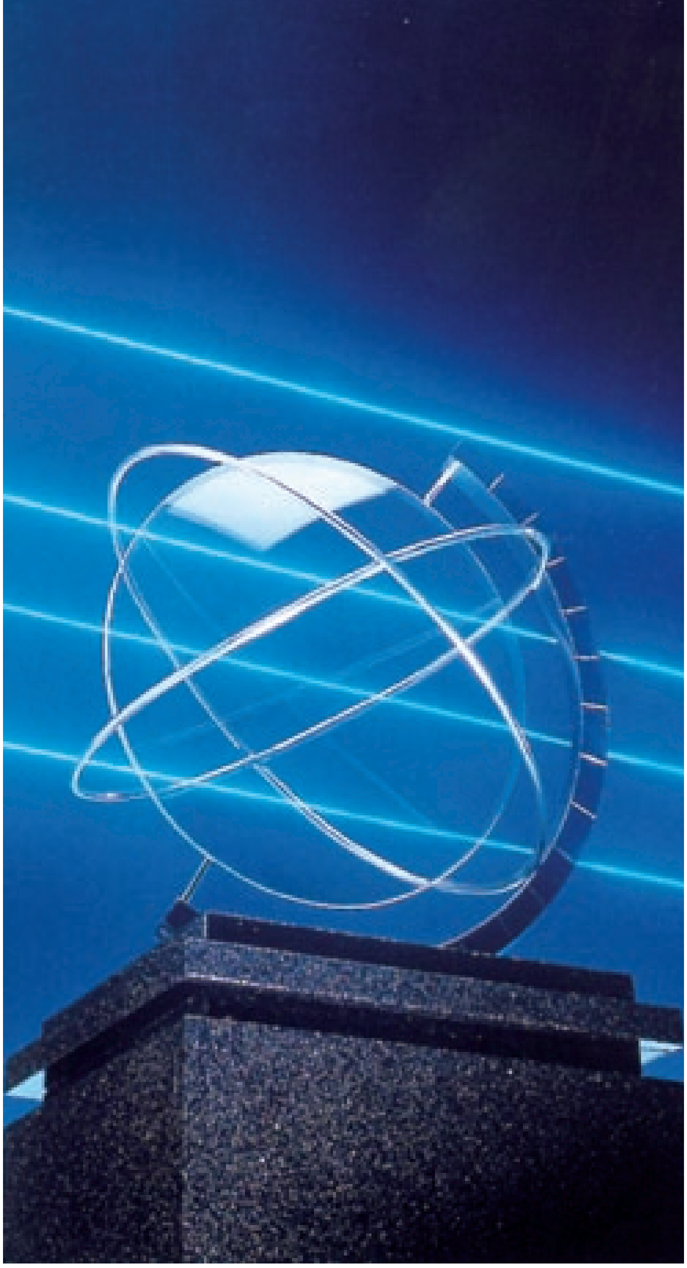


OPHTHALMIC
OPTICS
FILES

Progressive Addition Lenses

ESSILOR

IV

DESCRIPTION AND CONTROL OF PROGRESSIVE LENS DESIGNS

SUPPLEMENT:
MATHEMATICAL DESCRIPTION OF PROGRESSIVE SURFACES

V

ENHANCING THE CHARACTERISTICS OF FINISHED PROGRESSIVE LENSES

VI

THE EVOLUTION OF PROGRESSIVE ADDITION LENSES

PROGRESSIVE ADDITION LENSES

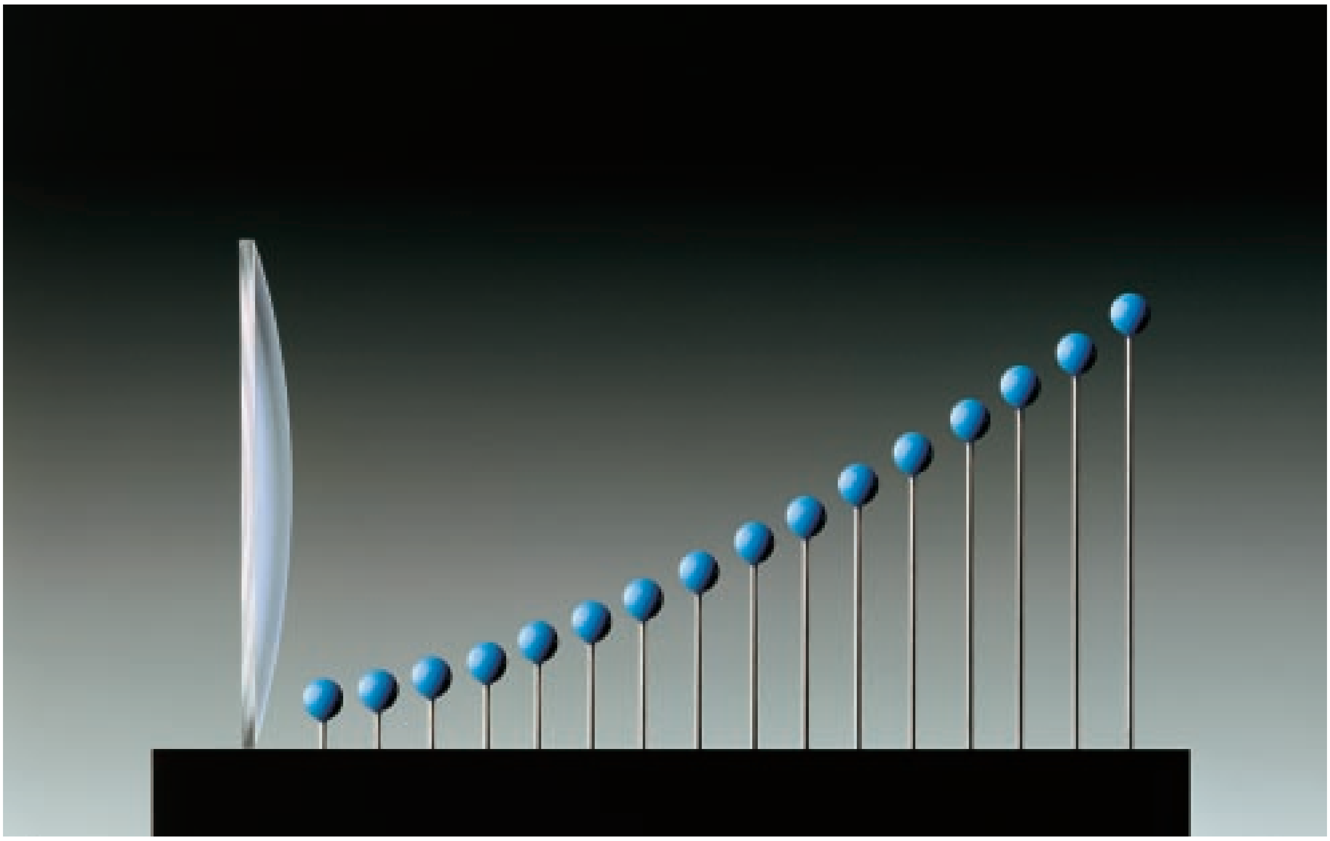


Fig. 1: *Progressive addition lens.*

Since their introduction by Essilor in 1959, progressive addition lenses (PALs) have gained worldwide acceptance as the most performant ophthalmic lenses for the correction of presbyopia because they provide comfortable vision at all distances.

They successfully and advantageously replace single vision and bifocal lenses, presbyopic corrections that do not offer such an advantage.

Experts project that, worldwide, about 22 percent of all presbyopes will be fitted with progressive lenses by 1994 and that this segment of the presbyopia correction market will continue to grow by about 10 percent a year.

Since more and more progressive practitioners systematically use PALs with most of their presbyopic patients, many presbyopes already enjoy the benefits of progressive lenses, and many more will do so in the future.

This volume of The Essilor Ophthalmic Optics Files series reviews the basic physiological and technical concepts behind progressive addition lenses.

A Basic design differences between Progressive, Single Vision, Bifocal and Trifocal Lenses:

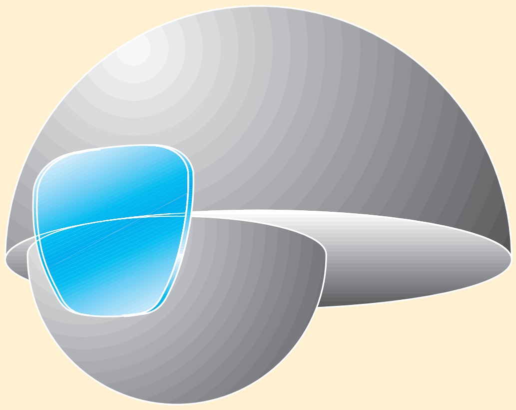
A **single vision reading lens** consists of a single sphere of appropriate radius providing correction for near vision only (see Fig. 2a). Distance vision through the lens is blurred and there is no specific correction for intermediate vision.

Bifocal, trifocal, and progressive lens designs combine areas of correction for both distance and near vision in a single lens and link them in different ways:

– In a **bifocal lens,** a distance vision sphere is placed above a near vision sphere and linked by a single "step" creating a visible segment line.

Fig. 2

a

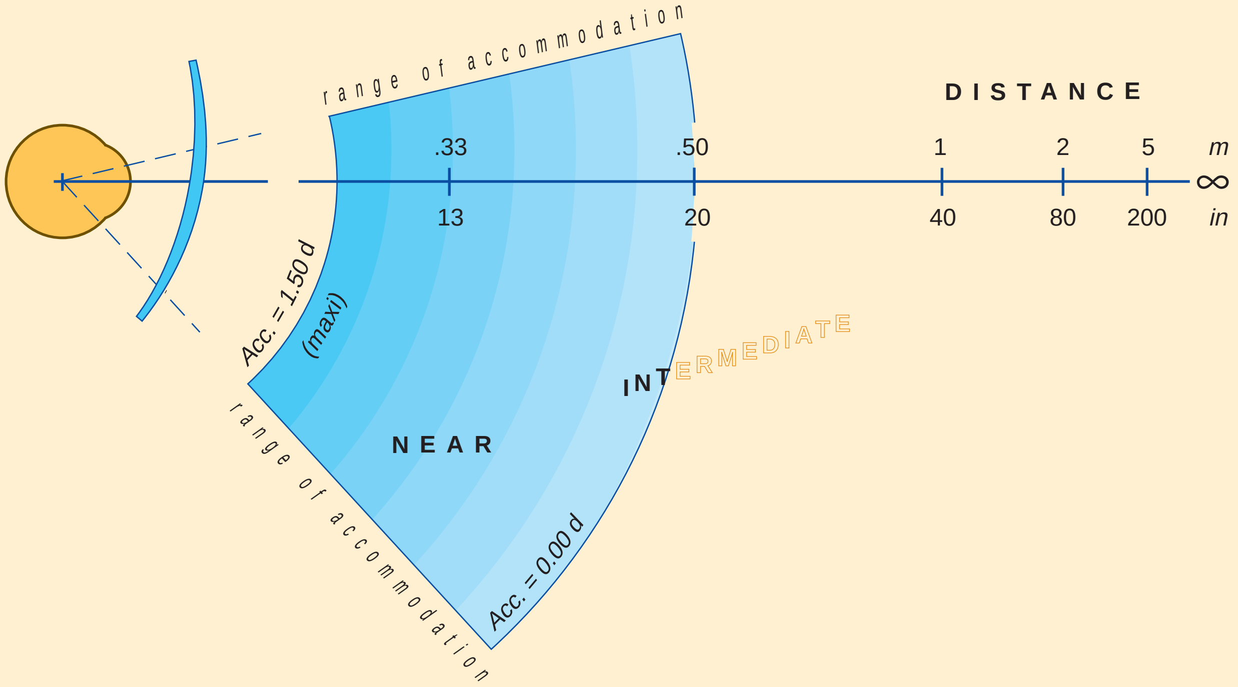


b

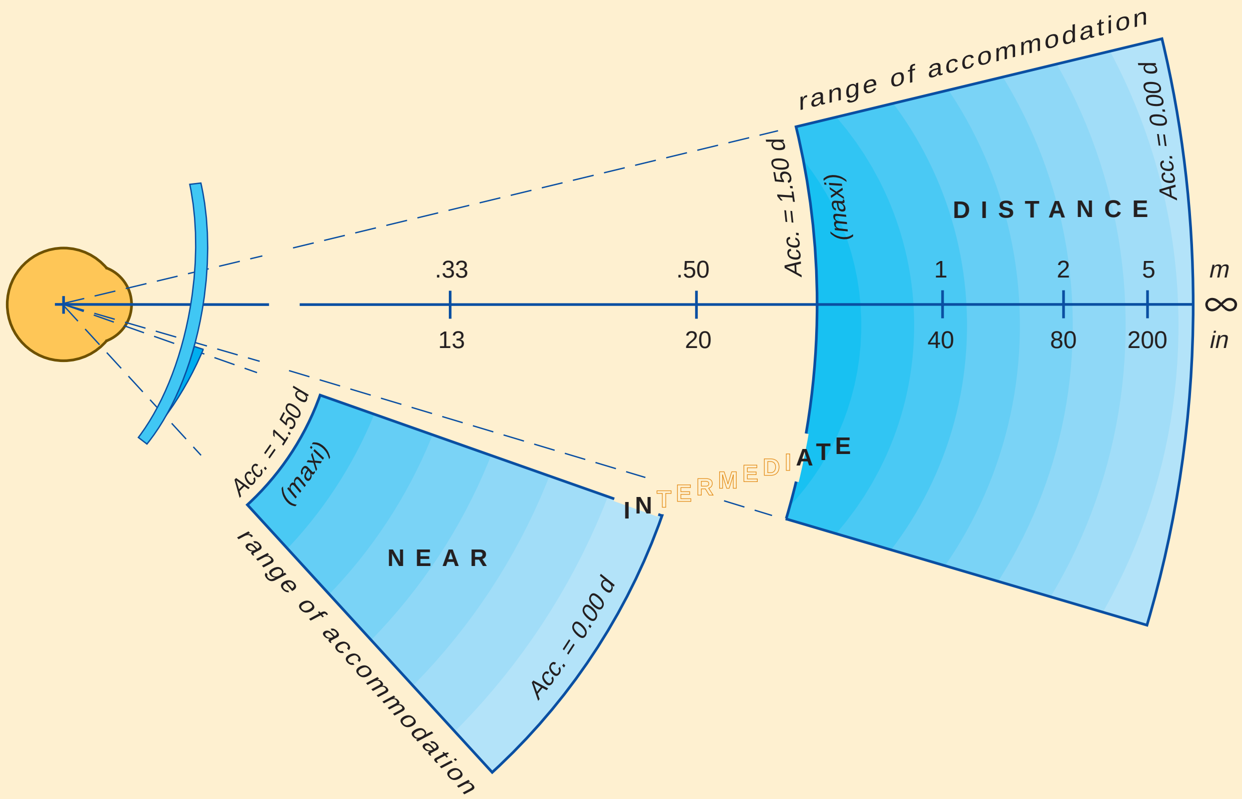
Fig. 2: *Basic design principles of single vision, bifocal, trifocal and progressive lenses.*
a) Single vision.
b) Bifocal.

