1 CE Credit

The Optics of Free-Form Progressive Lenses

By Darryl Meister, ABOM

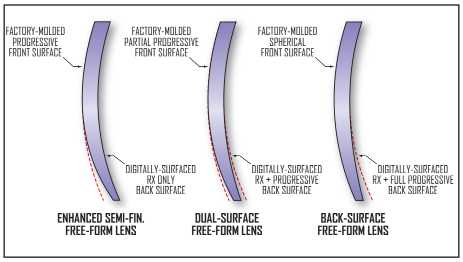

Figure 1. Common free-form progressive lenses are available in three different configurations.

FREE-FORM TECHNOLOGY

Free-form surfacing, also referred to as direct or digital surfacing, refers to a process that is capable of producing complex surface shapes, including aspheric, atoric and even progressive addition surfaces. A typical process begins by generating the lens surface using a three-axis, computer numerically controlled (or CNC) generator. With three possible axes of movement, single-point cutting tools can produce virtually any lens surface shape with a high degree of accuracy and smoothness. The worked lens surface is then polished to a high luster using a flexible polishing pad that is also dynamically controlled by a computer.

Using free-form surfacing, a laboratory can directly surface a variety of lens designs directly onto a semi-finished lens blank in addition to the prescription curves. With two surfaces to work with, free-form progressive lenses represent a combination of factory-molded and free-form-surfaced lens curves that range in complexity from simple spherical surfaces to progressive surfaces that have been combined with the prescription curves (Figure 1).

Back-surface lenses employ a factory-molded spherical front and a free-form-surfaced progressive back surface that has been combined with the prescription curves; the progressive optics are directly surfaced. Enhanced semi-finished lenses employ a factory-molded progressive surface on the front and free-form surfaced prescription curves that have been optically optimized on the back; the progressive optics are factory-molded. Dual-surface lenses employ a factory-molded progressive surface with a portion of the total addition power on the front and a free-form surfaced progressive surface with the remaining addition power that has been combined with the prescription curves on the back; the progressive optics are split between both lens surfaces.

Regardless of the type of free-form lens, the placement of the actual progressive optics, whether on the front surface, back surface or split between both, has minimal impact on the magnitude of the inherent unwanted astigmatism of the design. Because a typical spectacle lens represents an "optical system" of fairly negligible thickness, the optics of each surface are essentially additive. Consequently, the inherent unwanted astigmatism of progressive lenses is not significantly influenced by placement of the progressive optics (Figure 2).

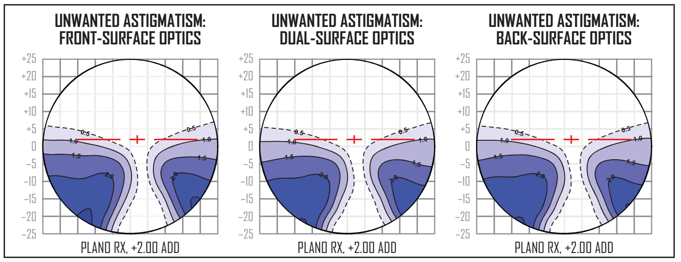

Figure 2. Plots of ray-traced optical astigmatism for lenses that have been similarly designed using either front-surface, dual-surface or back-surface progressive optics are virtually identical.

Although the inherent astigmatism may not differ appreciably, placing the progressive optics on the back surface can minimize unwanted magnification effects. Skew distortion, an aberration that causes

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Learning Objectives:
Upon completion of this program, the participant should be able to:
1. Describe and define free-form technology as used in progressive lenses.
2. Demonstrate how progressive designs are better delivered when using a computer engine that can optimize Rxs and patient wearing conditions.
3. Describe the opportunities that free-form manufacturing has for future use in progressive lenses.

Faculty/Editorial Board: Darryl Meister is a Certified Master Optician and technical marketing manager for Carl Zeiss Vision.

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objects to appear sheared or "bowed" through the periphery of progressive lenses, is due both to magnification changes created by differences in curvature (or "shape") across the front surface and to magnification changes as a result of the unwanted cylinder power produced by these differences in curvature. Placing the progressive optics on the back surface of the lens eliminates the contribution of the front surface to these magnification changes. Moreover, because the progressive viewing zones are brought closer to the eye, slightly wider fields-of-view may be obtained when the progressive optics are located on the back surface.

