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A comparison of pre-coated stock antireflection coating lenses in terms of transmission, durability and quality

Authors:
Thokozile I. Metsing[1]
Anthony S. Carlson[1]

Affiliations:
[1]Department of Optometry, Faculty of Health Science, University of Johannesburg, Johannesburg, South Africa

Corresponding author:
Thokozile Metsing,
ingridm@uj.ac.za

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Background: Antireflection coatings (ARCs) applied to ophthalmic plastic lenses must have a good quality base hard coat for adherence of the ARC. The hard coating must be durable so as not to crack, craze or peel under different atmospheric conditions. The purpose of ARC is also to increase the transmission of light through the lenses and eliminate reflections.

Aim: The aim of this research was to compare the quality of eight different pre-coated ARC stock lenses in terms of light transmission and durability.

Setting: The measurements were taken in the Physics laboratory at the University of Johannesburg.

Methods: Eight different stock ARC lenses were obtained from different lens suppliers. The performances were assessed by measuring the light transmission through each lens, exposure to chemicals such as salt–water solution and adhesion and abrasion tests to assess the quality of the coatings.

Results: The performance and quality of the different lenses differed slightly in terms of hardness, durability and quality. The lenses also differed slightly in average transmission percentage. The difference between the control lens and the highest average percentage transmission was 4.8%, and the lowest average transmission was 2.2%. The lens that performed the best overall was Crizal Forte but limitations in sample size must also be considered here.

Conclusion: Not all lenses have the same quality of ARC applied and durable qualities. Quality control should be carried out regularly in batches so as to maintain high standards set out by the different suppliers.

Keywords: transmittance; reflectance; durability; quality; hardness; antireflection coatings.

Introduction

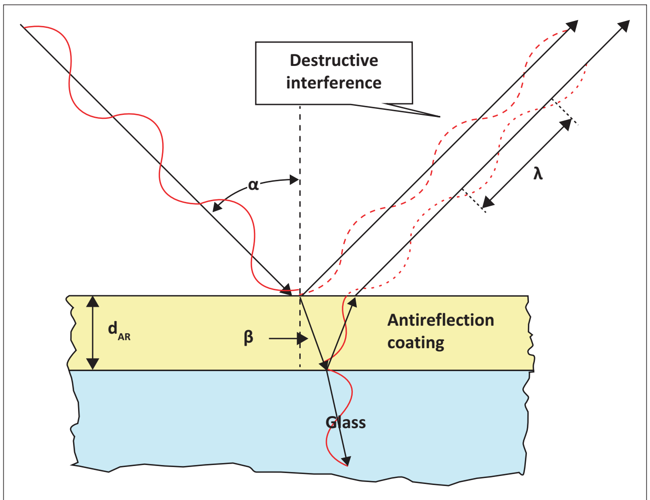
A spectacle lens comprises two interfaces and when light is incident upon them from both sides, a small percentage is reflected off each interface. The reflected light can cause unwanted ghost images within the lens that can cause visual discomfort, especially with patients who are wearing large frames and high index material lenses. Moreover, night driving could be problematic as some visible light is lost because of reflection off both surfaces of the lenses. In addition to reflections seen by the wearer are reflections of light sources and other objects reflecting off the lens surfaces seen by an observer. Antireflection coatings (ARCs) applied to both surfaces of the lenses reduce or eliminate these unwanted distractions.

Good-quality ARC must have a good base hard coating for ARC adherence. The hard coating must be tough and durable and should not crack under different atmospheric conditions. The coating must be easy to clean and more scratch resistant compared with uncoated lenses. Good-quality ARC lenses also have anti-tarnish, oleophobic and water-repellent properties and antistatic coatings applied to both surfaces that make the lenses easier to clean. These extra coatings are only a few nanometres thick and should have no effect on the performance of the ARC.[1] Not all companies have these added features applied to their lenses. Contrary to the uncoated lens, which remains stable over time, ARCs may appear perfect at the time they are applied, then show defects after a few weeks or months. Company procedures should include sample testing on a regular basis in order to maintain the quality of the coatings. The tests performed should simulate the day-to-day conditions and handling and wearing of spectacles as experienced by the wearer.[2]

With so many different companies supplying ARC lenses, how would one determine which one is the best or of a suitable quality. Up until recently, there were no official standards for ARC on spectacle lenses. However, international standards require, upon request, coating manufacturers to provide only two values: the mean reflectance (an average over the visible spectrum) and the luminous reflectance (hue). There are, however, standards for ARC on glass lenses set up by the military (Mil-C-48497). The aim of this study was to compare the quality and durability of eight pre-coated stock ARC lenses using the military standards.

