

## CONCISE REPORTS

## Fluorescent light activates the immunomodulator *cis*-urocanic acid in vitro: implications for patients with systemic lupus erythematosus

Hugh McGrath Jr, Janelle M Bell, John W Haycock

### Abstract

**Objective**—Erythemagenic (295–305 nm) ultraviolet-B (UVB) radiation is toxic to patients with systemic lupus erythematosus (SLE). Cool white fluorescent lamp emissions produce a similar toxicity even though the UVB radiation emitted is primarily at the relatively non-erythemagenic wavelength of 313 nm. The purpose of this study was to determine if fluorescent light, presumably acting predominantly along the 313 nm wavelength, exhibits photochemical activity sufficient to account for toxicity.

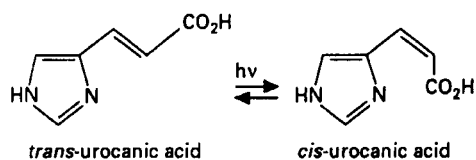
**Methods**—The photochemical activity of fluorescent light was assessed by testing its capacity to activate urocanic acid, a plentiful and potent epidermal immunological mediator normally activated by polychromatic UVB radiation but activated maximally at 313 nm. Irradiation-induced isomerisation of *trans*-urocanic to *cis*-urocanic acid was quantitated by UV spectroscopy after separation of the isomers by high performance liquid chromatography.

**Results**—Fluorescent light irradiation of solutions containing the photoreceptor *trans*-urocanic acid produced a cumulative conversion of *trans*- to *cis*-urocanic acid. This photochemical activity was compared with that of erythemagenic sunlamps, high in polychromatic UVB irradiance, the accumulation of *cis*-urocanic acid produced by both light sources was essentially equivalent. Conventional acrylic diffusers that absorb UVB emissions eliminated the fluorescent light-induced reaction.

**Conclusion**—The results indicate that radiation from fluorescent lamps possesses substantial photoimmunological capability, sufficient to activate a potent, potentially dangerous, disease-modifying, immunomodulatory pathway and that poorly erythemagenic, primarily monochromatic UVB photons are responsible.

triggered by erythemagenic (295–305 nm) ultraviolet-B (UVB; 280–320 nm) wavelengths,<sup>2</sup> even though the UVB emitted by fluorescent lamps is primarily at the relatively non-erythemagenic wavelength of 313 nm.<sup>3</sup> The purpose of this study was to determine if fluorescent light, presumably acting predominantly along the 313 nm wavelength, exhibits photochemical activity sufficient to generate toxicity. We assessed the photochemical activity of fluorescent light by testing its capacity to activate urocanic acid, a plentiful and potent epidermal immunological mediator<sup>4</sup> normally activated by polychromatic UVB radiation but activated maximally at 313 nm.<sup>5</sup> Although used here for testing photochemical potential, activation of the urocanic acid pathway in vivo would itself have ample potential for affecting SLE, a disease of immune dysregulation.

The *trans* isomer of urocanic acid is a naturally occurring photoreceptor in epidermis and comprises up to 1% of human epidermis dry weight.<sup>4</sup> Interaction of *trans*-urocanic acid with UVB and ultraviolet-A2 (320–340 nm) photons results in its isomerisation in vivo to *cis*-urocanic acid:



*cis*-urocanic acid is a physiological immunomodulator that mimics in vivo many of the immunosuppressive actions of UVB, down-regulating local and systemic cell-mediated immune responses to antigens.<sup>4</sup>

UVB radiation, whether delivered at high intensity from polychromatic sunlamps or at low intensity from cool white fluorescent lamps, produced an equivalent conversion of *trans*- to *cis* urocanic acid in vitro. Commercial acrylic diffusers, used widely for primarily aesthetic purposes, were found to virtually eliminate the isomerisation of urocanic acid by fluorescent lamps.

