



# UNDERSTANDING AND USING PROGRESSIVE ADDITION LENSES

■ Sidney Wittenberg, O.D.

**O**ne need only thumb through almost any current optometric journal to see how much progressive addition lenses (PALs) have become part of the routine delivery of eye care. Not too long ago, at least in the United States, PALs were only fit by more adventurous optometrists and opticians, but today there is hardly an ophthalmic professional who is not prescribing progressive addition lenses.

A number of factors have contributed to that change. Perhaps most significant is the technological progress that has stimulated the manufacture and use of a wide variety of alternative designs. Second in importance, but related, is the changing attitude of professionals toward the compromises that are required to achieve the enhancement of continuously changing power.

Better designs and an improved understanding of the application of these lenses have led not only to their wider use, but also to a realization that PALs have applications for other than presbyopes. In this paper I hope to spur you to think about circumstances in which PALs might be a tool for rendering care to your young patients and to review the general characteristics of PALs that might help you make that determination.

There are both cosmetic and functional reasons for considering the use of PALs for the youthful patient. An early and persistent criticism of progressive addition lenses was that the motivation for their wear was solely cosmetic and that they provided no useful intermediate lens powers. However, clinical studies in

which PALs were clearly preferred over blended bifocals, have established that while cosmesis is probably a factor in the growing use of PALs, the functional utility of the intermediate zone is recognized and appreciated.<sup>1</sup>

Cosmesis is certainly to be considered when deciding on the form of near correction to be provided the younger patient. Children very often object to the appearance of bifocals, and parents are prone to interpreting their child's wearing a bifocal as an indication of a serious defect reflecting unfavorably on their parental performance or heredity. As a result, it can be difficult to gain acceptance of a correction and/or proper compliance for its wear, when use of a near addition in the form of multifocals is the therapy of choice.

The issue of patient compliance is a serious one. It embraces not only wearing the spectacles, but ensuring its appropriate use as well. Francis Young,<sup>2</sup> a research psychologist who believes that the use of near additions by the young can inhibit the progression of myopia, was chagrined to find that bifocals prescribed for his son had failed to halt or slow the progression of his myopia. A conversation with his son indicated that he had been deliberately looking over, rather than through, the near addition. Subsequent refitting of a bifocal with a greater segment height and careful instruction as to the manner in which the lenses were to be used eliminated that problem and is reported to have resulted in slowing the myopic progression.<sup>2</sup>

Certainly, the PAL provides a solution to the problem of compliance based

## ABSTRACT

*There is wide-spread recognition of progressive addition lenses (PALs) as a tool for the correction of presbyopia. Less heralded is their utilization when the need for an addition is not based on this condition. The selective spatial effects of different PAL designs may prove useful in more specific optometric therapies. The potential to make such applications depends on an understanding of the underlying principles and consequences of PAL design. Those principles are dealt with qualitatively, affording the practitioner the opportunity to intelligently select and apply progressive addition lenses.*

## KEY WORDS

*progressive addition lenses, PALs, no line multifocals, lens design, lens therapy, vision therapy, esotropia, esophoria*

on cosmesis, but the PAL has an even more significant role to play because of its optical properties. Some of these are shared with bifocals. Be it in simple accommodative convergence problems or those sufficiently serious to create strabismus, the utility of an add in reducing esophoria and esotropia at near is well recognized.<sup>3</sup> The use of a progressive addition lens for such cases lends another dimension. Because the add of the PAL increases as depression of gaze advances, the effective convex lens power is roughly proportional to the accommodative demand. As a result, the PAL functionally decreases the accommodative convergence to accommodation (AC/A) ratio. In contrast, the bifocal imposes a discontinuity between the distance and near visual functions. The effective AC/A is unchanged, but accommodative demand changes as viewing crosses the line between the distance and near fields of the lens. The choice between these alternative forms of correction will depend on the patient's condition and the practitioner's rationale for therapy.

PALs also can be used in vision therapy. Continuous change in accommodative demand can be created by either raising or lowering the lens or changing the direction of gaze. A hand-held pair of PALs might be used in a therapy stage after accommodative rock, going from gross to more subtle changes in accommodative demand and response. Monitoring the accommodative response as the accommodative demand is changed gradually might provide useful diagnostic information.

Other optical characteristics of the PAL are more directly related to the theme of this journal. Behavioral optometry places an emphasis on the developmental aspects of vision and on the integration of vision with total organismic function. Optical manipulation of visual space is commonly used to that end at some stage of therapy. The fact that the continuous change in a PAL's power is accomplished only by allowing some areas of the lens to depart from its nominal power provides a tool for spatial manipulation. Differences in the design strategies of the many PALs enables the informed professional to select from numerous optical and spatial effects in dealing with visual problems, both therapeutically and palliatively.

