

Near-Infrared Radiation and Periocular Photoaging: Potential Role of NIR-Filtering Ophthalmic Lenses

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Publication Date: 2026/10/06

Abstract: Near-infrared (NIR) radiation is a part of sunlight that can reach deeper layers of biological tissue. Its possible contribution to skin ageing has gained attention in recent years. NIR exposure can increase tissue temperature and may affect cellular processes linked with oxidative stress, collagen changes and matrix metalloproteinase (MMP) activity. The skin around the eyes is thin and has less protective tissue than many other facial regions, so changes caused by long-term environmental exposure may become noticeable more easily. These changes can include loss of skin firmness, fine lines and alterations in tissue structure. This review focuses on the possible relationship between NIR radiation and ageing of the skin around the eyes. It examines the reported effects of NIR on tissue temperature, oxidative processes, MMP-related activity and collagen-related changes. The review also considers the potential use of NIR-filtering ophthalmic lenses to reduce exposure of the periocular region to selected NIR wavelengths. Absorptive, reflective and hybrid filtering approaches are discussed along with their basic optical mechanisms and practical limitations. NIR attenuation through ophthalmic lenses may offer an additional method of reducing cumulative environmental exposure to the periocular region. However, the available evidence is not sufficient to establish NIR-filtering lenses as a treatment for periocular ageing or infraorbital darkening. Further experimental and clinical studies are needed to determine the extent of NIR-related skin changes and the protective value of NIR-filtering ophthalmic lenses.

Keywords: Near-Infrared Radiation; IR-A; Anti-Ageing Lens; IR-Blocking Lens; Infraorbital Dark Circles; Photo Ageing; Collagen; MMP-1; Ophthalmic Optics.

How to Cite: Rajat Subhra Ghosh; Debprasad Sinha (2026) Near-Infrared Radiation and Periocular Photoaging: Potential Role of NIR-Filtering Ophthalmic Lenses. *International Journal of Innovative Science and Research Technology*, 11(9), 2944-2948. <https://doi.org/10.38124/ijisrt/26sep1437>

I. INTRODUCTION

Solar infrared radiation contributes to the thermal load experienced by ocular tissues. The resulting temperature elevation is determined by the spectral distribution of incident radiation, ocular geometry, and physiological responses such as pupillary constriction and eyelid closure. Protective eyewear with appropriate infrared-attenuating coatings can reduce IR transmission and thereby limit ocular heating. These findings highlight the importance of considering both the thermal characteristics of ocular tissues and the spectral properties of protective lenses when assessing IR-related ocular risk [1]. The biological effects of infrared (IR) radiation on the eye vary with wavelength because ocular tissues exhibit different absorption characteristics. High irradiance or prolonged exposure can increase tissue temperature and induce thermal stress or injury. Hence, controlling exposure conditions and monitoring ocular temperature are important for reducing potential IR-related damage [2]. Among the non-ionizing radiations, infrared (IR) radiation is particularly important because of its ability to

produce thermal effects in ocular tissues. Infrared (IR) radiation occupies the spectral region beginning at approximately 780 nm and extending to about 1 mm. According to the International Commission on Illumination (CIE) classification, IR radiation is subdivided into three spectral bands: IR-A (780–1400 nm), IR-B (1400–3000 nm), and IR-C (3000 nm–1 mm). The cornea, aqueous humour, iris, crystalline lens and retina absorb different proportions of incident IR according to wavelength. Prolonged or intense exposure may result in corneal injury, iris changes, lens opacification and cataract, and retinal thermal injury. Experimental studies have also demonstrated alterations in lens proteins and Na⁺-K⁺ ATPase activity following IR exposure [3,4].

Protection against optical radiation involves a combination of source control, minimization of exposure duration, engineering and administrative controls, and the use of appropriate personal protective equipment. Protective eyewear incorporating wavelength-selective absorbing or reflective filters can further reduce ocular exposure by

attenuating hazardous optical radiation while maintaining adequate visible-light transmission [5]. Reflective metallic coatings have been investigated as an effective approach for reducing the transmission of infrared (IR) radiation through protective eyewear [6]. Modern IR-filtering ophthalmic lenses can selectively attenuate specific infrared wavelengths, thereby reducing IR transmission and associated thermal load on ocular and periocular tissues. Although this provides a potential basis for periocular protection, current evidence does not establish that IR-blocking lenses prevent dark circles or age-related pigmentation. Further clinical studies are needed to determine their long-term protective and anti-ageing effects. [7,8].

Infraorbital dark circles are a common cosmetic concern and are multifactorial. Contributing factors include melanin pigmentation, thin and translucent lower-eyelid skin, visible superficial vasculature, edema, skin laxity, wrinkles,

tear-trough anatomy and shadowing [9]. The lower-eyelid region is particularly relevant to ageing because its delicate skin can make vascular and structural changes more visible.