### Methods

#### PHOTOMETRY

UVB radiation was measured with an SEE 240 UVB probe and a wide-eyed diffuser (International Light, Newburyport, MA) con-

Section of  
Rheumatology,  
Department of  
Medicine,  
Louisiana State  
University Medical  
Center,  
New Orleans,  
LA 70112, USA  
H McGrath Jr  
J M Bell

Department of  
Biochemistry and  
Molecular Biology,  
Louisiana State  
University Medical  
Center,  
New Orleans,  
Louisiana, USA  
J W Haycock

Correspondence to:  
Dr Hugh McGrath Jr,  
Section of Rheumatology,  
Department of Medicine,  
LSU Medical Center,  
1542 Tulane Ave.,  
New Orleans,  
LA 70112, USA.

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Cool white fluorescent lamp emissions produce in patients with systemic lupus erythematosus (SLE)<sup>1</sup> a toxicity similar to that

sisting of an SCS sharp-cut UVB-1 filter (response from 245 to 320 nm and 10% points at 240 and 320 nm) atop an SEE 240 solar blind vacuum photodiode. Ultraviolet A (UVA; 320–400 nm) radiation was measured with an SEE 015 photodetector and a wide-eyed quartz diffuser fitted with a UVA filter (320–400 nm; 360 nm peak response). Visible light was determined by a Gossen Luna Pro lightmeter (Calumet, Bensenville, IL).

#### LIGHT SOURCES

The cool white fluorescent light source was a panel of four F40 lamps (American Philips Lighting, Highstown, NJ). At a distance of 12 cm, this source delivered 4.1  $\mu\text{W}/\text{cm}^2$  of UVB radiation and 30  $\mu\text{W}/\text{cm}^2$  of UVA radiation. The calculated UVB dose was 0.12  $\text{J}/\text{cm}^2$  at 8 hours, 0.35  $\text{J}/\text{cm}^2$  at 24 hours, and 0.71  $\text{J}/\text{cm}^2$  at 48 hours. [Note: The minimal erythematous dose of UVB irradiance, calculated from wavelengths in the peak erythematous range of 295–305 nm, is 0.05  $\text{J}/\text{cm}^2$  for lightly to moderately pigmented white, or type II, skin.<sup>6</sup>]

High-intensity UVB radiation was provided by a panel of seven FS20 sunlamps (White-Westinghouse, Dublin, OH). At a distance of 25 cm this source delivered 430  $\mu\text{W}/\text{cm}^2$  of UVB and 380  $\mu\text{W}/\text{cm}^2$  of UVA radiation. The calculated UVB dose was 0.026  $\text{J}/\text{cm}^2$  at one minute, 0.26  $\text{J}/\text{cm}^2$  at 10 minutes and 0.77  $\text{J}/\text{cm}^2$  at 30 minutes.

#### UROCANIC ACID SOLUTIONS

A stock solution of *trans*-urocanic acid (Sigma Chemical Co; 5 mg/ml in dimethylsulfoxide) was made at the beginning of every experiment. Mixtures of *cis*- and *trans*-urocanic acid were prepared by irradiating 5 ml of *trans*-urocanic acid in a 60 mm diameter dish (Falcon 3002, Becton Dickinson, Lincoln Park, NJ) with the sunlamps at a distance of 25 cm. Irradiation for 15 and 90 minutes resulted in mixtures containing 22% and 61% *cis*-urocanic acid, respectively.

#### QUANTITATION OF UROCANIC ACID ISOMERS

The urocanic acid isomers were separated by high performance liquid chromatography. Samples were applied to a C18 column (4.7  $\times$  150 mm, Vydac TP218-5415) equilibrated in 0.1% trifluoroacetic acid and eluted with the same solution at 1 ml/minute. Absorbance at 277 nm was monitored on-line with a Gilson Holochrome detector, and integrals of the absorbance peaks were computed (Radiomatic Flo-One/Beta software). Separation of the urocanic acid isomers is illustrated in fig 1.