Blouin attributes specific beneficial effects to the use of a bifocal or PAL

because they produce relatively sharp images on peripheral areas of the retina. He deems the blend between the central and peripheral stimulation afforded by the PAL to be the more effective.<sup>4</sup>

Given the array of designs available, the clinician has many options from which to choose. Technical information about the design and features of lenses tends to be skimpy. However, by understanding the general design characteristics of progressive addition lenses, the clinician is in a position to evaluate unique spatial effects and identify the lens best suited for a particular clinical application. This paper reviews the principles of PAL design and their consequences, especially for practitioners who might otherwise tend to be less concerned with lens design, so that they can appropriately integrate PAL use into their clinical practices.

## SIGNIFICANT PRINCIPLES OF PAL DESIGN

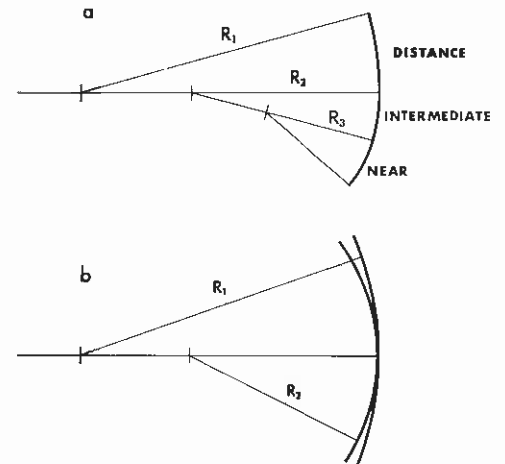
A PAL is a lens that contains a continuously changing range of powers over some portion of its extent. As most commonly prescribed, those powers will range from a distance correction to a near correction, although a new version aims only at providing a range of powers at near or intermediate points.

The continuous change of power gives rise to a number of functional properties. Most obviously, any object between the distance and near fields can be viewed with an appropriate spherical correction. There is no discontinuity between the distance and the near seeing zones, such as is characteristic of fixed segment multifocal lenses. This gives the progressive addition lens its desirable cosmetic feature--the absence of a visible line. All of this is accomplished at a price. That continuous change gives rise to areas containing undesirable cylindrical components--compromised lens areas. Those compromises create the potential for the distortion that plagued early PAL wearers. Such distortion is not avoidable, but can be decreased to be almost inconsequential. Those compromised lens areas can also give rise to troublesome binocular effects. Less often con-

sidered are aniseikonic differences in the images for the two eyes and induced prism. Attention has been paid to the vertical prism, which can be significant in the periphery of many progressive addition lenses. Knowledge of how progressive power is achieved will enable the clinician to understand the differences between lenses and the way in which they produce these effects.

The workings of the progressive addition lens can be understood as an extension of the Executive style trifocal, which is depicted in Figures 1a and 1b.

The cross-section in Figure 1a is idealized in that the curves for each intermediate power do not create even a slight ledge, i.e., their tangents are continuous. This is accomplished by having the longer radius of the distance section,  $R_1$ , change immediately to the shorter radius,  $R_2$ , of



**Figures 1a and 1b. The Executive multifocal model.** The cross-section in Figure 1a is idealized in that the curves for each intermediate power do not create even a slight ledge, i.e., their tangents are continuous. The radius of the distance section,  $R_1$ , changes instantaneously to  $R_2$ , the shorter radius of the intermediate section, which similarly changes to  $R_3$ , the radius of the most steeply curved section. Because the centers of curvature of the adjacent curves are on a line that passes through the point of changing curvature, the curve is smooth and image jump does not occur as fixation descends along the cross-section. As can be seen in Figure 1b, a horizontal cross-section through the point at which the curve's radius changes from  $R_1$  to  $R_2$ , as one proceeds away from the vertical cross-section, the ledge of the Executive multifocal becomes apparent. More frequent changes of power reduce the power increment and hence the size of the ledge. If the segments are made infinitely thin, the vertical curve changes continuously along that cross-section and the ledge is infinitely thin. A smooth surface curve can be defined, but the exact desired power change exists only along the infinitely thin vertical cross-section, the umbilicus. Unwanted astigmatism is introduced as one proceeds laterally from the umbilicus in the region where the power is changing. The magnitude of that astigmatism at a point is proportional to the rate of change of power on the umbilicus and to the distance of the point from it.

the intermediate section, which in turn changes instantaneously into the radius for the most steeply curved section, R<sub>3</sub>. These changes are responsible for the Executive multifocal not inducing image jump as viewing moves from one field to the next. But continuity exists only along the infinitely thin cross-section in which adjacent radii share common tangents. As can be seen in Figure 1b, a horizontal cross-section through the point where R<sub>1</sub> changes to R<sub>2</sub>, as one proceeds away from that cross-section the ledge of the Executive multifocal becomes pronounced. Increasing the number of segments over the same vertical distance will reduce the power increment and hence the size of the ledge.

