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Guidelines on the measurement of ultraviolet radiation levels in ultraviolet phototherapy: report issued by the British Association of Dermatologists and British Photodermatology Group 2015

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1.0 Purpose and scope

The overall objective of the guideline is to provide up-to-date, evidence-based recommendations for the dosimetry and calibration of ultraviolet (UV) radiation (UVR) therapy. The document aims to: (i) offer an appraisal of all relevant literature, focusing on any key developments; (ii) address important, practical clinical questions relating to the primary guideline objective, that is, accurate measurement, equipment variables, and human variables; (iii) provide guideline recommendations and, where appropriate, discuss health economic implications; and (iv) discuss potential developments and future directions

The guideline is presented as a detailed review with highlighted recommendations for practical use in the clinic [see section 18·0, in addition to a patient information leaflet on phototherapy, which is available on the website of the British Association of Dermatologists (BAD): www.bad.org.uk].

2.0 Stakeholder involvement and peer review

The guideline development group consisted of clinical scientists, consultant dermatologists and a nurse practitioner. The draft document was circulated for comments to the BAD membership, the British Photodermatology Group (BPG) membership, the British Dermatological Nursing Group, the Primary Care Dermatological Society, the Institute of Physics and Engineering in Medicine, the Psoriasis Association, the Psoriasis and Psoriatic Arthritis Alliance, and a patient, and peer-reviewed by the Clinical Standards Unit of the BAD (consisting of the Therapy and Guidelines Subcommittee) prior to publication.

3.0 Methodology

This set of guidelines has been developed using the BAD's recommended methodology,[1] and with reference to the Appraisal

of Guidelines Research and Evaluation II instrument (www.agreetrust.org).[2] Recommendations were developed for implementation in the National Health Service using a process of considered judgement based on the evidence.

Clinical trials are not appropriate for this guideline. The recommendations made are those that are currently considered best practice but will be modified at intervals in the light of new evidence. The structure of the 2002 guidelines was discussed and re-evaluated,[3] with headings and subheadings decided; different co-authors were allocated separate subsections. PubMed, MEDLINE and Embase were searched up to December 2014; search terms and strategies are detailed as in Appendix S1 (see Supporting Information). Additional relevant references were also isolated from citations in the reviewed literature. The results were split into two and, working in quartets, each group of co-authors screened a set of identified titles/abstracts, and those relevant for first-round inclusion were selected for further scrutiny. The authors then reviewed the abstracts for the shortlisted references with reference to their allocated subsection and the full papers of relevant material were obtained. Each co-author then performed a detailed appraisal of the selected literature, and all drafted subsections were subsequently collated and edited to produce the final guideline.

4.0 Limitations of the guideline

This document has been prepared on behalf of the BAD and is based on the best data available when the document was prepared. It is recognized that under certain conditions it may be necessary to deviate from the guidelines and that the results of future studies may require some of the recommendations herein to be changed. Failure to adhere to these guidelines should not necessarily be considered negligent, nor should adherence to these recommendations constitute a defence against a claim of negligence. Limiting the review to English-language articles was a pragmatic decision but the authors recognize this may exclude some important information published in other languages.

5.0 Plans for guideline revision

The proposed revision date for this set of recommendations is scheduled for 2020; where necessary, important interim changes will be updated on the BAD website.

6.0 Background

The key contribution of the medical physics community to the development of psoralen combined with UVA photochemotherapy (PUVA) and UVB phototherapy since its first use in the U.K. in the 1970s has been to ensure that the dose of UVR is administered quantitatively rather than qualitatively.[4] In 2002 the BPG published dosimetry guidelines that codified the experience gained in how best to ensure the phototherapy dose is accurately measured.[3] In the decade since, there have been some significant advances in technology for the delivery and measurement of phototherapy dose, as well as changes in regulatory and clinical governance environments affecting phototherapy dosimetry.[5,6] These guidelines take account of the advances and are intended to update and replace those previously published.[3]

The term 'dose' in the context of clinical phototherapy is taken to be the time integral of the irradiance of the therapeutic radiation over the time during which the skin is exposed.[7] The irradiance at the skin surface is typically measured in units of power per unit area [e.g. milliwatts per cm^2 (mW cm^{-2})] so that, for an exposure time in seconds, the dose takes on units of energy per unit area [e.g. joules per cm^2 (J cm^{-2})]. Confining the definition of dose to that delivered at the skin surface rather than at depth in a volume of tissue, as is common in experimental photobiology, has considerable advantages, not least being its relative ease and reproducibility of measurement.[7]

The early protagonists of UV therapy stressed the importance of careful dosimetry, particularly where patients needed to continue treatment on different irradiation units in the same or different centres,[8,9] and the need to base starting doses on either skin type or the results of phototesting.[10] Similarly, it was recognized that careful detector calibration was needed to measure the output of different irradiation units having different spectral emission characteristics.[11,12] Despite the early awareness of the need for accurate dosimetry in PUVA, intercomparisons of UVA dosimetry in the U.K. found wide variability in practices and in the accuracy of UVA measurement.[13–15] Incorrect use of radiometers and poor calibration was found to result in recorded irradiance values that were between 0·5- and 1·5-fold the true value.

In a survey of 115 UVB phototherapy centres in the U.K. in 1994,[16] it was noted that the overwhelming majority prescribed UVB by exposure time rather than in radiometric units. This is no longer considered good practice unless there is a calibration factor available to users that allows a conversion to dose, so that the dose, rather than a time, can be recorded in the patient's notes.

The erythemal sensitivity of skin changes very rapidly with wavelength in the UVB waveband; at 300 nm the skin is 100 times more sensitive than at 320 nm. Thus, the dose of UVB radiation from a particular lamp necessary to produce a given degree of erythema is markedly dependent on its spectral emission. The need for accurate UVB dosimetry became particularly apparent in the 1990s with the introduction of narrowband UVB (NB-UVB) treatment and the requirement to compare the effectiveness and safety of this new treatment with older broadband UVB (BB-UVB) treatments.[17] The short wavelengths found in BB-UVB are more likely to cause burning than NB-UVB. NB-UVB treatment has now virtually replaced BB-UVB. Guidelines regarding the clinical use of phototherapy have been developed.[18,19]

The calibration of UV radiometers for phototherapy has also improved markedly in the last decade with the introduction of traceability to national irradiance standards via the National

Measurement System (NMS).[20,21] This makes it possible to ensure that the irradiance measured in one centre is comparable with that measured at other centres using differently calibrated radiometers. Evidence of reduced variability in UV radiometer calibrations is seen in intercomparisons from around Europe published in the 1980s, which showed a spread in measured calibration factors of UVA radiometers of 23%,[14] while a more recent study demonstrated only a 6% spread.[22] Finally, there have also been valuable instrumental advances, with the introduction of compact solid-state spectroradiometers making it much easier than previously to capture spectral information from clinical UVR equipment.[23,24]

The role of phototherapy has recently been re-evaluated in response to the revolution in biological therapies for psoriasis.[25,26] Despite the benefits of these therapies that target specific components of the immune system, it seems clear that phototherapy will remain a cornerstone in the management of psoriasis, as well as in nonpsoriatic skin conditions, because of its acknowledged efficacy, its reasonable financial cost, its compatibility with other therapies and its historically proven utility.

