Report

Ultraviolet radiation properties as applied to photoclimatherapy at the Dead Sea

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Abstract

Background The Dead Sea basin, the lowest terrestrial point on earth, is recognized as a natural treatment center for patients with various cutaneous and rheumatic diseases. Psoriasis is the major skin disease treated at the Dead Sea with excellent improvement to complete clearance exceeding 85% after 4 weeks of treatment. These results were postulated to be associated with a unique spectrum of ultraviolet radiation present in the Dead Sea area.

Methods The UVB and UVA radiation at two sites is measured continuously by identical sets of broad-band Solar Light Co. Inc. meters (Philadelphia, PA). The spectral selectivity within the UVB and UVA spectrum was determined using a narrow-band spectroradiometer, UV-Optronics 742 (Orlando, FL). The optimum exposure time intervals for photoclimatherapy, defined as the minimum ratio of erythema to therapeutic radiation intensities, were also determined using a Solar Light Co. Inc. Microtops II, Ozone Monitor-Sunphotometer.

Results The ultraviolet radiation at the Dead Sea is attenuated relative to Beer Sheva as a result of the increased optical path length and consequent enhanced scattering. The UVB radiation is attenuated to a greater extent than UVA and the shorter erythema UVB spectral range decreased significantly compared with the longer therapeutic UVB wavelengths.

Conclusions It was demonstrated that the relative attenuation within the UVB spectral range is greatest for the shorter erythema rays and less for the longer therapeutic UVB wavelengths, thus producing a greater proportion of the longer therapeutic UVB wavelengths in the ultraviolet spectrum. These measurements can be utilized to minimize the exposure to solar radiation by correlating the cumulative UVB radiation dose to treatment efficacy and by formulating a patient sun exposure treatment protocol for Dead Sea photoclimatherapy.

Introduction

The Dead Sea, a salt lake located between the Judean mountains in Israel and the Moab mountains in Jordan, is one of the saltiest bodies of water known, with 345 g mineral salts per liter.[1,2] It is situated at the lowest terrestrial point on earth, approximately 400 m below mean sea level. The Dead Sea area is recognized as a natural treatment facility for patients with psoriasis, atopic dermatitis, vitiligo and other skin and rheumatic diseases.[3–7] Over the past 40 years, mainly psoriasis patients have been treated at the Dead Sea medical center.[8] The success rate measured in terms of excellent to complete clearance after 4 weeks of treatment exceeds 85%.[5,9] These clinical findings were presumed to be associated with a unique spectrum of ultraviolet radiation present in the Dead Sea basin.[10–12]

A research project was initiated in 1994 to examine the ultraviolet radiation in the Dead Sea basin. The goal of this investigation was to determine if the incident ultraviolet radiation has unique properties, which might contribute to the success of Dead Sea photoclimatherapy in the treatment of psoriasis or other skin diseases. A meteorological station located in the Dead Sea basin (Neve Zohar) was established to monitor continuously UVB and UVA radiation, measure spectral selectivity within the UV spectrum and investigate other relevant bio-climatological parameters. The same meteorological parameters were also monitored continuously by identical instrumentation at a second meteorological station located in Beer Sheva. The two sites provided a basis for an intercomparison of the measured parameters.

Materials and methods

Site parameters

The radiation data were monitored at two meteorological stations. The one located on the western shore of the Dead Sea, at a site called Neve Zohar, has an altitude of 375 m below mean sea level with a latitude of 31°12′ N and a longitude of 35°22′ E. The second station based in Beer Sheva has an altitude of 315 m above mean sea level with a latitude of 31°15′ N and a longitude of 34°45′ E. Beer Sheva is located in the southern Negev region of Israel, a semiarid zone, at a distance of *c.* 65 km to the west of the Dead Sea.

Broad-band measurements

The instrumentation utilized to measure the UV radiation at both sites is identical and consists of a Solar Light Co. Inc. Model 501 A UV-Biometer for the measurement of UVB and a Solar Light Co. Inc. analog UVA version of the Model 501 A UV-Biometer for the measurement of UVA. All UV radiation meters are positioned to monitor the UV radiation intensity on a horizontal surface. A Campbell Scientific Instruments datalogger (Logan, UT), located at each site (a Model CR21 at Neve Zohar and a Model CR10 at Beer Sheva), monitors and stores the data at 10-min intervals (i.e. the meters are scanned at 10-s intervals and average values at 10-min intervals are calculated and stored). The data from both stations are downloaded periodically by modem to a desktop computer located in the Solar Energy Laboratory at Ben-Gurion University of the Negev, Beer Sheva.