Extending the principle further, the sectors can be made infinitely thin, resulting in a curve that changes continuously along that cross-section. This will also make the ledge infinitely thin. As a result, a smooth surface curve can be defined, but with the exact desired power change existing only along the infinitely thin cross-section, the umbilicus. Unwanted astigmatism is introduced as one proceeds laterally from the umbilicus in the region where the power is changing. The magnitude of that astigmatism at a point is proportional to the rate of change of power on the umbilicus and to the distance of the point from it. While the actual curves may be generated by different strategies, the practical design consequences are as discussed above.

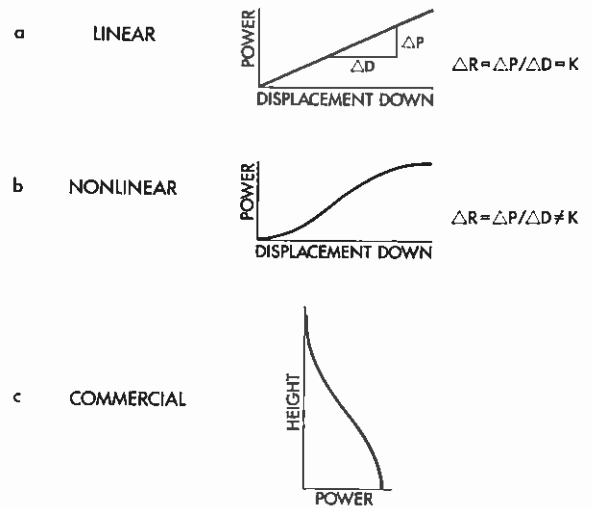
Two fundamental characteristics establish the basic differences between PAL designs. One is the formula by which the power is changed between the distance and near viewing regions, the power function; and the other is the strategy for distributing the unwanted astigmatism over the rest of the lens. But for all lenses the power is exact only in stabilized areas where lens power is not changing and along the umbilicus.

As a consequence, in the region of changing power between distance and near, one must determine the limits of acceptable unwanted astigmatism to establish its useful lateral extent, usually called its *corridor*. It is a function of both the induced astigmatism and the amount of astigmatism the patient will accept. Where power change is sufficiently gradual it is not uncommon for patients to report no apparent lateral restraint on function.

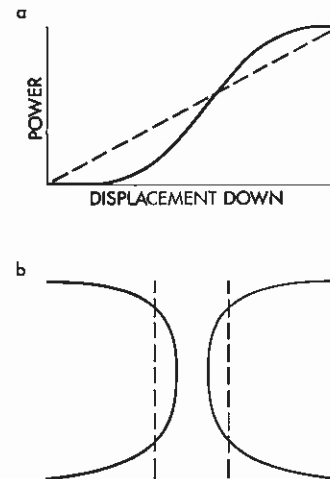
The power function can be visualized

more readily with the aid of Figures 2a, and 2b. In these two graphs the ordinate shows the power of the lens, and the abscissa the distance below the distance center, measured along the *umbilicus*. Figure 2a shows a linear power function,  $\Delta \text{power} / \Delta \text{distance} = K$ . Each millimeter of eye depression along the umbilicus induces an equal power change. Figure 2b shows a typical non-linear power function,  $\Delta \text{power} / \Delta \text{distance} \neq K$ . The slope of the curve expresses that function. The steeper the slope the greater the rate of change. In most commercial depictions of the power function, the displacement is placed on the Y axis and the power on the horizontal axis as in Figure 2c. In this format, lenses with greater rates of change will show the shallowest apparent slope. This can create some confusion. A clockwise rotation of 90 degrees provides the proper orientation.

An early lens design had a linear power function, but now almost all PALs have non-linear ones. The rate of change, as depicted in Figure 2b, is usually low leaving the distance viewing region, increases to roughly the middle of the umbilical length, and then decreases to, or into, the functional reading area. Within those limits, very different power functions are applied in the individual lens designs. Since the astigmatism is proportional to the rate of change, the shape of the so-called corridor will mimic the power function. The corridor is narrower where the power is changing more rapidly, and wider where the power is changing more slowly. In fact, it is this phenomenon that gives rise to the hourglass shape of the corridor of most progressive addition lenses. The effect is demonstrated schematically in Figures 3a and 3b.



**Figures 2a, 2b and 2c. The Power Function.** This describes how the add power changes along the umbilicus. Figure 2a shows a linear power function where  $\Delta R$ , the rate of change of power with displacement is,  $\Delta \text{power} / \Delta \text{distance} = K$ . Each millimeter of eye depression along the umbilicus induces an equal power change. Figure 2b shows a typical non-linear power function,  $\Delta \text{power} / \Delta \text{distance} \neq K$ . The slope of the curve expresses that function. The steeper the line the greater the rate of change. In most commercial depictions of the power function the displacement is placed on the Y axis and the power on the horizontal axis, as in Figure 2c. In this format, lenses with greater rates of change will show the shallowest apparent slope. This can create confusion. Rotating Figure 2c 90 degrees clockwise provides the proper orientation.



