye movements in the horizontal plane with Varilux Comfort® and a classic progressive lens.

For binocular vision, the asymmetry of the lenses had been redesigned to provide perfect balance in the perception obtained by the eyes. The geometrical profile of the progression – its position on the lens – had been considered by taking into account wearer behaviour, it no longer followed a straight line on the lens, but instead followed the path of the eyes during the lowering of the gaze for near vision. This operated in conjunction with the vertical movement of the head during the change from distance vision, through intermediate to near vision and also whilst using the near vision zone for prolonged periods. These two requirements lead to different rates of convergence making it necessary to employ two different rates of change in the power progression as indicated in Figure 34.
Furthermore, the concept of multi-design by addition found a new application with Varilux Comfort; that of a variable inset of the near vision zone with addition, which took into account the fact that presbyopes hold reading material closer to their eyes as the near addition increases. This provides them with some magnification to compensate for a reduction in visual acuity due to the loss of transparency in the optical media of the eye with age. The difference in inset of the near vision zone is about 1.6mm from the lowest addition to the highest addition (from 2.2 to 3.8mm). It is accompanied by a shortening of the progression length as the addition increases, more precisely, to a rise in the position of the near vision zone where 85% of the full reading addition has been obtained.

Varilux Comfort has met with resounding success and contributed to the perception of the progressive lens as the method for the correction of presbyopia. It has been followed by the introduction of many other progressive lens designs, including the Essilor Natural / BBGR Selective. There were up to 50 different types available around the world after the introduction of Varilux Comfort.

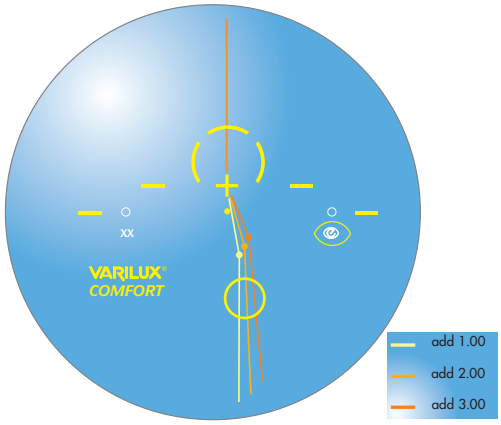


Fig. 34 : Variable inset of the near vision zone with near addition (Varilux Comfort®)

5th generation : the progressive lens with a “widened vision field”

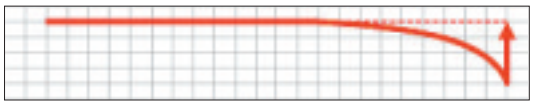
To improve lens performance even further, the designers considered more deeply the expectations expressed by wearers of progressive lenses. There were two main demands: young presbyopes looked, above all, for “quick and easy adaptation to their first pair of progressive lenses” whereas experienced wearers asked for “larger fields of vision”. The fifth generation progressive lens from Essilor, Varilux Panamic, introduced in the year 2000, had been designed to achieve these two expectations. To accomplish this, improvements were made to the use of the lens in peripheral vision in both binocular vision and in foveal vision, each improvement arising as a result of specific research in these areas.

In order to offer young presbyopes “quick and easy adaptation”, the following improvements were made (Figure 35):

- in peripheral vision, reduction of distortion by controlling the distribution of prismatic effects on the surface of the lens;
- in binocular vision, reduction of swimming effects by minimizing the difference in the apparent speed of movement of objects perceived by the right and left eyes. It had been discovered that the swimming effects which were sometimes felt by wearers have primarily a binocular vision origin;
- foveal vision, significant enlargement of the zones in which full visual acuity could be obtained for intermediate and near vision Varilux Comfort.

Fig. 35 : Improvements brought by Varilux Panamic to young presbyopes

Varilux Panamic®.