Although ultraviolet (UV) radiation remains the principal focus of photoprotection, growing evidence suggests that infrared-A (IR-A/NIR) exposure may also contribute to cutaneous ageing through thermal and cellular pathways. Findings from laboratory and in-vivo investigations indicate that IR-A exposure can influence molecular processes associated with skin ageing, including MMP-1 activity, oxidative balance, and collagen homeostasis. [10].

The scientific distinction is important: an IR-blocking lens is an optical protection technology, whereas prevention or treatment of dark circles is a clinical outcome that requires direct human evidence.

II. BIOLOGICAL SIGNIFICANCE OF IR RADIATION

Infrared radiation lies beyond visible red light.

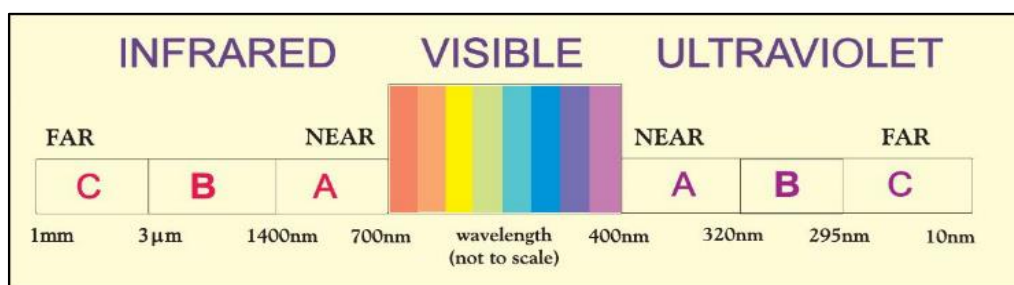


Fig 1 Electromagnetic Spectrum that Affects Eye.

For ophthalmic applications,

➤ 780–1400 Nm: IR-A

This is an important region for retinal thermal hazard because some near-infrared radiation can reach the retina. Retinal thermal hazards are commonly evaluated through approximately 1400 nm.

➤ Approximately 800–3000 nm: Lens Hazard

High IR exposure in this approximate range can heat the crystalline lens. Repeated or sufficiently intense exposure may contribute to lenticular injury and cataract formation.

➤ Approximately 1400 Nm–1 mm: Corneal Hazard

At longer IR wavelengths, absorption by the anterior eye becomes increasingly important. Strong exposure can be absorbed substantially by the cornea and may cause thermal injury at sufficiently high exposure levels.

➤ Biological Mechanism of IR Injury

For sufficiently intense exposure, the dominant mechanism of IR injury is generally photothermal rather than ionizing radiation damage. The sequence is:

IR absorption → molecular energy conversion → heat generation → temperature elevation → protein and cellular alteration → tissue damage.

- IR-A: Near-infrared radiation can penetrate ocular media more effectively than longer-wavelength IR. At sufficiently high exposure, energy may reach deeper structures and produce heating. Experimental work on near-1090-nm radiation supports a predominantly thermal mechanism for NIR-associated cataract under studied conditions.
- IR-B and IR-C: As wavelength increases, absorption by water-rich tissues increases. Longer-wavelength IR is therefore associated more strongly with anterior-eye absorption, particularly in the cornea. Heat may then be transferred toward deeper structures by conduction.

➤ Effect of IR Radiation on Skin

- IR-A has been investigated for its effects on skin ageing. Reported mechanisms include mitochondrial signaling, increased MMP-1 expression, oxidative changes and disruption of collagen homeostasis. MMP-1 is involved in collagen degradation, so persistent increases in this pathway may contribute to deterioration of the dermal extracellular matrix.
- The proposed relationship is: NIR exposure → cellular/mitochondrial signaling → oxidative and molecular stress → MMP-1 elevation → collagen degradation → dermal structural ageing.

- This pathway should be interpreted as a biologically supported mechanism for investigation, not as evidence that every NIR exposure produces clinically visible ageing.

➤ Risk of Ocular Structure

The eye does not transmit all infrared (IR) wavelengths equally. IR exposure can produce mainly thermal effects. The cornea, lens, iris, and retina may be affected depending on wavelength, intensity, and exposure duration.