The UVB database consisted of ongoing measurements beginning in February 1995, whereas the UVA database consisted of ongoing measurements from June 1995. The ultraviolet radiation was monitored continuously except for scheduled interruptions to enable annual factory calibration checks and random interruptions caused by power failures. The two meteorological stations are part of a national network and are connected by modem to the Israel Meteorological Service.

The selection of this particular type of UV meter (biometer) was dictated in part by one of the goals of this research program which was to develop a database for monthly average daily and hourly UVB and UVA values for the Dead Sea basin. The UVB radiation is measured in units of minimum erythema dose per hour (MED/h) for skin type 2. This unit is the product of the cross-multiplication (programmed into the meter) of the irradiating flux in the UVB spectral range and the erythema action spectra.[13] The UVA meter measures the irradiating flux in the UVA spectral range in units of W/m^2. Both the UVB and UVA Solar Light Co. Inc. meters are classified as broad-band meters and were installed at both meteorological sites. They measure the cumulative radiation flux over their respective spectral ranges and, consequently, they are not capable of providing any information regarding site-specific spectral selectivity within the ultraviolet spectrum.

Narrow-band measurements

Sporadic measurements utilizing a narrow-band spectroradio meter, UV-Optronics 742, to scan from 295 to 380 nm at 1-nm intervals (the band pass of the instrument is 1.5 nm, as per the manufacturers' specifications) were also made. Such measurements could not be carried out concurrently at the Dead Sea and Beer Sheva, as there was only a single spectroradiometer. In order to overcome this obstacle, the broad-band meter measurements at both sites were utilized to ascertain that the overall radiation flux densities were similar prior to performing an intercomparison between spectroradiometer measurements performed on two different but consecutive days. In addition, the horizontal global radiation intensity values measured at both sites were compared. They provide a better criterion for the justification of the intercomparison of the narrow-band spectra because they are least affected by the different optical path lengths (i.e. site altitudes) associated with the two sites because of their higher wavelength spectral range. The global radiation intensities are measured by Kipp & Zonen Model CM11 (Delft, Holland) and Eppley Model PSP (Newport, RI) pyranometers at Neve Zohar and Beer Sheva, respectively. The spectroradiometer and its peripheral equipment were transported to the Neve Zohar (Dead Sea) site approximately once every 2 to 3 weeks for a day of measurements. The latter consist of a single scan through the ultraviolet range (i.e. 295–380 nm) once an hour from about 0930 until 1530 h (Israel Standard Time). An identical set of measurements were made at the Beer Sheva site on a number of days both before and after the measurement day at Neve Zohar in order to enhance the probability of obtaining two very similar days for the purpose of intercomparison. Again, the spectral radiation intensities referred to the intensity on a horizontal surface.

The theory of light scattering holds that the degree of attenuation of a solar ray is inversely proportional to its wavelength raised to some power. The task was to determine if this spectral selectivity could be measured within the UV spectral range. These measurements were performed utilizing the narrow-band spectroradiometer.

Additional measurements

A third set of measurements, providing further insight as to the nature of the ultraviolet radiation environment in the Dead Sea basin, was initiated in March 1998 with the purchase of a Solar Light Co. Inc. Microtops II, Ozone Monitor-Sunphotometer. This is a portable meter consisting of three narrow-band light filters measuring the UVB radiation intensities at three wavelengths of the UVB spectrum, namely 305.5 ± 0.3, 312.5 ± 0.3 and 320.0 ± 0.3 nm. Its primary intended use is to determine the stratospheric ozone layer thickness, which is calculated as a function of the relative intensities of the three narrow-band UVB readings utilizing an algorithm programmed into the instrument.