The first interference-based coatings were invented and developed in 1935 by Alexander Smakula, who was working for the Carl Zeiss Optics Company.[3] Complete destructive interference between the incident and reflected light can be reached for a particular wavelength[4] provided the path and amplitude conditions are met as illustrated in Figure 1.[5]

A fraction of light or electromagnetic waves (EMWs) in general is reflected off a transparent material because of a mismatch in media caused by the abrupt change of refractive index. Such a quarter-wave coating is severely limited in application because of the strict condition on the thickness and refractive index of a coating material, whereas complex structures for broadband antireflection have no systematic design rules as a result of the lack of analytic solutions. The reflection of light passing through a medium with a graded refractive index was first studied in 1879 by Rayleigh, who analytically proved that reflection becomes significantly reduced if the medium, whose graded index is a function of the inverse square of the thickness, has an overall thickness greater than the wavelength of light.[6] He also found that the reflections off the surface were less than that of the air–glass interface, as can be calculated from the Fresnel equations.[7] Although the interpretation was carried out in the late 1800s, the manufacturing of ARC was performed as early as 1817 by Fraunhofer – this was when he observed that there was a decrease in reflection because of engraving a surface in the airspace of sulphur and also in nitric acid steam.[8]



Source: Interference Paradox [homepage on the Internet]. [cited 2022 Jan 30]. Available from: https://www.google.com/searchq=anti+reflective+coatings+images+destructive+interference+images

FIGURE 1: The principle of antireflection coatings (ARCs) showing destructive interference for a single wavelength λ in the reflected light of a transparent material. Light incident on a transparent air and thin ARC interface at angle α is refracted through angle β. A small percentage of the incident light is reflected. The refracted light incident on the ARC/glass interface is refracted into the glass whilst a small percentage is also reflected back through ARC and transmitted into the air. Assuming the path and amplitude conditions are satisfied, complete destructive interference will take place in the reflected light. No energy is lost. The energy is re-channelled through to the transmitted light.[5]

The properties of a Moths' eye are unusual. Their eyes are covered in arrays of tapered pillars of subwavelength in size that act as a graded refractive index medium that reduces reflection.[9] The structure consists of a hexagonal pattern of bumps, each roughly 200 nm high and spaced on 300 nm centres and their surfaces are covered with a natural nanostructured film, which eliminates reflections.[7,10] This makes the Moth's location not detectable by predators as this allows the moth to see well in the dark without any reflections from their eyes. This antireflective film works well because the bumps are smaller than the wavelength of visible light, so the light sees the surface as having a continuous refractive index gradient between the air and the medium, which decreases reflection by effectively removing the air–lens interface.[10] This moth eye antireflection model has been applied to various optoelectronic devices that include light-emitting diodes, displays, photovoltaic solar cells and micro sun sensors.[11,12,13,14]

Designers of antireflection coatings, utilising either a moth-eye structure or a multilayer coating, rely mostly on a numerical trial-and-error procedure to find optimised reflection structures.[15,16] Studies have shown that many patients who wear lenses with ARC have reported that the environment appears to be brighter and they feel they can see more detail.[17]

Multi-ARC consists of transparent thin-film structures with alternating layers of differing refractive indices. Layer thicknesses are chosen to produce constructive interference in the transmitted light and destructive interference in the reflected light. This makes the structure's performance change with wavelength and incident angle, so that colour effects often appear at oblique angles. A wavelength range must be specified when designing ARC and good performances can be achieved for a relatively wide range of frequencies: usually a choice of infrared (IR), visible or ultraviolet radiation (UVR) is offered. Antireflection coatings enhance the cosmetic appearance of the lenses. Such lenses are often said to reduce glare, but the reduction is very slight. Eliminating reflections allows more light to pass through, thus producing a small increase in contrast. The term 'antireflective' relates to the reflection from the surface of the lens itself, not the origin of the light that reaches the lens. Booth and Raj suggested that reducing reflections in a medium can improve contrast.[18]