See Appendix 1 for a glossary of terms; see Appendix 2 for a description of the level of evidence; see Appendix 3 for a description of the strength of recommendations.

7.0 Clinical requirements

7.1 Accuracy and reproducibility

Accurate and reproducible dosimetry is considered important in phototherapy, not only to ensure that patients can be treated consistently in the same centre or be transferred between centres, but also to ensure that a patient's absolute cumulative dose (in J cm^{-2}) can be accurately recorded to aid the management of long-term skin cancer risks (Ling *et al.*, British Association of Dermatologists and British Photodermatology Group draft 2014 guidelines for the safe and effective use of psoralen combined with ultraviolet A therapy).[27]

A dose measurement accuracy of 10% is generally considered adequate for clinical phototherapy.[28,29] In treatment cabins, for example, patient positioning and the nonuniformity of irradiation of the skin due to its curvature may be > 15%.[11] Similarly, differences in the output of the different lamps in the array can be 15% and fluctuations in the output of lamps during treatment can be as much as 10%.[30]

Modern solid-state UV filter radiometers can make highly reproducible measurements with sequential readings of a stable source varying by < 1%. However, a meter may provide a reproducible reading without the reading being accurate in terms of the absolute dose (in J cm^{-2}). Indeed, it is difficult in practice to calibrate a field UV meter with an accuracy much better than 10%.[28,29] The UV meter calibration uncertainties quoted by those U.K. laboratories operating to the standard ISO 17025 are typically of the order of 10% and are therefore adequate for most clinical UV dosimetry.[31] As the calibration factors provided are specific to radiometers being used with sources having a particular spectral output, the main issue for users is to ensure that they request and use the appropriate calibration factor. Users also need to be aware that UV meter degradation can cause the meter to drift out of calibration, so regular calibration is required.

Although the introduction of traceable dosimetry has been an important step in improving dosimetry accuracy in phototherapy centres, there remain areas of concern, particularly in the variability of dosimetry for NB-UVB phototherapy.[28] Large discrepancies in dosimetry between centres seem likely to be owing, at least in part, to poor matching of the cosine directional response of UV radiometers and unresolved calibration issues where the spectral output of a source varies rapidly with wavelength.[32,33]

7.2 Safety

UVR is carcinogenic; therefore, it is important that exposure of staff and members of the public is within acceptable limits.

Any potential exposure to UVR should be covered by a suitable and sufficient prior risk assessment that is subject to regular review. Any necessary control measures to reduce the risks associated with working with UVR should be documented in this risk assessment and be put in place. Staff should be trained to an appropriate level and be made aware of any control measures that may be required such as the use of personal protective equipment (PPE) or high-factor sunscreen.

Staff should be aware that there may be scattered UVR from ceilings or walls around the cabin when working in the general vicinity of cabin and partial-body irradiation equipment. Exposure to these devices and to the environmental scatter is generally low but an assessment of the level of environmental UVR should be carried out in line with the Control of Artificial Optical Radiation at Work Regulations 2010.[5] Such measurements could be carried out by a local medical physics department or others with the expertise to make such measurements. Measured irradiances should be compared with the legal limits laid down in these regulations, with due consideration made to occupancy and workload factors. There may be additional control measures that are required to reduce environmental UVR, such as the use of curtains and drapes.

7.2.1 Safety recommendations (strength of recommendation D; level of evidence 4)

A suitable assessment of risk should include the measurement of environmental UVR levels to which staff are exposed and the identification of appropriate control measures. Environmental UVR levels should be within the maximum permissible levels proscribed in the Control of Artificial Optical Radiation at Work Regulations 2010.

7.3 Clinical governance

Delivering safe care is a prime consideration for all healthcare workers. Legal claims can help highlight aspects of practice

prone to mishap or dispute. Although dermatology as a whole is a low-risk specialty, phototherapy has been highlighted as a vulnerable area, with a significant number of claims resulting from overexposure to UVR.[34–36] The potential long-term risk of skin cancer with cumulative phototherapy treatment is also an important clinical governance consideration.[37]

Audits of phototherapy provision have revealed great variation in the quality of service provided between centres. The BAD has recently recommended minimum service standards for phototherapy and offers supporting guidance to inform service.[38] These include a phototherapy service review toolkit to provide phototherapy units with a framework for assessing their service against these minimum standards.[39] Achieving a consistent standard for safe and effective phototherapy service provision across the U.K. should follow.

8.0 Phototherapy equipment

Most UV phototherapy treatments are delivered in hospital or clinic settings. As many patients have large proportions of their skin surface needing treatment, whole-body phototherapy cabins where the patient is surrounded on all sides by banks of UV lamps are the equipment of choice for most treatments. The last few decades have seen an increase in the use of NB-UVB phototherapy, with an accompanying decline in PUVA and BB-UVB treatments.[19] The use of whole-body UVA1 phototherapy has also become more common recently.

For areas with more remote populations without easy access to phototherapy centres, the use of home phototherapy units has proved popular and cost-effective in enabling self-administration of treatment.[40,41] Whole-body home phototherapy units are more usually an open single bank of lamps rather than an enclosed whole-body cabin. Any one treatment session therefore consists of four separate exposures: to the front and back, and to the left and right sides.

Partial-body irradiation equipment is also widely used for both self-administered and clinic-based phototherapy. A small bank of lamps in either a flat or curved array is suitable for treating hands, feet or lower limbs. Smaller, hand-held devices are often used for less accessible treatment sites such as the scalp. All such units should be operated in areas where access can be controlled to avoid unnecessary exposure to the beam. In the case of the patient, untreated skin and eyes should be protected as necessary by means of clothes, drapes, goggles or face shields.

Equipment management issues associated with whole-body treatment cabins are considered in the following subsections. Whole-body cabins are typically more sophisticated in operation than partial-body irradiation units, with many having inbuilt automated dosimetry systems. They also present a greater potential hazard because of the higher UV irradiances they generate and the fact that a larger area of the patient's skin is typically irradiated. However, many of the UV dosimetry principles discussed will apply equally to the smaller partial-body units.