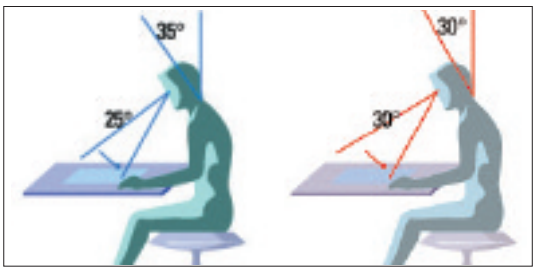
Classic progressive .

a) Peripheral vision.

Varilux Panamic®.

Classic progressive.

b) Binocular vision.



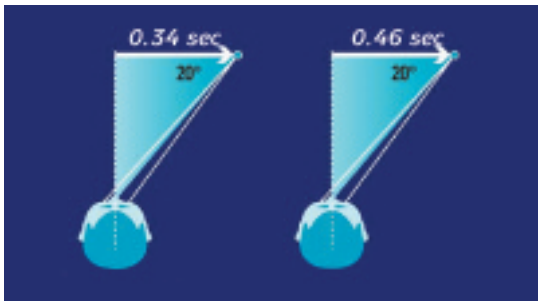
Varilux Panamic®. Varilux Comfort®.

Classic progressive.

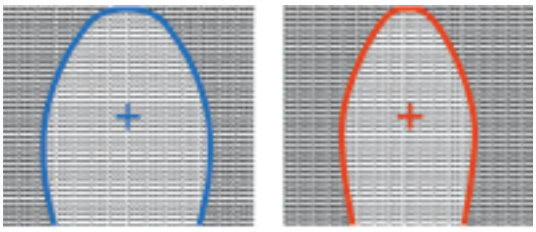
c) Foveal vision.

In order to offer experienced presbyopes "larger fields of vision", the following improvements were made (Figure 36):
— in peripheral vision, reduction of the time required for identifying a target by softening the progressive surface
— in binocular vision, enlargement of the horopters – where points are binocularly seen single – for all eyes positions and obtained thanks to the slow variation of the lens prismatic effects
— in foveal vision, significant enlargement of the lens areas offering maximum visual acuity in intermediate and near vision.

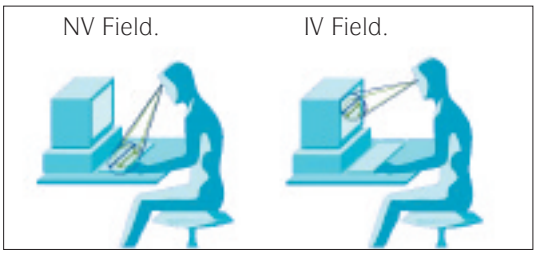
Fig. 36 : Improvements brought by Varilux Panamic® for experienced presbyopes.



Varilux Panamic®. Classic progressive.
a) Peripheral vision.



Varilux Panamic®. Classic progressive.
b) Binocular vision.



Varilux Panamic®. ⟷
Varilux Comfort®. ⟷
c) Foveal vision.

Overall, Varilux Panamic was a progressive lens of softer design than previous generations and resulted from the improvements in the optical characteristics of the lenses relative to their absolute values as suggested by progressive lens wearers.

In addition, the concept of multi-design had taken on a new dimension with the Varilux Pamamic, that of varying the inset of the near vision zone as a function of the distance prescription and not only the value of the near addition. The distance prescription introduces horizontal prismatic effects in the near portion which alter the actual position of the visual point used by the eye on the lens. Thus, the inset must be decreased for a myope and increased for a hypermetrope. It is necessary to vary the inset on the lens according to the distance prescription and more precisely of the base. As a result, the inset might vary by as much as 3.2mm per lens between a strong myope with a low addition, and a strong hypermetrope with a high addition (2.0 to 5.2mm). Note that this does not necessitate any change in the method by which the lens is centered, since the distance correction and the usual reading distance of the wearer are not taken into account when measuring the monocular PDs for distance vision. (figure 37).