Samples were diluted sufficiently to ensure that absorbances were linear with respect to concentration (verified by dilution and standard curves). The validity of  $\text{OD}_{277}$  as a measure of both *cis*- and *trans*-urocanic acid is supported by the observation that (*cis* + *trans*) values were equal to the value for *trans*-

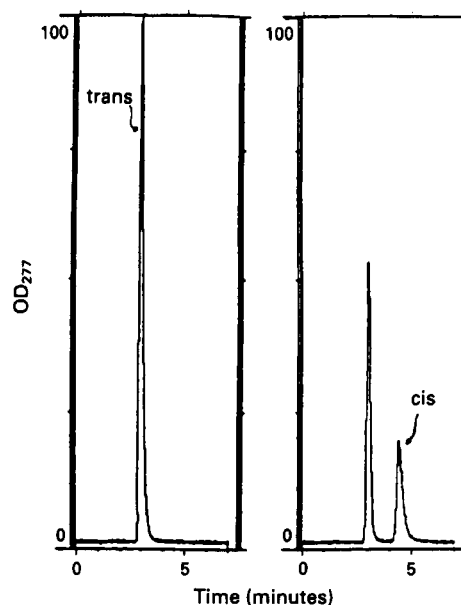


Figure 1 Separation of urocanic acid isomers by reverse-phase high-performance liquid chromatography. Aliquots from a solution of *trans*-urocanic acid were taken before (left panel) and after (right panel) fluorescent lamp irradiation and then chromatographed, as described under Methods. Chromatographs were developed isocratically with 0.1% trifluoroacetic acid at 1 ml/minute, and the UV absorbance at 277 nm was monitored on-line. The peak retention times of the isomers differed by 1.6 minutes.

urocanic acid in non-irradiated samples (fig 1).

#### IRRADIATION

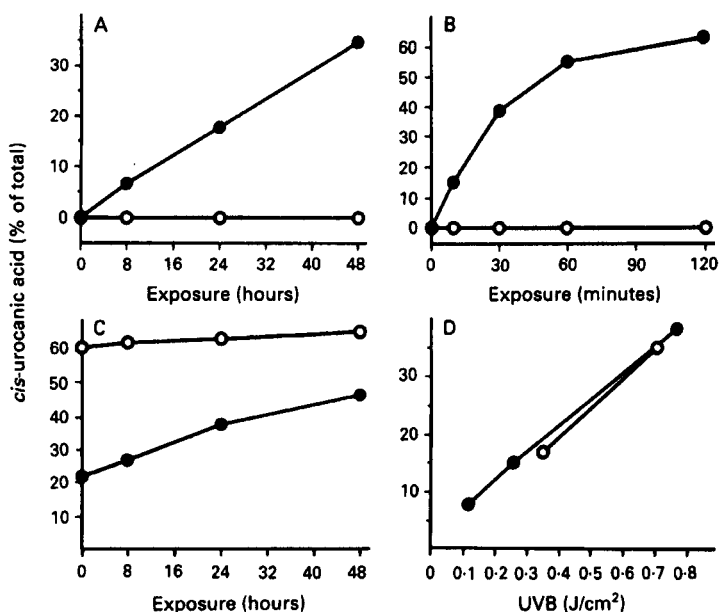
Samples of urocanic acid (5 mg/ml) in uncovered petri dishes containing 0%, 22% and 61% *cis*-urocanic acid (see above) were exposed to the panel of fluorescent lamps at a distance of 12 cm for 0, 8, 24 and 48 hours at room temperature (26°C). Samples of *trans*-urocanic acid (5 mg/ml) were exposed to the panel of sunlamps at a distance of 25 cm for 10, 30, 60 and 120 minutes. Controls included (1) samples of the urocanic acid mixtures placed adjacent to the lamps but kept in the dark and (2) irradiated and non-irradiated dimethyl sulfoxide (no urocanic acid).