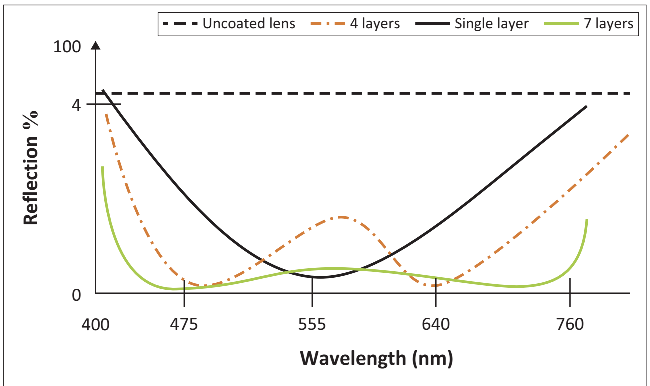
When the coating is antireflecting for the middle of the visible spectrum, some reflection occurs at the extremities of the visible spectrum, that is, the red and violet light wavelengths. This gives the lens a purplish appearance. The wavelengths for visible light range from approximately 390 nm to 760 nm.

It is impossible to produce an antireflection coating that will satisfy the path and amplitude conditions (zero reflection) for the whole range of the visible spectrum. Multiple layers of thin films of different refractive indices are applied to both sides of lenses to reduce the reflections over a wider range of wavelengths.[2] Figure 2 shows the reflectance as a function of the incident wavelengths for uncoated and various multilayer ARCs applied to CR39 lenses.

To prevent any variation in the reflected hue from the lenses, the refractive index of the hard-coating layer should match that of the lens substrate, and the thickness of the coating must be uniform across the surface of the lens.[2] Unfortunately, applying the hard coating to any plastic lens reduces the impact resistance considerably. Moreover, by applying an ARC, it is reduced even more.[19]

A common complaint is that ARCs are difficult to keep clean. The lenses are more transparent, and dust and oily particles are more visible because of less light being reflected. By applying good antitarnish, oleophobic, antistatic and hydrophobic coatings, the adherence of dust, oily matter and water is considerably reduced. When a liquid drop is placed onto a solid surface, if the adhesive forces are attractive, the drop of liquid is pulled towards the surface producing a wetting angle that spreads the liquid along the given surface (low wetting angle). This type of surface is then referred to as 'hydrophilic', meaning water loving. In contrast, if the adhesive forces are repellent, the drop of liquid minimises its contact with the surface and it is said to be 'hydrophobic' (high wetting angle). Hydrophobic surfaces play a vital role in protecting surfaces from water damage and stains.[2] Unfortunately, not all manufacturers apply these extra coatings.[19]

A study aiming to better the perceptibility of digital devices such as mobile phones, computer screens and television suggests lens wearers coat their lenses with ARC, thus giving them sharper and more comfortable vision. Antireflection coatings suitable for this venture are applied in multilayer stacks onto the display screens by various coating techniques. However, coating the lenses with ARC directly is considered better than laminating the screens.[20]



Source: Adapted from Jalie M. The Principles of ophthalmic lenses. 4th ed. London: Association of British Dispensing Opticians; 1984, p. 501, 511.

FIGURE 2: The reflectance as a function of incident wavelengths for uncoated and various multilayer antireflection coatings applied to CR39 lenses.[21]

According to Hiller,[22] the reflectance of 4.0% to more than 6.5% of incident light on the air–substrate interface has a refractive index of 1.45–1.7 in optical elements based on glass and usual plastics.

Coating procedures should include sample testing on a regular basis. Contrary to the uncoated lens, which remains stable over time, ARCs may appear perfect at the time they are applied and then may show defects after a few weeks or months. The tests performed should simulate the day-to-day conditions and handling and wearing of spectacles as experienced by the wearer.[18] These tests include artificial accelerated ageing, high- and low-temperature testing, hot and cold salt water testing, mild and severe abrasion testing, to name a few. The aim of this study was to compare the quality and durability of eight pre-coated stock ARC lenses.

Aim and objectives

The aim of this study was to compare the transmission of light through eight pre-coated stock ARC lenses and the quality and durability of the lenses using the military standards.