8.1 Numbers of fluorescent lamps

Different models of whole-body phototherapy cabins contain differing numbers of lamps – 24, 26, 40 or 48 lamps being the more common. The UV irradiance comprises UVR emitted directly from the lamps and UVR reflected from polished surfaces to the side and rear of the lamps. The angles of these reflectors have a significant influence on the overall cabin efficiency.[42,43] The reflectivity coefficients of different materials used for the reflectors by the various cabin manufacturers can also vary significantly.[42] Increasing the number of lamps within a cabin beyond a certain point does not necessarily increase the irradiance proportionately. A recent study compared the outputs from two sets of cabins, with similar dimensions, differing only in the numbers of lamps, from the same manufacturer.[43,44] Cabins with 24 lamps gave irradiances that were only 11% less than those with 40 lamps. It was concluded that the smaller reflector angle in the 40-lamp cabins reduced the useful output per lamp by a third. The uniformity of illumination, which is the most important factor for treatment delivery, was found to be similar in the cabins with 24 and 40 lamps. Cabins that only employed a simple, flat reflector behind the lamps had lower efficiencies. Irradiances in the range of 6–8 mW cm^{-2} are generally required for NB-UVB therapy and in the range of 10–14 mW cm^{-2} for UVA therapy. Therefore, cabins with > 24–30 lamps may offer little advantage in terms of treatment times.

To allow treatment with either spectrum, some cabins have a combination of UVA and UVB fluorescent lamps that are operated using separate controllers. These cabins hold either 16 UVB and 32 UVA lamps or 13 UVB and 27 UVA lamps. Although these cabins save space, the overall cabin irradiance of each modality is proportionally reduced and, consequently, treatment times are increased. There is also the risk of selecting the wrong treatment mode, although internal dosimetry systems, if these are used, will typically include exposure limits that prevent the longer UVA exposure times being given by the UVB lamps. Therefore, this type of cabin is not generally recommended. If it is necessary to have a dual cabin because of space limitations, extreme care must be exercised when entering the lamp type and treatment dose.

The number of lamps in a cabin may affect installation and running costs. Cabins with fewer lamps require less complex electrical supply arrangements, whereas those with 40 or more fluorescent lamps typically require a three-phase electricity supply that may not be readily available on some sites. They also produce more heat and therefore efficient air conditioning systems are required to maintain patient comfort.

8.2 Exposure control systems

Exposure control in whole-body phototherapy cabins can be either time-mode or dose-mode. Some cabin designs can be operated in only one of these modes, while others offer a choice of either mode of operation. Depending on user

preferences, the choice of control modes may be an important consideration when acquiring a new treatment cabin.

Time-mode may be the only control method available on older cabins. The user sets an exposure time corresponding to the prescribed treatment dose, and based on prior irradiance measurements. The cabin's inbuilt electronic timer then controls the exposure; there is no automatic allowance for differences in patient size or variations in the cabin irradiance.[30] To maintain accuracy, a programme of regular irradiance calibration tests is necessary, typically after 50 h of use and repeated at least every 4 months.

Most currently available cabins are capable of dose-mode control. The cabin is fitted with internal detectors that measure the internal irradiance in real time during treatment. The operator sets the required dose on the controls and starts the treatment. The control system electronically integrates the continuous irradiance reading, and the exposure is automatically terminated when the set dose is reached. Dose-mode operation can also compensate automatically for fluctuations in irradiance arising both during individual treatments and over a full clinic session. More consistent doses may then result.

The effectiveness and accuracy of inbuilt sensor systems is dependent on detector position and cabin geometry. Some early designs have been prone to give misleading readings (Moseley, personal communication).[30,45] Especially problematic are types reliant on monitoring a small number of lamps.[46] More recent types compensate reasonably well for differences in the amount of shielding of the fluorescent tubes by patients of differing sizes.[29,47,48] However, it should be recognized that internal dosimeters monitor the UV that is reflected from a relatively small area of skin and do not measure the average irradiance to the whole patient.

Internal detectors may also be sensitive to the patient's relative position within the cabin. If a patient moves off centre, the detected cabin irradiance level will alter as the different banks of lamps within the cabin will contribute more or less to the total irradiance. This may cause some variation in the patient's actual received dose, leading to either under- or overdosing.

It has been shown that cabins fitted with a pair of detectors are less susceptible to this type of dose error than cabins with single detectors.[30,48]

When inbuilt, dose-mode sensors are fitted, users should not assume that the dose displayed on the cabin's control panel is correct. A programme of regular calibration checking of any inbuilt metering system should be in place to ensure accuracy and to guard against malfunctions. To avoid confusion, this should be done even if the cabin is usually operated in time mode.

8.3 Safety features

Should a patient fall against unprotected lamps inside a phototherapy cabin, there is a high risk of laceration. Many older phototherapy cabins either had no protection at all against this or had relatively open metal grilles. Now, full acrylic guards over the lamps are generally fitted as standard. Users of phototherapy cabins without guards in place were required to consider retrofitting them following the publication of the medical device alert (MDA/2003/006) issued by the Medical Devices Agency (now the Medicines and Healthcare products Regulatory Agency) in 2003 and the associated Scottish Safety Action Notice in 2003 [(SAN(SC)03/14].[49,50]

Improved ventilation within cabins has also enhanced safety by increasing patient comfort and making it less likely that they will become faint and stumble.

Through better-fitting doors and UV-opaque viewing windows, newer cabin designs generally have lower UV leakage. Moreover, most cabin doors are now interlocked so that the exposure will stop immediately if a patient pushes against the door. Interlocked patient-actuated pull cords fitted in some cabin designs have a similar safety function. It may be acceptable to continue to use older cabins without such safety features provided an assessment is made of their safety in the light of current regulatory requirements and best practice guidance.

Regular cleaning of cabins is imperative for infection control. Accumulated skin flakes and dust on lamps can also degrade the cabin output and internal dosimetry systems. Thorough cleaning of cabins – screens taken out and cleaned, reflectors and lamps wiped, and accumulated dust removed – can increase the output of cabins by up to 20% (Amatiello, personal communication).