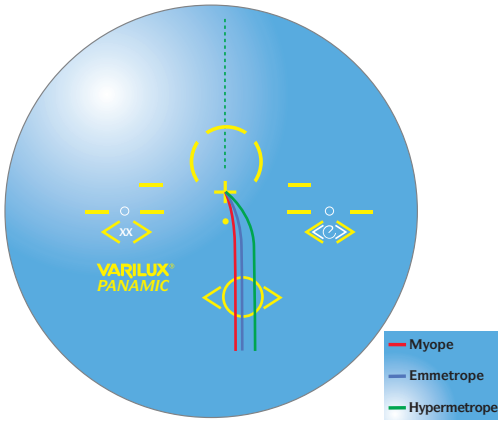


Fig. 37 : Inset of near zone with addition and degree of ametropia with Varilux Panamic®.

Following the introduction of Varilux Panamic, other progressive designs have been introduced such as the Essilor Ovation / BBGR Evolis, the Seiko P-1SY with the progression on the concave surface, the Johnson & Johnson Definity lens which shares the progression between the front and back surfaces and the Hoyalux ID design from Hoya which is also a double-sided progressive. Whether by design or method of manufacture all these progressive lenses seek, in common with Varilux Panamic, a softening of the progressive surface to provide more comfortable vision for presbyopes.

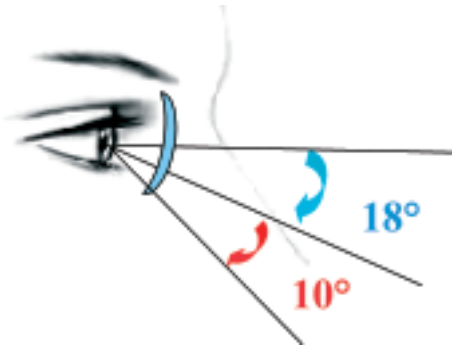
Progressive lenses for “small frames”

With the evolution of fashion, the choice of spectacle wearers has turned to smaller spectacle frames, which has posed a special problem if they are to be fitted with progressive lenses. To ensure adequate zones of comfortable vision it is necessary to have sufficient depth of lens for the progression together with sufficiently large zones of the lens for distance and near vision.
In addition, wearers of small frames develop a peculiar wearing habit in that they tend to lower their heads more and their eyes less, than wearers of normal size frames, to maximize their fields of vision. It is considered that the small frame wearer reduces vertical eye rotation to less than 20°, compared with 35° in the case of wearers of large frame designs. They also exploit a greater horizontal field in distance vision. In terms of progressive surface design, it is necessary to provide a progressive lens with a short progression and wide field of vision for distance vision.

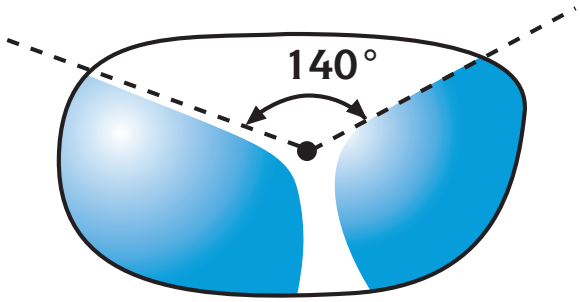
This is the case with Essilor’s Varilux Ellipse design which has a very short progression zone, such that the start of the near vision zone (the point where 85% of the full addition is obtained) is just 9.5mm below the fitting cross (compared with 12mm for other Varilux designs). This requires the eyes to be lowered by barely 18° to obtain near vision. It enables frames to be chosen which provide just 14mm depth below the fitting cross (figure 38a). The lens also offers a distance zone angle of about 140°, over 20° more than with a classic progressive design (figure 38b).

Note that there should also be a minimum depth of 10mm of lens from the fitting cross to the lower edge of the top rim of the frame in order to ensure an adequate zone for comfortable distance vision. Hence the total depth of the frame should be at least 24mm. (we state 30mm in our materials) It goes without saying that these are absolute minimum values for these dimensions.