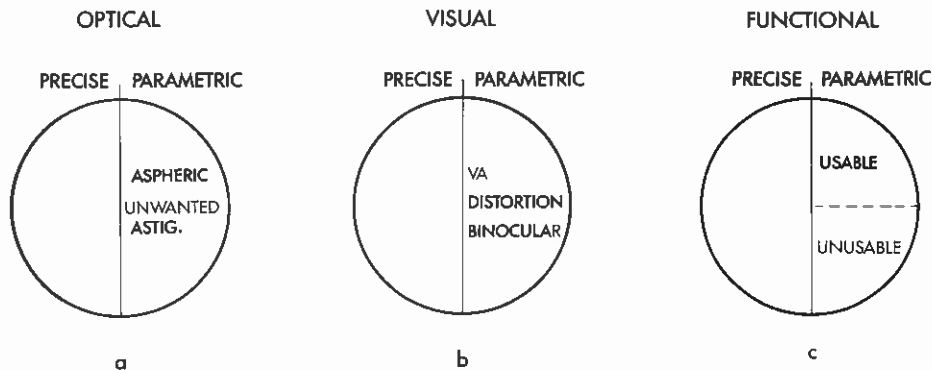
**Figures 3a and 3b. Consequences of the Power Function.** Figure 3a combines a plot of a linear power function, dashed line, and a non-linear one, solid line, generated by a polynomial expression. Figure 3b shows how the boundary for a given amount of acceptable cylinder. The linear power function has a constant rate of change and, hence, its boundary is formed by a pair of vertical lines. The non-linear power function starts off with a slower rate of change, so that the lateral extent of the region between the limits of acceptable cylinder is wider than that for the linear power function. Further along the non-linear curve, the slope is seen to increase with a consequent decrease in the width of the zone. When the rates of change become equal, the zone limits for the two power functions are seen to be equal. Beyond that point the non-linear function's width is the narrowest because the rate of change is still increasing. At some point the rate of change becomes a maximum and the zone's width is narrowest. Beyond, the rate of change continues to decrease and the changes described above are retraced in reverse order.

Figure 3a shows linear and non-linear power functions and Figure 3b suggests how the boundary for each might look for a given amount of acceptable cylinder when viewed along the optical axis. The linear power function in Figure 3a (dashed line) has a constant rate of change and, hence, its boundary is seen in Figure 3b to be formed by a pair of vertical lines. The non-linear power function begins with a slower rate of change (shallower curve), so that the lateral extent of the region between the limits of acceptable cylinder is wider than that for the linear power function. As one proceeds along the non-linear curve, the slope is seen to increase with a consequent decrease in the width of the zone. When the rates of change become equal, the zone limits for the two power functions are seen to be equal. Beyond that point the non-linear function's width is the narrower (Figure 3b) because the rate of change is still increasing (Figure 3a). At some point the rate of change reaches a maximum and the zone's width is the narrowest because the rate of change is still increasing. At some point the rate of change becomes a maximum and the zone's width is narrowest. Beyond that point the rate of change continues to decrease and the changes described above are retraced in reverse order.

There are three related classes of consequences of the design; optical, visual and functional (see Figures 4a, 4b and 4c). Optically (Figure 4a) we can think of the PAL as divided into precise and parametric areas. The precise area is the region that has the nominal distance and near power; no variation, change, or progression occurs within that area. The remainder of the lens is parametric in the sense that changes are occurring within it and in that its nature is a consequence of the designer's art. The distribution of power between the distance and near, not only along the umbilicus, but throughout the remainder of the lens, and the distribution of unwanted astigmatism, define the parametric area.

The visual or perceptual effects (Figure 4b) are the consequence of the optical factors noted above. They include the impact on visual acuity, the potential for distortion, both monocular and binocular, and binocular effects including vertical prism.

Figure 4c illustrates a basic functional



**Figures 4a, 4b and 4c. Design Consequences.** There are three interrelated areas of consequences to PAL design. The most general optical consequence is the division into precise and parametric areas. The precise area has the nominal distance and near power. The remainder of the lens is parametric, changes occurring within it that are a consequence of the designer's art (see text for further discussion.)

consideration; a lens area can be either usable or unusable. The precise area is obviously usable, at least at one distance. However, the parametric areas can either be usable or unusable. The corridor is, essentially, a parametric area and usable by definition. The limits of the usable area are very much a function of the individual and the environment in which the individual is operating. For subjects with small pupils and for less sensitive subjects, more of the parametric area will be usable. For all subjects, more of the parametric area will be usable in bright surroundings. There is certainly a core parametric area that all would find useful. Because of its indeterminate nature, the boundary between the usable and unusable area is designated by a dotted line.

### ALTERNATIVE DESIGN STRATEGY

The designer, as he develops a strategy for producing a new progressive addition lens, must deal with the interactions of the triad just discussed. In doing so he has three major parameters at his disposal. One is the extent of the stable area he will assign. This may range from zero, where changes occur over the entire lens surface, to a maximum, embodied in the invisible bifocal. The latter, in effect, has no functional intermediate zone. The second is the treatment of the corridor. By increasing the length of the corridor, the rate of change is decreased so that the corridor width is maximized for any given change in power between distance and near. The power function affects the nature of the corridor, as demonstrated pre-

viously. Finally, there is the distribution of power change and unwanted cylinder throughout the remainder of the lens.