Although concerns have been raised about the safety of patients with artificial implanted devices, a recent investigation in two phototherapy cubicles demonstrated that the cabinets were safe for patients fitted with electrical implanted devices, such as pacemakers.[51]

8.4 Fluorescent tube replacement

The absolute output declines as lamps age. For Philips type TL-01 100 W fluorescent tubes, this decline is rapid over the first 200 operating hours, dropping to 60–70% of the initial intensity, before maintaining a relatively constant output until lamp failure. There is a large variation in operating life depending upon local circumstances: in one study, mean $\pm$ SD lamp lifetime was observed to be 470 $\pm$ 170 h.[30]

When lamps fail, 'cold spots', or areas of lower localized irradiance, are formed within the overall irradiance distribution, thereby underdosing an area of the patient. New tubes have higher irradiances and so create 'hot spots' or areas of higher localized irradiance. For cabins of the size supplied by most manufacturers, single-lamp failures give cold spots with 7–12% lower irradiances, and replacement with a new lamp gives hot spots of 3–6%. If failed lamps are replaced promptly, localized patient erythema is unlikely. However, in cabins with fewer lamps, where each lamp contributes more to the overall irradiance, and in smaller cabins where the contribution to irradiance from individual lamps is more localized, irradiance may be some 30% lower in cold spots from single-lamp failures. This effect is particularly important

in dual UVA/NB-UVB cabins as these have fewer lamps of each type, meaning the impact of a failed lamp is greater. An added complication is that failed lamps are more difficult to identify among lamps of the other type that are not illuminated.[30] A robust system to identify and replace failed lamps is therefore required.

Replacement of lamps should be carried out in accordance with an agreed policy that is known and understood by the end-users. One option is to replace all lamps when treatment times become unacceptably long; an alternative strategy is to replace those lamps showing a low output so that irradiance in the cabin is kept constant, for example within 10–20% of a desired figure.

To avoid accidental treatment with the wrong UV spectrum, it is critical that the correct fluorescent tubes are fitted in the cabin. Some suppliers label NB-UVB tubes with blue and red stickers for easy identification but this helpful practice is not a requirement. This means that there remains a risk of an unlabelled NB-UVB tube being fitted in to a UVA cabin, or vice versa, with potentially serious clinical consequences. Recommendations concerning identification have been made in the 2012 Estates and Facilities Alert (EFA/2012/002).[52]

8.5 Phototherapy equipment recommendations (strength of recommendation D; level of evidence 4)

Consider uniformity of dose distribution, treatment times, control mode options and installation implications when selecting whole-body cabins. Cabins fitted with tubes providing identical spectral output are recommended over cabins that can be switched to operate two (or more) different spectral outputs. The use of cabins with dosimetry systems providing a biologically weighted dose are not recommended. Regular measurements using a calibrated UV radiometer should be made in order to assess the irradiance to which patients are exposed by phototherapy equipment and to check the accuracy of any dosimetry systems that are incorporated within the equipment. An infection control and hygiene policy should be in place to ensure adequate cleaning of equipment and other surfaces in phototherapy areas. A lamp replacement policy should be in place to ensure that failed or low-output lamps are replaced with lamps of the correct type, and that localized areas of low or high irradiance are avoided.

9.0 Ultraviolet lamp types

Most UV sources for phototherapy are low-pressure, mercury vapour fluorescent lamps (Fig. 1). See elsewhere for a comprehensive description of optical radiation sources in healthcare.[53] NB-UVB is provided by Philips TL-01 lamps with peak output at 311 nm, or Arimed 311 lamps with a slightly longer wavelength peak at 313 nm. Both of these are within the action spectrum for the clearance of psoriasis established by Parrish and Jaenicke,[54] but the Arimed 311 has slightly more energy in the lower, more erythemogenic region below 310 nm. Philips supply the same phosphor in 9 W bi-pin and 36 W four-pin compact fluorescent tube format, and in 20 W (0·6 m), 40 W (1·2 m), 100 W (1·8 m) and the newer 120 W (2 m) straight-tube format.

BB-UVB lamps emit energies from UVC through to UVA, with peak energy in UVB. Waldmann UV6 and UV21, and Philips TL-12 emit their main energy between 280 nm and 360 nm, with a maximum at 320 nm. They emit wavelengths outside the action spectrum for the clearance of psoriasis so are more erythemogenic than NB-UVB lamps. Their use has declined significantly since the introduction of NB-UVB lamps.

PUVA uses BB-UVA lamps that emit over the whole of the UVA spectrum (315–400 nm, peak 350 nm). Lamps manufactured by Philips are labelled as tanning products in the Cleo range ('Cleo Performance' tubes are often supplied for PUVA). There are many Cleo lamps, and recently the 'Cleo Natural' lamp has been introduced, which has a higher UVB content. They are also supplied as 'PUVA lamps', and are available in similar size and wattage options as described above for NB-UVB lamps. Some UVA lamps have an inbuilt reflector to increase the irradiance; these are designated 'R-UVA'.

There is some evidence for the effectiveness of long-wave UVA1 (340–400 nm) for phototherapy. Fluorescent lamps of

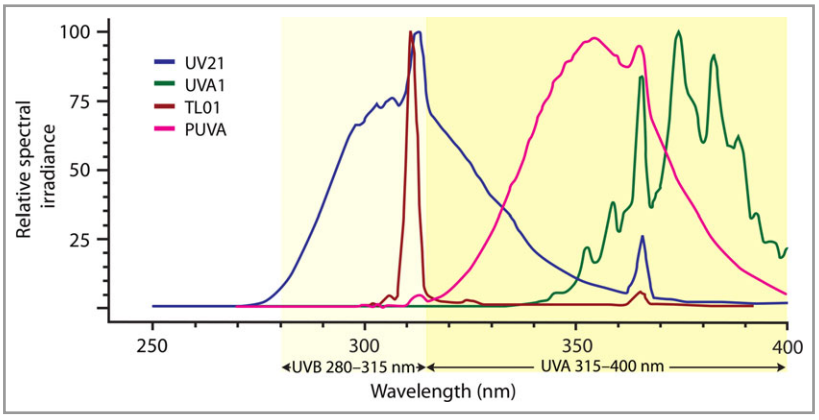

Fig 1. Spectral outputs of typical fluorescent ultraviolet (UV) therapy lamps. PUVA, psoralen combined with UVA photochemotherapy.

the Philips TL-10 phosphor are available for populating conventional phototherapy cabins. This is a NB-UVA lamp with emission between 350 nm to 400 nm, peaking at around 370 nm.

Other phototherapy sources include medium-pressure metal halide lamps (iron or cobalt halides are common). These emit broadly across the UV and visible spectra, so are almost exclusively used with filters to shape the output spectrum. They are available in power ratings up to 2–3 kW, so are used in UVA1 phototherapy units with output irradiances in the range of 90–130 mW cm^{-2}.