Fig. 3: *Comparative fields of clear vision with single vision, bifocal, trifocal and progressive lenses (2.00D add).*
a) Single vision (2.00D add).
b) Bifocal (2.00D add).

Fig. 3


range of accommodation
DISTANCE
.33
.50
1
2
5
m
13
20
40
80
200
in
Acc. = 1.50 d
(maxi)
INTERMEDIATE
NEAR
range of accommodation
Acc. = 0.00 d

a


range of accommodation
Acc. = 1.50 d
(maxi)
Acc. = 0.00 d
DISTANCE
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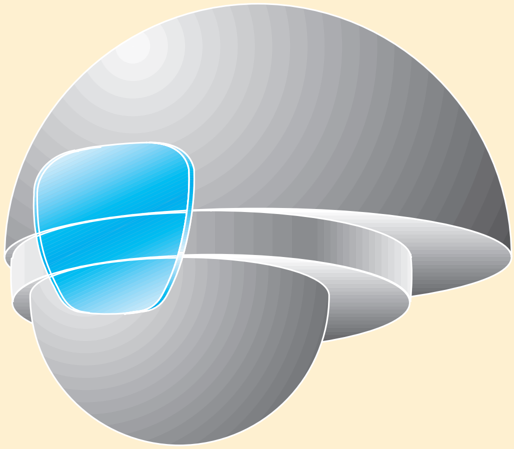
INTERMEDIATE
Acc. = 1.50 d
(maxi)
NEAR
Acc. = 0.00 d
range of accommodation

b

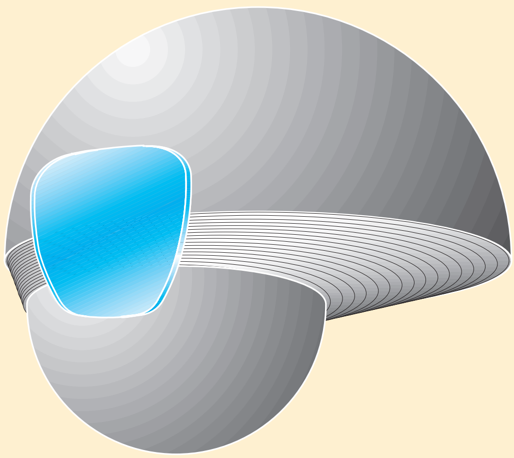
– In a **trifocal lens,** a third sphere is added between the distance and near vision spheres to produce an intermediate vision power. This gives rise to two segment lines on the lens surface.

– In a **progressive lens,** an uninterrupted series of horizontal curves links distance vision, intermediate vision, and near vision with no visible separation. Lens power increases smoothly from the distance vision area at the top of the lens, through an intermediate vision area in the middle, to the near vision area at the bottom of the lens.

Fig. 2 (contd.)



c

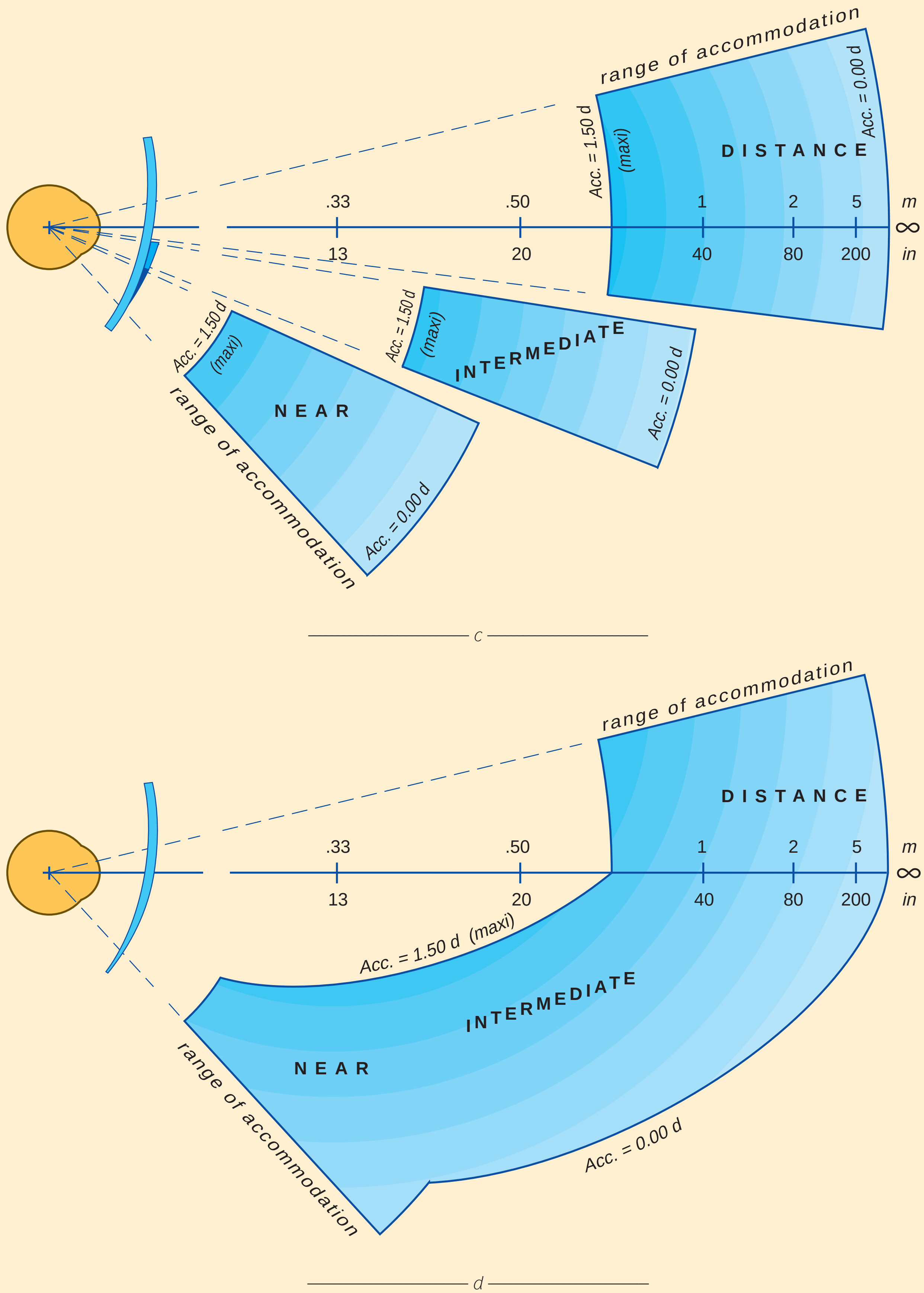


d

Fig. 2 (contd.):
c) Trifocal.
d) Progressive.

Fig. 3 (contd.):
c) Trifocal (2.00D add).
d) Progressive (2.00D add).

Fig. 3 (contd.)


range of accommodation
Acc. = 1.50 d
(maxi)
DISTANCE
Acc. = 0.00 d
.33
.50
1
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m
∞
13
20
40
80
200
in
INTERMEDIATE
NEAR
c
DISTANCE
INTERMEDIATE
NEAR
Acc. = 1.50 d (maxi)
Acc. = 0.00 d
d

B Advantages of Progressive Addition Lenses:

1) Continuous field of clear vision: Progressive addition lenses offer a continuous field of clear vision from distance to near. Single vision reading lenses offer a field of clear vision limited to the near area only, while the abrupt change of power in a bifocal creates completely divided fields for distance and near vision (Fig. 3).

2) Comfortable intermediate vision: Progressive addition lenses are the only lenses providing clear and comfortable intermediate vision whatever the addition as the progression of power gives rise to an area specifically designed for intermediate distance correction.

Only in the early stage of presbyopia, can single vision and bifocal wearers enjoy clear intermediate vision, as they can still accommodate and adjust their head position (Fig. 4).

For high additions, progressive lenses continue to offer clear vision at intermediate distance while bifocal and single vision lenses do not. For the latter, the ageing eye can no longer accommodate to compensate for the lack of intermediate vision power.

Despite their clear intermediate field of vision, trifocal lenses are not ideal, since wearers must cope with the image jumps at the two segment lines.

3) Continuous support to the eye's accommodation: In a single vision reading lens, the eye's accommodation is supported for near vision only. In a bifocal lens, the eye's accommodation experiences abrupt changes when the gaze shifts from distance to near vision across the segment line. Only, for each point of the progressive lens meridian does the power exactly correspond to the eye's focusing distance.

4) Continuous perception of space: Progressive lenses offer global perception of space: the power changes continuously and gradually in all directions. Single vision reading lenses do not allow real spatial perception, since they provide only a near vision correction. The two portions of bifocal lenses split and alter spatial relationships. Vertical and horizontal lines appear broken and image jump hampers the wearers' vision.

Many clinical studies conducted over the last 20 years have demonstrated the superiority of progressive addition lenses over bifocal and single vision reading lenses for correcting presbyopia. Studies such as by Drs Borish [1], [2], Cho [3], Davidson [4], Krefman [5] in the U.S.A., and by Dr Gresset [6] in Canada have documented a success rate higher than 95 percent with progressive lenses while a survey by Dr Shultz [7] had shown that 11 percent of bifocal wearers never adapt to their lenses.

References:

(1) - Borish I.M., Hitzeman S.A., and Brookman K.E.; Double-masked Study of Progressive Lenses, Journal of the American Optometric Association, Vol. 51, No 10, October 1980.

(2) - Borish I.M., Hitzeman S.A.; Comparison of the Acceptance of Progressive Multifocals With Blended Bifocals, Journal of the American Optometric Association, Vol. 54, No 5, May 1983.

(3) - Cho M.H., Barnette C.B., Aiken B., Shipp M.; A Clinical Study of Patient Aceeptance and Satisfaction of Varilux Plus and Varilux Infinity Lenses, Journal of the American Optometric Association, Vol. 62, No 6, June 1991.

(4) - Gatoura J., Study Cites Success Of Spectacle Lens Presbribed For Presbyopia, Ophthalmology Times, Vol. 9, No 12, 1984.

(5) - Krefman R.A., Comparison of Three Progressive Addition Lens Designs: A Clinical Trial, Southern Journal of Optometry, Summer 1991.

(6) - Gresset J.; Subjective Evaluation of a New Multi-Design Progressive Lens, Journal of the American Optometric Association, Vol. 62, No 9, September 1991.

(7) Shultz L.B.; Adaptation to Bifocals, American Journal of Optometry and Archives of the American Academy of Optometry, Vol. 50, No 3, March 1973.

Fig. 4

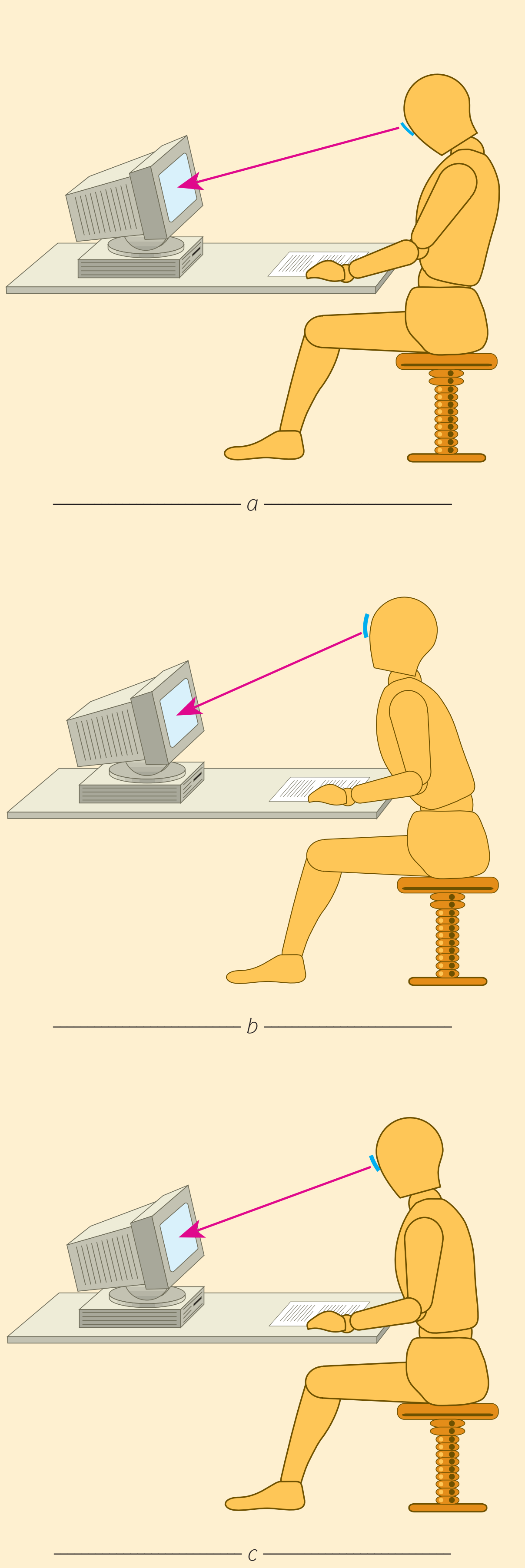


Fig. 4: *Intermediate vision.*
a) Using the distance vision portion of a bifocal.
b) Using the near vision segment of a bifocal.
c) Using the intermediate portion of a progressive.

A progressive lens is designed not only to restore a presbyope's ability to see clearly at all distances but also to optimally respect all physiological visual functions, in particular:

A Foveal vision:

The retina's foveal area permits sharp vision of details at any distance within a very small field which follows the eye's rotation (usually within a 30° angle). To this end, the lens areas used for foveal vision must provide for perfect retinal images.