Fig. 38 : Design principle for a progressive lens for a small-eye frame (Varilux®Ellipse).



a) Short progression.



b) Widened field for distance vision.

6th generation : the “high resolution” progressive lens

For an even greater improvement in the quality of vision, the 6th generation of progressive lenses have sought to maximize the visual performance of the wearer. In the design of progressive lenses only rays of light which arrive at the eye after passing through the lens are considered. With the new generation, the designers have also interested themselves in the nature of the entire light beam which enters the pupil. The principle is to optimize the visual performance in all viewing directions by mastering the characteristics of the light beams which enter the pupil.

Varilux Physio, introduced by Essilor in 2006, is the first progressive lens designed on this principle and more specifically to :
- maximize visual acuity in distance vision by correction of coma-like aberrations,
- optimize the accommodative function in intermediate vision by facilitating clear vision in the vertical,
- increase the amplitude of movement of the eyes in near vision by enlarging the field of acuity.

This optimization has been possible by employing a new method of calculation based upon the wavefronts of light.

1) Maximization of visual acuity in distance vision

Whatever the method of correction, the system comprising the lens and the eye is afflicted with optical aberrations. As well as the usual aberrations – power error and astigmatism of oblique rays – coma, among the higher order of aberrations, that which is present in progressive lenses and influences both visual acuity and contrast sensitivity. It is due to a variation in power of the lens - inside as well as the projection of the pupil of the eye on the lens – and affects the quality of vision of the wearer especially in the distance zone where the pupil is largest.

Thanks to the technique of controlling wavefront aberration, coma can be measured and controlled in a large area around the center of the distance vision zone. With Varilux Physio the aberrations experienced by the wearer are considerably reduced compared with those of a standard progressive lens. For the wearer this translates as more precise imaging offering better visual acuity and higher contrast.

2) Optimization of the functioning of accommodation in intermediate vision

In the presence of astigmatism such as that which lies in the lateral zones of the intermediate portion, the eye would prefer the axis to be vertical. This is the case in a progressive lens which has an inevitable amount of residual surface cylinder in the intermediate zone on either side of the meridian line of the progression.
A new principle which has been incorporated in the design of the of Varilux Physio is to ensure that the most positive focus is orientated vertically so as to increase the image clarity and minimize the necessary effort of accommodation. The technique of wavefront control enables management of the resultant astigmatism across the entire pupil, to minimize its value and to ensure that it is orientated in the vertical. For the wearer, the clarity of the scene appears natural and the visual field in intermediate vision is perceived to be larger by over 30% compared with a classic progressive design.

3) Increase in the amplitude of movement of the eyes in near vision

In near vision the eyes naturally explore the field in the vertical direction. In a progressive lens, the possible amplitude of the eye’s movement is defined by the zone of the lens where the near vision power has been stabilized. If this zone is limited, it is necessary for the wearer to make frequent vertical adjustments of the head often accompanied by enforced changes in posture. In the design of Varilux Physio, the stabilized zone has been increased in height. The wearer benefits from a larger near field of clear vision in the vertical meridian with better respect of natural posture.