These factors are not independent, but interact. As one makes the precise area larger there is less room for change between the distance and near zones, resulting in a shorter corridor length and, hence, reduced corridor width and greater unwanted astigmatism throughout the lens periphery. There are a number of basic ways in which these factors can be manipulated to produce a specific lens design.

The most common strategy in the early '50s and '60s was to attempt to maintain as much stable distance and near field as possible. This forced a relatively short corridor and minimal peripheral area in which to accomplish the power change. This resulted in a very large peak of unwanted astigmatism in the more limited regions between those two areas. Many severe symptoms were associated with these earlier commercial lenses.

One way in which the unwanted astigmatism was decreased was by reducing either the distance or near precise areas. Many designs have biased toward reducing one or the other. The first significant modern success came with lenses that allowed asphericity in rather large portions of the distance and near fields. At least one modern lens allows some unwanted astigmatism over the entire lens surface. This total asphericity allows the lens designer to minimize the greatest amount of unwanted astigmatism produced. That reduction is enhanced by increasing the corridor length.

How much the corridor can be

lengthened is limited by the fact the near power must be achieved with a reasonable lowering of gaze. A longer corridor has been incorporated in a PAL used primarily for intermediate and near use. The increased corridor results in the distance field being reduced in size and more elevated than usual. The reduced astigmatism for a given addition power results in wide functional intermediate and near fields. This is further enhanced by slowing the rate of change of power in the lower portions of the lens.

Varying strategies for distributing unwanted astigmatism in the periphery of a lens are used. One of the newer uses a bipolar design in which the power changes gradually between the distance and near fields. This model emulates the physical principle, Dirichlet's Principle,<sup>5</sup> commonly applied in the analysis in the distribution of energy between two points on a thin plate maintained at different temperatures. The resulting distribution of temperature is the smoothest possible and its optical analog is believed to provide the smoothest optical change. Other designers have taken different tacks. One keeps a large distance precise area, allowing a relatively high amount of unwanted astigmatism in the inferior nasal quadrant of the lens. Increasing addition power creates an increasing rate of change and thus an increase in maximum astigmatism for all designs. Some manufacturers change the nature of the power function and the length of the corridor in an attempt to compensate for that increase. These manufacturers advertise different designs for each add power. The practitioner would be better served if the nature of the design differences and their consequences were provided.

In attempting to deal with the prevalence of dizziness and similar symptoms experienced by users of early PAL designs, much thought was given to the orientation of the unwanted cylinder, orthoscopy. It was felt that to the extent that unwanted cylinder was oriented more vertically and horizontally, symptoms would be decreased. However, the visual instability experienced with PALs is more likely a function of changing vertical displacement of the image. This is a consequence of the change of spherical power as one scans horizontally with head fixed or as one's head turns while fixation is maintained.

Symmetry is an important design parameter. Most lenses are symmetric, allowing a single lens design to be used for both eyes. The lens is rotated to achieve right or left eye orientation. This results in mismatched nasal and temporal fields. Those differences can be small, except in the case of large precise areas which have a propensity for inducing large amounts of vertical prism, anisometropia and disparate images. Asymmetric designs allow one to individualize lenses for each eye that have similar nasal and temporal distance fields.

Given the number of design parameters and the different ways in which they are treated, it is surprising to hear some eye care professionals speak of PALs as virtually interchangeable. Although it is not obvious visually, because there is no visible line, PALs differ from each other at least as much as segmented multifocals. However, the absence of discrete borders makes it difficult to assess the operational attributes of the lenses.

If I have been successful in providing a basic understanding of what you can expect from a PAL and in stimulating you to consider ways in which you might apply these effects, about now you should be asking, "Yes, but how do I determine the operational characteristics of a given lens?" Manufacturers frequently report selected properties of their lenses in tabular form--items such as corridor length, width of corridor, etc. Because the consequences of lens design have implications for the entire lens extent, and because there is an obligatory trade-off between performance features, those specifications almost always provide only a part of the information that you will require.

The need for a precise and objective format for the reporting of the characteristics of a PAL was recognized by the American Optometric Association Commission on Ophthalmic Standards (AOA CmOS). Sheedy et al. undertook to define and provide just such information.<sup>6</sup> The AOA CmOS, working together with industry representatives, established that the data required to characterize a lens's performance could be included in two plots. The effective powers, cylindrical and spherical, were to be measured throughout a Plano lens. Points of equal astigmatism would be joined together to form an isocylinder contour and points of equal