In one series of experiments, the fluorescent lamps were covered with a fine-mesh acrylic diffuser, a coarse-mesh acrylic diffuser or a sheet of polyester to decrease UVB emissions, and samples were irradiated for 48 hours as above.

## Results

#### ISOMERISATION OF *TRANS*- TO *CIS*-UROCANIC ACID

Irradiation of *trans*-urocanic acid solutions with the panel of fluorescent lamps produced a time-dependent isomerisation of *trans*- to *cis*-urocanic acid (fig 2A, solid circles). After 48 hours of exposure to the fluorescent lamps, *cis*-urocanic acid accounted for 34% of total urocanic acid. During this period no spontaneous isomerisation was observed (open circles), and the total amount of urocanic



**Figure 2** Isomerisation of *trans*-urocanic acid by fluorescent light. (A) *trans*-urocanic acid solutions were exposed to the panel of F40 fluorescent lamps at a distance of 12 cm for up to 48 hours (solid circles). Matched control samples (open circles) were kept in the dark. Levels of the urocanic acid isomers were quantitated spectrophotometrically after chromatographic separation, as shown in fig 1. Values represent the average of three independent determinations. Standard deviations were less than 15% of the mean. (B) *trans*-urocanic acid solutions were exposed at a distance of 25 cm from the panel of FS20 sunlamps for up to 120 minutes (solid circles). Matched control samples (open circles) were kept in the dark. Other details were as in A. (C) *trans*-urocanic acid solutions were pre-irradiated as described under Methods to produce samples having different initial *cis*:*trans* ratios (open circles, 61%; solid circles, 22%) and then irradiated with fluorescent lamps as in A. (D) values of *cis*-urocanic acid production from A (open circles; fluorescent lamp irradiation) and B (solid circles, sunlamp irradiation) have been replotted as a function of the calculated UVB irradiance of the exposure.

acid remained unchanged (not presented). Irradiation of similar samples with the panel of sunlamps produced a much more rapid increase in *cis*-urocanic acid (fig 2B). The isomerisation produced by irradiation with either type of lamp was stable for at least 48 hours post-irradiation, irrespective of the duration of exposure (not presented).

The net conversion of *trans*- to *cis*-urocanic acid produced by exposure to the sunlamps had reached approximately 65% after 120 minutes of irradiation. This appeared to represent the maximal photostationary state because additional irradiation failed to further increase *cis*-urocanic acid levels (see also below). In contrast, the apparent rate of isomerisation of *trans*- to *cis*-urocanic acid produced by irradiation with fluorescent lamps was relatively constant over the duration of exposure, and the percentage of *cis*-urocanic acid (34%) achieved after 48 hours was much lower than that achieved with the sunlamps. This percentage of *cis*-urocanic acid after 48 hours of

fluorescent lamp irradiation is well within the range of values (15–40%) reported for normal human epidermis *in vivo*.<sup>7</sup> An additional 48 hours of fluorescent light increased *cis*-urocanic acid in previously irradiated samples from 22% to 46%, demonstrating that normal *in vivo* levels could be exceeded, and from 61% to 65%, indicating that the same apparent steady-state *cis* to *trans* ratios were reached by fluorescent lamp and high-intensity UVB irradiation (fig 2C).

#### UVB-DEPENDENCE OF *TRANS*- TO *CIS*-UROCANIC ACID ISOMERISATION

Despite a difference of over two orders of magnitude in the intensities of UVB emissions from the fluorescent lamps versus sunlamps, a UVB-dependent mechanism appeared to underlie the isomerisation of *trans*- to *cis*-urocanic acid produced by either light source. As illustrated in fig 2D, *trans*- to *cis*-urocanic acid isomerisation was essentially identical when expressed as a function of UVB irradiance, irrespective of the light source. Moreover, filters that decreased UVB fluences by >90% decreased isomerisation of *trans*- to *cis*-urocanic acid almost equivalently (table). A decrease in the ultraviolet-A2 wavelengths may have contributed marginally to the decrease in isomerisation since wavelengths up to 330 nm are absorbed by urocanic acid.<sup>3</sup>