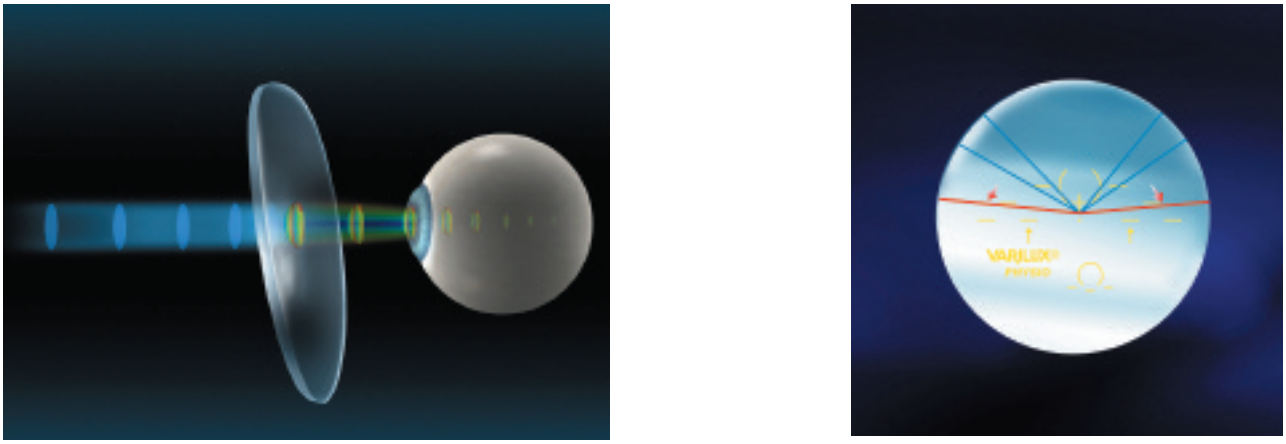


Fig. 39 : Control of coma in distance vision (Varilux Physio®)

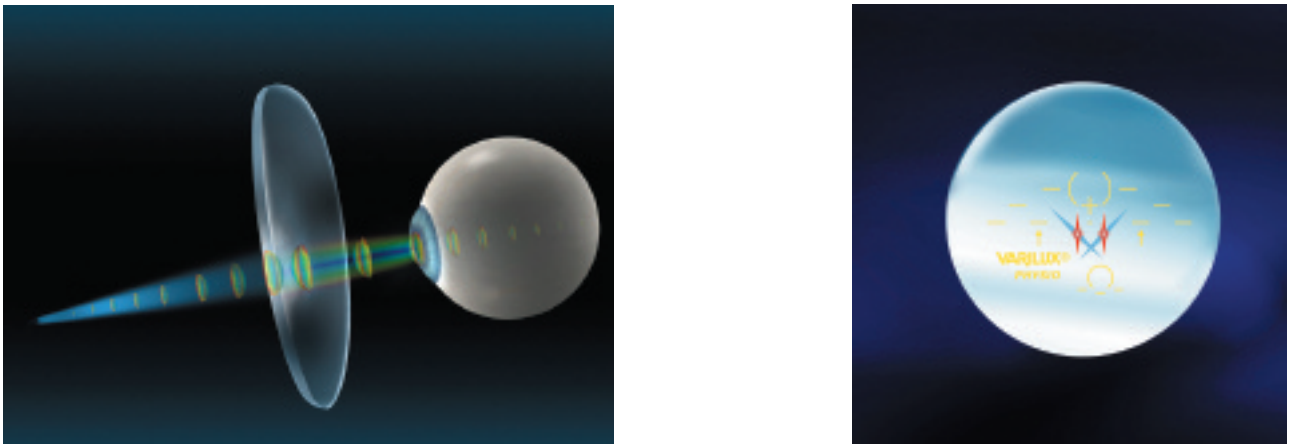


Fig. 40 : Control of the residual cylinder axis in intermediate vision (Varilux Physio®)

