Ray-tracing customized progressive lens calculation

Pupil diameter software optimization

The emergence and development of free-form LDS software for the ophthalmic lenses optical surface calculation represents the most important technological revolution in the ophthalmic industry in recent decades. Besides optimizing the lens manufacturing process and the size of semi-finished goods warehouses, this technology significantly improved progressive lens optical quality, thanks to arbitrary surfaces implementation. *By Gaetano Volpe and Pasquale Fanell*

That alone is the reason progressive lenses are now considered the first choice for presbyopia compensation by most of the eye care professionals (ECP) worldwide. Indeed, modern ray-tracing algorithms with wavefront analysis, like ProCrea WFRT Optimization, enable PAL power distribution recalculation according to the position of wear parameters (PoW parameters). These parameters, represented in figure 1, usually include: pantoscopic angle, monocular pupil distances, frame wrap angle, fitting height, and back vertex distance (also called corneal apex-lens distance). In addition, modern WFRT algorithms also offer visual space customization, by varying the near working distance to which the lens will be used. As a result of this complex algorithm, the lens power calculation is highly customized and better compensates oblique aberrations thus improving comfort in multiple gaze directions. The main outcomes are an increased field of view (better visual acuity curve as a function of eccentricity) and faster lens adaptation.
Despite the major contribution of this recalculation, the final optical surface can be further optimized, modulating other parameters aiming to improve residual high order aberrations. In fact, the free-form software features a modular layer-based structure, in which the result of one optimization level becomes the input for the next algorithm. In this way the final surface continues to be refined, improving its optical performance.

> Ultimately, wearers will benefit from a faster lens adaptation and from a wider visual field perceived in focus, characteristic of high-end customized progressive addition lenses.

Therefore, the ProCrea research team started to consider the exit pupil diameter in the WFRT simulation as a customizable variable, in addition to the classical PoW parameters. This value, in fact, is usually set around the default average value of 4 mm. Moreover, this exit pupil is placed between the calculated progressive lens and the fovea (retinal site with maximum visual acuity), and it acts similarly to a human pupil, adjusting the number of traced rays and high-order aberrations.

Pupil diameter influence

The ability of an exit pupil to influence the number of total aberrations in an optical system is obviously well documented, as well as the limits dictated by diffraction.
Eye care professionals continuously experience the pupil diameter influences in daily clinical practice. For example, the phenomenon of "night myopia" (nearsightedness in low-light conditions) is known since the early 18th century and it is widespread among the population. Although it is also affected by the night light spectral composition (blue-oriented), it depends mainly on the increase in pupillary diameter.
Indeed, larger pupils don't cut out peripheral light rays (distant from the system optical axis) inevitably increasing spherical aberration (as the eye is not a perfect optical system).
In addition, we would draw on lens geometric optics, where all mathematical considerations rely on the Gauss's approximation of paraxial light rays. Translated into 3D space, this concept is simply represented by an exit pupil, which masks peripheral light rays, reducing aberrations.

Software optimization

As mentioned earlier, usually the exit pupil diameter in the ray-tracing simulation is set at 4 mm. However, considering the graph in figure 2, it can be observed that the residual dioptric error (unwanted aberrations) for each gaze angle varies depending on the pupil diameter chosen. In fact, each pupil diameter generates its own power distribution function (dashed lines).

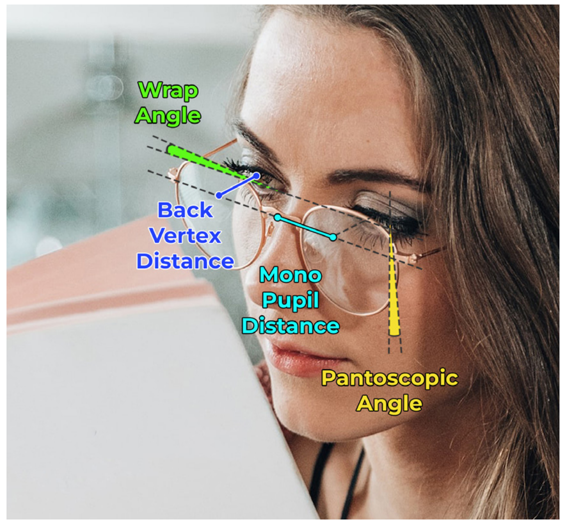

Fig. 1: The most relevant position of wear parameters: pantoscopic angle, monocular pupil distances, frame wrap angle, back vertex distance

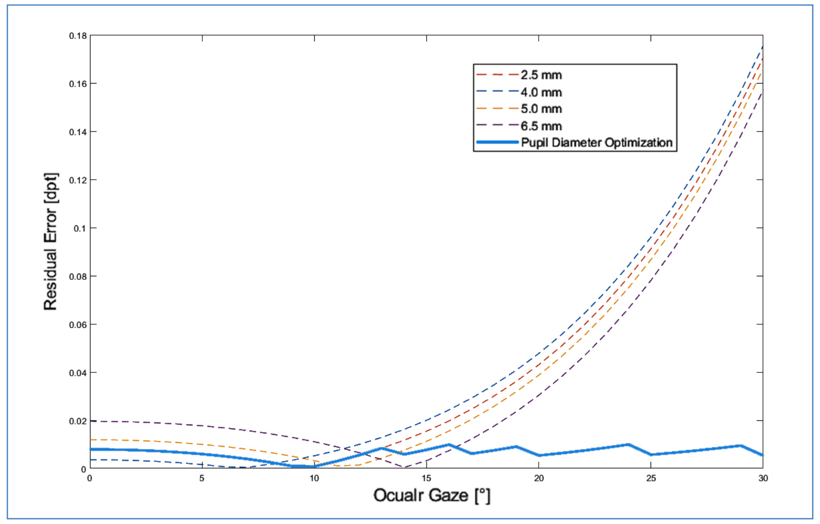

Fig. 2: Residual power error as a function of ocular gaze direction. Curves of various exit pupil diameters are shown, as well as the curve optimized by the algorithm. distances, frame wrap angle, back vertex distance

Therefore, the pupil opening algorithm considers all diameters for an optimal interval, ranging from 2.5 mm to 6.5 mm. For each value, a surface wavefront analysis is performed, also considering all other position of wear parameters.
Subsequently, in this higher optimization level, it proceeds by computing all these ray tracing simulations together, giving a weight to each contribution and generating the final optical surface.
Hence, in this way it is possible to incorporate the contribution of multiple exit pupil diameters in the final optical surface, which will benefit from a better power distribution and minimized high-order aberrations.
Ultimately, wearers will benefit from a faster lens adaptation and from a wider visual field perceived in focus, characteristic of high-end customized progressive addition lenses.

Conclusion

Despite the significantly higher quality of free-form progressive lens surfaces compared with earlier technologies, it is possible to further improve free-form technology by combining position of wear recalculation with other optimization algorithms.
Given the well-known correlation between exit pupil diameter and total aberrations, we investigated the role of this parameter in ray tracing software for customized progressive lenses, creating a new optimization layer.
The pupil opening technology algorithm developed by ProCrea, considers a wide range of pupillary diameters instead of the standard fixed value. These simulations results are combined in a single optical surface that benefits from the contribution of all pupillary diameters considered.
As can be seen in the graph (Fig. 2), a more effective minimization of residual dioptric error (lateral aberrations) has been achieved, which will improve final lens optical quality and consequently wearer's comfort. ◆

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