#### Discussion

While sunlight, which contains all the UVB wavelengths, is obviously capable of activating the urocanic acid pathway, the present results indicate that prolonged exposure to the discontinuous spectrum of emissions from fluorescent lamps does so as well. Cool white fluorescent lamp emissions produced a cumulative *trans/cis* isomerisation of urocanic acid *in vitro*, resulting in *cis* to *trans* ratios exceeding the normal *in vivo* range and, when expressed as a function of UVB irradiance, quantitatively equivalent to that produced by the high-intensity polychromatic spectrum of UVB wavelengths emitted by sunlamps. Standard commercial filters that absorbed UVB blocked the isomerisation, indicating that UVB wavelengths were responsible.

The capacity of fluorescent light, which is essentially non-erythemagenic, to isomerise urocanic acid results from the unique spectrum of emissions of white fluorescent lamps and from the action spectrum of *cis*-urocanic acid production. Approximately 90% of the UVB emissions from fluorescent lamps come from the mercury line at 313 nm, while ≈10% comes from the line at 302 nm.<sup>8</sup> Whereas the action spectrum for *trans* to *cis* isomerisation of urocanic acid is maximal at 313 nm,<sup>5</sup> that for erythemagenicity, DNA absorption, (qualities previously considered critical to toxicity in SLE),<sup>2,9</sup> and tanning, peaks at 300 nm which represents only a minor portion of the fluorescent lamp emission.<sup>9,6</sup> The present results not only indicate that fluorescent light has telling photochemical activity, but point to

**Effects of filters on the isomerisation of *trans*- to *cis*-urocanic acid produced by 48 hours of fluorescent light irradiation.**

Filter	UV Light transmitted				Isomerisation <i>cis</i> -urocanic acid (% of total)
	UVB		UVA		
	J/cm <sup>2</sup>	%	J/cm <sup>2</sup>	%	
None	0.71	100	5.2	100	37
Acrylic diffuser (fine)	0.04	5	3.5	67	5
Acrylic diffuser (coarse)	0.04	5	1.6	30	3
Polyester sheet	0.06	8	4.4	84	7

a pathway along which this light source may be eliciting toxicity in SLE and suggest that UVB toxicity need not be intrinsically linked with the propensity of UVB photons to induce erythema or be absorbed by DNA. A dissociation between erythema and other UV-mediated dermal events is supported by the observation that sunscreens, although protective against the erythemagenic and carcinogenic effects of UVB, fail to retard the suppression of contact hypersensitivity.<sup>10</sup>

As to a possible role for cis urocanic acid itself in fluorescent light-induced toxicity, it would seem that suppression by cis urocanic acid of cell mediated immunity may well be harmful to patients with SLE in whom cell mediated immunity is already impaired.<sup>11</sup> Moreover, recent studies disclose that cis-urocanic acid mediates this suppression by increasing levels of tumour necrosis factor- $\alpha$ ,<sup>12</sup> a cytokine shown to produce tissue damage in animals and humans with SLE.<sup>13</sup> Also of possible harm is the potent suppression of natural killer cells in vivo by ultraviolet wavelengths of 313–315 nm, an action that may be mediated by urocanic acid.<sup>14</sup> Natural killer cells downregulate immunoglobulin secretion and are already functionally impaired in SLE.<sup>15</sup>

The potential relevance of the present in vitro findings to in vivo events is underscored by the fact that isomerisation of trans- to cis-urocanic acid in vivo actually requires less photon energy than isomerisation in vitro.<sup>7</sup> For example, 600 mJ of UVB radiation was required from either light source to increase the content of cis-urocanic acid from 0% to 30%, and even greater amounts were required to increase the amount from 30% to 60%. By contrast, 32 mJ of UVB elevated cis-urocanic acid levels to 60% in human skin and 96 mJ of UV increased dermal levels in mice from 4% to 31%.<sup>6</sup> Thus the levels of fluorescent lamp UVB emissions shown to be capable of isomerising urocanic acid in the present in vitro studies are predicted to be at least as, if not more, effective in activating urocanic acid in vivo.