Nevertheless, the differences in optical performance due only to the placement of the progressive optics are generally small. When free-form surfacing is utilized in conjunction with sophisticated optical design software capable of designing progressive lenses on the fly, however, it becomes possible to match the optics of each progressive lens exactly to the visual requirements of the individual wearer, prior to fabrication. Given the inherent limitations of traditional progressive lenses, this application of free-form technology offers the most meaningful visual benefit.

Semi-finished progressive lens blanks are factory-molded in mass quantity. These lenses are typically available in 12 addition powers per eye, in up to a dozen materials, resulting in hundreds of lens blanks for each base curve offered. A "short-corridor" version of the design doubles the total number of lens blanks needed. Consequently, traditional progressive lenses necessitate massive product development and inventory costs. Changes to the basic design of these lenses have therefore been limited to subtle variations in optical design across a handful of base curves that must work sufficiently well over relatively broad prescription ranges. Hence, traditional progressive lenses are designed for a few "average" prescription powers, using "average" fitting parameters, for either "standard" or "small" frame sizes.

Unfortunately, no single progressive lens design will deliver optimum performance for every possible combination of prescription, fitting and frame size values. Each prescription requires a unique optical design to fully eliminate lens aberrations. The position of the fitted lens can introduce additional power errors. Moreover, unless the corridor length of the lens design matches the ideal length associated with a given frame, visual utility is further compromised. Although certain wearers may enjoy the intended optical performance in traditional progressive lenses, many wearers must tolerate reduced optical performance (Figure 3).

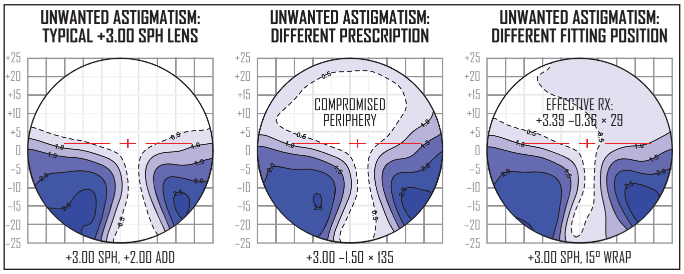


Figure 3. Plots of ray-traced optical astigmatism demonstrate that the optical performance of traditional progressive lenses is sensitive to both the prescription and position of the fitted lens.

FREE-FORM CUSTOMIZATION

Now, progressive lens designs can be fully customized to the visual requirements of individual wearers. In the 1990s, lens designers in Germany first began customizing progressive lenses using free-form technology by applying atoric lens designs to the back of progressive lens blanks using free-form surfacing. Today, their technology has evolved into a powerful optical design engine that performs complex calculations online in a centralized server computer using parameters supplied by the eyecare professional. The final lens calculations are then transmitted directly to free-form surfacing equipment for fabrication.

Each design is dynamically manipulated in "real time" to create a unique progressive lens fully customized to the wearer's prescription, fitting geometry and frame information. The ideal geometry of the lens design is first determined, including the best corridor length and appropriate near zone inset. The initial optical performance is then compared against the performance of the ideal or "target" lens, while the optics of the actual lens design are fine-tuned on a point-by-point basis, using complex aspherization algorithms, until the final lens reproduces the desired optical performance of the target lens as closely as possible (Figure 4).