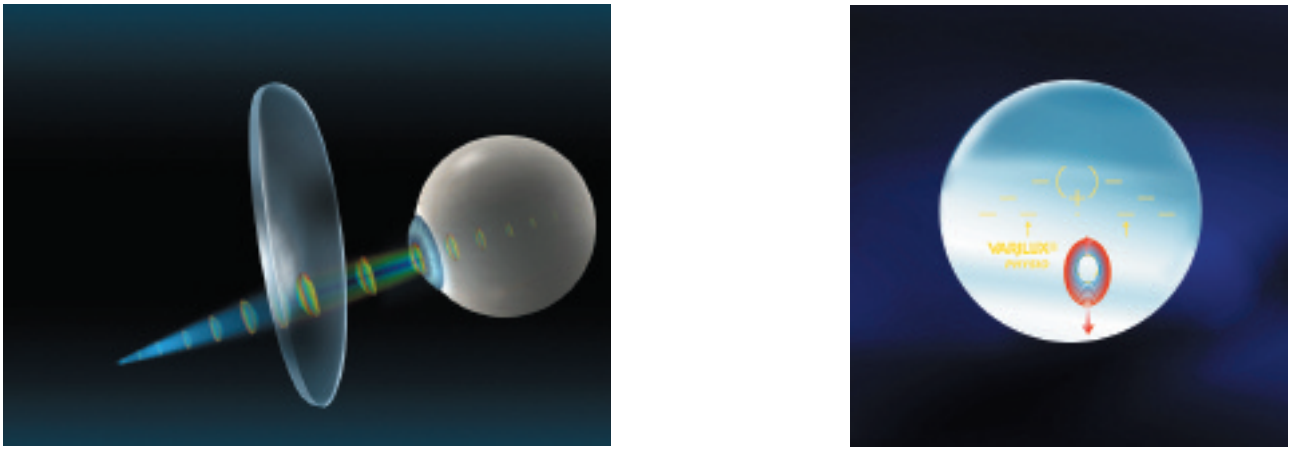


Fig. 41 : Increase in the stabilized zone of near vision (Varilux Physio®)

A new technology : the “W.A.V.E.™ Technology”

The development of Varilux Physio has been made possible by two innovations in technology : the calculation involved using “Wavefront Management System” and a procedure known as “Point by Point Digital Surfacing”. The combination of these two innovations constitutes the “Wavefront Advanced Vision Enhancement” or “W.A.V.E. Technology”.

Wavefront Management System™ :

All progressive lenses, because of their variations in power, deform light beams and hence, their wavefronts. This results in optical aberrations which reduce the visual acuity of the wearer. In order to obtain a retinal image of high resolution, it is necessary to be able to analyse the light beam which passes through the lens and enters the eye, for all viewing directions and to reduce the deformation of the wavefront as it enters the eye’s pupil as much as possible. Management of such a beam cannot be performed by traditional ray tracing methods which consider only a single ray passing through the centre of the pupil. Only the technique of wavefront management allows optimization of the whole beam of light entering the pupil. It consists of carrying out a local calculation of the surface which allows the designer to obtain an emergent wavefront which is as regular and spherical as possible. It is the first time, with Varilux Physio, that such a technique has been used to calculate a progressive lens.

Point by point digital surfacing™ :

The design of a progressive surface results in a complex calculation which integrates all the optical functions determined by the technique of wavefront management for each point on the lens and for each direction of view. The complex optical design involves a high-precision calculation for the back surface of the lens which adjusts the front progressive surface for every direction of gaze. Calculation software carries out point by point twinning of the front and back surfaces of the lens to determine the complementary surface to manufacture in order to obtain the optical function which is sought after. Point by point surfacing technology known as “Advanced Digital Surfacing” allows the complex back surface to be manufactured.
The innovation resides in the fact that each lens is optimized for each prescription. Using classical methods only one power for each base curve was optimized exactly. Today, numerical surfacing permits the manufacture, point by point, of the back surface allowing precise optical characteristics to be obtained and thus perfect optimization of the lens whatever its prescription.

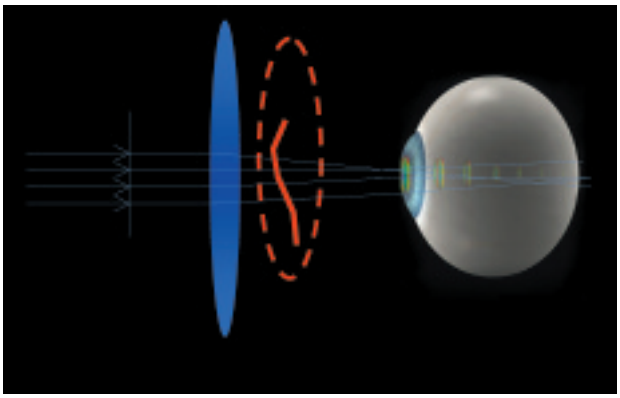


Fig. A : Wavefront Management System™.