Methodology

Eight stock lenses with different ARCs were tested and analysed. An additional uncoated clear CR39 lens was used as a control lens. All lenses were pre-coated ARC stock lenses. To prevent any bias, the suppliers' lenses were numbered from 1 to 8 so that they were not identifiable by manufacturer or brand names. The lenses were cleaned before and after each procedure with methylated spirits and a lint-free cloth. All the test results were inspected visually using a 60-watt light source against a black background and a lens of magnification 6. The tests chosen for this study were to try to simulate the cleaning and handling of the lenses by the wearer and the different climatic conditions the lenses would be exposed to. The lenses together with their parameters are shown in Table 1. Spectral transmission curves were measured and compared for all nine lenses using the Cary Varian 5000 photo spectrophotometer from the Physics Department at the University of Johannesburg. The wavelengths measured ranged from 340 nm to 800 nm.

TABLE 1: Showing pre-coated stock lens parameters that were used for this study, which includes refractive index (*n*), front surface power (D) and centre thickness (mm).

Brand	*n*	Front surface power (D)	Centre thickness (mm)
Uncoated CR39	1.5	5.00	2.0
Hoya SVV	1.5	6.00	2.2
Hoya HVLL	1.5	5.50	2.2
Crizal Easy	1.5	5.50	2.0
Lenz Xpress	1.56	5.50	2.0
Crizal Forte	1.5	5.50	2.0
Zeiss Drive	1.6	5.50	2.0
Lens tech	1.5	4.00	2.0
Precision	1.5	5.50	2.0

Note: All lenses had zero power (0.00 dioptre [D]).
D, dioptre.

Additional tests that were carried out included:

- **The adhesion test:** Cellophane tape was applied to the anterior and posterior surfaces of each lens and then removed quickly to test the adherence of the ARC. The coated surfaces should show no evidence of coating removal. One
- **The moderate abrasion test:** A standard 'crock meter' was used for this test. A one-kilogram (kg) weight was placed on the lenses. A cheesecloth pad that was washed and rinsed was then placed between the weight and the lens in the crock meter. The cheesecloth oscillates back and forth over the convex surface of the lens over a distance of approximately 6 cm. The pad oscillates in a forward and backward direction over the lens. Hence, this test simulates the cleaning procedure as done by the wearer and the test tests the durability of the coating. A back-and-forth oscillation counts as two strokes. The lenses were placed in the crock meter and run for 10 strokes at a time and then inspected for defects that were visible under magnification and not visible to the naked eye. If no defects were visible, another 10 strokes were run until defects were visible under magnification. The coated surface should show no signs of deterioration such as streaks or scratches.
- **The severe abrasion test:** A standard pencil eraser was placed between the 1 kg weight and the lens in the crock meter. The test was used to test the durability and slightly heavier duty cleaning by the wearer. The lenses were placed in the crock meter and also run for 10 strokes at a time and then inspected for defects that were visible under magnification and not visible to the naked eye. If no defects were visible, the process was repeated until defects were observed.
- **The steel wool abrasion test:** First-grade steel wool was placed between the 1 kg weight and lens in the crock meter. This simulates continuous cleaning. The same procedure was performed as with the moderate and severe abrasion tests. The lenses were placed in the crock meter and also run for 10 strokes at a time and then inspected. The same procedure was performed until the defects were just visible under high magnification. These measurements were then recorded.
- **High temperature test:** To test under environmental conditions, the lenses were placed in an oven at a temperature of 70 °C for a period of 2 h. The coatings should show no signs of flaking, peeling, cracking and blistering.
- **The solubility salt–water test:** The lenses were immersed in a salt–water solution consisting of 89.4 g sodium chloride diluted in 2 L of distilled water for a period of 24 h. This tests the corrosion resistance of the coatings under exposure to such conditions. The coating should show no evidence of physical defects such as peeling, cracking, blistering, staining, cloudiness or discolouring.
- **Hydrophobic layer test:** A subjective test was conducted to test the water-repellent properties and ease of cleaning of the coatings. All the lenses were cleaned with a lint-free cloth, firstly with water and then with methylated spirits. Methylated spirits were sprayed onto the convex surface of the lenses, and the size of the droplets that were formed on the lenses was observed. The lenses were graded according to the size of the droplets formed when incident on the lens. The ease of cleaning each lens was then conducted and compared. The exercise was then repeated, but this time with water and again the results were compared.

Data analysis

This is a comparative research project. Transmission curves and values for each lens are recorded and compared with one another using Microsoft Excel. Averages of transmitted wavelengths and comparisons of the additional tests are shown in tables and graphs and then compared.

Ethical considerations

Ethical clearance to conduct this study was obtained from the University of Johannesburg, Faculty of Health Sciences Research Ethics Committee (number: 241112-035).