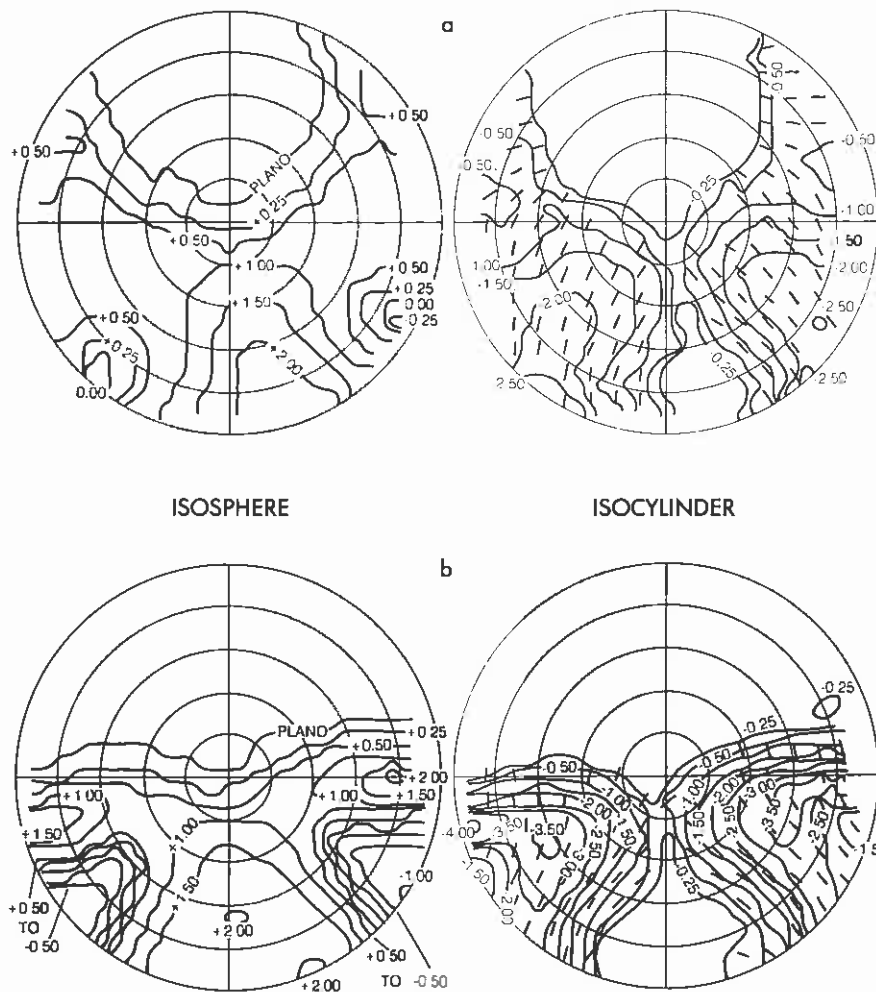
spherical equivalent powers would be joined together to form isosphere contours. The axis of the resultant cylinder at the measured points would be indicated on the isocylinder plot by a short line. The "iso" lines would be drawn at 0.50 diopter intervals with a 0.25 line added to better demarcate what I have called the precise region.

In their application of this approach, the investigators measured 300 points throughout a Plano lens with a nominal +2.00 addition. They abstracted some of the data in tables, but all of the information required could be obtained by analysis of the two plots. The plots allow for in-depth analysis of lens types and protect the professional from the commercial propensity to construct tables that show off the more advantageous features of a particular lens. While discussing how to use this information, I will review and expand on some of the points made previously.

Figures 5a and 5b are derived from their plots of this data. I have chosen two of several pairs of plots to illustrate how a lens's optical characteristics can be evaluated. Because it is beyond the scope of this paper to characterize the universe of lenses available, I have chosen not to identify lenses. Diagrams are used to illustrate principles. The reader should request the plots for individual lenses.

The figures provide a snapshot of most of the useful information one would want to know about a progressive addition lens. For lens 5a, the maximum unwanted astigmatism is greater than 2.50 diopters, but it is located more than 40 degrees from the lens center. In contrast, 5b has a maximum unwanted astigmatism in excess of 3.50 diopters and that within 25 degrees of the optical center. Where there are many lines, the lens has greater unwanted astigmatism. The closer together the lines, the more likely one is becoming involved in a lens area that is unusable. Note the design trade-off that gave lens 5b a larger precise distance area. There can be no a priori judgment as to which lens is preferable. The "best lens" is a function of an individual's visual demands and mode of perceptual adaptation; however, some generalities apply. Those can only be determined in clinical trials, but more about that later.

The width and extent of the corridor and reading areas are not bounded simply by a region in which the unwanted



**Figures 5a and 5b.** American Optometric Association Commission on Ophthalmic Standards format for reporting PAL characteristics. The effective powers, spherical and cylindrical, are measured throughout a Plano lens. The isosphere plots are shown on the left sides of Figures 5a and 5b. The isocylinder contours are on the right. The "iso" lines are drawn at 0.50 diopter intervals with a 0.25 line added to better demarcate what I have called the precise region. The axis of the resultant cylinder at the measured points is indicated by the short lines on the isocylinder plot. Each circle represents 10° of visual field. (After Sheedy et al.)