In summary, non-ionising radiation from fluorescent lamps possesses substantial photo-immunological activity, sufficient to activate a potent in vivo immunomodulatory pathway, potentially dangerous to patients with SLE.

Essentially monochromatic poorly erythemagenic 313 nm UVB photons appear to be responsible. The findings offer some basis for the reported noxiousness of fluorescent light in SLE.<sup>1</sup> The failure of fluorescent lamp emissions to elicit the erythema that typically signals toxicity in SLE makes exposure to this light source somewhat insidious. Fortunately, acrylic diffusers, commonly used for aesthetic purposes, effectively eliminate these UVB emissions and should offer protection from whatever noxious actions these emissions and the trans/cis isomerisation of urocanic acid produce.

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- Rihner M, McGrath H Jr. Fluorescent light photosensitivity in patients with systemic lupus erythematosus. *Arthritis Rheum* 1992; 35: 949–52.
- Rothfield N F. Systemic lupus erythematosus: clinical and laboratory aspects. In: D J McCarty, ed. *Arthritis and allied conditions*, 9th ed. Philadelphia, Lea and Febiger, 1979.
- Cole C, Forbes P D, Davies R E, Urbach F. Effect of indoor lighting on skin. In *The Medical and Biological Effects of Light*. *Ann NY Acad Sci* 1985; 453: 305–27.
- Norval M T, Simson T J, Ross J A. Urocanic acid and immunosuppression. *Photochem Photobiol* 1989; 50: 267–75.
- Gibbs N K, Norval M, Traynor N J, Wolf M, Johnson B E, Crosby J. Action spectra for the trans to cis photoisomerization of urocanic acid in vitro and in mouse skin. *Photochem Photobiol* 1993; 57: 584–90.
- Parrish J A, Jaenicke K F, Anderson R R. Erythema and melanogenesis action spectra of normal human skin. *Photochem Photobiol* 1982; 36: 187–91.
- Norval M, McIntyre C R, Simpson T J, Howie M, Bardshiri E. Quantification of urocanic acid isomers in human stratum corneum. *Photodermatol* 1988; 5: 179–86.
- Kobza A, Ramsey C A, Magnus I A. Photosensitivity due to the 'sunburn' ultraviolet content of white fluorescent lamps. *Br J Dermatol* 1973; 39: 351–9.
- Tan E M, Freeman R G, Stoughton R B. Action spectrum of ultraviolet light-induced damage to nuclear DNA in vivo. *J Invest Dermatol* 1970; 55: 439–43.
- Fisher M S, Menter J M, Willis I. Ultraviolet radiation induced suppression of contact hypersensitivity in relation to Padimate O and oxybenzone. *J Invest Dermatol* 1989; 92: 337–41.
- Horowitz D A. Impaired delayed type hypersensitivity in systemic lupus erythematosus. *Arthritis Rheum* 1972; 15: 353–9.
- Streilein J W. Sunlight and skin-associated lymphoid tissues (SALT): If UVB is the trigger and TNF $\alpha$  is its mediator, what is the message? *J Invest Dermatol* 1993; 100: 47S–52S.
- Deguchi Y, Kishimoto S. Tumour necrosis factor/cachectin plays a key role in autoimmune pulmonary inflammation in lupus-prone mice. *Clin Exp Immunol* 1991; 85: 392–5.
- Gilmore J W, Vestys J P, George S, Norval M. Effect of phototherapy and urocanic acid isomers on natural killer cell function. *J Invest Dermatol* 1993; 101: 169–73.
- Sibbett W L Jr, Likar L, Spellman C W, Bankhurst A D. Impaired natural killer cell function in systemic lupus erythematosus. Relationship to interleukin-2 production. *Arthritis Rheum* 1983; 26: 1316.