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

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

Fig. 5

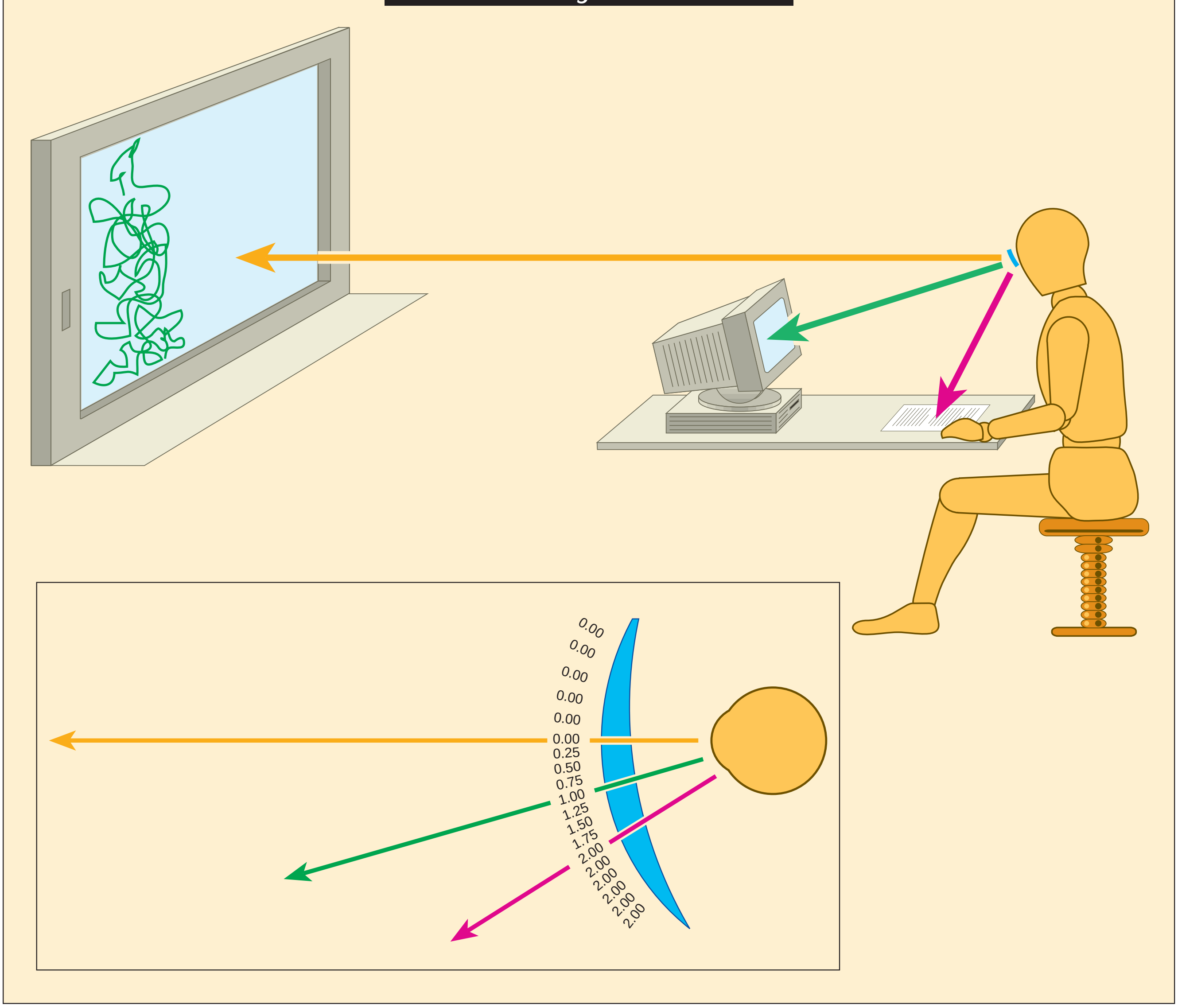
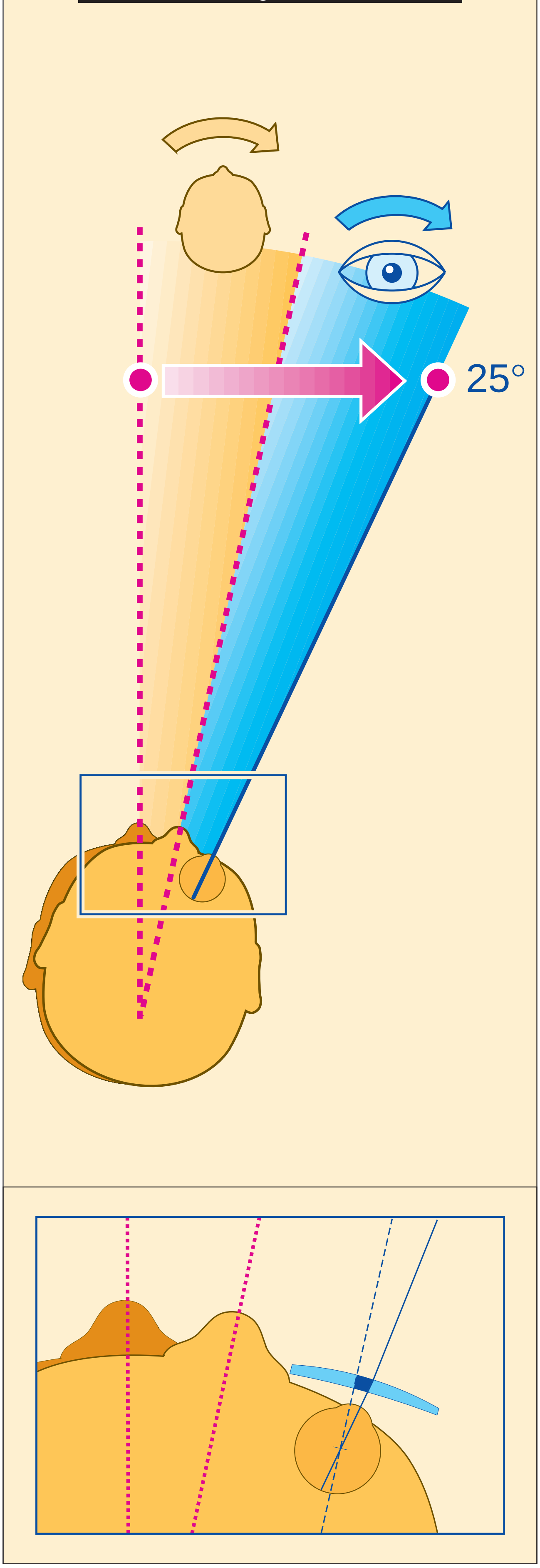


Fig. 6



2) Horizontal 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 used for foveal vision (usually less than 15°).

3) Visual acuity: To maximize wearer's visual acuity in the lens' central area, the unwanted, induced cylinder of the progressive lens must be kept to a minimum and be pushed to the peripheral parts of the lens.

Fig. 6: *Horizontal eye/head movement coordination and width of field.*

B Extra-foveal vision:

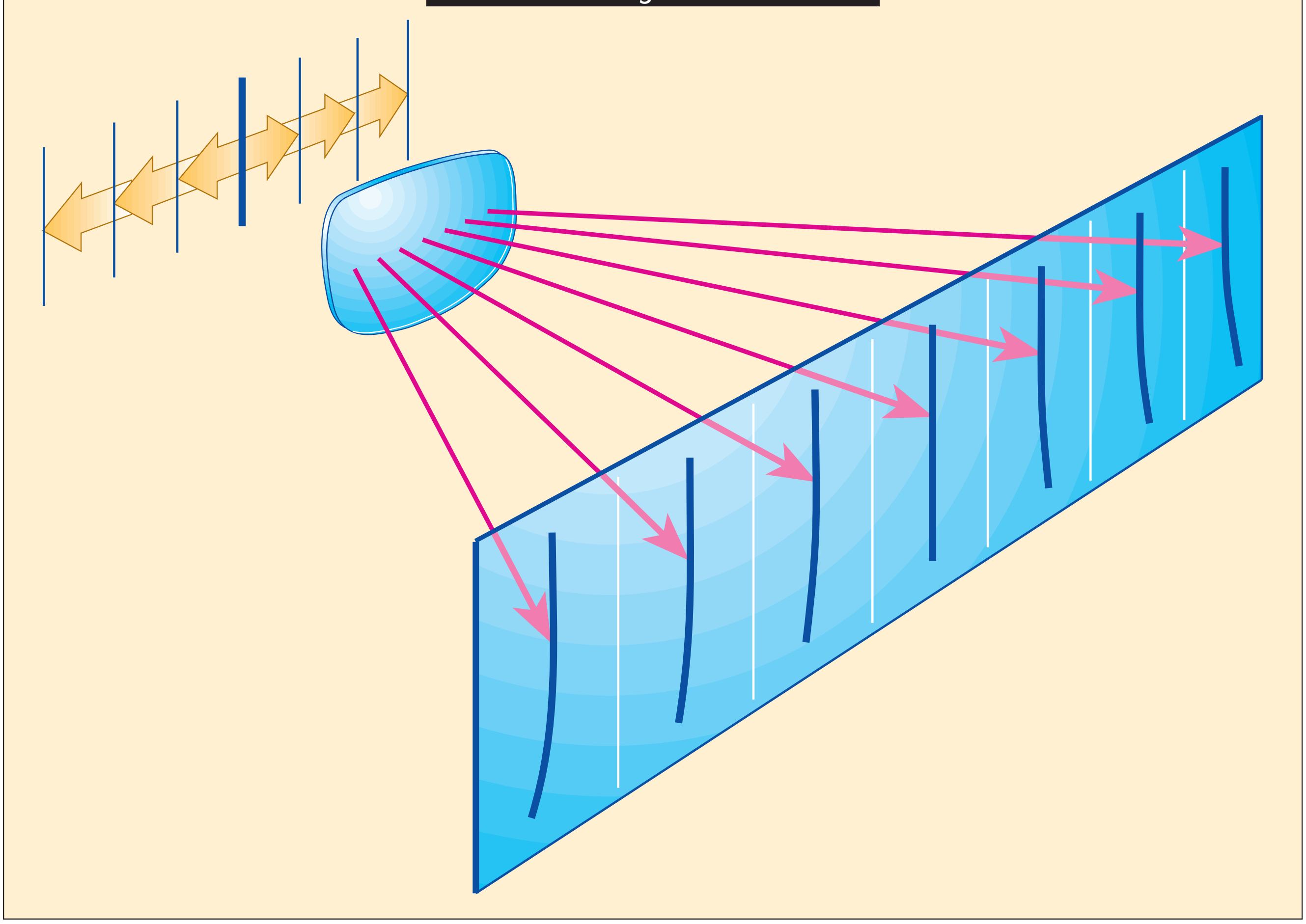
Extra-foveal vision refers to the visual perception provided by the periphery of the retina. In extra-foveal vision, wearers do not see objects sharply but locate them in space, perceive their forms and detect their movements.

1) 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.

2) Perception of movement: Movement is perceived by the whole of the retina which is almost homogeneously sensitive to motion. Here also, the variation of 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.*

Fig. 7



C Binocular vision:

Binocular vision refers to the simultaneous perception of the two eyes. For optimal fusion, the images produced by the right and left lenses must be formed on corresponding retinal points and display similar optical properties.

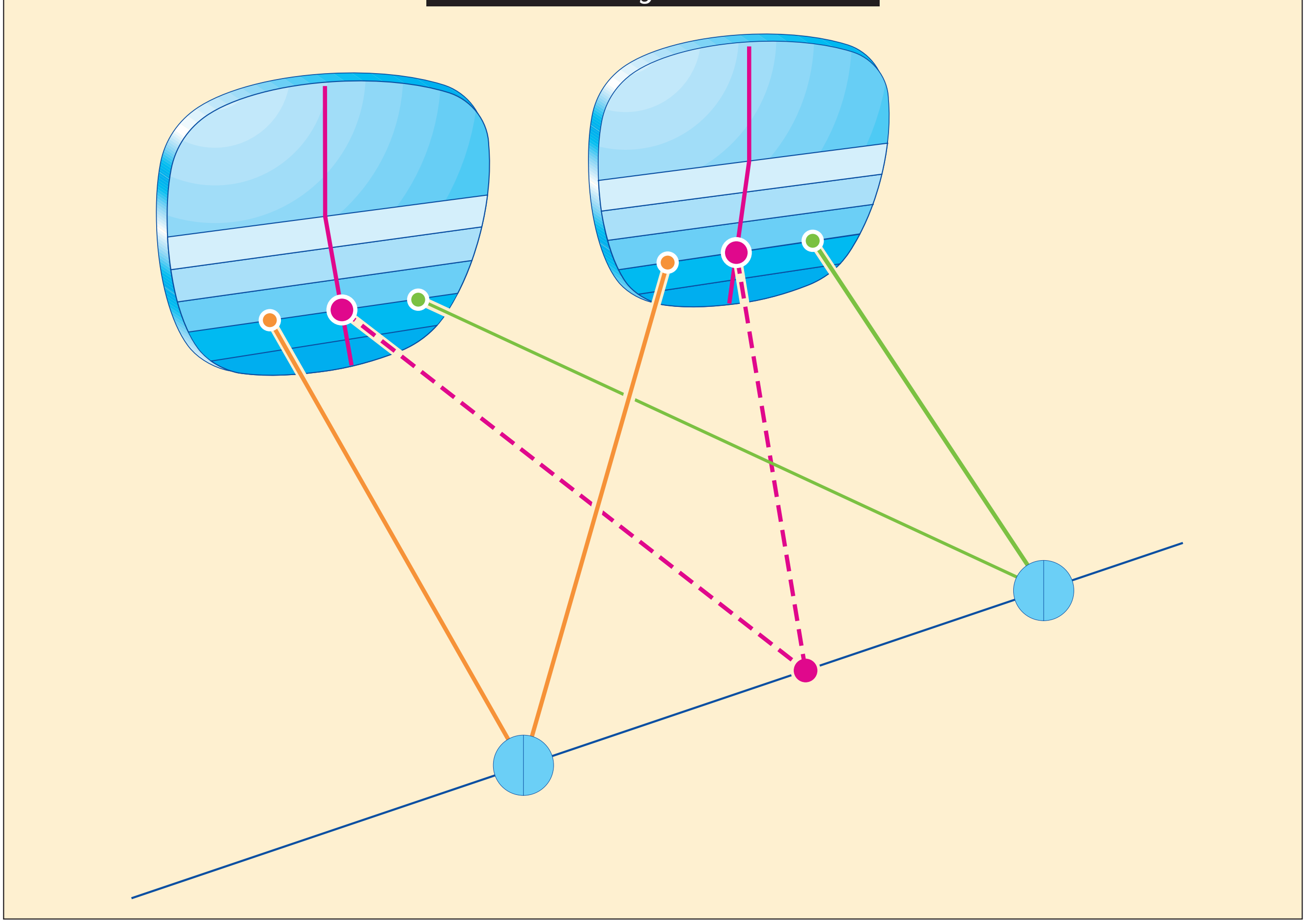
1) Corresponding retinal points: The eyes naturally converge when the wearer's gaze is lowered for near vision. The power progression must be positioned in the lens in order to follow the eyes' path of convergence downwards in the nasal direction. For ease of motor fusion, in all directions of gaze, both right and left lenses must offer approximately equal vertical prism on each side of the power progression path.

2) Similar images: To ensure sensorial fusion, the retinal images formed in both eyes must be similar in all directions of gaze. For that purpose, the power and astigmatism encountered on corresponding points of right and left lenses must be approximately equal.

Progressive lens designers work towards respecting these physiological functions. The following section, illustrates the methods used to accomplish this.

Fig. 8: *Binocular vision with progressive lenses.*

Fig. 8



A Modern conception of ophthalmic lens design:

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 sphere is the optical conjugate of the retina of the unaccommodated eye in rotation. The image of an object point formed on this sphere is usually a blurred spot instead of a sharp point due to the aberrations of the lens. To measure the quality of the image of any object point, the lens designer “sends” a set of selected light rays which enter the eye’s pupil after refraction 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. The lens designers strive to improve the quality of this image by controlling the lens’ optical aberrations in the best possible way.

