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The role of glass as a barrier against the transmission of ultraviolet radiation: an experimental study

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Summary

Background/Purpose: Excessive exposure of the skin to sunlight may cause many symptoms and skin cancer. The aim was to measure the transmission of ultraviolet (UV) A and UVB radiation through glasses of different types, according to the distance from the light source.
Methods: The baseline radiation from UVA and UVB sources was measured at different distances from the photometers. Next, the radiation from the same sources was measured at the same distances, but transmitted by different types of glass. The baseline values were compared with the results after protection using glass.
Results: Laminated glass totally blocked UVA radiation, while smooth ordinary glass transmitted the highest dose (74.3%). Greater thicknesses of glass implied less radiation transmitted, but without a significant difference. Green glass totally blocked UVA radiation, while blue glass transmitted the highest dose of radiation (56.8%). The presence of a sunlight control film totally blocked UVA radiation. All glasses totally blocked UVB radiation.
Conclusion: The main characteristics of glass that make it a photoprotective agent are its type (especially laminated glass) and color (especially green), which give rise to good performance by this material as a barrier against the transmission of radiation.

The effects on the skin from short- and long-term exposure to ultraviolet (UV) radiation have already been extensively dealt with in the literature (1–4). The main acute effects are erythema, feelings of heat, edema, pain and pruritus. Other events include late bronzing, thickening of the epidermis and dermis, immunosuppression and vitamin D synthesis. On the other hand, the chronic effects of this exposure consist of early aging of the skin and carcinogenesis (5–7).

Nowadays, huge amounts of time in our daily lives are spent in closed environments and in vehicles. Although the adverse effects of UV radiation are well known, the function of the glass for photoprotection has little coverage in the literature (8–10).

Recent advances in the glass industry have resulted in the manufacture of window glass that provides broad protection against UV radiation, but without causing losses in visible light transmission. Some characteristics of glass material may have an influence on the properties of protection against UV radiation, such as the type, color, layers and coating of the glass (9).

Clear ordinary glass: This is transparent and colorless. Its main characteristic is its capacity to provide protection against the outside elements, while at the same time allowing transmission of visible light into the interior. Depending on the thickness, clear glass can transmit $> 90\%$ of visible light (between 400 and 780 nm) and up to 83% of solar heat (9). It is also possible to obtain imprinted glass by means of continuous melting of the vitreous mass. Metal rollers are used to print a wide variety of textures onto its surface.

Laminated glass: This is produced by associating two laminae of glass with a layer of plastic (PVB – polyvinyl butyral), under heat and pressure. Once the glass-and-plastic composite has been cast, the result is a single lamina that is generally very similar to clear ordinary glass. The benefit of laminated glass is that, if it breaks, the fragments continue to adhere to the PVB layer, instead of becoming scattered, thereby reducing the risk of accidents. PVB filters approximately 99% of UV radiation without diminishing the transmission of visible light (9).

Tempered glass: This is obtained by gradually heating the glass and then abruptly cooling it in a vertical or a horizontal tempering furnace. This is essentially a type of safety glass. In the event of breakage, it shatters into very small pieces that are not sharp (9).

Variation in the thickness of the glass has limited influence with regard to blocking UV radiation, according to studies (9). Tinted glass contains special colored components that absorb up to 50% of the incident solar energy, thereby reducing the undesired heat gain and transmitting less UV and visible light, in comparison with ordinary glass (9). A study on the penetration of UV radiation through car window glass demonstrated that this transmission depended on whether the glass was tinted or not. The results demonstrated that the colored sample completely removed the UVB spectrum and only allowed a small proportion of UVA to pass (10).

UV transmission through vehicle window glass depends on the type and tinting of the glass. For safety reasons, all windscreens are made of laminated glass, which is able to filter out practically all of the UVA. However, the glass for the side and rear windows is normally tempered and therefore some of the radiation is able to pass through. Plastic film to control sunlight, which is often applied to these windows, results in 20–35% visibility (transmission of visible light) and filters out the UVA of wavelengths $< 380–370$ nm (9).

The aim of the present study was to measure the transmission of UVA and UVB radiation through samples of various types of glass used in the windows of vehicles and houses, taking into consideration the following variables: type, thickness and color of the glass, application of sunlight control film and distance between the light source and the glass.

Materials and methods

The following materials were used in the experiment:

(1) Glass

a. Window glass from built environments, with the following variables: type (smooth ordinary, imprinted ordinary, tempered and laminated), thickness (from 0.4 to 0.8 cm) and color (colorless, green, wine, yellow and blue).

b. Window glass from vehicles, taking into consideration the type (laminated and tempered) and application of sunlight control film of the brand Insulfilm™ (Brazil), type G50 (which allows 50% visibility).

(2) Handisol™ UVA(315–400nm) and UVB(280–320nm) emission sources, UVA-400C (315–400nm) and UVB(280–320nm) photometers and goggles for protection against UV radiation, all manufactured by National Biological Corporation (Beachwood, OH, USA).