Results

Broad-band measurements

The results of the intercomparison of the broad-band radiation intensities measured by the UVB and UVA meters at both sites are presented in Tables 1 and 2, respectively. The UV radiation intensities are given as monthly average daily values (the number of days in each monthly database are reported in column 3 of the tables) and the relative attenuation, column 5, is defined as

$$\%\ \text{relative attenuation} = (\mathrm{UVi}_{\text{Neve Zohar}} - \mathrm{UVi}_{\text{Beer Sheva}}) \times 100/\mathrm{UVi}_{\text{Beer Sheva}}, \quad (1)$$

Table 1 Monthly average daily UVB radiation intensities (MED) in the Dead Sea Basin and Beer Sheva and their relative difference

Month	Neve Zohar UVB (MED)	Days	Beer Sheva UVB (MED)	% relative attenuation
Jan	5.65	151	5.83	–3.19
Feb	8.57	121	9.23	–7.08
Mar	12.17	207	13.35	–8.85
Apr	15.99	197	18.27	–12.49
May	19.80	217	23.14	–14.42
Jun	22.85	206	26.76	–14.62
Jul	21.48	217	25.59	–16.07
Aug	19.26	196	22.75	–15.36
Sep	15.58	181	18.31	–14.89
Oct	10.76	204	12.56	–14.32
Nov	7.01	160	8.00	–12.37
Dec	5.02	105	5.60	–10.30

Table 2 Monthly average daily UVA radiation intensities (W/m^2) in the Dead Sea Basin and Beer Sheva and their relative difference

Month	Neve Zohar UVA (W/m^2)	Days	Beer Sheva UVA (W/m^2)	% relative attenuation
Jan	140.33	151	141.36	–0.73
Feb	186.73	105	192.43	–2.97
Mar	246.86	178	249.68	–1.13
Apr	303.33	168	312.82	–3.03
May	353.20	180	372.28	–5.12
Jun	389.21	187	407.35	–4.45
Jul	366.69	217	389.42	–5.84
Aug	342.50	193	357.47	–4.19
Sep	292.22	181	304.93	–4.17
Oct	220.43	217	233.01	–5.40
Nov	165.30	210	172.00	–3.89
Dec	131.08	147	137.98	–5.00

where i refers to either the B or A type of UV radiation. The greater magnitude of the corresponding monthly values for the percentage relative attenuation for UVB compared to that for UVA was a result of the attenuation being inversely proportional to the wavelength and, thereby, greater for the shorter UVB wavelengths. The per cent relative attenuation is also presented graphically in Fig. 1. The variation in the monthly per cent relative attenuation values for a particular UV type of radiation is also influenced by site climatic conditions, i.e. microclimate. The mountains just to the west of the Dead Sea basin prevent winter rain clouds coming from the Mediterranean Sea from passing over and depositing rain in the basin. Consequently, the Dead Sea area is characterized by a much clearer sky, relative to Beer Sheva, during the rainy season from January through March. This is also attested to by the relative magnitudes of the monthly average daily global radiation measured at both sites: they were, within the measurement uncertainty ±3%, the same for all months with the exception of January through March (cf. Fig. 1). This explains the relatively low magnitude of per cent relative attenuation during these months, as the higher incidence of partially cloudy and cloudy sky conditions results in an enhanced attenuation of the UV radiation in Beer Sheva.

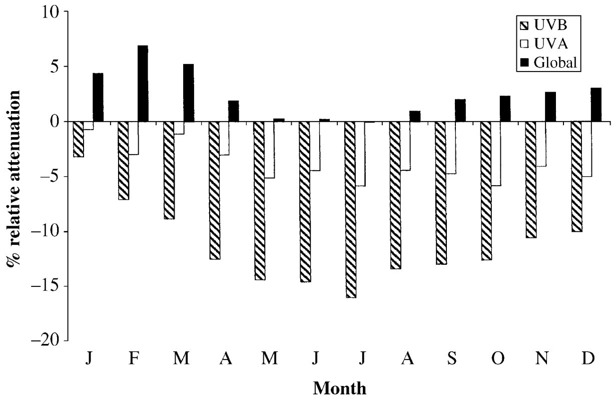

Figure 1 Monthly average daily percentage relative attenuation of UVB, UVA and global radiation intensities: [%(Neve Zohar – Beer Sheva)/Beer Sheva]

It should be emphasized that the broad-band meters measure the cumulative UVB and UVA radiation intensities within their respective spectral bands. As can be seen from the tables, both the UVB and UVA radiation intensities are attenuated by the ~700-m drop in altitude because of the increase in the optical path length. The actual additional optical path length, Δ(OPL), which a solar ray has to transverse as a result of the drop in altitude is given by

$$\Delta(\text{OPL}) = \text{change in altitude}/\cos \theta_z, \quad (2)$$

where θ_z is the solar zenith angle. The solar zenith angle is that angle which the solar ray subtends with the normal to the surface. Consequently, θ_z decreases and its cosine increases, approaching unity, with solar altitude, i.e. the height of the sun in the sky. This explains why the magnitude of the UV radiation intensity peaks during the summer months: the solar rays have to transverse a shorter optical path length. This also explains the increased attenuation in the radiation intensity as the time from solar noon increases towards sunrise or sunset.