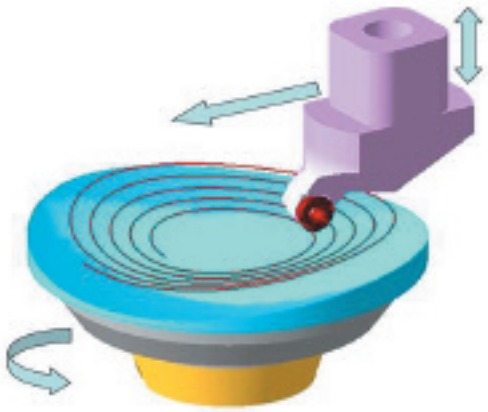


Fig. B : Advanced Digital Surfacing™.

A new dimension : “personalized” progressive lenses

With the advent of direct surfacing technologies, it has become possible to tailor a progressive lens design to take into account certain characteristics of the wearer. By means of this technology a new era has arrived, that of the “personalized” progressive lens made individually for each wearer.

A first approach to individualization of progressive lenses was that of Rodenstock with their ImpressionILT (Individual Lens Technology) design and Zeiss with their Individual design who enabled criteria linked to the prescription and the frame, such as the monocular PDs, vertex distance, pantoscopic and dihedral tilts, to be incorporated in the design. The basic idea was to provide each presbyope with the same vision as that obtained by an emmetropic presbyope with the same near addition.

A different approach was adopted by Essilor with the Varilux Ipseo. For this lens, the design and manufacture is based upon the visual behavior of the wearer. The design is personalized to take into account the actual degree of head and eye rotation which the wearer employs when viewing through the intermediate and near zones of the lens. It was recognized that each individual has a specific head and eye behavior. One can distinguish two opposite types of wearer behavior.
- subjects who tend to turn their eyes more often, keeping their heads fixed (“eye movers”)
- subjects who tend to turn their heads more often, keeping eye rotation to a minimum (“head movers”)
These visual strategies, acquired since childhood, are unique to each individual. The characteristics are permanent, reproducible and independent of the degree of ametropia, the stage of presbyopia or the age of the subject. All types of behaviour are to be found and vary from those who fall into the category of “eye movers” who almost never turn their heads, to those who fall into the category of “head movers” who almost never turn their eyes. As far as progressive lens design is concerned, this characteristic is of fundamental importance since it defines the way in which the eye uses each different zone of the lens. In particular :
- an “eye mover” uses the lens in a static fashion : most movements are made by the eyes and the vision is mainly foveal, the subject is more sensitive to the clarity of the image and it is necessary to provide such a subject with a large field of clear vision.
- a “head mover” uses the lens in a dynamic fashion : most movement is made by the head, peripheral vision becomes important, the subject is more sensitive to swimming effects and it is necessary to provide a lens with soft peripheral zones.

So, based upon the behavior of the individual wearer, the most appropriate progressive surface can be incorporated on the lens to provide maximum comfort for the wearer.

In practice, it is necessary to be able to measure the head/eye behavior for each wearer and a new instrument has been designed to determine the behavior known as the “Vision Print System” (Figure 42). The subject is seated before the instrument wearing a pair of spectacles equipped with ultrasound sensor transmitters (one in the unit and one in the headset) which enables head movement to be recorded. The task is to go see the lamps (luminous diodes) which are positioned 40° on each side of the field and which are illuminated at random then returning their gaze to a centrally mounted lamp after each lateral excursion The measurement is taken some 20 times at a distance of 40cm. Two pieces of information result :
- a head/eye coefficient (a value lying between 0 and 1) which gives the proportion of head movement employed by the subject during the measurement. The subject is considered to be an “eye mover” if the coefficient is less than 0.5 and a “head mover” if the coefficient is between 0.5 and 1.
- a stability coefficient which gives the standard deviation of the measurements.