10.0 Patient variables

Skin type and habits affecting routine UV exposure together determine the UV dose that the skin can endure without an adverse reaction. The choice of irradiance level at which treatments can begin is not straightforward as skin responses will vary for different parts of the body. It is further complicated by the fact that the shape and size of each individual influence the irradiance levels at the skin.

The overriding factor determining the dose at which to start a phototherapy treatment is the patient's own UV skin sensitivity. The UV dose required to produce erythema, the minimal erythema dose (MED), varies by a factor of about four in white people.[55,56] Owing to differences in psoralen pharmacokinetics, the minimum phototoxic dose (MPD) for PUVA treatment is even more variable,[57] varying by a factor of at least 10 between individuals.[58] Therefore, the appropriate starting dose must be determined for any treatment; this can be done either by skin phototyping or measurement of the MED or MPD.

Phototyping is used by two-thirds of U.K. dermatology departments.[59] Most employ a simple visual assessment based on the Fitzpatrick scale.[55] However, this is subjective and combines two different types of skin reaction: generation of erythema and the ability to tan.[55] Some studies show that skin type and MED are correlated, although with significant overlap between types,[60–63] while others report that it is not a good predictor of erythemal response.[64–66]

To select the starting dose and exclude the possible risk of severe burns many centres measure MED for each patient prior to commencement of treatment. An assessment is then made of the dose for which a trace of erythema is apparent 24 h later. A similar system is used for measuring the MPD prior to PUVA, but the erythema has a delayed onset, so the assessment is made 72 h after exposure. Commercial units enable the phototherapist to expose small areas of skin to different UV doses. One type that closes electrically operated shutters at predetermined times can be used with the treatment source. Another has a series of windows covered by grids of differing hole size that attenuate the UV by different amounts, allowing a range of doses to be given with a single treatment time.[4,59,67,68] If these MED testers are to be useful it is important that they are calibrated to the same UV spectrum as the treatment units. An important requirement for accurate use of these testers is that the aperture through which a patch of skin is irradiated is located in close contact with the skin.

The UV sensitivity of an individual varies by a factor of about 1·5 between body sites.[69] Skin on the trunk is typically more sensitive than on the limbs,[70] and is recommended for MED testing. Following a test, the treatment starting dose is typically chosen to be 40–70% of the MED or MPD.[71]

Clearing of psoriasis is faster from the trunk than the lower legs. One reason for this is that the legs tend to have a thicker stratum corneum and higher pigmentation.[71] However, in addition, the intensity towards the base of the cabin is lower, as fluorescent UV outputs fall towards the ends of the lamps in treatment cabins.[48] Increasing the treatment time for the lower legs by a factor of 1·5 can compensate.

Measurements on manikins show that for a walk-in, whole-body cabin, the majority of the body receives > 70% of the maximum dose (Fig. 2).[11] Higher irradiance levels occur at the outer aspects of the arms and shoulders, and those at the lower legs are 25% less.[48] Sites inclined at an angle to the plane of the lamps, such as the tops of the feet and shoulders, receive lower doses; doses to the sides of the body may only receive 50% of the maximum because the area is shielded by the arms. Areas such as the axillae, groin and palms of the hands may receive only about 30% of the maximum dose.[72] Although there is a paucity of published data, it is expected that the dose to the face is reduced in tall patients.

Phototherapy cabins incorporate reflectors, usually made from aluminium, to the rear of the lamps to enable as much of the light emitted to be utilized;[43] these also reflect UV from

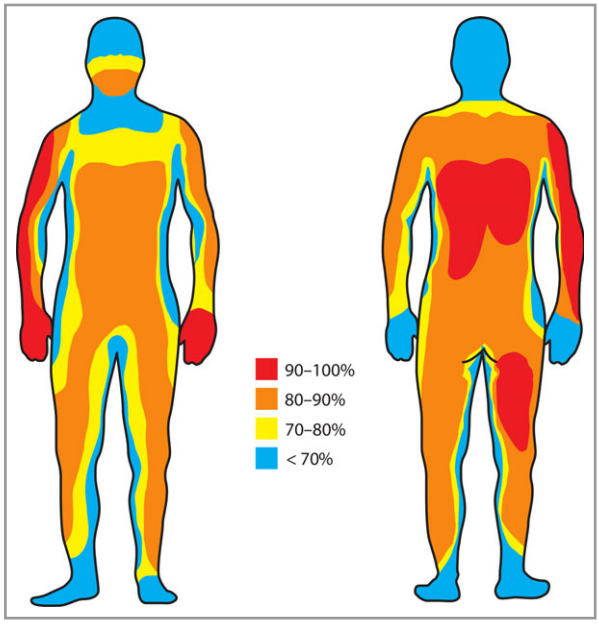

Fig 2. The relative distribution of ultraviolet (UV) dose on the surface of a manikin resulting from whole-body radiation in a psoralen combined with UVA photochemotherapy 6000 unit (n.b. the difference in UV dose between the two arms is due to higher intensity on one side of the cabin). Adapted from Diffey *et al.*[11]

other parts of the cabin. Thus, when there is a patient in the cabin, the UV irradiance level falls because the patient absorbs some of the UVR. Correction factors are applied to allow for this, with measurements made by the indirect method, described in section 14·2. For NB-UVB, factors between 0·85 and 0·96 have been reported, and for UVA factors between 0·80 and 0·87 have been reported.[47,73] The factor may be less for both smaller and elliptical cabins, as the patient intercepts a larger proportion of the UVR emitted. For the small Waldmann UV 1000 PUVA cabins, the correction factor is 0·68–0·75.[45,47] These differences depend on the reflectivity of the aluminium, but large body sizes also reduce the conversion factor by up to 10%.[47,73]

10.1 Patient variables recommendation (strength of recommendation D; level of evidence 3)

The spectral output of a source used for MED/MPD testing should be identical to that used for the treatment.

11.0 Ultraviolet measuring equipment

11.1 Ultraviolet radiometers

The importance of using appropriate and suitably calibrated UV radiometers has been repeatedly recognized as critical for the safe and effective delivery of phototherapy treatments.[3,17,45,74–76] Several descriptions of the features and characteristics of UV radiometers have been published previously.[77,78] The key components of a radiometer and its performance attributes are summarized in the following subsections.

11.1.1 Ultraviolet sensor

The UV sensor converts incident UV energy into an electrical signal. In many radiometers, the sensor is a silicon photodiode. Silicon photodiodes have a spectral response extending over UV wavelengths, visible light and near-infrared radiation. At shorter UV wavelengths, vacuum photodiode sensors are often employed.[28,29,79] Gallium arsenide phosphide photodiodes are also effective UV sensors.[80] Thermopile sensors have been used in the past for UV dosimetry work,[81,82] but are now normally used only in special situations where their distinctively flat spectral response is advantageous.