Results

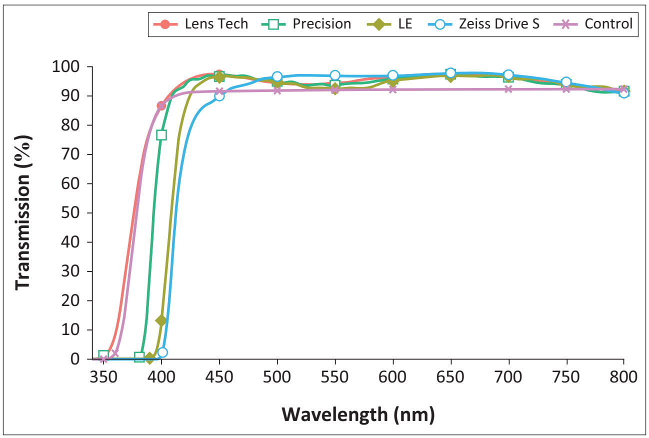
The ultraviolet C (UVC) waveband lies between about 10 nm and 280 nm, which is absorbed by the ozone layer (O_3). Ultraviolet B lies between wavelengths 280 nm and 320 nm and ultraviolet A (UVA) between 320 nm and 390 nm. The visible spectrum lies approximately between wavelengths 390 nm and 760 nm and the infrared waveband (IR) lies beyond 760 nm.[22]

Figures 3 and 4 show the transmission curves for all nine lenses including the control lens. These two figures show the amount of radiation transmitted through each lens for each wavelength between 340 nm and 800 nm. The transmission curves show that all lenses absorb UVB (280 nm – 320 nm); however, all transmit UVA. Figure 5 shows the amount of UVR transmitted between 320 nm and 400 nm through each lens whilst Figure 6 shows the amount of visible light that is transmitted between 400 nm and 760 nm. A summary of the durability and other tests are shown in Table 2.

Discussion

Ultraviolet radiation transmission

Figure 5 shows that the uncoated control lens transmits the same amount of UVA as the Crizal Easy (25.0%). When compared with the other coated lenses, the uncoated lens transmits less UVA than the Hoya SVV, Hoya HVLL and Lens Tech lenses that transmit 33.4%, 29.7% and 28.0%, respectively. This appears to be in agreement with a study performed by Carlson[18] on blue control lenses for the HVLL lens. The Hoya lenses do not appear to have extra UV coatings applied to them. Crizal Forte transmits 23.0% UVA that is only 2.0% lower than the control lens. It is interesting to see that only two of the ARC lenses have UV protection close to 400 nm (Lenz Xpress 0.5% and Zeiss 0.03%). The Precision ARC (8.5%) was the only other



LE, Lenz Xpress.

FIGURE 3: Transmission curves for four lenses with antireflection coatings. Lens Tech (red), Lenz Xpress (green), Precision (green), Zeiss Drive S (blue) and the control lens (magenta).

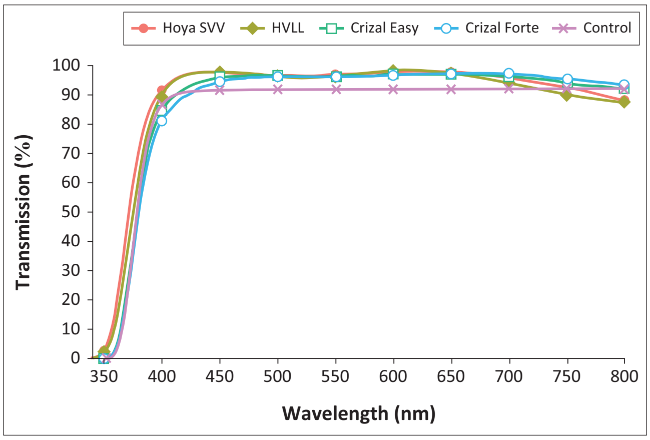


FIGURE 4: Transmission curves for four lenses with antireflection coatings. Hoya SVV (red), Hoya HVLL (green), Crizal Easy (green), Crizal Forte (blue) and the control lens (magenta).

lens that transmitted less than 10.0% UVA. What this implies is that only these three lenses have additional UV coatings applied, whereas others do not.