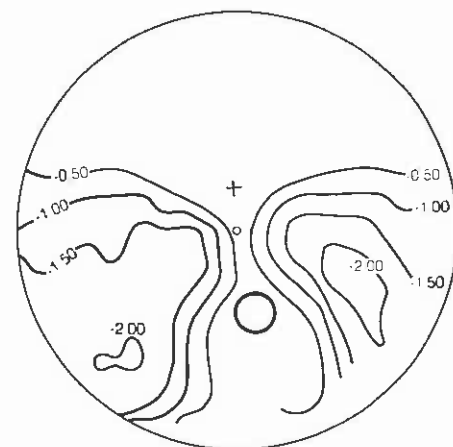
cylinder is less than -0.25 diopters. Of particular interest is the density of isocylinder lines surrounding the reading area. Where those lines are widely spaced one is more likely to have a usable parametric area to add to the precise reading zone. Where there is a tight cluster of isocylinder lines around the reading zone that zone is sharply delimited. Thus, the apparent difference in the reading area as defined by the astigmatism free zones in lenses 5a and 5b may not translate into a larger usable area because of the more rapid increase in astigmatism surrounding lens 5b's astigmatism free reading area. It should also be noted that even though there are no sharp discontinuities on any progressive addition lens, the zones of rapid change, those with dense concentration of isocylinder lines, tend to be more visible because of the warp they can

produce on head movement.

The effect of rate of change of addition on the width of the corridor can be seen in these figures. Lens 5a goes from Plano to +1.50 in 24 degrees, while lens 5b does so in less than 20 degrees. Note the concomitant constriction in the corridor for lens 5b in this region. In contrast, the interval between +1.50 and +2.00 is greater for lens 5b, with flaring of the reading zone that becomes wider than that for lens 5a.

In general, there is a relatively close parallel between the change in mean power and the density of isocylinder lines. Where sphere is changing rapidly, unwanted astigmatism is going to be great. The same principle applies in the periphery. In effect, the mean sphere power changes and the isocylinder curves tend to predict one another.

## ASYMMETRIC LENS ISOCYLINDER



**Figure 6.** Asymmetric Isocylinder Plot. In contrast with the relatively symmetrical distribution of lines of the lens in Figure 5b, the nasal and temporal portions have dissimilar patterns. Note that this plot does not match the specifications of the Commission on Standards.

Plots can be used to determine the symmetry of a lens design. In these plots one has mentally only to draw a line through the optical center, rotated approximately 10 degrees counterclockwise with respect to the vertical axis of the figure, to determine an axis of symmetry. Plots almost never show exact symmetry because of minor irregularities of the molding process by which most PALs are produced and because of difficulties in the measurement technique. Figure 6 shows an asymmetric lens. The data is not from the Sheedy study and is presented differently; note the absence of the 0.25 isocylinder line. However, the asymmetry of this lens is readily apparent.

A comparison of this plot with that for lens 5b illustrates one of the differences between symmetrical and asymmetrical lenses having large distance precise fields. The lateral and nasal distance fields of the lens of Figure 6 are similar with respect to the unwanted astigmatism. Lens 5b has a rapid change of power near the horizontal axis so that its required rotation produces 3.00 diopters unwanted astigmatism in the nasal field and less than 1.00 diopter in the temporal. Note a parallel difference in the mean power nasally and temporally. This difference suggests that considerable vertical prism is induced on lateral gaze. I believe that the astigmatism is at least as limiting to utilization of that lens area as is the vertical prism.

The information is completed with a description of the orientation of the axis of

the cylinder. This is included as short lines throughout the isocylinder plot, Figure 5b. As was suggested previously, the orientation of these lines is probably not critical, especially for small amounts of cylinder. However, with the addition of this information, one has a relatively complete picture of the optical effect in the lens field. It is interesting that while base curve and bifocal lens structure are often viewed as critical factors in prescribing and dispensing, progressive addition lenses are often accepted with relatively little knowledge of their complex power distributions.

Your complete dossier for any lens type should include the plots for most of the add powers.

### PULLING IT ALL TOGETHER

Perhaps emulating issues in contact lens practice, there is a tendency to talk about progressive addition lenses as being either hard or soft. In organizing this paper I had to resist the temptation to resort to that categorization too soon. With the more fundamental concepts in place, however, this characterization will prove useful.

A hard lens is one which has large precise areas and consequently high amounts of unwanted astigmatism. In contrast, soft lenses sacrifice precise area to gain parametric usable area and low amounts of unwanted astigmatism. Maximum softness can only be accomplished by allowing unwanted cylinder over the entire lens surface. Soft lenses must be expected to contain some mean spherical plus power in the periphery. It should be readily apparent that Figure 5a contains plots of a relatively soft lens, while Figure 5b depicts a basically hard lens. Lenses that are harder and softer than these do exist.