Narrow-band measurements

The results of these measurements are shown in Figs 2 and 3 for the UVB (295–320 nm) and UVA (320–380 nm) spectral ranges, respectively. These data refer to measurements performed on two consecutive days during the month of August,

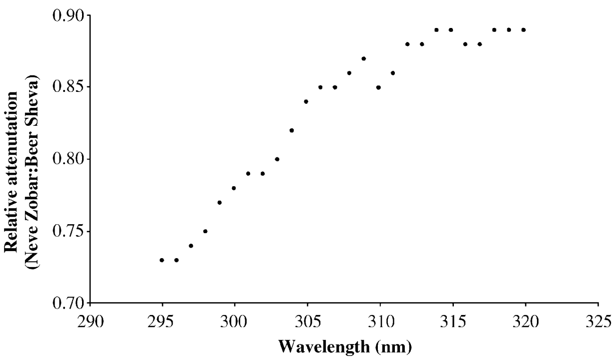

Figure 2 Relative attenuation of UVB radiation within spectral range: Neve Zohar:Beer Sheva

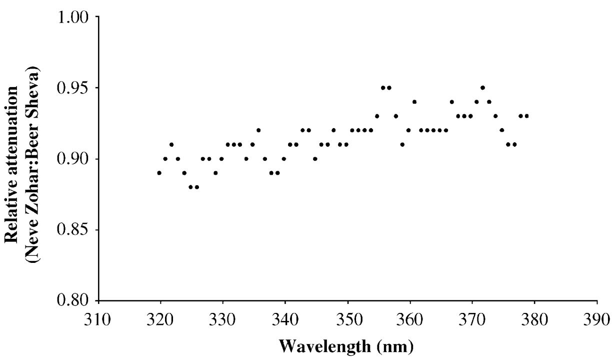

Figure 3 Relative attenuation of UVA radiation within spectral range: Neve Zohar:Beer Sheva

i.e. one day of measurements at each site, Dead Sea and Beer Sheva, and are representative of these types of measurements. As mentioned previously, the criteria for intercomparison were based primarily on the relative magnitude of the horizontal global radiation intensities, i.e. their approach to unity. The graphs depict the ratio of the radiation intensities at the two sites (Dead Sea:Beer Sheva) as a function of wavelength throughout the UVB and UVA spectral ranges. A marked spectral selectivity was observed for the case of the UVB radiation, with the degree of attenuation decreasing as the wavelength increased. In the vicinity of the peak erythema action spectra, *c.* 300 nm, the degree of attenuation was in the range of 0.73–0.79 (27–21%), whereas in the spectral range of the UVB beneficial to psoriasis, *c.* 312 nm[14], the degree of attenuation was 0.85–0.89 (15–11%). The degree of attenuation in the case of the UVA radiation was less than that for the UVB radiation and its spectral selectivity was much less marked, varying in the range of 0.89–0.95 (11–5%). The scatter of the measured data was not unexpected considering the very low radiation intensities being measured by the spectroradiometer.

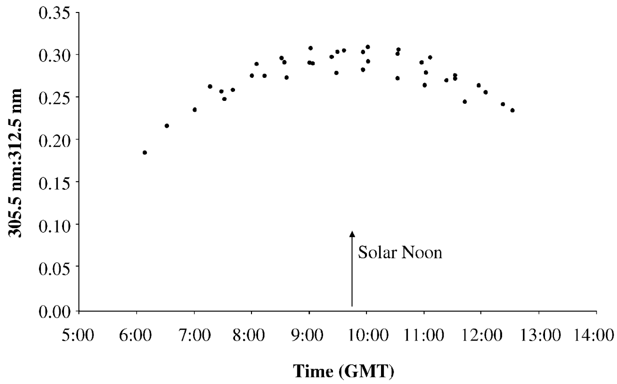

Figure 4 Ratio of 305.5 : 312.5 nm radiation intensities for Neve Zohar during the month of July as a function of time of day

Additional measurements

The results of the Microtops II, Ozone Monitor-Sunphotometer measurements performed at the Dead Sea during the month of July are shown in Fig. 4. The radiation intensity ratios are presented as a function of time of day referred to GMT and attained a maximum at solar noon. The local Israel Standard Time is given by GMT + 2 h and during the month of July solar time precedes local time by about 15 min. As a result, the shortest optical path length during the month of July occurs at approximately 0945 GMT, as attested by the minimum attenuation of the 305.5-nm relative to 312.5-nm radiation intensity. The optical path length varied diurnally and attained its daily minimum at solar noon and increased towards sunrise and sunset. Consequently, the degree of attenuation and resultant spectral selectivity varied in the same manner, i.e. with a daily minimum at solar noon.

