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Photoprotection beyond Ultraviolet Radiation – Effective Sun Protection Has to Include Protection against Infrared A Radiation-Induced Skin Damage

P. Schroeder C. Calles T. Benesova F. Macaluso J. Krutmann

Institut für umweltmedizinische Forschung (IUF) an der Heinrich-Heine-Universität Düsseldorf gGmbH, Düsseldorf, Deutschland

Key Words
Solar radiation · Infrared A radiation · Skin ageing · Photoageing

Abstract
Solar radiation is well known to damage human skin, for example by causing premature skin ageing (i.e. photoageing). We have recently learned that this damage does not result from ultraviolet (UV) radiation alone, but also from longer wavelengths, in particular near-infrared radiation (IRA radiation, 760–1,440 nm). IRA radiation accounts for more than one third of the solar energy that reaches human skin. While infrared radiation of longer wavelengths (IRB and IRC) does not penetrate deeply into the skin, more than 65% of the shorter wavelength (IRA) reaches the dermis. IRA radiation has been demonstrated to alter the collagen equilibrium of the dermal extracellular matrix in at least two ways: (a) by leading to an increased expression of the collagen-degrading enzyme matrix metalloproteinase 1, and (b) by decreasing the de novo synthesis of the collagen itself. IRA radiation exposure therefore induces similar biological effects to UV radiation, but the underlying mechanisms are substantially different, specifically, the cellular response to IRA irradiation involves the mitochondrial electron transport chain. Effective sun protection requires specific strategies to prevent IRA radiation-induced skin damage.

Physics of Infrared Radiation, Natural and Artificial Sources, Experimental Infrared A Irradiation Doses

Solar radiation is filtered by the atmosphere and when it finally hits human skin, it includes photons of 290–4,000 nm in wavelength. This portion of the electromagnetic spectrum is divided into three major bands: ultraviolet (UV) radiation (290–400 nm), visible light (400–760 nm) and infrared (IR) radiation (760–4,000 nm), with IR radiation being further divided into IRA (760–1,440 nm), IRB (1,440–3,000 nm) and IRC (3,000–1 mm).

Concerning the impact of the three major bands, approximately 54% of the solar energy reaching the human skin is IR radiation, while UV radiation only accounts for 7% of the energy [1]. Within IR radiation, roughly 30% of the total solar energy is IRA which penetrates deeply into the human skin [1].

Most of the IRA radiation load of human skin is of solar origin, but in recent years artificial IRA sources are used increasingly. Besides therapeutic approaches the use of IRA for nontherapeutic, i.e., wellness and lifestyle, purposes is steadily rising [2].

The question which IRA doses are of physiological relevance has been addressed in a recent discussion [3]; therefore, some facts on that matter will be presented here as well.

Human dermal fibroblasts withstand IRA doses up to at least 1,200 J/cm^2 [4]; the gene-regulatory effects can

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Peter Schroeder
Institut für umweltmedizinische Forschung (IUF)
an der Heinrich-Heine-Universität Düsseldorf gGmbH
Auf'm Hennekamp 50, DE–40225 Düsseldorf (Germany)
Tel. +49 211 338 9240, Fax +49 211 319 0910, E-Mail peet@gmx.de

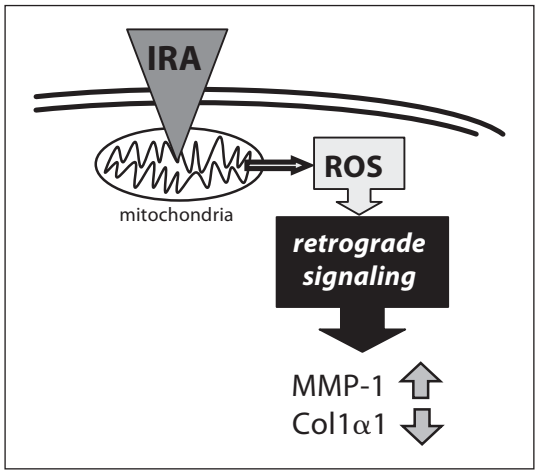

Fig. 1. IRA irradiation leads to increased formation of mitochondrial ROS and in turn to activation of retrograde signaling pathways from the mitochondria to the nucleus. It results in a disturbance of the dermal collagen equilibrium by increased collagen degradation by MMP-1 and decreased collagen de novo synthesis.

already be observed at much lower doses, e.g. 54 J/cm^2 [5], 240 J/cm^2 [6], or 360 J/cm^2 [7]. Increased levels of cytosolic and mitochondrial reactive oxygen species (ROS) were detected even after treatment with 30 J/cm^2 [7].

A dose of 300–800 J/cm^2 can be obtained during a summer day in central Europe [8].