Fig. 9: *Image formation on the far-point sphere.*

Fig. 10: *Lens + Eye optical model.*

Fig. 11: *Image calculation.*

Fig. 9

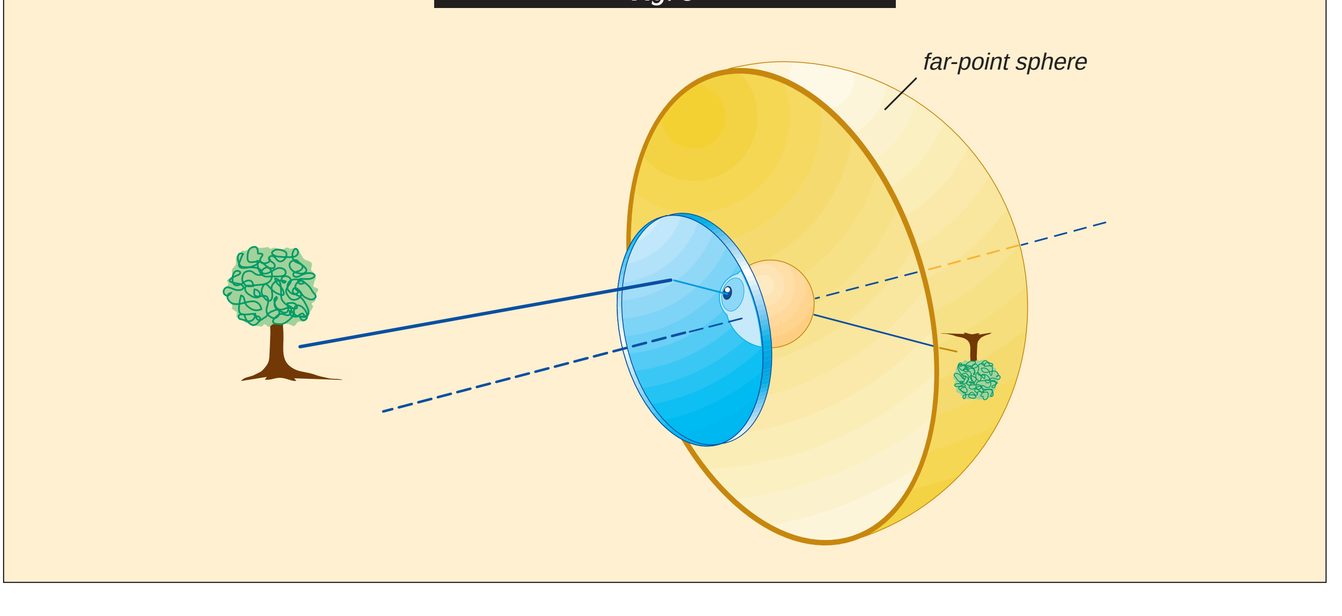


Fig. 10

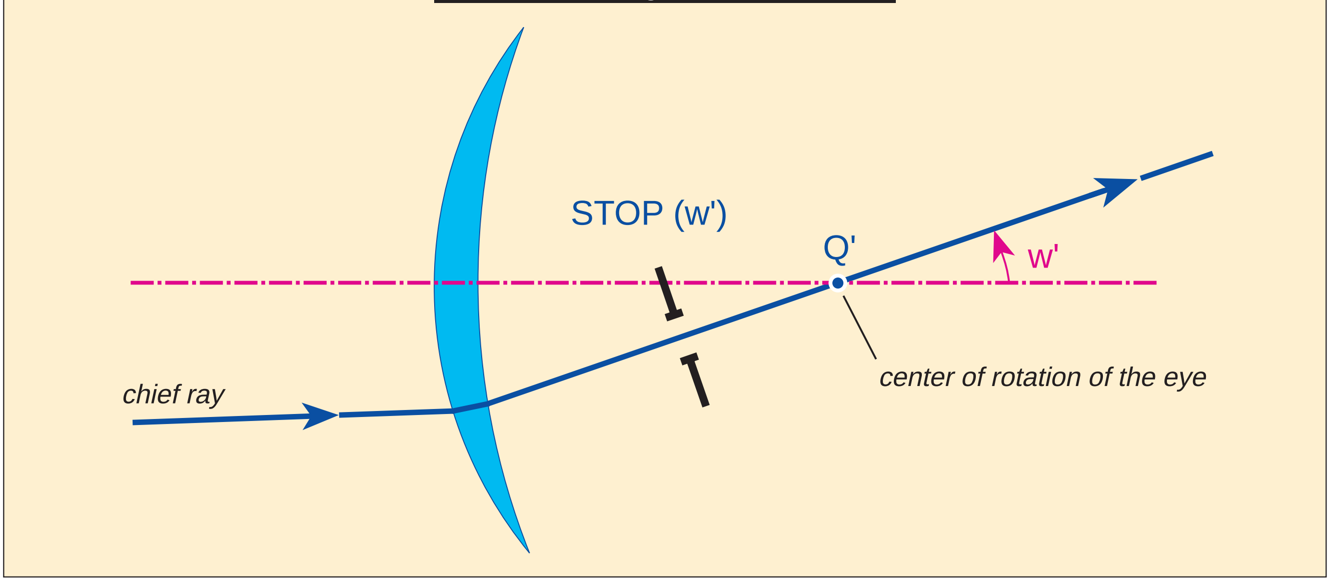
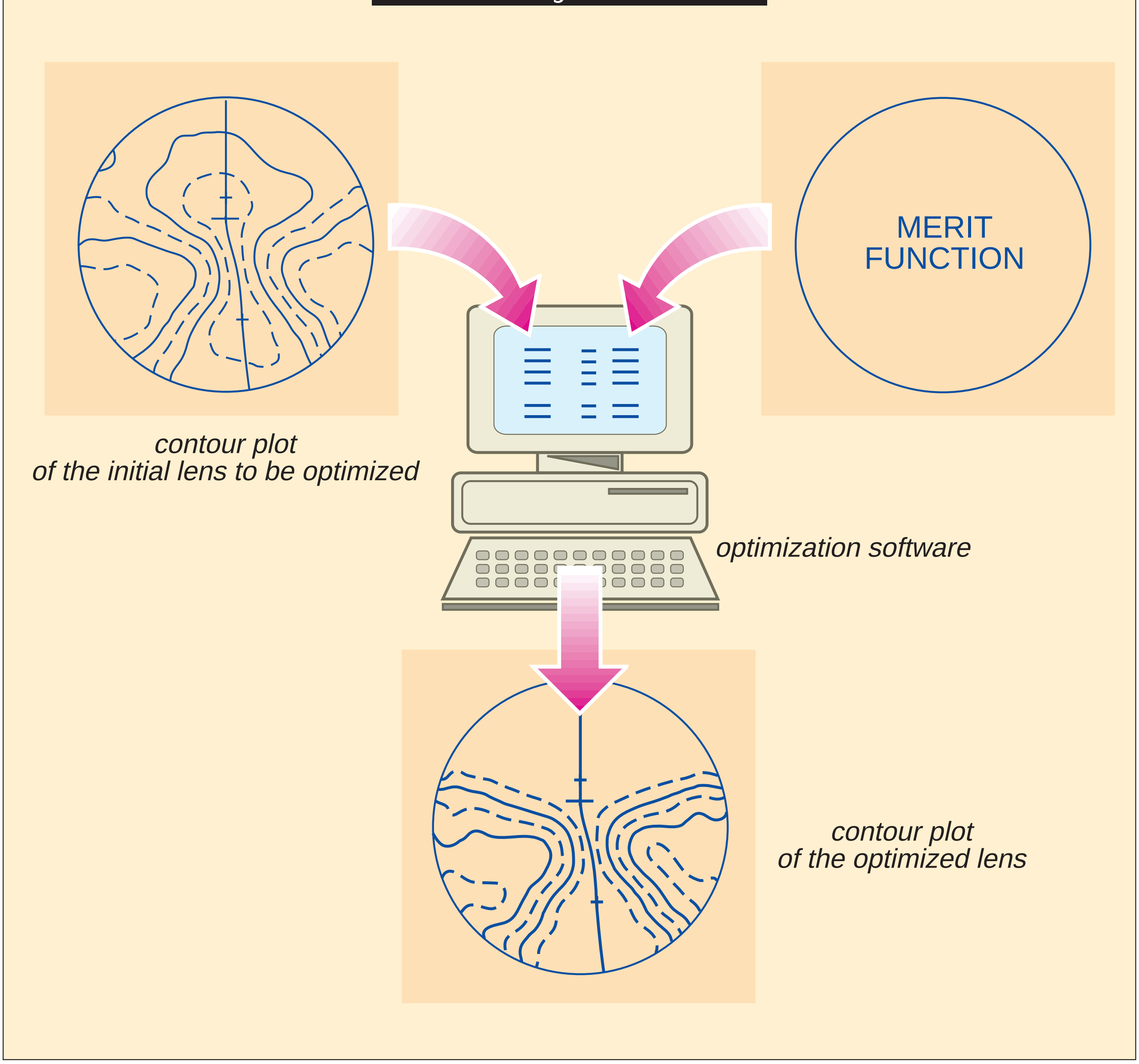

STOP (w')
Q'
w'
chief ray
center of rotation of the eye

Fig. 11


MERIT
FUNCTION
contour plot
of the initial lens to be optimized
optimization software
contour plot
of the optimized lens

2) "Optimization" software and "Merit Function": Lens designers cannot create optimized optical systems in a single step. Instead, most designers employ an iterative process using an optimization computer software. In this process, the designer defines an initial optical system and a "Merit Function" used to rate the optical system's overall performance. 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 found.

The Merit Function evaluates numerous points of 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 the actual characteristics Aj of the system.

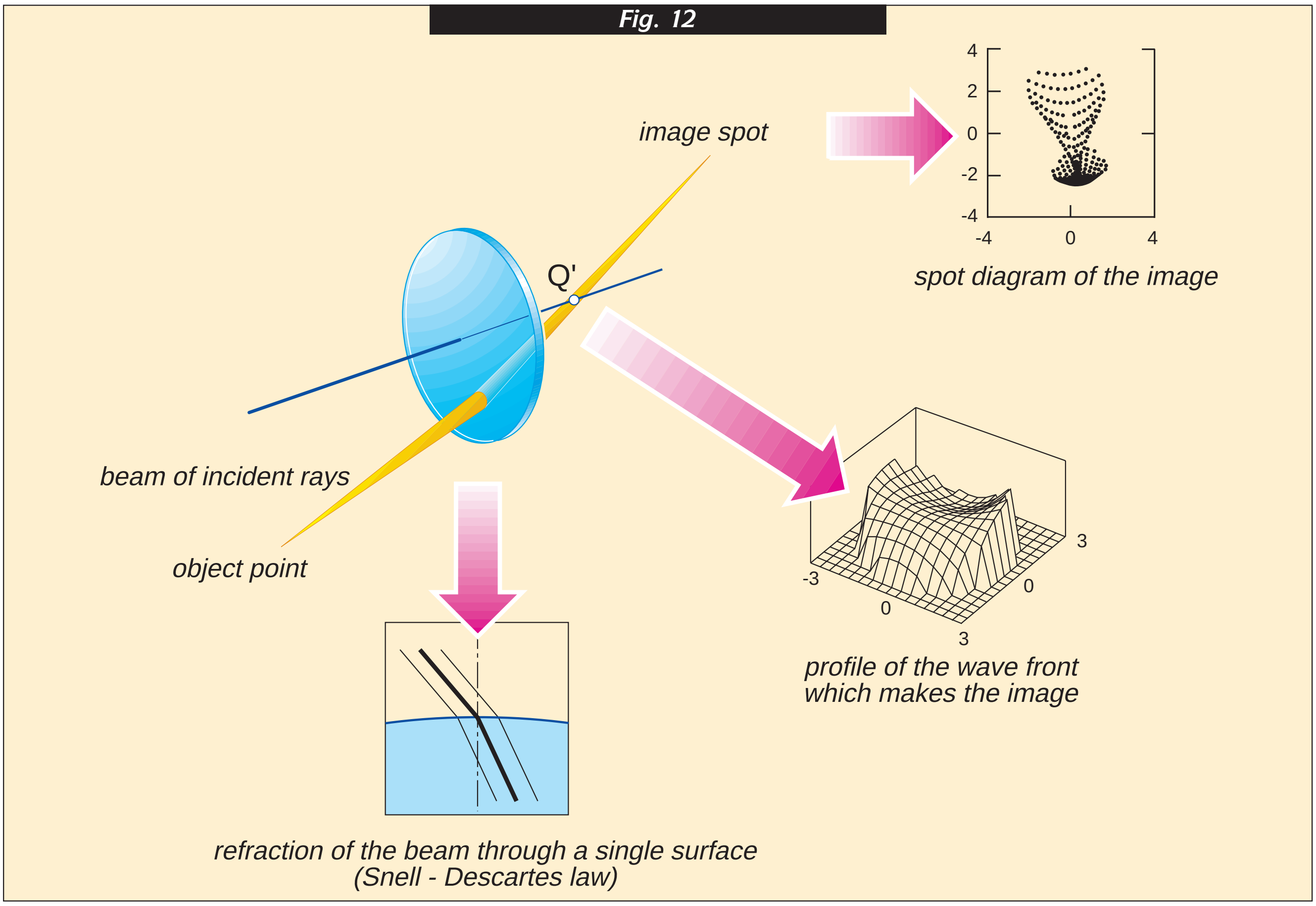
The overall performance of the lens is then evaluated by the weighted sum of the found Merit Function values according to the following formula:

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

with
- 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. 12: *Optimization software.*



B Designing progressive addition lenses:

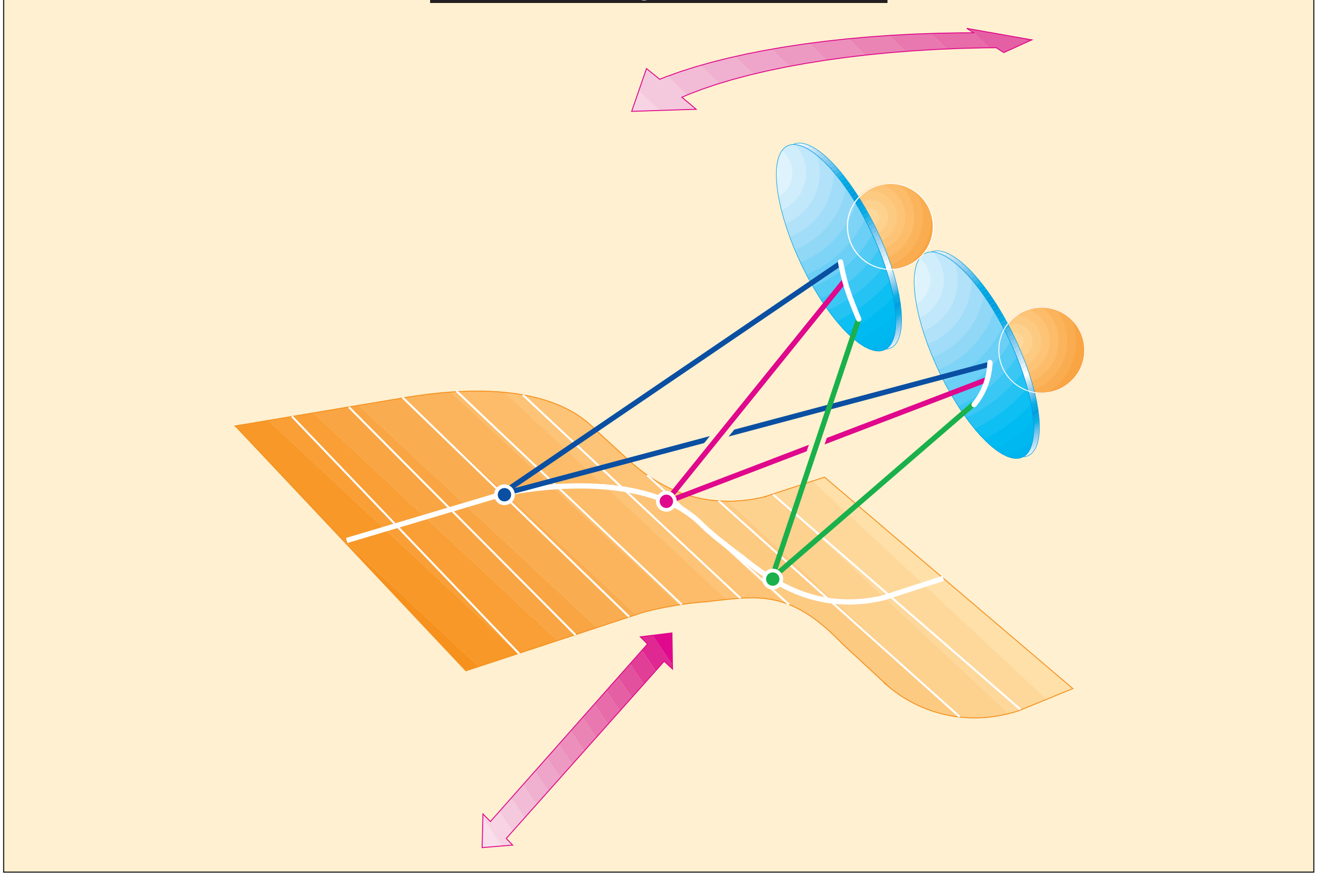
1) Specific optical requirements of a PAL: The optical characteristics of a progressive lens are defined by the visual physiology and postural behavior of the wearers, as determined by clinical experiments. They can be divided into two categories:

1) characteristics that must respect strictly determined values,

2) characteristics that should be kept below given thresholds.