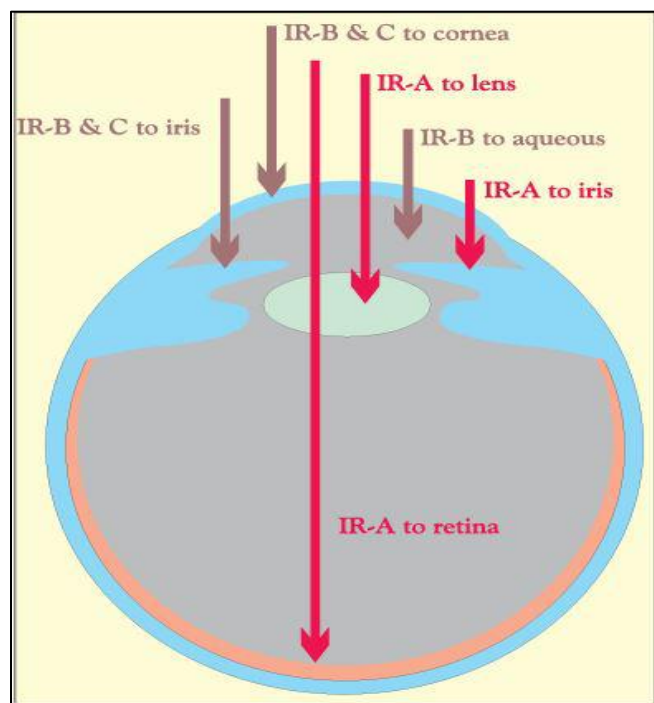


Fig 2 Infrared Radiation Absorbed by the Ocular Tissues [10]

- **Cornea:** The water-rich cornea strongly absorbs long-wavelength IR radiation, converting it into heat and increasing corneal temperature. Excessive or prolonged exposure can impair the corneal epithelium and cause deeper tissue damage. The extent of injury depends on wavelength, intensity, exposure duration, and heat dissipation.
- **Crystalline lens:** The avascular lens has limited heat dissipation capacity. Repeated or intense IR exposure may cause thermal stress and contribute to cataract formation. The effect depends on wavelength, intensity, exposure duration, and thermal conditions.
- **Retina:** Radiation that passes through the eye's anterior media can reach the retina, where ocular focusing concentrates the energy onto a small area. High irradiance or prolonged exposure to visible and near-infrared radiation can therefore cause localized retinal heating and cellular injury. The extent of damage is governed by wavelength, irradiance, exposure time, spot size, and the degree of optical focusing.

➤ IR is Not Uniformly Harmful to the Eye

The ocular effects of infrared (IR) radiation depend strongly on wavelength because different ocular tissues

absorb and transmit IR differently. Near-infrared wavelengths may penetrate the anterior eye and reach the retina, whereas longer wavelengths are absorbed predominantly by the water-rich cornea and other anterior tissues. Consequently, the potential site and type of thermal injury vary across the IR spectrum. Exposure intensity, duration, tissue absorption, and ocular focusing further influence the severity of the biological response. Ocular risk from infrared radiation can be conceptually describe as function of wavelength, irradiance, exposure area, exposed area, and tissue absorption [11].

III. ROLE OF OPHTHALMIC BLOCKING LENS TO PREVENT IR RADIATION

Existing work has reported about different types of ophthalmic lenses to prevent IR. They are given as follows:

➤ Absorptive Filters:

Absorptive IR-blocking lenses incorporate filter materials that selectively absorb targeted infrared wavelengths, converting the absorbed energy predominantly into heat. They offer simple fabrication and broad spectral attenuation; however, excessive absorption can increase lens temperature, reduce visible-light transmission, and limit precise wavelength selectivity [5].

An IR-blocking ophthalmic lens should ideally maintain useful visible transmission while attenuating selected NIR wavelengths. Infrared radiation has wavelengths longer than visible red light:

$$\lambda_{IR} \approx 700 \text{ nm to } 1 \text{ mm}$$

An IR-blocking lens is designed to reduce the transmission of selected infrared wavelengths while allowing an appropriate amount of visible light to pass. Spectral transmission is described by:

$$T(\lambda) = \frac{I_t(\lambda)}{I_i(\lambda)} \quad (1)$$

Where:

$T(\lambda)$ = spectral transmission,
 I_i = incident radiation intensity,
 I_t = transmitted radiation intensity.

For an IR-protective lens:

$$T_{IR} \ll 1$$

This condition applies to the wavelengths that the lens is specifically designed to block. A lower $T(\lambda)$ in the targeted NIR band represents stronger attenuation. Absorptive filtering uses materials incorporated into the lens substrate. Materials described in the supplied technical material include copper-, iron- and cobalt-containing glasses, rare-earth-doped glasses, and IR-absorbing polymers or dyes.

➤ *Common Materials Used*

Table 1 Tabular Literature Summaries the Available Materials and their Main Optical Properties.