Fig. 42 : Vision Print System™.

The two coefficients are used to calculate the parameters of the progressive surface according to the following parameters :
- the head/eye coefficient indicates the size of the zone of the lens which is required for maximum acuity and, therefore, how in the design of the lens, this area, which is needed for foveal vision, should be shared with the lateral zones where only peripheral vision is required : the central zone of good visual acuity would be increased for an “eye mover” and the peripheral zones softened for a “head mover”.
- the stability coefficient indicates the reproducibility of the head/eye behavior and how the area between the zone of maximum acuity and the peripheral zone of the lens should be managed : the transition from the central zone to the peripheral will be more marked in the case of high repeatability and much softer when the repeatability is poor.

Hence, in addition to the usual prescription characteristics, a new component has been added which specifies the dynamic use of the lens allowing personalization of progressive surfaces according to individual wearer behavior. Designed to match a precise measure of wearer behavior, it offers better visual performance. Furthermore, the design benefits from all the advantages offered by the latest advances in technology : different lengths of progression, W.A.V.E. Technology etc...

The criterion of head/eye coordination employed for the Varilux Ipseo is just one criterion of personalization. It will be followed by other approaches. Today, we are at the dawn of an era of personalized progressive lenses.

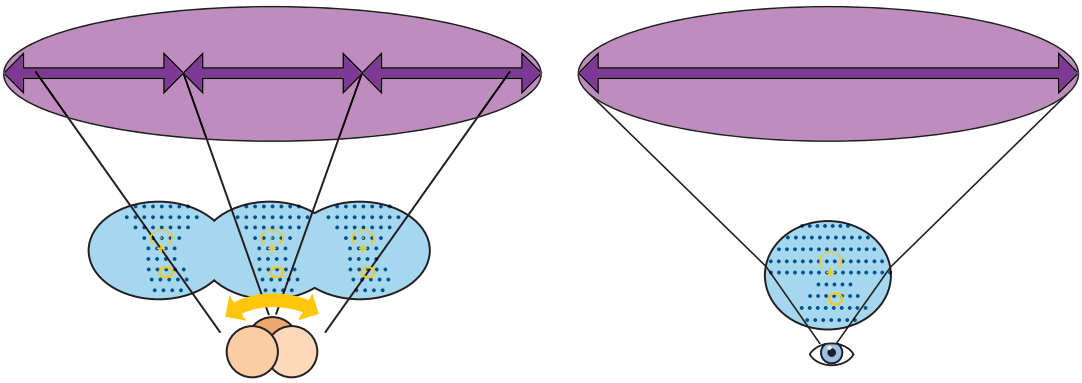


Fig. 43 : Principle of personalization of Varilux® Ipseo™.

Conclusion

Since the appearance of progressive lenses, almost 50 years ago, the technology employed in their design and manufacture has evolved continuously : from progressive surfaces made by the original, almost craftsman-like methods, to the most recent computer numerically controlled digital surfacing methods, considerable progress has been made.

At the same time the comfort of vision for presbyopes has been very clearly improved. If, originally, progressive lenses required a real effort of adaptation on the part of the wearer, adaptation is almost immediate with modern surfaces.

Today, it is no longer necessary to demonstrate the advantages of progressive lenses and their superior performance compared with bifocal and single vision lenses. Development will continue and accelerate : since over five hundred million presbyopes have already benefited from the comfort offered by these lenses, the next target of one billion wearers is sure to be reached in the next decade.

The worldwide adventure of the correction of presbyopia by progressive lenses will continue. Ever-increasing numbers of presbyopes will adopt progressive lenses in order to continue to “see better” for a “better life”.

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