Fig. 13: *Near and intermediate vision.*

Fig. 13



a) Power progression requirements:

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

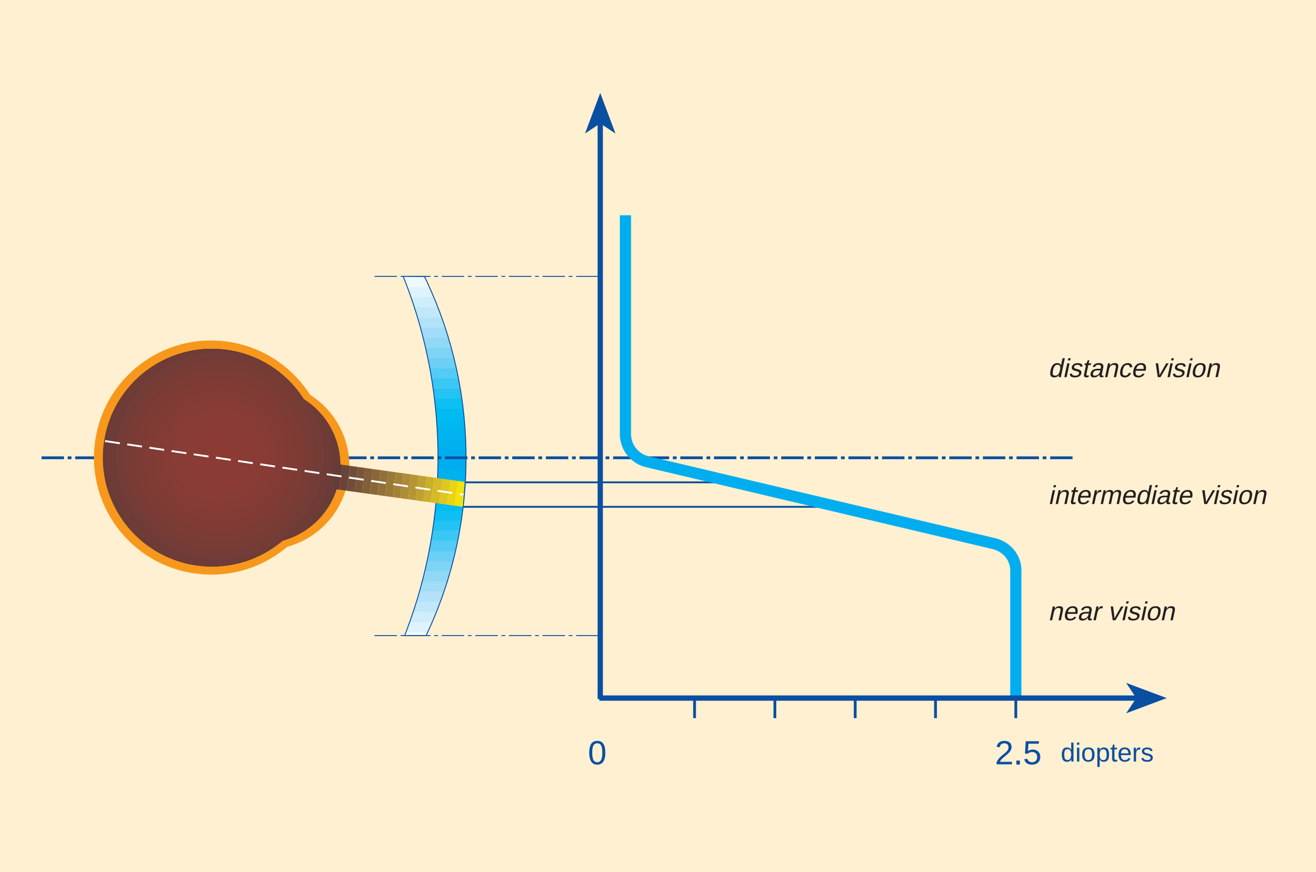
– Vertical location of the near vision area: physiological considerations, such as strain of extra-ocular muscles or limited range of binocular fusion with downward gaze, favor a high position of the near vision area in the lens. Unfortunately, a short progression usually results in rapidly varying peripheral aberrations. Lens designers redress this conflict. A good compromise consists in locating the usable near vision at a downward gaze position of about 25 degrees.

– Profile of power progression: a suitable power progression, along the meridional line, enables the wearer to explore the object field without tiresome vertical head movements. This is achieved by associating the shape of the power progression to the orientation of the vertical horopter linked to the natural tilting of reading material.

– Horizontal (lateral) location of the near vision area (meridian): once the power profile has been defined, its lateral positioning on the lens must be adapted to the natural convergence of the eyes and the value of the addition. Since, the more advanced the presbyopia, the closer the reading distance, the meridional line must be shifted nasally as the addition increases.

Fig. 14: *Power progression.*

Fig. 14



b) Visual perception requirements:

To ensure optimal performance in foveal vision, image aberrations must be kept at the lowest possible levels on the lens surface, in particular along the meridional line and in its vicinity.

In the central lens area great care must be taken balancing vertical prism between right and left eyes to perfectly respect retinal image fusion in binocular vision. This is achieved by an asymmetrical design of the progressive lens surface coupled with proper positioning of the meridional line.

In the lens periphery, used 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.

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

2) Clinical studies and prototypes: Following the lens optimization and calculation process, the design team – composed of physiologists and engineers – propose several tentatively optimized designs. Numerous lens prototypes of each design are then produced and tested through rigorous clinical trials. Comparative lens evaluations are made after in-depth analysis of clinical evidence and patients' comments, leading to a final selection of lens design.

Since there is usually no exact relationship between lens design calculations and wearer satisfaction, information gathered from clinical experiments is also used to improve the Merit Function. This Merit Function represents the accumulated theoretical and clinical expertise and savoir faire of the design team.

A Optical description of a progressive lens:

Lens designers use different methods to graphically represent the optical characteristics of progressive lenses, in particular:

1) Power profile: (Fig. 15) The curve represents the power progression of the lens along its meridional line from distance to near vision. This power progression is a result of a continuous shortening of the radius of curvature of the front surface.

2) Contour plot: This is a two dimensional map of the lens representing either the distribution of power (Fig. 16) or of astigmatism (Fig. 17). The map shows lines of equal dioptric value (iso-power or iso-astigmatism). Between two consecutive lines, the power or astigmatism varies by a constant value, 0.50 D, in these examples.

Fig. 15

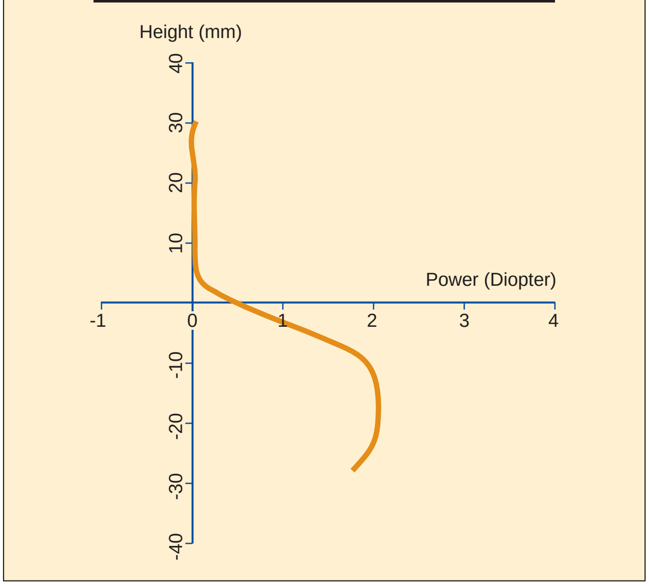


Fig. 16

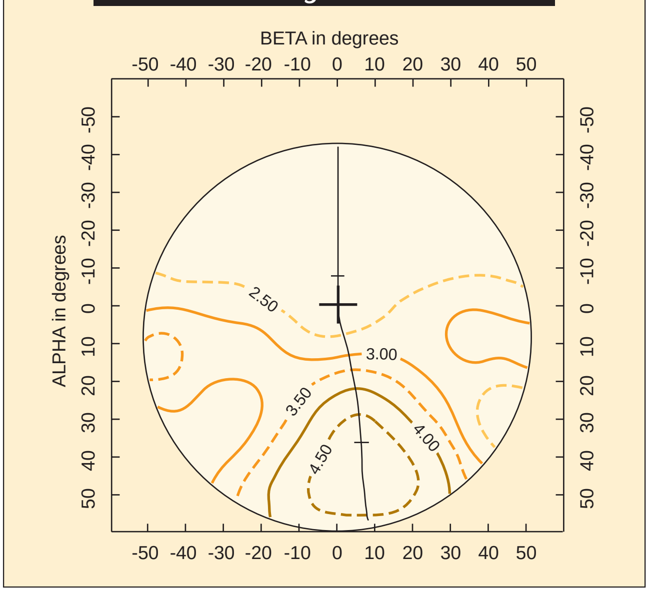


Fig. 17

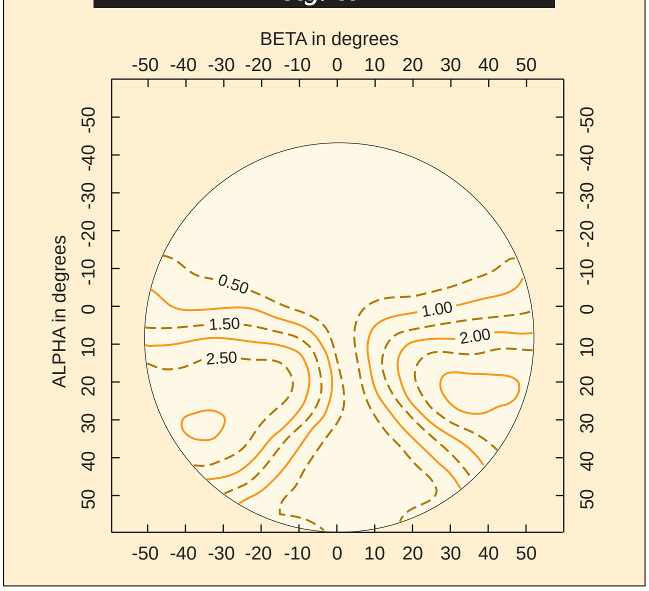


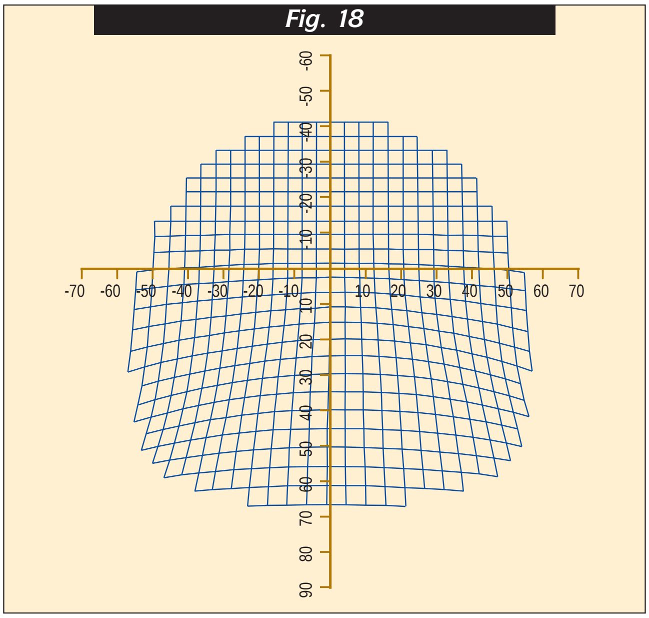
Fig. 15: *Power profile of a PAL (2.00D add).*

Fig. 16: *Power contour-plot of a PAL (+ 2.00DV with a 2.50D add).*

Fig. 17: *Astigmatism contour-plot of a PAL (2.50D add).*

3) Grid plot: (Fig. 18) The grid highlights the distribution of the prismatic effects of the lens by showing how they alter a regular rectangular grid.

Fig. 18: *Grid-plot of a PAL (2.50D add).*



4) Three dimensional plot: 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 power (Fig. 19), astigmatism (Fig. 20), prismatic effects, gradients of power variation (Fig. 21), etc... These three-dimensional plots are more demonstrative of lens characteristics than contour-plots.