Visible light transmission

Figure 6 shows the amount of visible light transmitted through each lens between wavelengths 400 nm and 760 nm. The Hoya SVV transmitted the most (97%) followed by Crizal Easy, Hoya HVLL, Crizal Forte and Lens Tech all transmitting 96%. Precision transmitted 95% followed by Lenz Xpress (93%). The Zeiss Drive transmitted the same percentage of visible light as the uncoated control lens, which was 92%. The Zeiss Drive appeared to have a stronger absorption in the blue region of the visible spectrum than the other lenses, thus giving a lower percentage of visible light transmission.

Durability test

All the lenses passed the cello tape adhesion test. The test was performed three times on each lens, and no visible defects or peeling of the coating were detected using the naked eye. The moderate and severe abrasion tests using the cheesecloth pad and eraser, respectively, showed good

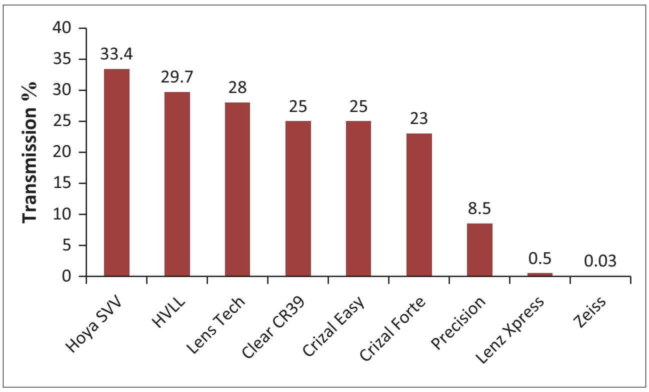


FIGURE 5: The amount of ultraviolet A radiation transmitted, as a percentage (between 320 nm and 400 nm), through each lens. The percentage is shown at the top of each bar.

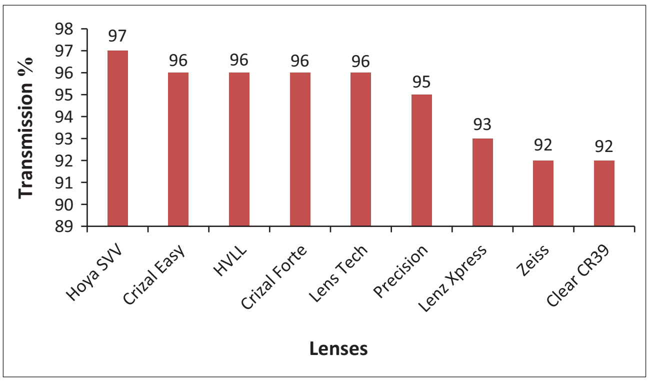


FIGURE 6: The amount of visible light transmitted, as a percentage (between 400 nm and 760 nm), through each lens. The percentage is shown at the top of each bar.

results for all the samples. All the samples suffered more than 350 strokes without any visible defects under 6× magnification or the naked eye. The crock meter was run for 20 strokes; then the lenses were inspected. If no defects were visible, the strokes were repeated only up to 350 strokes. For the steel wool test, the Crizal Forte featured the best with 60 strokes before showing any abrasions followed by the Hoya HVLL, Crizal Easy and Zeiss Drive, all with 30 strokes before any abrasions were detected under 6× magnification. This was followed by the Hoya SVV with 20 and then the Lenz Xpress, Lens Tech and Precision after 10 strokes, respectively. All the lenses passed the solubility salt–water test.

Not all lenses passed the high-temperature test. The only coatings that did not crack were the Crizal Forte, Hoya HVLL and Crizal Easy. Perhaps, the reason why the Zeiss Drive failed the high-temperature test was that it is of a higher refractive index, which is 1.6.

The hydrophobic coatings were graded according to the size of water droplets formed on the lenses and the ease of cleaning the lenses. The smaller the water droplets formed on the lens and the ease of cleaning, the higher the rating. The overall ratings were rated in order on a scale from 1 to 5 with 1 being the best and 5 the worst. Not all of the coatings were rated equally and did not appear to have the same quality coatings. The Crizal Forte (1) showed the smallest droplets and cleaned

TABLE 2: A comparison of all tests performed on the antireflection coatings.