Firstly, the baseline radiation from the UVA emission source was measured. This was measured after the source had been switched on for 15 min, at distances of 0, 25, 50 and 100 cm, without any glass as a barrier. The same procedure was then followed using the UVB emission source.

The transmission of UVA and UVB radiation was then measured through the different glass samples, taking the following variables into consideration: type, thickness and color of the glass, application of sunlight control film and distance from the light source to the glass, up to the distance of 50 cm. Lastly, the percentages of radiation transmitted through the glass were calculated from the baseline values, thereby allowing these materials to be evaluated as photoprotection agents.

Results

From the measurements of baseline radiation from the UVA emission source, it was found that the initial radiation at the distance of 0 cm from the photometer was 7.4 W/cm^2; it was 0.6 W/cm^2 at 25 cm; 0.1 W/cm^2 at 50 cm; and no radiation was detected by the photometer at 100 cm. UVB radiation without glass protection gave the following results: 0.92 mW/cm^2 at 0 cm; 0.06 mW/cm^2 at 25 cm; 0.01 mW/cm^2 at 50 cm; and no radiation was detected by the photometer at 100 cm.

In measuring the intensity of the radiation from the UVA source, a considerable reduction in the quantity detected by the photometer was observed as it was moved away from the source. At a distance of 25 cm, the measurement was 0.6 W/cm^2, which corresponded to only 8% of the baseline UVA. This signifies a loss of 92% of the irradiation when the measuring instrument was moved away. With the photometer at a distance of 50 cm, 0.1 W/cm^2 was detected, corresponding to 1.3% of the UVA radiation transmitted by the source.

Tables 1–4 show the radiation detected by the photometer after introducing the protective barriers of glass. With regard to the types of glass used in buildings (Table 1), it was found that laminated-glass totally blocked the UVA radiation, independent of the distance from the source. At 0 cm from the source, smooth ordinary glass was the type that transmitted the greatest amount of radiation (74.3%), followed by tempered glass (71.6%) and imprinted glass (44.6%). At a distance of 50 cm, all four samples totally blocked the radiation.

Analysis of the smooth ordinary glass alone (Table 2) showed that greater thicknesses blocked the passage of radiation more, but without reaching statistical significance. At a distance of 50 cm, all the samples of smooth ordinary glass totally blocked the radiation.

With regard to the color of imprinted ordinary glass (Table 3), it was found that green glass totally blocked the UVA radiation, independent of the distance from the source. At 0 cm from the source, blue glass transmitted the greatest dose of radiation

Table 1. Radiation from UVA emission source that was transmitted by different types of glass, according to distance from source

	Radiation transmitted according to distance from source					
	0 cm (7.4 W/cm^2)		25 cm (0.6 W/cm^2)		50 cm (0.1 W/cm^2)	
Type of glass	W/cm^2	%	W/cm^2	%	W/cm^2	%
Smooth ordinary glass (4 mm)	5.5	74.3	0.4	66.6	0	0
Imprinted ordinary glass (4 mm)	3.3	44.6	0.3	50	0	0
Tempered glass (4 mm)	5.3	71.6	0.4	66.6	0	0
Laminated glass (8 mm)	0	0	0	0	0	0

Table 2. Radiation from UVA emission source that was transmitted by smooth ordinary glass of different thicknesses, according to distance from source

Thickness of smooth ordinary glass (cm)	Radiation transmitted according to distance from source					
	0 cm (7.4 W/cm^2)		25 cm (0.6 W/cm^2)		50 cm (0.1 W/cm^2)	
	W/cm^2	%	W/cm^2	%	W/cm^2	%
0.2	5.6	75.7	0.5	83.3	0	0
0.3	5.5	74.3	0.4	66.6	0	0
0.4	5.5	74.3	0.4	66.6	0	0
0.5	4.7	63.5	0.4	66.6	0	0
0.6	4.5	60.8	0.4	66.6	0	0
0.8	3.8	51.4	0.3	50	0	0
1.0	3.8	51.4	0.3	50	0	0

Table 3. Radiation from UVA emission source that was transmitted by imprinted ordinary glass of different colors, according to distance from source

Color of imprinted ordinary glass	Radiation transmitted according to distance from source					
	0 cm (7.4 W/cm^2)		25 cm (0.6 W/cm^2)		50 cm (0.1 W/cm^2)	
	W/cm^2	%	W/cm^2	%	W/cm^2	%
Colorless (3 mm)	2.7	36.5	0.2	33.3	0	0
Blue (3 mm)	4.2	56.8	0.3	50	0	0
Wine (3 mm)	2.3	31.1	0.2	33.3	0	0
Yellow (3 mm)	0.1	1.3	0	0	0	0
Green (3 mm)	0	0	0	0	0	0

Table 4. Radiation from UVA emission source that was transmitted by vehicle window glass of different types, according to distance from source

Type of glass	Radiation transmitted according to distance from source					
	0 cm (7.4 W/cm^2)		25 cm (0.6 W/cm^2)		50 cm (0.1 W/cm^2)	
	W/cm^2	%	W/cm^2	%	W/cm^2	%
Tempered vehicle window glass (3 mm)	1.3	17.6	0	0	0	0
Tempered vehicle window glass with G50 protective film	0	0	0	0	0	0
Laminated glass (8 mm)	0	0	0	0	0	0

(56.8%), followed by colorless (36.5%), wine (31.1%) and yellow (1.3%). Once again, at 50 cm, all the samples analyzed totally blocked the emitted radiation.

