Anti-reflective coatings reflect ultraviolet radiation

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Abstract Anti-reflective (AR) coatings provide numerous visual benefits to spectacle wearers. However, coating designers and manufacturers seem to have placed little or no emphasis on reflectance of wavelengths outside the visible spectrum. Ultraviolet (UV) radiation from sources behind the wearer can reflect from the back lens surface toward the wearer's eye. Various clear lens materials, with and without AR coatings, were tested for their transmittance and reflectance properties. Although the transmittance benefits of AR coatings were confirmed, most coatings were found to reflect UV radiation at unacceptably high levels. Tinted sun lenses also were tested with similar results. Frame and lens parameters were evaluated, confirming that eyewear that incorporates a high wrap frame and high base curve lenses can prevent UV radiation from reaching the eye. The findings strongly suggest that clear, flat lenses should not be dispensed for long-term use in sunny environments, even if clip-on tints are provided.
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Anti-reflective (AR) coatings have long been known to provide numerous visual benefits to spectacle wearers, including increased transmissibility, reduced surface reflections and ghost images, and decreased glare.[1-5] Although AR coating is essential for high-index materials such as polycarbonate and many proprietary plastics and glasses, it also is beneficial for lower index materials such as crown glass, CR-39™, and Trivex™ (PPG, Pittsburgh, Pennsylvania). For maximum advantage, both surfaces of the spectacle lens should be coated, as has been shown for both dress[1-4] and occupational/safety[5,6] eyewear.

Nonetheless, coating designers and manufacturers seem to have placed little or no emphasis on reflectance of wavelengths outside the visible spectrum. To wit, a colleague who conducts eye movement research with an infrared eye monitor noted that subjects cannot wear spectacles during his projects because the increased reflectance of infrared caused by AR coatings typically interferes with the reflected ocular images (Zikos G., Personal communication, December 9, 2006). Likewise, from the characteristic reflectance increase that most AR coatings show in the violet region of the visible spectrum, it seems likely that the reflectance of ultraviolet (UV) radiation is not negligible.

With this latter point in mind, the public is increasingly being made aware of the dangers of ocular exposure to UV radiation. For example, advertisements from manufacturers of photochromic lenses tout the fact that their lenses absorb UV radiation, which is an initiating factor of the photochromic process.[7,8] As well, a contact lens manufacturer has received the World Council of Optometry's Seal of Acceptance for the UV protection provided by its products.[9] Ocular health effects of short- and long-term environmental UV exposure are well known, including increased risk of photokeratitis, pterygium, cataract, and melanoma of the adnexa.[10-12] Exposure to UV-C (far or germicidal UV, 200-290 nm), or high-intensity UV-B (middle or erythemal UV, 290-315 nm) or UV-A (near UV, 315-380 nm), in industrial settings causes similar acute damage to the superficial structures of the eye and orbit.[6]

Previous studies have found that spectacles that are not fit properly to the wearer's head can expose the eye to UV radiation from the side and even from reflection off the back surface of the spectacle lens.[13-15] This report confirms the transmittance properties and shows the reflectance proper-

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ties of common lens materials and coatings for sources located behind the spectacle wearer. In addition, it provides lens parameter options for the ophthalmic dispenser to minimize the patient's ocular exposure to UV radiation.

Methods

Test lenses

Clear lenses of several common ophthalmic materials with popular coatings, identified in Figure 1, were provided by the Pacific University Family Vision Center. Most were actual prescription lenses, with 2 exceptions: CR-39 with Teflon® AR coating (Carl Zeiss Vision, San Diego, California) was a demonstration lens provided by the manufacturer to the dispensary, and acrylic was a display lens for a frame. This latter lens material was included because, even though it is not dispensed by practitioners, it is encountered in "toy" and counterfeit eyewear. In addition, Zeiss 1.9-index glass with Gold ET AR coating was provided by a patient from Canada but because of its low center thickness is not legal for dispensing in the United States. All but one of the lens coatings were applied by the lens manufacturers; the UV400 coating on a CR-39 lens was applied by the local optical laboratory.

Several common tinted nonprescription sun lenses from the author's collection also were tested. Many of these lenses have high base curves (8 diopters [D] or greater), are intended for use in high wrap frames, and do not have AR coating. One of the lenses, purchased at a roadside stand, was marked "UV500" and made of acrylic with a silver flash front surface coating. It is important to determine the reflectance properties of such lenses in the event that the eyewear is worn incorrectly. For example, light can reflect easily from the rear lens surface if the frame size, frame contour, or vertex distance are inappropriate for the wearer, such as a small child wearing an adult frame.

Measurements

Back vertex power was measured with a standard manual lensmeter (Marco, Jacksonville, Florida), surface curvature was measured with a lens clock calibrated for index 1.53 (Vigor Optical, Carlstadt, New Jersey), and thickness at the distance reference point of the lens was measured with a precision depth gauge (Starrett, Athol, Massachusetts). Parameters of the clear and tinted lenses are listed in Figures 1 and 2, respectively.

Spectrophotometry was conducted over the wavelengths of 200 nm to 800 nm in 5-nm increments with a Perkin-Elmer Lambda 20 UV/VIS Spectrometer (Norwalk, Connecticut). Lenses were assessed for total transmittance and back surface specular reflectance at their distance reference points.

Transmittance and reflectance calculations

All transmittance properties for visible light, UV-A, and UV-B were analyzed according to the U.S. nonprescription sun eyewear standard, ANSI Z80.3-2001,[16] because the prescription lens standard, ANSI Z80.1-2005,[17] describes only how to calculate mean UV transmittances but makes no recommendations regarding visible or UV transmittance.

Transmittance requirements for UV-C are not included explicitly within any standard. However, the occupational safety eyewear standard, ANSI Z87.1-2003,[18] does define "effective far ultraviolet," which extends from UV-C to UV-B (200-315 nm), but clear safety lenses (i.e., visible light transmittance >85%) are exempt from this requirement. Nonetheless, UV-C transmittance was calculated using an equation similar to those for UV-A and UV-B transmittances, as described in ANSI Z80.3.

Reflectance characteristics also are not included in any standard but were analyzed for visible and UV regions using procedures similar to those defined above for transmittances. Reflectance was calculated only with regard to the specular performance of the lens. An integrative procedure to determine the overall amount of radiation to strike the eye and adnexa, along the lines used by other researchers,[14,19] is not relevant here because the only interest of the current study was to determine if, and how much, a particular lens could reflect UV radiation.

Frame and lens parameters

With regard to the actual performance of the eyewear when worn, several parameters of the frame, lens, and wearer contribute simultaneously to the ability of the eyewear to reduce ocular exposure to either direct or reflected UV radiation. These parameters include rear surface curvature of the lens, lens size, vertex distance, structure of the wearer's facial features, frame wrap, and frame temple or sideshield properties. A mathematical analysis was conducted to assist the dispenser in the judicious selection of eyewear for a given patient.

Results

Reflectance characteristics of the back surfaces of the test lenses are listed in Figures 1 and 2, and spectral reflectance curves are shown in Figures 3 through 6. Note that the luminous reflectances, even of uncoated crown glass and acrylic, are slightly different than what is expected based on the Fresnel equation.[20] This occurs for several reasons:

- Internal reflection from the inside of the front lens surface contributes to the result.
- Luminous reflectance is calculated across the entire visible spectrum, in which refractive index of the reflecting material varies with wavelength.
- Luminous reflectance takes into account the spectral sensitivity of the eye, such that the result is weighted