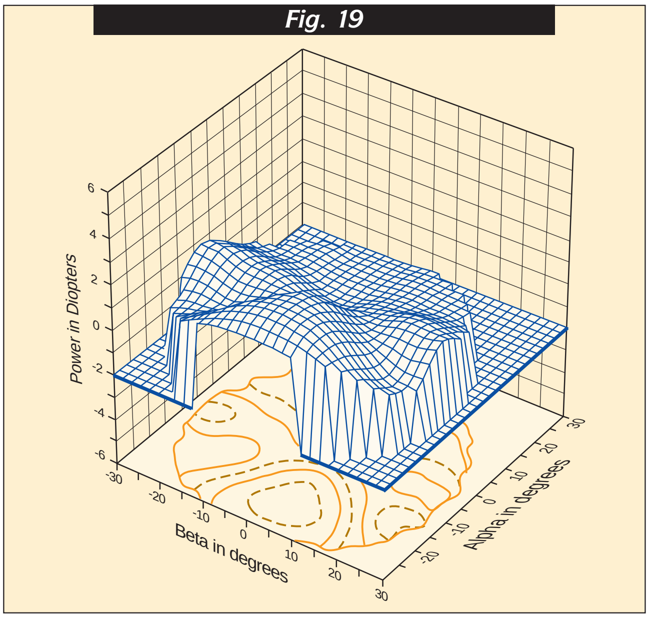
Plot interpretation:

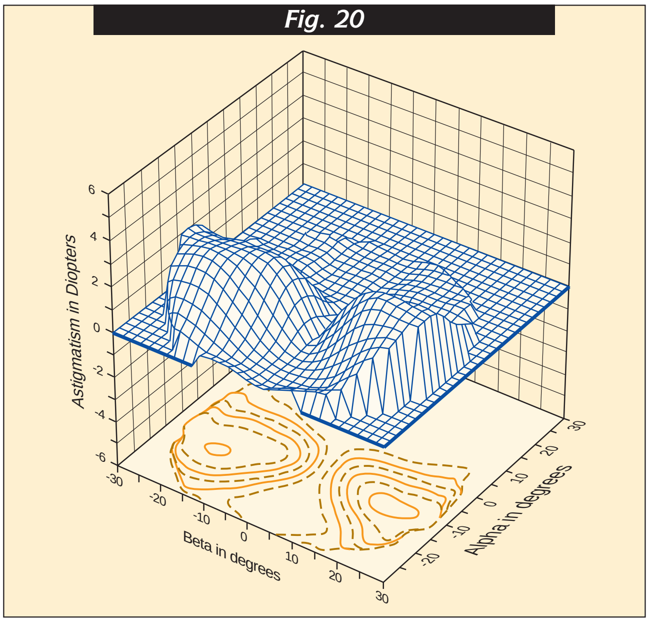
Though useful in the lens design process, all these plots are mere representations of PAL characteristics and do not really correlate with wearers' acceptance. As such, plots cannot be used to make significant PAL design comparisons or predict patients' visual comfort. The only trustworthy way for assessing or comparing lenses consists in conducting well monitored wearer tests.

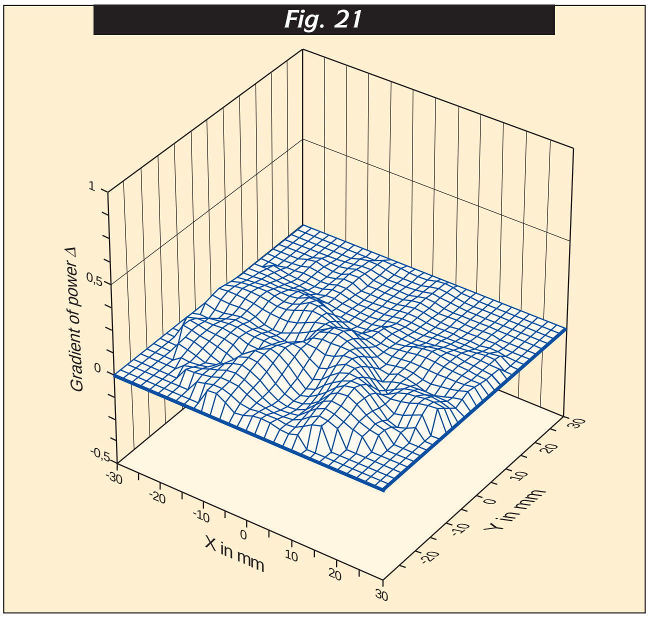
Fig. 19: *3D power plot of a PAL (2.50D add).*

Fig. 20: *3D astigmatism plot of PAL (2.50D add).*

Fig. 21: *3D power gradients plot of PAL(2.50D add).*







B Progressive lens design control:

Progressive lens design control is a very critical but little known activity of lens designers and manufacturers.

1) In lens development: In the PAL designing process, checking the conformity of a finished lens to a wearer's needs, requires the re-creation of the true conditions under which the eye will use the lens. This is done in one of two ways:

1) A direct method which uses a special focimeter simulating lens wearing conditions.

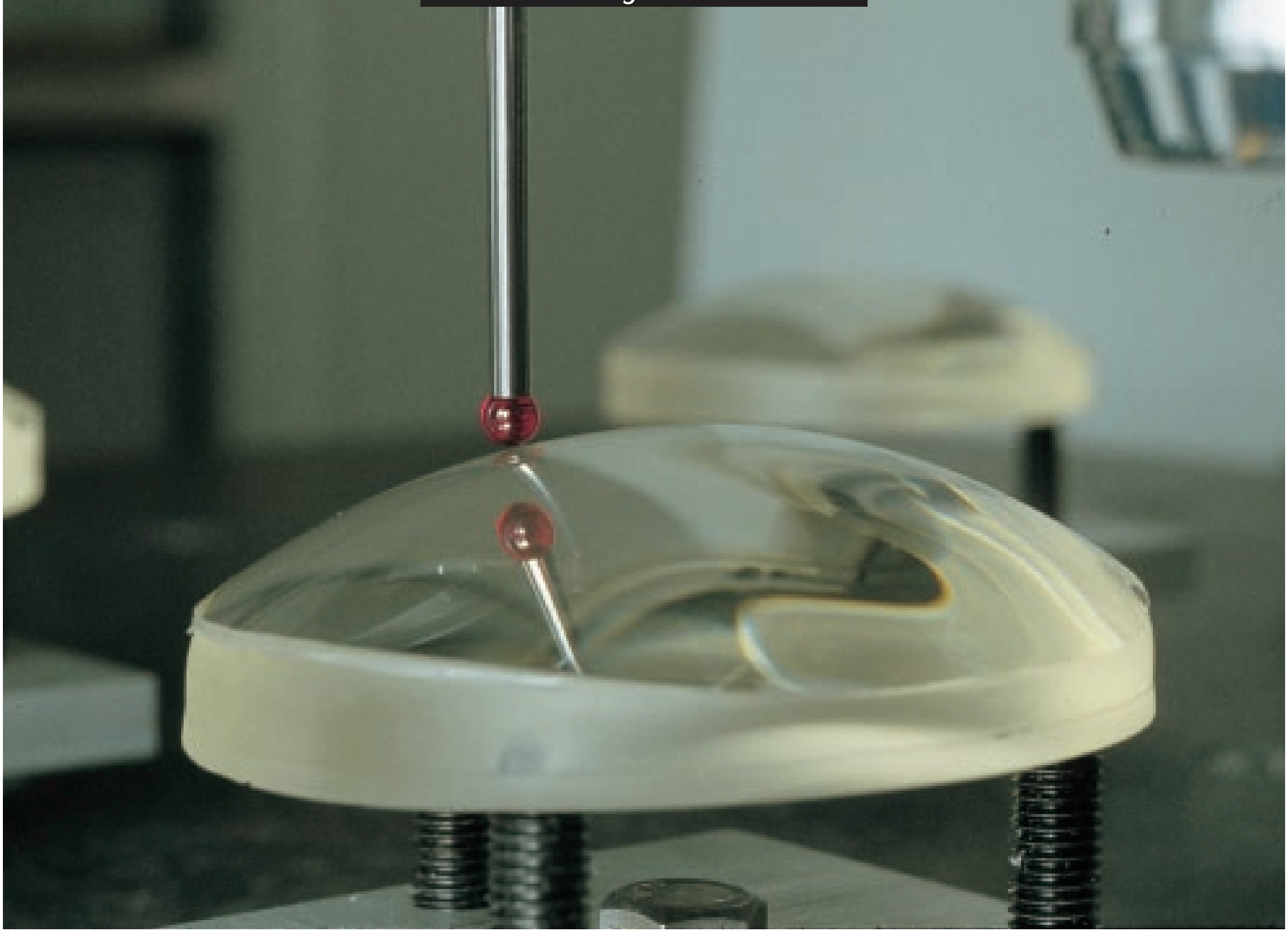
2) An indirect method in which the progressive lens characteristics are measured with the wearer's eye being simulated by calculations.

Three-dimensional mechanical measurement or deflectometric methods (analysis of deviation of light rays produced by the surface) may be used to measure the geometry of a progressive lens' surface.

2) In lens production: During mass production, the conformity of a lens to its technical specifications and its reproducibility are checked either by means of traditional focimetry, direct geometric or interferometric measurement of the progressive lens surface.

Fig. 22: *Coordinate Measuring Machine.*

Fig. 22



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 quadric surface is osculatory with the surface at point O (ie. its curvatures are identical to those of the real surface) and is defined by the equation:

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

where 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 C1 and C2 and by its axis derived from the following equations:

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

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

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

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

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

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 remarkable mathematical and physical applications: the 5th gives access to the mean curvature of the surface, the 4th and 6th to its cylinder and axis, the 7th and 10th 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 wavefront analysis. The lens surface is mathematically expressed by:

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

with P_i: Zernike polynomials
Z_i: Coefficients
y, z: reduced variables

Geometrical or optical meaning	*Zernike polynomials*	*Coefficients*
Piston	1	Z_0
Tilt in y	y	Z_1
Tilt in z	z	Z_2
Asti ±45°	$2.y.z$	Z_3
Defocus	$-1+2.y^2+2.z^2$	Z_4
Asti 0,90°	z^2-y^2	Z_5
Coma tr y	$3.y.z^2-y^3$	Z_6
Coma y	$-2.y+3.y.z^2+3.y^3$	Z_7
Coma z	$-2.z+3.z.y^2+3.z^3$	Z_8
Coma tr z	$z^3-3.z.y^2$	Z_9

Expansion of a surface into the first 10 Zernike polynomials.

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

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

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

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

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

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

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

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.

Fig. A: *Local description of a surface.*

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

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

Fig. A

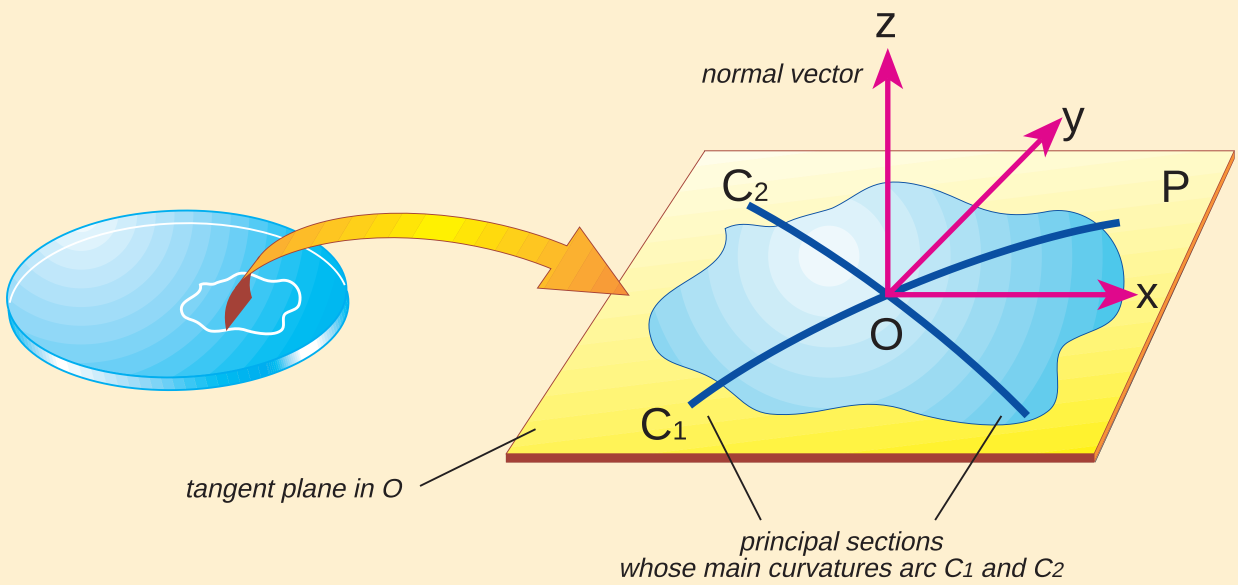


Fig. B

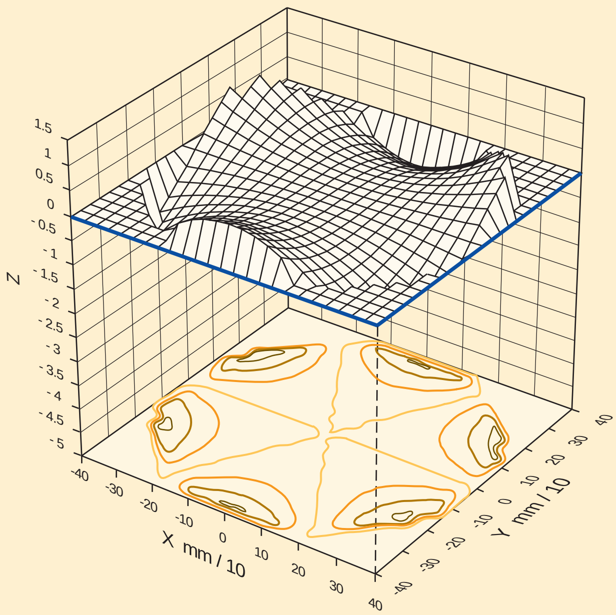
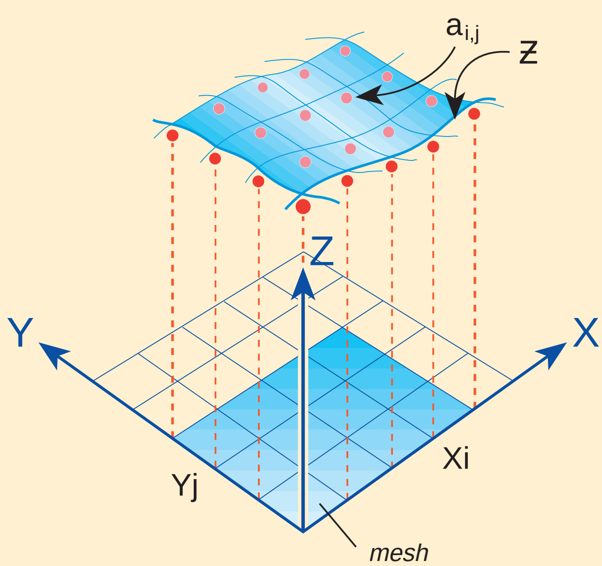


Fig. C



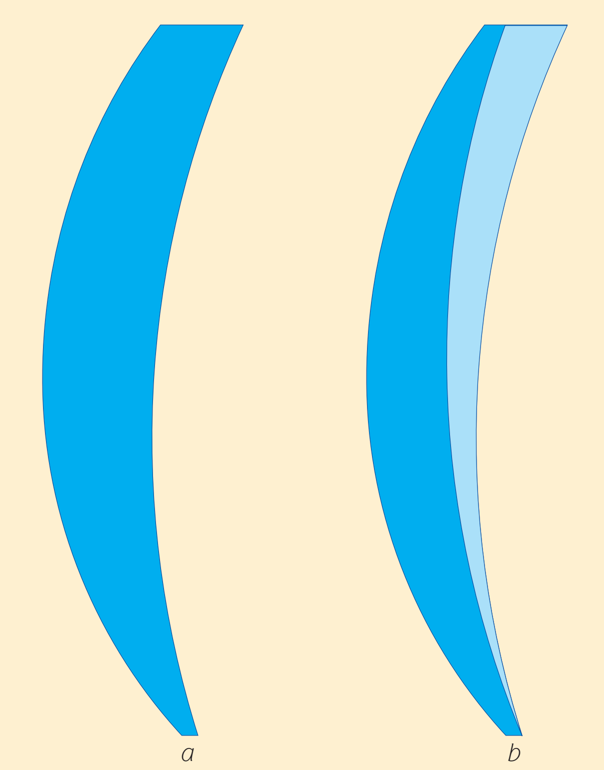
A "Equithin" Progressive Lenses:

As a result of the increase of curvature of the progressive surface in the near vision portion, a PAL is naturally thin at the bottom and thick at the top (Fig. 23a). To produce thinner lenses, lens surfacers generally use an "equithin" technique which consists of tilting the back side of the lens to equalize its thickness at the top and bottom (Fig. 23b). This "equithin" process induces a base-down prism; its value - expressed in prismatic diopters or cm/m - is generally 2/3 the value of the addition and can be measured at the optical center of the lens. For example, in a 3.00 D add "equithin" progressive lens, a 2 diopter base down prism would be read. "Equithin" prisms of identical value must be provided on both right and left lenses to avoid the introduction of any vertical prism imbalance.