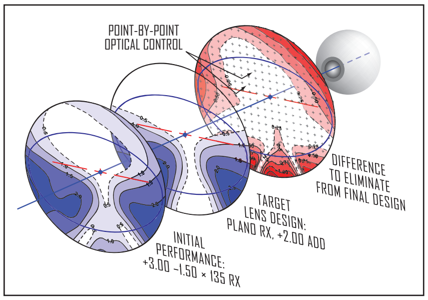
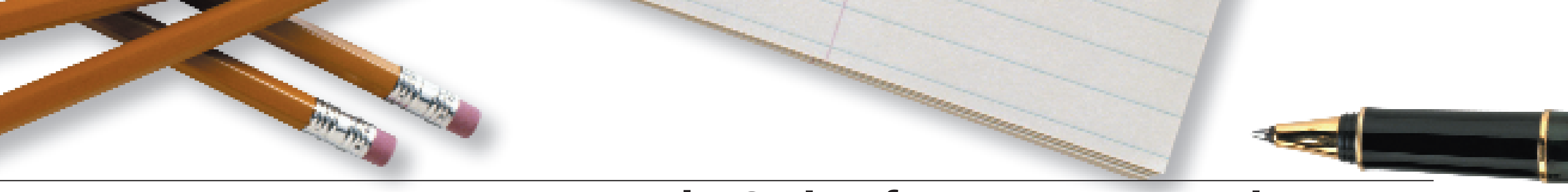


Figure 4. In one application of free-form technology, a powerful optical design engine customizes the optics of each progressive lens design on a point-by-point basis.

CUSTOMIZATION FOR THE PRESCRIPTION

When the wearer looks through the peripheral regions of a spectacle lens, aberrations such as oblique astigmatism produce unwanted sphere and cylinder power errors that degrade vision quality and narrow the field of clear vision. (Figure 5). Traditional lenses are only available in a limited number of base curves. They deliver optimum optical performance only for sphere powers located near the center of the prescription range associated with each base curve. Other prescriptions will suffer residual aberrations, particularly when the prescription includes cylinder powers, since conventional lens designs cannot eliminate the errors



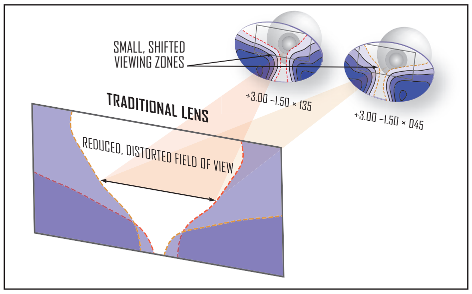


Figure 5. For many prescriptions, the field of clear vision may be significantly reduced and distorted in shape by uncorrected lens aberrations.

produced by the sphere and cylinder power simultaneously.

The optical effects of lens aberrations are exacerbated in progressive lenses. Oblique astigmatism interacts optically with the surface astigmatism of the progressive lens design, causing the zones of clear vision to shrink. Lens aberrations can also cause the viewing zones of a progressive to become distorted from their ideal location as certain regions of unwanted astigmatism become more blurred while other regions actually become clearer. This distortion of the central viewing zones disrupts binocular vision through the lenses by moving the "sweet spots" of the lens.

With sufficiently advanced software and a free-form delivery system, it becomes possible to customize the progressive lens design based upon the unique prescription requirements of each wearer (Figure 6). By fine-tuning the optical design of the progressive lens for the exact prescription using a sophisticated optical optimization process, residual lens aberrations are virtually eliminated. Wearers can therefore enjoy the widest fields of clear vision possible, regardless of prescription. Furthermore, the binocular utility of the lenses is maintained with more symmetrical fields of view.

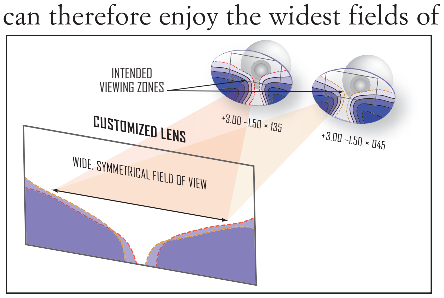


Figure 6. This free-form progressive lens by Carl Zeiss Vision is precisely customized for the wearer's exact prescription requirements, which ensures wide, symmetrical fields of clear vision.

CUSTOMIZATION FOR THE POSITION OF WEAR

The position of wear is the position of the fitted lens relative to the actual wearer, as measured by pantoscopic tilt, face-form wrap and vertex distance of the lens. Spectacle prescriptions are typically determined using refractor-head or trial-frame lenses that are positioned perpendicular to the wearer's lines of sight. Once fitted to the wearer's face, however, eyeglass frames generally leave spectacle lenses tilted. Lens tilt introduces oblique astigmatism, which results in an increase in sphere power and unwanted cylinder power. These unwanted power changes can reduce the optical performance of a progressive lens, particularly through the central viewing zones (Figure 7).