Discussion

As discussed in numerous publications,[5,9] excellent to complete clearing is achieved in over 85% of the psoriasis patients treated at the Dead Sea medical center. The main goal of this research project was to determine if the ultraviolet environment in the Dead Sea basin possesses unique properties, which contribute to and explain the clinical results observed. In addition, the findings will be applied to the development of a patient sun exposure treatment protocol. The ultraviolet environment in the Dead Sea area was studied in detail using both broad- and narrow-band instrumentation and an intercomparison was made with a set of identical measurements performed at a second site, Beer Sheva. The two locations are characterized by ~700 m difference in altitude with the Dead Sea being 375 m below mean sea level and Beer Sheva 315 m above mean sea level.

Because the Dead Sea basin is the lowest terrestrial point on earth, increased attenuation of the solar rays is expected with the increased optical path length and consequent enhanced scattering. The attenuation of terrestrial solar radiation with optical path length (i.e. the distance the sun's rays transverse through the earth's atmosphere prior to being incident on the surface of the earth) is well documented.[15–20] The optical path length varies with site altitude (increasing with decreasing altitude), time of year (shortest in the summer and longest in the winter months) and time of day (shortest at solar noon and increasing towards sunrise and sunset). The terrestrial radiation is also attenuated by two different phenomena: (1) atmospheric scattering by air molecules, water vapor and aerosols, and (2) atmospheric absorption by ozone, water and carbon dioxide.

The attenuation of the beam radiation as a result of scattering by air molecules, water vapor and aerosols has been the subject of numerous studies, and approximate correlations have been developed to estimate the magnitude of the effect.[21,22] Air molecules are small compared to the wavelengths (λ) of radiation significant in the solar spectrum. Scattering of solar radiation by air molecules is in accordance with the theory of Raleigh, which predicts that the degree of scattering varies approximately as λ^{-4}. The scattering of solar radiation by water molecules is a function of the amount of precipitable water (the amount of water vapor in the air column above the observation site), and an empiric scattering coefficient for water vapor that varies approximately as λ^{-2} has been proposed. Moon[21] developed an empiric scattering coefficient for aerosols, which varies approximately as $\lambda^{-0.75}$. In all cases, the degree of attenuation by scattering is an inverse function of wavelength raised to some power. Consequently, in theory the degree of attenuation of a solar ray is inversely proportional to its wavelength and the shorter wavelengths are more attenuated by the scattering phenomena.

Absorption of solar radiation in the atmosphere is attributable mainly to ozone in the ultraviolet range and water vapor, in specific bands, in the infrared range ($\lambda > 780$ nm) of the solar spectrum. Three types of ultraviolet radiation have been defined as a function of their wavelength range: (i) UVC, with a spectral range from 100 to 280 nm, which is completely absorbed by the stratospheric ozone layer, (ii) UVB, with a spectral range from 280 to 320 nm, which is mostly absorbed by the stratospheric ozone layer with virtually no solar radiation below 295 nm being incident on the earth's surface, and (iii) UVA, with a spectral range from 320 to 380 nm, where stratospheric ozone layer absorption is minimal. Thus ozone absorption decreases with increasing λ and above 350 nm there is no absorption. There is, also, a weak ozone absorption band in the visible range ($380 < \lambda < 780$ nm) of the solar spectrum, at about 600 nm.

Results from the broad-band measurements, as reported in Tables 1 and 2, showed a general attenuation of Dead Sea UVB and UVA relative to that for Beer Sheva, with the UVB radiation attenuated to a greater extent than the UVA radiation relative to Beer Sheva. The annual average daily attenuation relative to Beer Sheva was 12.0 and 3.83% for UVB and UVA, respectively. Based on these findings, patients undergoing photoclimatherapy at the Dead Sea would require longer periods of sun exposure in order to obtain the same dose of UV radiation as compared to other locations. Consequently, there would be no overt advantage to Dead Sea photoclimatherapy unless a difference in the relative concentrations of the spectral rays within the erythema and therapeutic action spectrum beneficial to psoriasis[14] was demonstrated.