11.1.2 Optical filter and spectral response

UV sensors have broad spectral responses so the UV wavelength range to be measured must be separated from any unwanted or out-of-band radiation by an optical filter. With different filters, radiometers based on silicon photodiodes can be made to respond primarily either to UVA or UVB wavelengths. Practically achievable spectral responses do not cut off sharply at exact wavelengths but instead tail off at either end of the range. Several examples of radiometer spectral responses have been published.[29]

A special example of a filter-modified response is that of a radiometer with a net spectral response mimicking the hazard-weighted action spectrum. This can be achieved with a vacuum photodiode sensor and a matched filter.[79] Such radiometers can be calibrated to indicate directly hazard-weighted irradiances with acceptable accuracy, irrespective of the exact emission spectra of the UV source. This can aid the assessment of occupational UV exposures.

11.1.3 Input optic and angular response

The input optic of a radiometer is of great importance in UV phototherapy measurements. To measure irradiance correctly, the radiometer response must vary as the cosine of the angle of incidence of UV rays. This is often referred to as the 'cosine response'. Irrespective of type, no UV sensor will give a true cosine response on its own. The closeness or otherwise of a radiometer's angular response to a true cosine response can be described by the f_2 error.[32,83] The ideal cosine response can be closely approximated by fitting an optical diffuser as the front element of the UV radiometer. Commonly, diffusers are formed of either a Teflon® disc or of quartz. The quality of the angular response depends critically on the exact construction and shape of the diffuser.[32] Other examples of radiometer angular responses have been given by Coleman *et al.*[29] As a deficient angular response can cause substantial errors in some UV irradiance measurements, especially those within whole-body phototherapy cabins, this aspect of radiometer performance has been investigated in detail.[32,33,84] It has been concluded that an f_2 error of $\leq$ 10% is necessary for good accuracy in calibrating whole-body cabins,[45] and that reducing the f_2 error to $\leq$ 5% is desirable.[3,32]

11.1.4 Dynamic range

Dynamic range is the span between the lowest and highest UV intensities to which a radiometer responds correctly. A range of 0·05–50·00 mW cm^{-2} is likely to be adequate for normal phototherapy work.[3]

11.1.5 Linearity

If a radiometer has a linear response, it will indicate fractional changes in UV irradiance correctly, irrespective of the general irradiance level. The wider the dynamic range, the more important it is to ensure accurate linearity of response throughout that range. For routine phototherapy work, a deviation of < 2% from true linearity has been recommended.[3] Safety measurements around UV phototherapy equipment are particularly demanding of dynamic range and linearity,[85] but higher-quality radiometers are likely to offer sufficient performance.[79]

11.1.6 Resolution

Within the electronic circuitry of the radiometer, any internal analogue-to-digital convertor and the meter display must have

sufficient resolution to indicate the measured UV irradiance to adequate numerical precision for the purpose. Typically, a digital readout with a display resolution of $\pm 0{\cdot}1$ mW cm^{-2} is adequate for most clinical phototherapy applications.

The foregoing considerations result in UV radiometers coming in many formats and with differing levels of performance. Several examples are shown in Figure 3. One size does not fit all; the imperative is to match the radiometer's capabilities to the measurement task, taking into account such factors as the spectrum to be measured, irradiance levels and whether the measurement is a relative check of constancy of an absolute calibration.

11.2 Spectroradiometers

Spectroradiometers separate electromagnetic radiation into its component wavelengths and measure spectral irradiance within each waveband. The measured radiation is expressed in radiometric units such as mW cm^{-2} nm^{-1}. There are two types of spectroradiometer, the scanning spectroradiometer (SSR) and the charge-coupled device (CCD) array. SSRs have more sensitivity than CCD arrays but are slower and less suitable for field-based measurements. CCD arrays are used where simultaneous, almost real-time updating of the whole spectrum is required, although some CCDs suffer from high levels of stray light. CCD spectroradiometers utilizing two-dimensional arrays can be used as imaging spectroradiometers. Spectroradiometers may be calibrated by exposure to a well-characterized source of light with known spectral irradiance. The National Physical Laboratory (NPL) in the U.K. provides calibrations of such reference sources. Such sources need to be highly stable. Typically, deuterium and/or tungsten lamps are used with stabilized power supplies.

CCD arrays are relatively cheap and are easy to use in the field. However, they must be used with the same level of care in terms of calibration and conditions of use as apply to the traditional SSRs. They are prone to high levels of stray light, which can introduce significant errors, and they also require to be calibrated to compensate for quantum efficiency.

Fig 3. Examples of ultraviolet radiometers.

11.2.1 Scanning spectroradiometers

Input optics gather radiation from a specific field; for phototherapy lamp measurements a cosine diffuser on the input is required if the spectroradiometer is to provide irradiance at a surface such as that presented by the skin.

The monochromator consists of a diffraction grating of finely etched or holographically printed parallel lines that produce a wavelength-dependent angular dispersion of light. Light enters through an input slit and is directed onto the diffraction grating via collimating optics. The grating is rotated to scan the separated spectrum across an exit slit, which delivers a small range of wavelengths to the detector. The exit slit (usually the same width as the input slit) then defines the range of wavelengths of light (typically a few nanometres) emerging from the monochromator. As stray light can introduce significant measurement errors in phototherapy applications, double monochromator spectroradiometers are typically recommended where accurate measurements are required. Stray-light rejection factors (the ratio of stray to incident light) of up to 10^{-6} are achievable with double monochromator systems – some 1000 times better than single monochromator designs.

The detector measures the intensity of radiation within each wavelength range: commonly used detectors are photodiodes or photomultiplier tubes.

11.2.2 Charge-coupled device array

Input optics usually comprise an optical fibre with a diffuser at the distal end. However, for accurate measurements from phototherapy lamps, a cosine-corrected diffuser is essential.

The monochromator is a compact static grating.

The detector is a CCD array (single-line or two-dimensional array), which measures the whole or a large part of the spectrum reflected from the grating. This allows capture of the whole spectrum simultaneously. Wavelength resolution is determined by the number, size and separation of the CCD elements, the grating characteristics and the optical geometry.

More information on spectroradiometry can be found elsewhere.[77,86,87]

11.3 Ultraviolet calibration recommendations (strength of recommendation D; level of evidence 4)

A spectroradiometer used to calibrate phototherapy sources should itself be traceably calibrated to a primary reference standard at regular intervals.