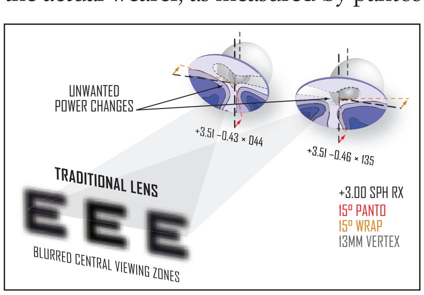


Figure 7. Vision may be significantly degraded by the position of the fitted lens.

With sufficiently advanced software, it is possible to customize the progressive lens design based upon the unique fitting parameters of each wearer (Figure 8). If the wearer's pantoscopic tilt, face-form wrap and vertex distance are supplied, the position of wear of the fitted lens may be modeled using ray tracing in order to apply the necessary optical corrections across the lens surface during the optical optimization process. Wearers can therefore enjoy the best optical performance possible, regardless of their unique fitting requirements.

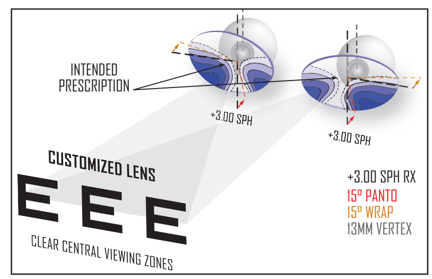


Figure 8. This free-form progressive lens by Carl Zeiss Vision is precisely customized for the wearer's exact fitting parameters in order to deliver clear vision through the central viewing zones.

Traditional progressive lenses are often designed to exhibit the specified optical performance only when measured using a focimeter, such as a lensometer (Figure 9). Free-form progressive lenses customized for the position of wear are designed to provide the wearer with the prescribed optical performance in the actual position of wear. As a result, small changes to the original prescription are required at the distance and near verification points of the lens. These sphere, cylinder, axis and addition power adjustments are supplied as a compensated prescription, which represents the correct lens powers to verify when using a standard focimeter.

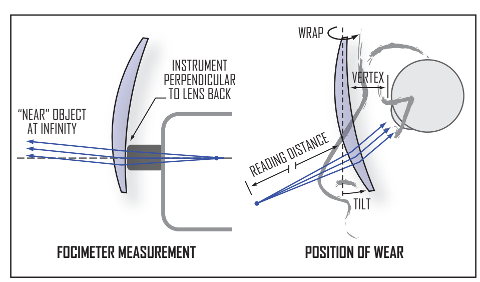


Figure 9. Although traditional progressive lenses are often designed to exhibit the specified powers when measured using a focimeter, free-form progressive lenses customized for the position of wear provide the specified powers when worn.

CUSTOMIZATION FOR THE FRAME SIZE

The optical performance of a progressive lens is significantly influenced by the length of the corridor. If the corridor is too long for a given frame size, reading utility is greatly reduced, since the near zone is essentially cut away. If the corridor is too short, the optics of the lens design must be essentially "compressed." Due

to the mathematical constraints of progressive surfaces, the rate of change in unwanted astigmatism across a progressive lens design must increase as the corridor length decreases, resulting in narrower central viewing zones, reduced intermediate utility and higher levels of peripheral astigmatism.

The corridor length of a progressive lens design should therefore be no shorter than necessary, within the limits of physiologically comfortable vision. Nevertheless, the corridor lengths of "standard" progressive lenses generally offer insufficient reading utility at shorter fitting heights. "Short-corridor" progressive lens designs are frequently designed to work at extremely short fitting heights, often resulting in significant optical compromises in all but the smallest frames (Figure 10).