As observed in the narrow-band measurements shown in Fig. 2, the attenuation within the UVB spectral range for the Dead Sea basin decreased significantly with increasing wavelength relative to Beer Sheva. The range of relative attenuation within the peak erythema action spectra was from 27 to 21%, and within the therapeutic action spectral range beneficial to psoriasis it decreased from 15 to 11%. Relative to Beer Sheva, the attenuation within the UVA spectral range for the Dead Sea basin decreased much less with increasing wavelength, as observed in Fig. 3. The range of relative attenuation within the UVA spectrum was from 11 to 5%.

The UVB spectrum at the Dead Sea basin contains less of the shorter, more deleterious erythematous rays, as the narrow-band measurements showed that the UVB radiation incident at the Dead Sea basin was attenuated to a much greater degree at the shorter end of its spectrum, i.e. at lower wavelengths. However, the wavelengths within the therapeutic action spectrum for psoriasis and utilized in narrow-band UV light therapy[23] were also attenuated, but to a lesser degree. Consequently, as a result of this wavelength selectivity there was proportionally a lower amount of the shorter erythema wavelengths in the incident UVB radiation and a greater amount of the longer therapeutic UVB rays in the Dead Sea basin.

The question of the safety of patient exposure to both solar and artificial phototherapy has been raised in recent years,[24] and a reduction in the cumulative UVB exposure dose during photoclimatherapy could reduce possible dangerous side-effects.[25,26] Measurements with the Microtops II, Ozone Monitor-Sunphotometer, as seen from Fig. 4, showed that the relative radiation intensities within the UVB spectrum between erythema and the therapeutic wavelengths were also a function of time of day. The relative radiation intensities (i.e. the ratio of the 305.5-nm to the 312.5-nm radiation intensities) peaked at solar noon and decreased towards sunrise or sunset. They decreased by more than 20% relative to solar noon for times 2 h prior to or after solar noon at the Dead Sea Basin (from a peak ratio of ~0.31 at solar noon to ~0.25). Therefore, a patient treatment protocol can be employed using the diurnal measurements of the relative radiation intensities at 305.5 to 312.5 nm to minimize the exposure to the erythema rays (305 nm) and at the same time obtain the optimum dose of the wavelengths beneficial to treatment, i.e. 312 nm. It should be noted that the radiation intensity at 305.5 nm is at the high-wavelength end of the erythema range and it is justifiable to assume, as a result of the spectral selectivity of the attenuation, that this ratio will be even lower for the stronger, shorter wavelength erythema radiation. Solar exposure during photoclimatherpy therefore should be limited to the early morning and later afternoon hours.

The relevance of the above data in developing a sun exposure treatment protocol will be contingent on cross-referencing these findings with the broad-band measurements, i.e. the average hourly UVB radiation intensities for each month, to ascertain that the daily dose is sufficient. As a result, patients will receive the correct daily dose of UVB radiation and the total exposure to solar radiation will be reduced without sacrificing treatment efficacy. It should be noted that the observed scatter in the ratio values (cf. Fig. 4) is caused by daily variations in aerosol content, precipitable water and ozone layer thickness, which affect the relative attenuation within the UVB spectral range.

In conclusion, broad-band measurements at the Dead Sea revealed a general attenuation of both the UVB and UVA wavelengths relative to Beer Sheva, with the UVB attenuated to a greater extent than the UVA. The narrow-band UVB measurements demonstrated that the relative attenuation within the UVB spectral range was greatest for the shorter erythema rays and less for the longer therapeutic UVB wavelengths, thus producing a greater proportion of the longer therapeutic UVB wavelengths in the ultraviolet spectrum. These data help explain phototherapeutically the rationale for the results obtained with photoclimatherapy at the Dead Sea. Broad-band UVB measurements, i.e. the tabulated monthly average daily radiation intensity values, as well as specific hourly spectral measurements can be utilized to minimize the exposure to solar radiation by correlating the cumulative UVB radiation dose to treatment efficacy. These findings are applicable in developing sun exposure treatment protocols compatible with Dead Sea photoclimatherapy.

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