Detrimental Effects of IRA Radiation and Underlying Molecular Mechanisms

One of the most prominent detrimental effects of sunlight exposure is sun-induced premature skin ageing.

The term photoageing refers to changes in the skin that superimpose the alterations of chronological ageing. Clinically, photoageing is associated with several macroscopic and functional changes, e.g. the formation of coarse wrinkles, uneven skin pigmentation, loss of elasticity and disturbance of skin barrier functions [9]. Among the radiation bands, UVA (λ = 320–400 nm) and UVB (λ = 280–320 nm) have long been in the focus, but results obtained during the last few years emphasize the role of IRA (760–1,440 nm) in photoageing of the skin [4, 7, 10–12], which has first been described more than 25 years ago [13]. UVA, UVB and IRA all penetrate into the skin, with UVB being mainly absorbed in the epidermis, while UVA reaches the epidermis and dermis [9]. IRA penetrates deeply into the skin and reaches even the subcutis; approximately half of the IRA is absorbed in the dermis [14].

Schieke et al. [4] assessed the molecular basis of IRA-induced photoageing of the skin. This study was the first to report that physiological doses of IRA lead to a disturbance of the dermal extracellular matrix by upregulation of the dominant collagen-degrading enzyme, matrix metalloproteinase 1 (MMP-1), on the level of mRNA, protein and enzyme activity. This finding has since been confirmed in independent studies by different laboratories in vivo and in vitro [11, 12].

Recently, it has also been demonstrated that IRA exposure leads to a downregulation of collagen de novo synthesis [6]. Thus, the biological endpoints of IRA exposure, at least with regard to the collagen equilibrium of the skin, are similar to the outcome of UV exposure, but the underlying mechanisms are not the same.

The IRA-induced upregulation of MMP-1 was found to differ substantially from that induced by UV radiation at the mechanistic level [2, 7] since it utilizes mitochondrial ROS as the initiating event to alter transcription and translation of the MMP-1 gene via activation of the MAP kinases ERK1/2 (fig. 1) [4, 7]. The formation of ROS due to IRA could be confirmed by electron spin resonance spectroscopy in skin biopsies [15].

The influence of IRA on the mitochondria was suggested by the finding that components of the mitochondrial respiratory chain absorb IRA [16].

This might in turn cause a disruption of the mitochondrial electron flow, which results in an increased production of mitochondrial ROS. This disruption of the mitochondrial function has been shown to trigger retrograde signaling processes eventually regulating nuclear gene expression [17]. Mitochondrial ROS generation induced by IRA is highly specific compared to UV radiation: UVA- or UVB-induced increased expression of MMP-1 remains unaffected by the use of antioxidants which specifically target the mitochondria or by the manipulation of the function or mass of mitochondrial respiratory chain components, while the IRA response is significantly altered by these strategies [7].

Beyond its role in premature skin ageing, IRA has been reported to interfere with apoptotic pathways, preventing UV-damaged cells from executing programmed cell death, which indicates a co-carcinogenic potential of IRA [18, 19]. This suspicion is further supported by findings that IRA alters the carcinogenic potential of UVB [19, 20].

The omnipresence of IRA, its biological effects, biophysical properties and the fact that it acts differently from UV point to the necessity for a complete sunscreen to include specific IRA-directed strategies.

Protection Strategies against IRA

Obvious approaches against IRA radiation would be the use of chemical or physical filters, but currently there are no specific chemical or physical filters available against IRA and existing compounds have not been shown to possess IRA-filtering capacity. While it is unlikely that UV-specific filters work against IRA, physical filters might provide protection. It should be noted, however, that filters reflecting IRA (e.g. titanium dioxide) might raise cosmetic issues as may the color of the skin. Controlled studies determining the effectiveness of UV filters in IRA protection are currently not available.

An alternative approach is the use of antioxidants, especially mitochondrially targeted antioxidants. Accordingly, it has been demonstrated that N-acetylcysteine, MitoQ, ascorbic acid and some flavonoids provide effective protection against IRA-induced upregulation of MMP-1 in vitro [7, 12]. In vivo, topical application of a sunscreen containing such antioxidants prior to IRA treatment abrogates the IRA-induced detrimental shift in dermal gene expression [12].

Conclusions

Several independent studies carried out during the last few years clearly show that IRA radiation can damage skin. Therefore, effective sun protection should not exclusively focus on UV but also include protection against IRA.

IRA photoprotection requires specific strategies, because existing UV protective measures ignore the problem. An effective, feasible approach is the topical application of mitochondrially targeted antioxidants.

Additionally, unnecessary exposure to IRA radiation from artificial irradiation devices should be avoided.

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