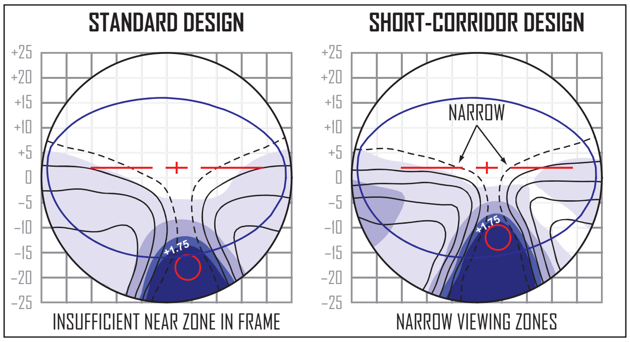


Figure 10. Unless the corridor length of the lens design coincides with the optimal length required for a given frame size, the wearer must tolerate insufficient reading utility or smaller viewing zone sizes and higher levels of peripheral astigmatism.

With sufficiently advanced software, it becomes possible to customize and match the corridor length of the lens design to the fitting height required by the wearer's chosen frame style (Figure 11). This maximizes the utility of the central viewing zones without unnecessarily compromising optical performance in other regions of the lens. Wearers can therefore enjoy sufficient reading utility with the largest viewing zones possible, regardless of frame size.

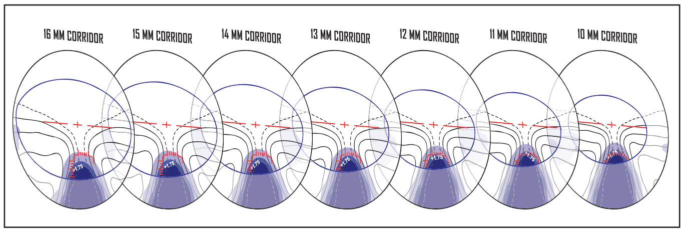


Figure 11. This lens by Carl Zeiss Vision varies the corridor length continuously from 10 to 16mm to match the optics of the design precisely to the size and fitting height of the wearer's chosen frame.

ADDITIONAL FORMS OF CUSTOMIZATION

Other forms of optical customization for the wearer are also possible. Each additional degree of customization serves to diminish the gap between the unique visual needs of each wearer and the optical design of the lens. The ideal progressive lens design for a given wearer will depend upon the visual demands specific to his or her lifestyle. By assessing the need, using a questionnaire, the ideal balance between the distance and near viewing zones of the lens design can be tailored to the individual. Progressive lens wearers more frequently engaged in tasks associated with far vision may prefer progressive lens designs customized with larger distance zones, whereas wearers with greater near vision demands may prefer lens designs customized with larger near zones.

It has also been demonstrated that individuals vary in their habitual head movement. The total change in the wearer's gaze is due to a combination of head movement and eye movement. Individuals who tend to exhibit more relative head movement are frequently referred to as "head movers," whereas individuals who exhibit more eye movement are referred to as "eye movers" (Figure 12). Because the limited width of the viewing zones of a progressive lens may restrict lateral eye movement, "eye movers" may benefit from lens designs customized with wider viewing zones. "Head movers," on the other hand, may benefit from lens designs customized with softer gradients of power and astigmatism in order to minimize image swim and similar magnification effects that can disrupt vision during compensatory head movements.

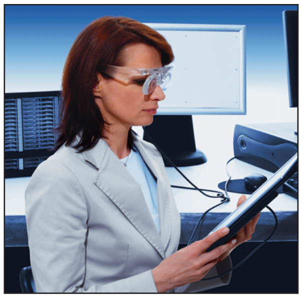


Figure 12. Head-tracking devices are utilized to determine whether a given individual is a "head mover" or an "eye mover" (photo courtesy of Carl Zeiss Vision GmbH).

CONCLUSION

The use of free-form surfacing to deliver customized progressive lenses is arguably the most meaningful visual benefit of this technology to wearers. The full potential of free-form technology will only be realized when utilized in conjunction with powerful software tools capable of "real-time" optical design using input specific to the individual wearer.

It is possible, for instance, to use free-form surfacing technology to deliver traditional-type progressive lenses on demand, often by mathematically combining a predefined progressive lens design (or "points" file) with the prescription curves normally applied to the back of the lens blank. Free-form progressive lenses of this type essentially replicate the performance of traditional, semi-finished progressive lenses. A sufficiently advanced optical design and free-form delivery system, on the other hand, can minimize patient non-adapts and maximize patient satisfaction. ■