What are the trade-offs in the design balance between hard and soft lenses? Harder lenses tend to have a shorter corridor and, hence, a higher rate of change of power and thus a narrower useful intermediate zone. Another consequence is that if the hard design is made in a symmetrical form, the 10 degree rotation required to orient the lens appropriately for the right and left eyes produces marked vertical prism and gross binocular differences in the periphery close to the horizontal axis. An asymmetric hard lens can eliminate that problem. The asym-

**TABLE 1**  
**COMPARISON OF CHARACTERISTICS OF HARD AND SOFT LENSES.**

Lens Feature	Lens Type	
	Harder	Softer
Precise area	Greater	Less
Unwanted astigmatism	Greater	Less
Functional width of corridor	Less	Greater
Distortion	Greater	Less
Depression of gaze to achieve add	Less	Greater
Vertical Prism	Greater*	Less

*\*Asymmetric hard designs can have minimum vertical prism in the distance periphery, although few, if any, have been designed to accomplish that potential. Relative terms are used in this table to remind the reader that there is no boundary differentiating a hard and a soft lens; they occupy a continuum.*

metric form will, however, tend to contain somewhat greater amounts of unwanted astigmatism for a given power function, especially in the inferior nasal quadrant. In contrast the softer lens can be rotated with less effect because the nasal/temporal difference in optical characteristics is not nearly as marked. In fact, induced prism is very low, being hardly differentiable from that for an optimized asymmetrical hard lens. Maximal softening is accomplished by lengthening the corridor, which has two principle effects. On the positive side, exceedingly wide corridors or channels can be achieved with most adds. The consequent problem is that the nominal add is forced lower in the lens. This necessitates a greater depression of the eyes to achieve the full near lens power. It is more of a factor for higher adds. That is somewhat compensated for by the fact that because of the lesser rate of change, lateral areas depart more gradually from the desired power.

A soft lens will tend to offer a better match of monocular images over the total field, and will tend to have more unwanted cylinder and usually undesired power in the distance periphery than the other types. Greater depression of the eyes would be required to achieve full near power, but this is balanced by the fact that there will be less maximum astigmatism and generally less vertical and lateral prism.

The harder lens affords a larger precise viewing area, usually for the distance. There is generally somewhat better peripheral acuity in the distance, more so for the asymmetric lens. The symmetrical lens will give good acuity in the periphery

in one eye but poorer acuity in the other. There will be greater amounts of maximum astigmatism with the harder lens. As a result, waviness and distortion and the consequent symptoms, especially with patient movement, are more likely with the harder lens. The functional differences between soft and hard PALs are outlined in Table 1. Relative terms are used because there is a continuum between hard and soft lenses, rather than an absolute boundary.

Clinical studies have demonstrated that for a general purpose progressive addition lens, softer lenses are adapted to more easily and tend to be preferred. Those preferences are not universal, as is to be expected from the variation in individual visual needs.<sup>1</sup>

### SUMMARY AND CONCLUSIONS

Each progressive addition lens is the result of a series of design compromises. These varying design strategies give the behavioral optometrist a variety of optical tools with which he can create selective effects for both routine vision therapy and for dealing with behavioral optometric problems. The contour plots that include sphere and cylinder information provide the practitioner with almost all of the information he needs to make judgments about how and which lenses he will apply to his patients. Manufacturers have not been as forthcoming as they might be in providing such information. There is a tendency to rely on general descriptive terminology in promoting the individual lenses. It was not the purpose of this paper to provide the practitioner with a detailed information about each of those lenses. It

was intended to provide insights into what makes the lenses tick, stimulate thinking about how the alternate designs might be implemented in vision therapy, and finally to stimulate the practitioner to demand this basic information from those who wish to have him use their particular lens designs. Not only is the PAL a potentially valuable tool for the traditional behavioral optometrist, but the number of factors, including patient adaptability and perceptual style, that must go into determining the type of PAL to prescribe for a particular patient, makes each clinician something of a behavioral optometrist.

For the reader interested in examining the results of clinical data related to PAL use more closely, Reference 1 contains an extensive listing of such studies.

## REFERENCES

1. Wittenberg S, Borish IM. Progressive addition lenses. Sheedy J, Guest Ed., London, R, Ed-in-Chief. *Prob Optom* 1990; 2(1):77.
2. Young FA. The whys and wherefores of the plus lens. Monograph on Lifetime Vision, Am Optic, in press.
3. Smith JB. Progressive addition lenses in the treatment of accommodative esotropia. *Am J Ophthal*, 1985; 99:55-62.
4. Blouin JP. The black book of the year 2000. Santa Ana, CA, Optom Extension Prog, 1991.
5. Kellogg OD. Foundations of potential theory. New York: Dover Press, 1953.
6. Sheedy J, Buri EM, Bailey IL, Borish IM. Optics of progressive addition lenses. *Am J Optom Physiol Opt*, 1987; 64(2):90-99.

Corresponding author:  
Sidney Wittenberg, O.D.  
Adjunct Professor of Clinical  
Research  
New England College of Optometry  
52 Surrey Lane  
Sudbury, MA 01776  
Date accepted for publication:  
August 16, 1991