The effect of the "equithin" prism is a slight upward shift of the whole vision field which has been clinically proven to have no significant effect on wearers' visual comfort. Since it offers dramatically thinner, lighter, more comfortable lenses, the use of "equithin" is highly recommended for progressive lenses of any distance and add powers.

Fig. 23: *"Equithin" progressive lens.*

Fig. 23



B “Precalibration”

The most effective way of reducing the center thickness of plus lenses is to produce them in “precalibrated” form. This consists in surfacing the lens as thin as possible based on the chosen frame and the patient’s Rx. Wearer’s PDs, fitting heights, frame shape and size are transmitted to the lens surfacer who calculates the optimal center thickness of the finished lens. Although not specific to progressive lenses, the results obtained with “precalibration” are more spectacular for this type of lens which already benefits from the “equithin” process.

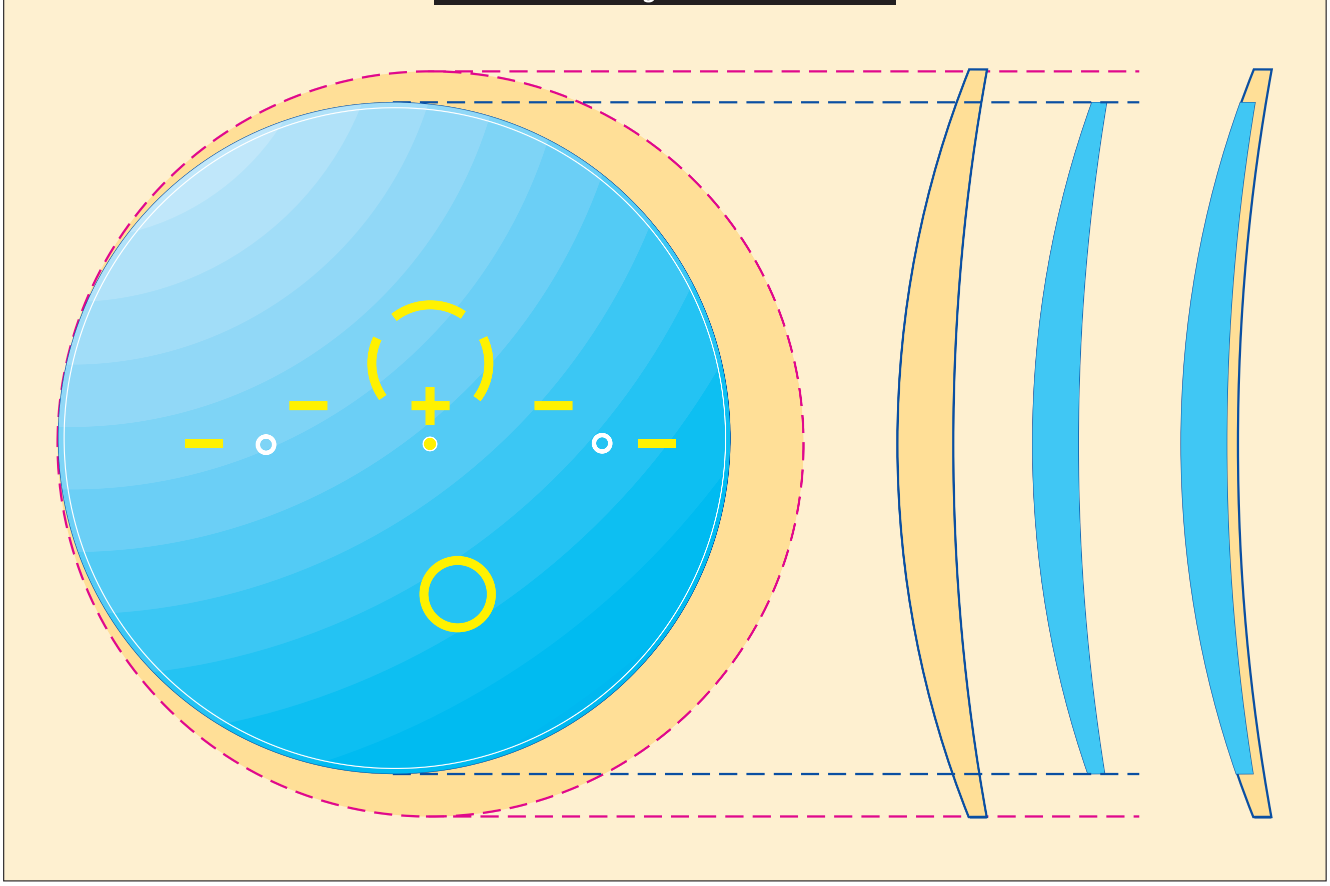
C Pre-decentered uncut finished progressive lenses

In the markets where round uncut lenses are distributed (Europe), pre-decentration of PALs is a method used by manufacturers to produce thinner plus-power lenses. To thin the lenses, the lens diameter is reduced, and so as not to lose temporal capacity, the progressive surface is nasally decentered. Pre-decentered finished lenses are produced, eg. in a 65/70mm diameter, meaning that the lens has a 65mm geometric diameter but a 70mm effective diameter.

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

Fig. 24: *Pre-decentered uncut progressive lenses.*

Fig. 24



The very first progressive lens - introduced by Essilor under the name of Varilux 1 (1959) - had a basic design linking two large and spherical distance and near vision zones. In designing the lens, more attention was paid to distance and near vision rather than peripheral vision.
The second generation of progressive lenses was introduced as Varilux 2 the “physiological” progressive addition lens (1972). While providing large distance, intermediate and near fields of vision, V2 also took into account the importance of extra-foveal and dynamic vision thanks to the new concept of “horizontal optical modulation”. Binocular vision was optimized as a result of an asymmetric design.The overall design of the lens is represented by a succession of conic sections (Fig. 26).

Fig. 25: *The “First” progressive addition lens.*

Fig. 26: *The “Physiological” progressive addition lens.*

Fig. 25

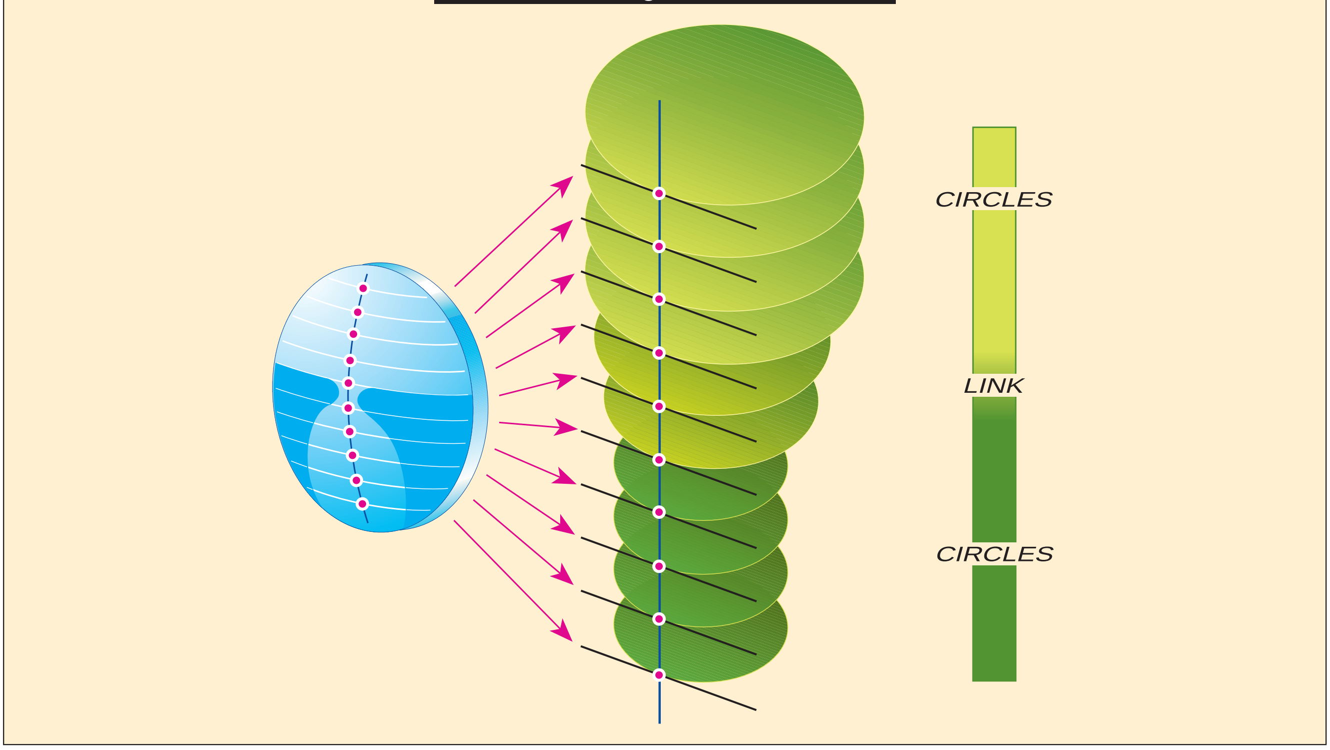
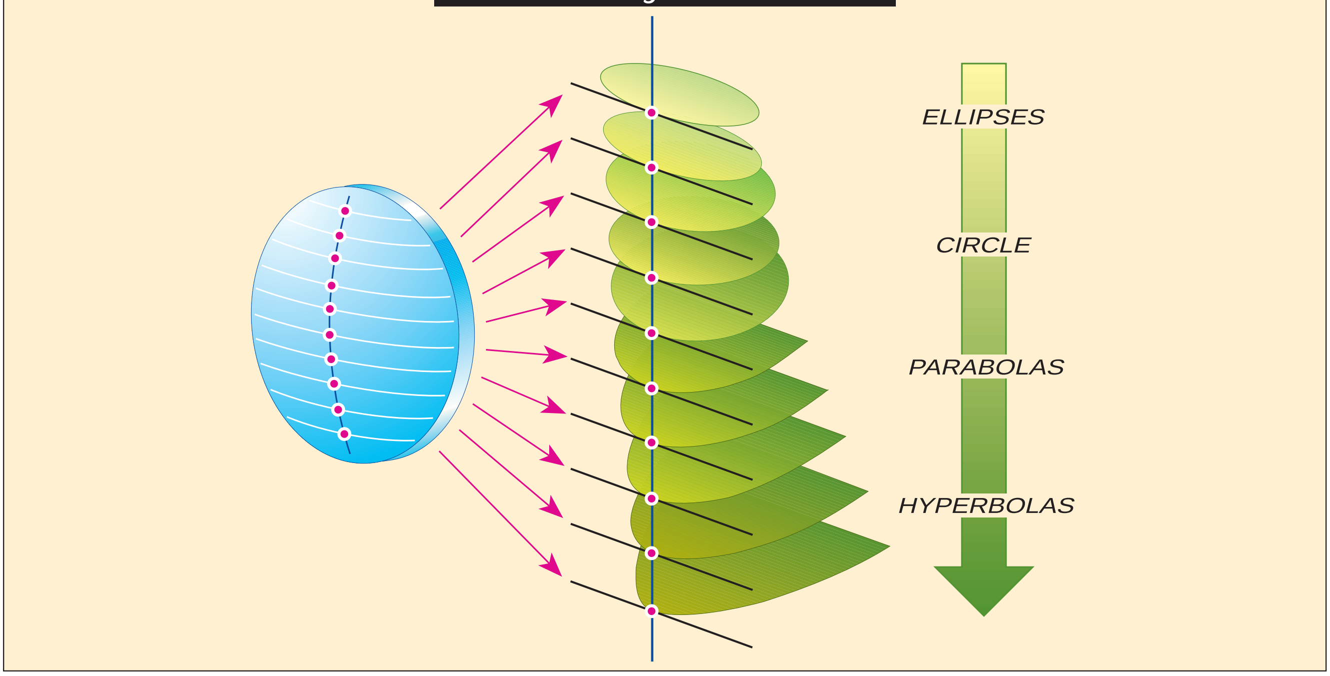


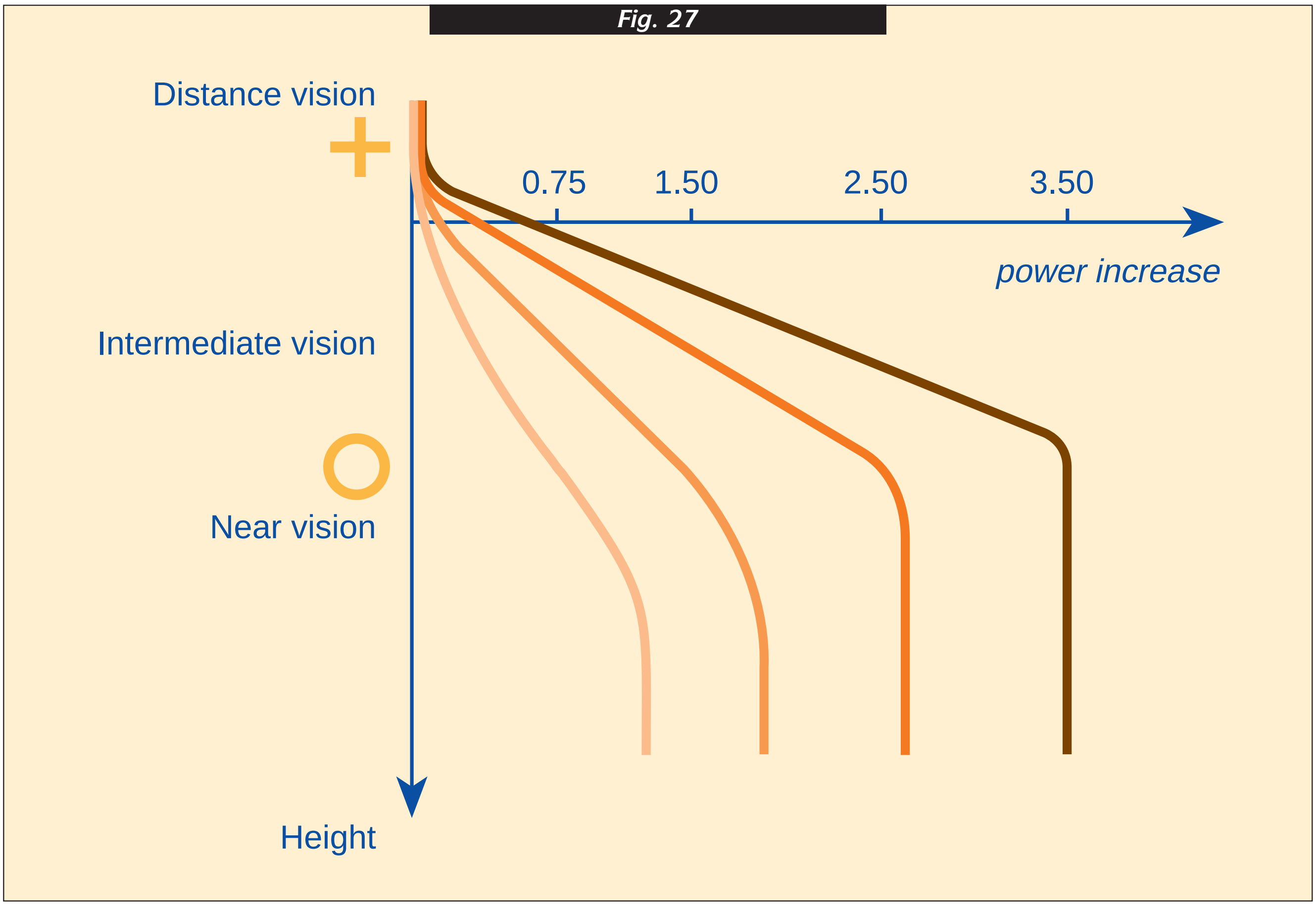
Fig. 26



During the decade following the introduction of Varilux 2, other manufacturers developed alternative progressive lens designs focusing on specific optical characteristics. Some emphazised large near and distance vision zones, while concentrating unwanted astigmatism in the lens periphery *(American Optical Ultravue, Rodenstock Progressiv R, Silor SuperNoLine, Sola VIP).* 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).*

A further step in the enhancement of progressive lens performance was the introduction of the Multi-Design concept with the Varilux Multi-Design / Varilux Infinity lens (1988). This lens used distinct designs to match the wearer's changing needs as presbyopia advances. Multi-design concept aims at optimizing visual comfort for each stage of presbyopia and making changes of addition easier for the wearer. The "Multi-Design" concept is well illustrated with the change of power progression profile by addition (Fig. 27).