With regard to UVB radiation, for all the variables analyzed (type, thickness and color of the glass), it was observed that the samples totally blocked the UVB radiation at any distance from the emission source.

Among the types of vehicle window glass (Table 4), it was found that laminated glass totally blocked UVA radiation, independent of the distance from the source. Tempered glass for vehicle windows transmitted 17.6% of the radiation at 0 cm from the source and totally blocked the radiation at greater distances. Application of G50 sunlight control film to the tempered glass totally blocked the UVA radiation emitted by the source.

For all the variables analyzed (type of glass and application of G50 sunlight control film), it was observed that the samples totally blocked the UVB radiation, at any distance from the emission source.

Discussion

Some studies have reported the importance of glass for blocking UVB radiation and a certain wavelength range of UVA radiation (2). Others have proven the importance of glass as a photoprotective agent against undesirable biological effects. Bernstein *et al.* (8) demonstrated that the decreased transmission of UV radiation caused by glass drastically reduced the cytotoxicity measured using the neutral red uptake photoprotection assay. However, little is known about the influence of each characteristic of glass samples on photoprotection (such as the type, thickness and color of the glass and, in the case of vehicles, the application of sunlight control film) and the impact of these effects on different skin phototypes.

In the present study, it was observed that all of the types of glass decreased the transmission of UVA. Glass of laminated type was the most efficient for totally blocking the UV radiation. This may be explained by its production characteristics: an association between two glass laminae and a layer of plastic (PVB), which makes it an effective barrier against UVA (9).

The differences related to the UVA-laminated glass transmition may be explained by the different manufacturers and the technique utilized to obtain the measures. But as we know the laminated glass is efficient to protect from the UVA radiation (9).

Some works published showed that the UV exposition through car or home windows may favor the skin damage with the windows opened, without the presence of glass protection (11–13).

The transmission of radiation decreased with increasing thickness of the glass, but not significantly, thus demonstrating that this variable has little influence on blocking the radiation, in comparison with the other variables analyzed. On the other hand, the color of the glass had a huge influence on the transmission of radiation. The sample of green glass totally blocked the radiation and yellow glass only allowed the passage of 1.3%, which may have occurred because of the properties of the tinting pigments present. In glass manufacturing, colored additives can be used, such as Fe^{3+}, which confers a brownish yellow color, or a mixture of Fe^{3+} and Fe^{2+}, which provides a green color. The Fe^{2+} ion absorbs light in the infrared region, while Fe^{3+} absorbs light in the UV region. Thus, samples containing Fe^{3+} in the tinting pigment are more efficient in diminishing the transmission of UVA (14).

As already demonstrated in other studies, application of a protective film to vehicle window glass gives rise to lower UVA transmission than in the window glass alone (9). The results from the present study demonstrated that the glass with the G50 sunlight control film totally blocked the UVA radiation.

The UVB radiation was totally blocked in the presence of all of the glass samples used, at any distance from the emission source, because its power of penetration is lower than that of UVA (2). It can be affirmed that glass is an excellent filter for this type of radiation, independent of its type, thickness or color.

Furthermore, the distance of the glass from the emission source significantly influenced the quantity of baseline radiation, such that the greater the distance, the lower the irradiation and therefore the lower the transmission of UV through the glass. This may be explained by the huge dissipation of energy that occurs at greater distances under environmental conditions.

Applying the above results to a situation within day-to-day life, the UVB radiation incident on an individual inside a car with closed windows is zero. Even in the case of UVA radiation, the transmission would be insufficient to produce actinic damage, given that not only does the glass block a large proportion of the radiation but also small changes in the distance from the emission source significantly decrease the irradiation.

Therefore, internal environments protected by glass can be considered safe with regard to photoprotection. This observation is also important within the field of occupational medicine, in which the use of glass in vehicles used professionally would be a preventive health measure for workers. Even taking into account the radiation produced by artificial light bulbs within closed environments, such as homes and offices, there is no risk of phototoxicity. Even if these bulbs transmit some quantity of UV radiation, this radiation is blocked by the glass of the light bulb or the lamp itself, along with the distance between the source and the individual.

It can be inferred that window glass may act as a photoprotective agent to prevent skin damage, by blocking the transmission of UV radiation. This conclusion has a positive impact on society, given that this material has a constant presence in day-to-day life because of its versatility. The use of glass within the fields of architecture, civil construction and the car industry implies optimization of care relating to photoprotection.

There is a new type of glass called UV-blocking coated glass (9). It is almost indistinguishable from standard clear glass and blocks $> 98\%$ of UV radiation while transmitting all the visible light. It can be combined with a variety of other glass products, often resulting in nearly complete UV blockage. This show the industry's concern for human health.

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