A double-grating design is recommended to ensure adequate rejection of stray light by the spectroradiometer.

12.0 Ultraviolet radiometer calibration certificates

One of the significant advances in dosimetry for U.K. phototherapy over the last decade has been the introduction of traceability in UV radiometer calibrations. It is now considered good practice for phototherapy centres to retain documentary evidence of traceable UV radiometer calibrations. Such evidence, typically in the form of a calibration certificate, should contain – at the very least – details of the provenance of the calibration, the date it was carried out, the calibration factor for the identified radiometer and a statement of the uncertainty of the calibration. It is important to calibrate the radiometer to the correct source, that is, the lamp spectrum that it will be used to measure. Although frequency of calibration is somewhat arbitrary, it is generally accepted that recalibration should be carried out annually. These certificates represent a phototherapy centre's evidence that they are managing the UV dosimetry in a manner that provides consistency with other centres. The term 'measurement traceability' is used to refer to an unbroken chain of comparisons relating an instrument's measurements to a known standard. In the U.K., traceability can be obtained under the NMS. The NMS promotes an infrastructure of calibration laboratories that can demonstrate traceability of measurement to primary scales at a National Measurement Institute (NMI) via ISO 17025 compliance. These laboratories are currently audited and accredited by the United Kingdom Accreditation Service (UKAS). It is good practice to use an accredited laboratory to undertake radiometer calibration.

The National Physical Laboratory is the U.K.'s NMI and realizes the national scales and standards for UVR from which UKAS-accredited laboratories themselves ultimately acquire their traceability. NMIs in other countries include the National Institute of Standards and Technology (U.S.A.), the Laboratoire National de Métrologie et d'Essais (France) and the Physikalisch-Technische Bundesanstalt (Germany). An intercomparison of spectral irradiance measurements by 12 NMIs in 1991 found the SD was about 2% in the UV region, demonstrating the high level of measurement accuracy and consistency that these laboratories can achieve.[88]

12.1 Ultraviolet radiometer calibration certificates recommendation (strength of recommendation D; level of evidence 4)

Phototherapy centres should retain certificates to demonstrate traceability of calibrations for any UV radiometers used in patient dosimetry. Recalibration of the radiometer should be performed regularly. It is good practice to do this annually.

13.0 Meter calibration methodology

Performing accurate and traceable calibration of UV radiometers for phototherapy applications is difficult and is most appropriately provided by specialist laboratories that can provide users with documentary evidence of traceability to national standards by, for example, accreditation to ISO 17025, the globally recognized standard developed specifically for testing and calibration laboratories. Such laboratories can

provide calibrations either by comparison with measurements of a BB-UV source made with a traceably calibrated spectroradiometer, or by comparison with measurements made in a monochromatic beam with a traceably calibrated radiometer. These two approaches are both valid and require access to calibrations made at a national measurements laboratory.

A UV radiometer calibration must not only be accurate, but must also be appropriate for the particular application in which the radiometer is used. Some manufacturers provide new radiometers with a calibration at a single wavelength, typically 365 nm for a UVA radiometer. This may be adequate for many industrial uses but for most phototherapy applications an appropriate BB-UV calibration is required. All UV radiometers must therefore be individually calibrated for every type of UV source to be measured, typically UVA, NB-UVB and BB-UVB. Similarly, UVA1 treatments can be provided by mercury discharge, metal halide lamps or fluorescent tubes. These can have significantly different spectral outputs and a radiometer calibration factor is needed for each type of source. ISO 17025 requires that the calibration provided must be appropriate for its intended use. This standard therefore provides users with some assurance that the calibration is appropriate for the specified phototherapy application. The following sections describe how BB-UV calibrations are made.

13.1 Calibration using a calibrated spectroradiometer

In this method, a lamp that has been calibrated at the NPL functions as the transfer standard.[89] It is set at a defined distance from a spectroradiometer (which should be a double-grating device) in an accurate and reproducible manner, such that it replicates the distance and orientation at the NPL when the calibration was carried out. The calibration laboratory should have at least one other similar lamp and a second lamp of a different type, for example a tungsten filament lamp and a deuterium lamp, to allow for internal quality control checks to be performed. The spectroradiometer should be calibrated either each time it is used or on a regular basis (e.g. annually), with checks carried out in between. The calibrated spectroradiometer may then be used to calibrate the UV detector against specific lamps, for example PUVA and TL-01 in the following way: (i) measure the spectral irradiance from the desired lamp using the calibrated spectroradiometer; (ii) integrate the spectral irradiances across the waveband of interest; (iii) substitute the UV detector in place of the spectroradiometer and note the reading; (iv) adjust the meter display or provide a correction factor to give agreement with the integrated spectroradiometer value

Because UV detectors do not have a uniform wavelength sensitivity, calibration must be repeated for each different type of lamp.

13.2 Calibration using a calibrated radiometer

This method uses a calibrated reference detector as the transfer standard.[21] The responsivity of the test detector at a particular wavelength in a normally incident beam is measured. It is determined by intercomparison with the calibrated reference detector in light generated by a Xe(Hg) arc lamp, which passes through a condenser lens, filter and monochromator system. The absolute spectral responsivity of the test detector is determined at a single wavelength, and the relative spectral responsivity at other wavelengths is obtained. Angular response of the detector is then measured and an angular correction factor applied to take into account the angular distribution of radiance in a whole-body treatment cabin. The measured meter characteristics are then used along with tabulated data on the spectral properties of the source, obtained using a spectroradiometer.

Uncertainty of the reference detector is slightly less than that of the calibration lamp but the final overall uncertainty of the UV detector calibrated by either method is very similar. Intercomparisons between two accredited laboratories following ISO 17025, one using a lamp-based calibration and the other detector-based, show good agreement (within 4%; Moseley and Coleman, personal communication).[89]

13.3 Meter calibration recommendations (strength of recommendation d; level of evidence 4)

UV radiometers used for dosimetry in phototherapy should be calibrated annually with a calibration traceable to a national standard.

Users should ensure that calibrations are obtained from calibration laboratories that have a robust methodology in place so that the UV radiometer calibration is accurate, reproducible and appropriate for the application.