Material	Optical Property
Special optical glasses containing metal ions	Selective absorption of IR/near-IR
Copper containing glass	Strong absorption in portions of the near-IR
Iron containing glass	Absorbs portions of IR and visible spectrum
Cobalt containing glass	Selective spectral absorption
Rare-earth doped glasses (e.g., neodymium)	Narrower, wavelength-dependent absorption bands
IR absorbing polymers	Used in some plastic optical filters

Their behaviour can be represented by the Beer–Lambert relationship:

$$I = I_0 e^{-\alpha d} \quad (2)$$

Where:

I_0 = incident intensity,

I = transmitted intensity,

α = absorption coefficient,

d = filter thickness.

Absorbed optical energy is converted predominantly into thermal energy.

➤ *Reflective/Interference IR Filters:*

A reflective interference filter attenuates IR transmission primarily by reflecting selected wavelengths. These filters employ multilayer dielectric coatings composed of materials with contrasting refractive indices. Appropriate control of layer thickness and refractive index produces wavelength-selective reflection of IR radiation while maintaining transmission of the required visible spectrum [6]. A reflective IR filter uses a stack of thin dielectric films with different refractive indices to control the passage of radiation through the filter. When visible and infrared radiation strikes this layered structure, part of the radiation is reflected at each film boundary. The thickness and refractive index of the individual layers are selected so that the reflected components associated with the specified IR range reinforce one another. This produces high reflectance within the targeted infrared band. Radiation in the visible region, for which the interference condition is different, can pass through the coating with comparatively high transmission. Thus, the filter suppresses the transmission of selected infrared wavelengths primarily through reflection, reducing the amount of IR radiation that reaches the eye [12]. For a layer designed around wavelength λ_0 ,

$$n_i d_i \approx \frac{\lambda_0}{4}$$

Where n_i is the refractive index and d_i is the physical thickness of the layer.

At the interface, partial reflected waves are generated. For the wavelengths targeted for rejection, the layer thicknesses are designed so that these reflected waves combine constructively, increasing reflectance.

Consequently,

$$R_{IR} \uparrow \Rightarrow T_{IR} \downarrow$$

While the coating can simultaneously be designed for high transmission in the desired spectral region. Interference filters therefore produce wavelength-dependent reflection and transmission rather than relying primarily on absorption.

➤ *Hybrid Filters:*

A hybrid protective lens brings together different optical materials or coatings within a single lens. The filtering elements can be selected to reduce particular portions of the ultraviolet and infrared regions, while allowing most of the useful visible light to pass. IR control may involve both reflection from thin-film coatings and absorption within suitable lens materials. An anti-reflective treatment can be added to improve the transmission characteristics of the lens surface, and a hard coating can protect the optical structure from scratches and wear. The final spectral response depends on the materials, layer arrangement, thickness, and optical properties chosen for the lens [5,7].

➤ *IR Blocking should Not be Claimed to Cure Dark Circles*

Infraorbital dark circles are multifactorial. Pigmentation, vascular visibility, thin skin, edema, tear-trough anatomy, fat redistribution, wrinkles, laxity and shadowing can all contribute. Therefore, dark circles cannot be attributed to NIR exposure alone.

IR filtering could theoretically address environmental photo ageing, but it cannot be expected to correct anatomical tear-trough changes, established pigmentation, vascular prominence or orbital volume changes. A scientifically appropriate claim is therefore potential reduction of IR-associated periocular photo ageing,” rather than “prevention or cure of dark circles [10, 14, 15].

IV. CONCLUSION

Anti-ageing NIR-blocking ophthalmic lenses represent a promising photoprotective concept based on established principles of optical filtering. Their ability to selectively attenuate specific near-infrared wavelengths while maintaining useful visible-light transmission is beneficial. Apart from that, different possibilities for controlling spectral attenuation, thermal behaviour, optical transmission, and coating durability make NIR-blocking lenses a potentially useful non-invasive strategy for reducing environmental infrared exposure to ocular and periocular tissues.

➤ *The care must be taken for:*

- Absorptive filters may convert absorbed infrared energy into heat and may compromise visible transmission or colour neutrality when strong attenuation is required.
- Reflective and interference filters can provide greater spectral selectivity but may exhibit angle-dependent performance and dependence on coating durability and manufacturing precision.
- In addition, blocking selected NIR wavelengths does not necessarily eliminate exposure to the entire infrared spectrum.
- Most importantly, infraorbital dark circles are multifactorial and may result from pigmentation, vascular visibility, thin skin, edema, tear-trough anatomy, wrinkles, laxity, fat redistribution and shadowing. Therefore, NIR blocking should not currently be considered as a treatment or cure for dark circles.

Although experimental and biological evidence provides a justification involving oxidative stress, mitochondrial signaling, MMP-1 expression and collagen homeostasis. The transition from these molecular mechanisms to a measurable long-term clinical benefit is a big challenge.

Future research should therefore move beyond demonstrating that a lens blocks NIR and should determine whether a quantified reduction in NIR exposure produces a reproducible clinical benefit.

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