Manufacturer	1 Hoya SVV	2 Hoya HVLL	3 Crizal Easy	4 LE	5 Crizal Forte	6 Zeiss D	7 Lens Tech	8 Precision
Adhesion test	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Moderate abrasion test	> 350	> 350	> 350	> 350	> 350	> 350	> 350	> 350
Severe abrasion test	> 350	> 350	> 350	> 350	> 350	> 350	> 350	> 350
Steel wool abrasion test	20	30	30	10	60	30	10	10
Soluble salt-water test	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
High temperature test	Fail	Pass	Pass	Fail	Pass	Fail	Fail	Fail
Hydrophobic layer	3	2	2	5	1	3	5	5

LE, Lenz Xpress.

The brand names are stated below the numbers. The numbers in the Abrasion columns indicate the number of strokes performed by the crock-meter. The numbers in the Hydrophobic column indicate the rating of the lenses. The water-droplet size and ease of cleaning with 1 showing the smallest water droplets and easier to clean and 5 showing larger droplets and more difficult to clean.

the easiest. This was followed by the Hoya HVLL and Crizal (2). These two coatings appeared to be very similar. The Hoya SVV and Zeiss Drive (3) then followed and also appeared to be similar to each other. The Lenzxpress, Precision and Lens Tech (5) all showed the largest droplets that were similar in size and were more difficult to clean when compared with the others.

Although the LenzXpress and Zeiss lenses transmitted the least amount of UVR 0.5% and 0.03%, respectively, both lenses transmitted the least amount of visible light (93% and 92%, respectively, and both cracked under the high-temperature test. The Hoya SVV and HVLL transmitted the most UVA (33.4% and 29.7%) whilst transmitting the highest percentage of visible light (97% and 96%), respectively. The HVLL passed the high-temperature test, whilst the SVV did not. The lens that appeared to feature the best overall was the Crizal Forte that transmitted 23% of UVA, 96% of visible light, passed the high-temperature test and suffered the most steel wool strokes on the crock meter (60) before showing any defects making it the most durable when compared with the others. The HVLL, Crizal Easy and Zeiss lenses appeared to feature second with the three suffering 30 strokes on the crock meter. The HVLL and Crizal Easy transmitted 96% of visible light whilst the Zeiss lens transmitted only 92%. The HVLL did, however, transmit the most UVA (29.7%) with the Crizal Easy (25%) and Zeiss transmitting the least (0.03%). The lenses that appeared to feature the worst from a durability point were the Precision, LenzXpress and Lens Tech. They all failed the high-temperature test and could only manage 10 strokes with the steel wool test.

Conclusion

Not all lenses have the same quality ARC applied and durable qualities and not all ARC lenses are marketed as UV protection lenses. An uncoated CR39 lens absorbs all UVB and transmits about 24% of UVA. The lenses that were tested available in the market that provides extra UV protection are Crizal Forte, Crizal Easy, Lenzxpress, Zeiss and Precision. There were no notifications on the Hoya's and Lens Tech packaging regarding UV protection. What this implies is that some of these lenses do have additional UV coatings applied, whereas other do not.

Stock plastic lenses that are coated with ARC are mass produced. Quality control should be carried out regularly in batches so as to maintain high standards set out by the different suppliers. A point to consider is the price one is paying for the lenses. A large amount of money is spent on research and development on ARC. The better quality ARC lenses are more expensive and has added benefits such as hard-coatings, antistatic, oleophobic and water-repellent coatings that make the lenses easier to clean and require less wiping. The cheaper lenses do not have these extra features. The chief complaint that people have is that some ARCs are difficult to keep clean. This would apply more to the cheaper lenses as they do not have these added features.

The differences in visible light transmission through the different lenses are negligible. What definitely does play a role is the cleaning of the lenses. The more expensive lenses do have the added features that make cleaning easier and also have a stronger scratch-resistant coating applied. Does the price of the ARC play an important role? Absolutely yes. Not everyone's budget is the same. The cheaper lenses may be slightly more difficult to keep clean, may scratch a bit easier and the ARC may start showing slight deteriorations sooner than the more up-market coatings; however, they do eliminate the unwanted reflections. All uncoated CR39 have similar optical qualities. It is the characteristics of the ARC that makes the difference. It is safe to conclude that the more expensive the lens, the more added features the coating has.

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Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

M.I.M. and A.S.C. contributed equality to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript.

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Data availability

Data supporting the findings of this study are available from the corresponding author, M.I.M., upon reasonable request.

Disclaimer

The views and opinions expressed in this article are those of the authors and do not necessarily reflect the official policy or position of any affiliated agency of the authors.

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