Fig. 27: *The "Multi-Design" progressive addition lens.*



The latest generation of progressive lenses, introduced under the name of Varilux Comfort (1993), offers wearers more “natural vision” than any previous progressive lens.

Comfortable posture in near vision: Varilux Comfort’s near vision area is located high in the lens so that the wearer can reach it easily and naturally on downward gaze (Fig. 28). To explore the near and intermediate vision fields, fewer head and eye movements are required and the wearer enjoys more comfortable posture (Fig. 29).

These advantages are a result of Varilux Comfort’s specific power progression profile (Fig. 30) : for a 2.00 D add, 85% of the addition is reached 12mm below the distance fitting cross, compared to a minimum of 14 to 15mm for a classical progressive.

Fig. 28: *Comparative head and eye posture: Varilux Comfort, Classical Progressive and “non presbyope”.*

Fig. 29: *Comparative head and eye movements (vertical plane): Varilux Comfort, Classical Progressive and “non presbyope”.*

Fig. 28

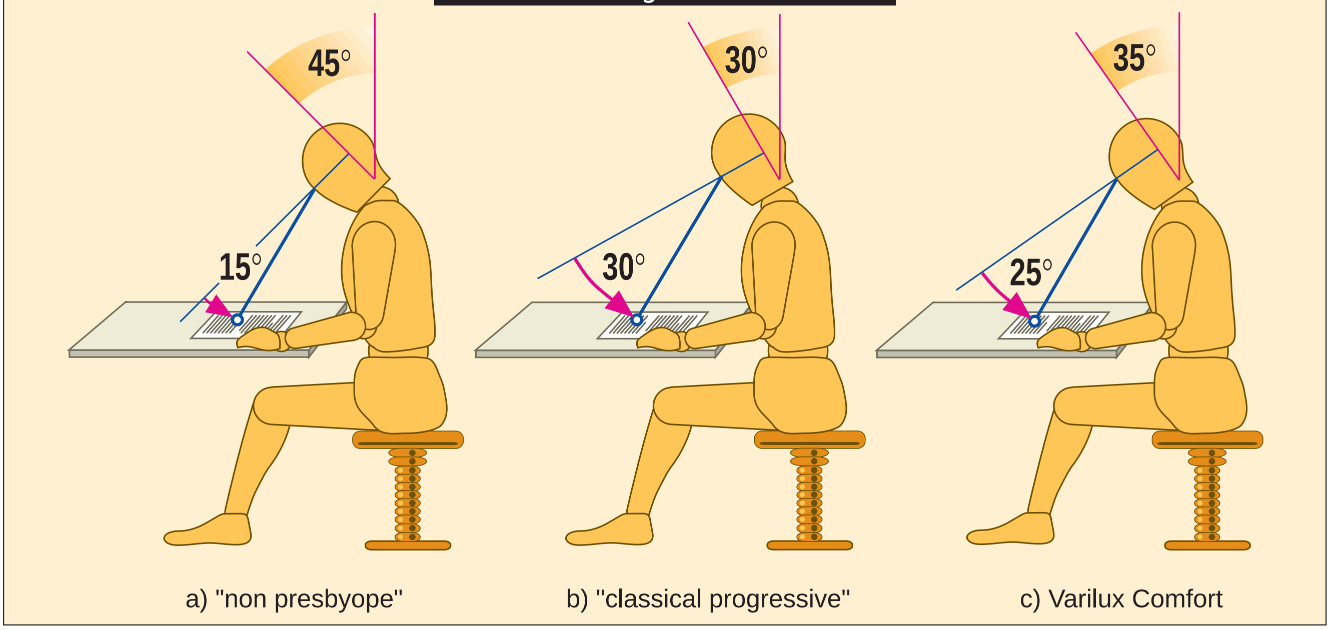
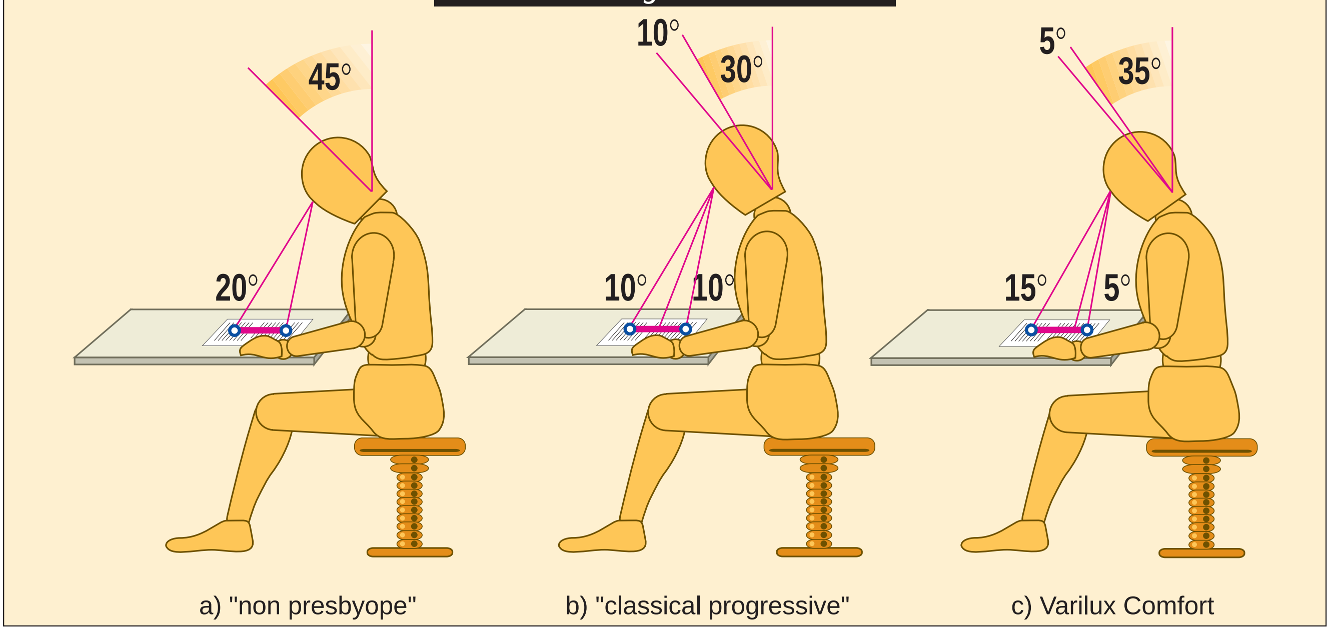


Fig. 29



True comfort in peripheral and dynamic vision: Varilux Comfort offers the wearer larger fields of clear vision as well as additional comfort in peripheral and dynamic vision. This is due to the softness of the lens periphery, which greatly reduces horizontal head movements necessary to explore the full width of the field (Fig. 31). Furthermore, there is a dramatic reduction of all "swim effects" to greatly improve wearer comfort in dynamic vision.

Binocular comfort and multi-design: Moreover, Varilux Comfort offers perfectly balanced binocular vision thanks to its asymmetry, and also integrates the multi-design concept of previous Varilux generation lenses which have been retained and improved.

Fig. 30: *Power profile of Varilux Comfort add 2.00.*

Fig. 31: *Comparative head and eye movements (horizontal plane): Classical Progressive and Varilux Comfort.*

Fig. 30

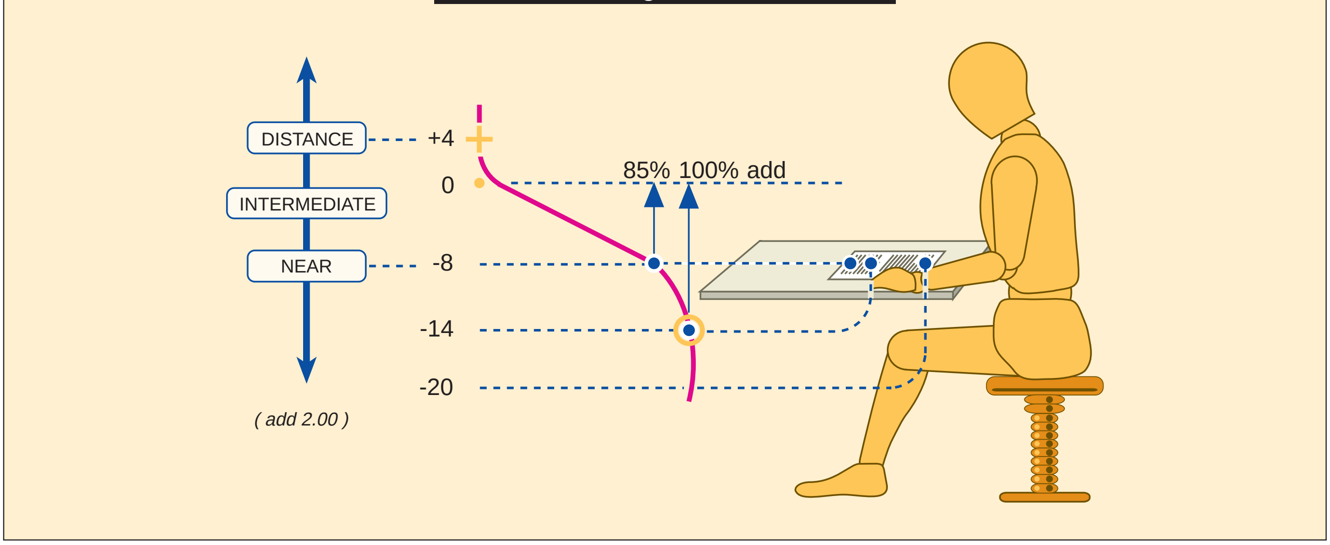
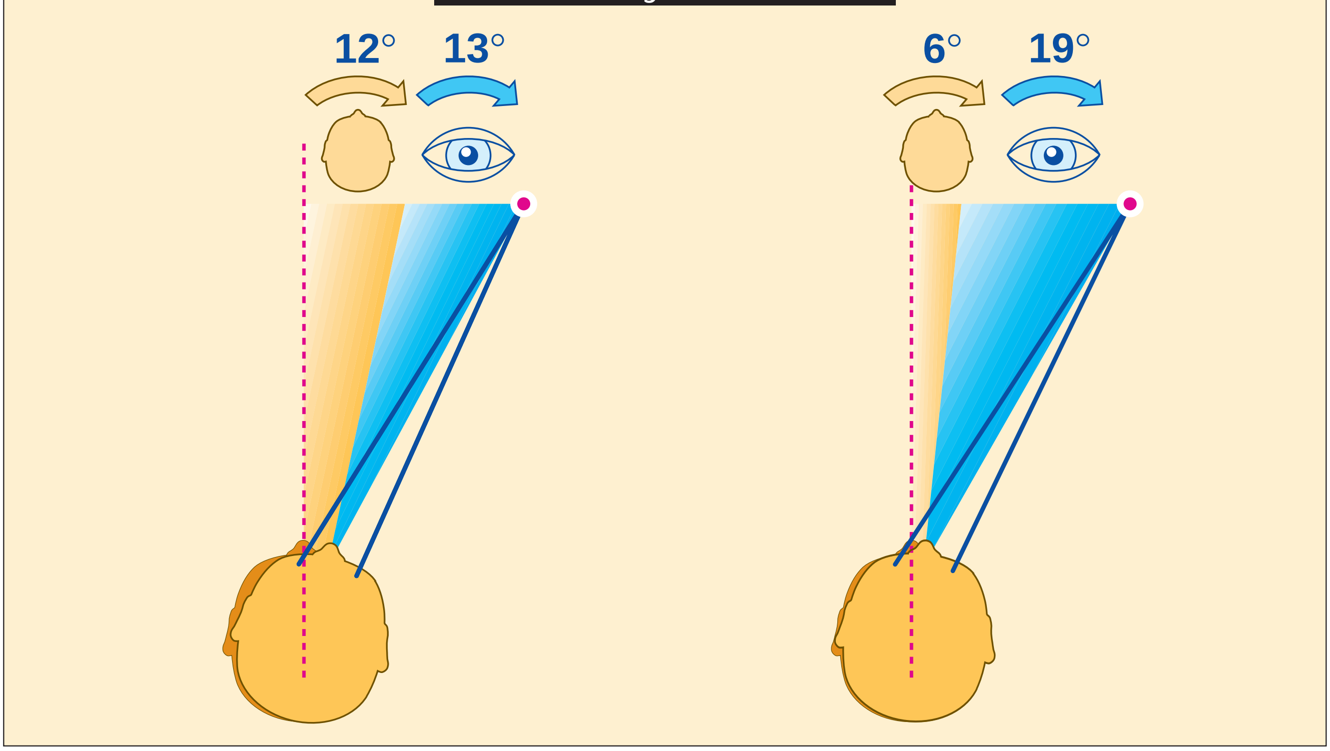


Fig. 31



CONCLUSION

Latest advances in progressive lens technology have further improved patient satisfaction.

Progressive lenses will continue to develop ensuring success to eye-care practitioners and visual comfort to an ever-increasing number of their presbyopic patients.

seeing the world better