14.0 Whole-body cabin measurements

The dose the patient receives during UVR exposure should be as close to the prescribed dose as possible. There are a number of methodologies to help achieve this but all involve competent calibration of the phototherapy units. Light output and performance of the fluorescent lamps are affected by the temperature of the lamp wall. For this reason, the lamps should be switched on for a sufficient time (usually around 5 min) to allow the output to stabilize before taking measurements.[90] It is well understood that the final radiation incident upon the patient's skin is from both direct irradiance from the lamps and from reflected radiation from the reflectors. The patient's skin absorbs some of the incident radiation and also reflects some back into the cabin. The calibration method employed should make allowance for this patient effect on the final irradiance. There are two commonly used approaches to achieve this: the direct and the indirect method.[45]

14.1 Direct method

In this approach the patient effects on the cabin irradiance are accounted for by physically entering the cabin (while fully protected from the UV) and holding the radiometer close to

the body to measure, as realistically as possible, the irradiance at the position of the skin. While the cabin is switched on, the assessor takes 12 body site measurements: four at chest level (anteriorly, posteriorly, and on their left and right sides), four at waist level and four at knee level (Fig. 4). The mean of these 12 irradiance measurements, the designated patient irradiance, is then taken as the irradiance used to determine treatment times for UV dose delivery, and inherently accounts for the effect on the irradiance of the presence of the patient in the cabin. Some centres measure around the body at mid-tube height only in order to capture the highest irradiance values but this overestimates the average dose to the body. Any potential problems caused by using the DPI are easily rectified by using a slightly lower treatment dose. The advantage of DPI is that it is a standardized methodology that facilitates intercomparison between treatment centres.

As an assessor is physically entering a cabin there is an obvious requirement for them to wear the necessary PPE and ensure that all exposed skin (including areas that may be overlooked, such as the top of the head or the back of the neck) and the eyes are adequately protected. Generally, the use of overalls and gloves are employed, supplemented by the use of a high-factor sunscreen on skin that cannot be covered. The eyes and face should be protected with the use of a visor. It should be noted that some protective clothing may be more reflective than human skin.[76,91]

14.2 Indirect method

This method does not involve a person entering the cabin to perform the calibrations, which gives an obvious safety advantage. Instead, the radiometer is set up in an empty cabin, at mid-height on a tripod or similar support. The irradiance of each bank of detectors is measured in turn. A device for automating the measurements by scanning a radiometer probe around a 360° circle, 30 cm in diameter, at waist height has been described.[92]

The mean irradiance measured in this way will generally be higher than that actually incident on the patient's skin as there will be no patient shielding of the radiometer. Therefore, it cannot be used as the DPI. In this case, the mean irradiance must be corrected for patient effects by multiplying by an occupancy correction factor (the ratio of the irradiances measured in the occupied and unoccupied cabin). Occupancy correction factors are tabulated for the more common cabin designs, obviating the need for their measurement in most cases.[45,47,73,93] However, as the occupancy correction factor can depend somewhat on the combination of the cabin design and the angular response of the radiometer, there is merit in checking the factor for each combination of cabin type and radiometer in use at each centre.

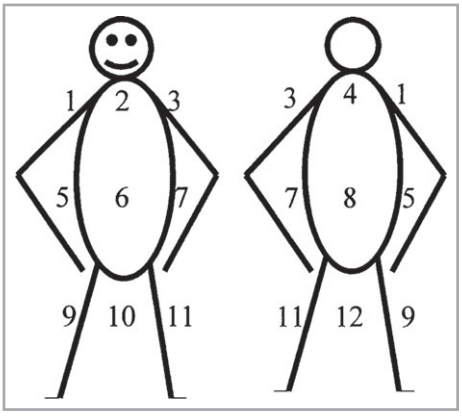

Fig 4. Diagram showing the body sites used to determine the designated patient irradiance.

14.3 Application of irradiance readings

Having obtained a DPI directly or indirectly, it is relevant to discuss how this value should be used. This will depend on the clinical mode of operation of the cabin.

14.3.1 Time-controlled mode

Where cabins are operated in time-control mode, the DPI value is used to calculate the treatment time to deliver the prescribed dose.

$$\text{Dose } (\text{mJ cm}^{-2}) = \text{DPI } (\text{mW cm}^{-2}) \times \text{time (s)}.$$

Likewise, for equipment such as the Waldmann UV1000L, where the cabin controller nominally operates in a dose–control mode but where the exposure time is actually calculated internally by the controller from a stored irradiance value, it is the patient irradiance figure that must be programmed into the cabin controller.

14.3.2 Manual dose–control mode

Some other cabins, such as the Waldmann UV5001 series units, operate in a manual dose–control mode. The operator enters a dose in J cm^{-2}, which is automatically converted to an exposure time based on a stored irradiance value. This stored irradiance value is periodically refreshed by an internal self-test. In this case, the measured DPI should be compared with the stored irradiance value to determine whether the cabin calibration based on the self-test is satisfactory. Agreement should be within 10%.

14.3.3 Automated dose–control mode

For cabins fitted with a continuously integrating internal irradiance metering system and operated in dose–control mode, the DPI should be compared directly with the irradiance value from the cabin's internal metering system. Verifying that the internal detector system compensates appropriately for patient occupancy requires some form of direct-method measurement.[48] Again, the cabin dosimetry system should provide an irradiance that is within 10% of the DPI obtained using either the direct or indirect method.

14.4 Whole-body cabin measurement recommendations (strength of recommendation d; level of evidence 4)

The DPI in all treatment cabins should be regularly measured, directly or indirectly, using a traceably calibrated radiometer.

All irradiance values used in the calculation of patient dose should be within 10% of the measured DPI.

15.0 Organizational and financial implications

Any organization providing phototherapy or photochemotherapy must have a system in place to ensure that any patient undergoing treatment receives the prescribed dose to an acceptable level of accuracy. To this end, there must be a person with suitable expertise in medical physics appointed who has the knowledge and experience to oversee the dosimetry programme. This person will have the responsibility for the UV measurement programme, whether it is carried out in-house or outsourced. The responsible person should ensure that measurements are performed in a suitable manner, at the required frequency, and using appropriate and calibrated equipment. This is equally applicable to units that use internal detectors, as their calibration must also be monitored.

16.0 Future directions

NB-UVB treatment represents an important and relatively new therapy for psoriasis.[94] It has largely replaced both BB-UVB and PUVA as the initial choice for full-body phototherapy.[95] However, dosimetry in clinical NB-UVB (311 nm) therapy remains a problematic area. An intercomparison of the calibrations provided by seven medical physics departments for the same radiometer showed that the ratio between the maximum and minimum calibration factors was 2·74 for NB-UVB.[28] It is clearly important that treatment centres should all be using radiometers with calibrations performed by laboratories offering assured traceability. Clearly, continued data gathering and evaluation is needed to provide assurance that NB-UVB therapy doses are consistent across the U.K. and that sources of uncertainty that apply particularly to NB-UVB dosimetry are fully understood.

Single monochromator detector CCD array spectroradiometers have become widely available over the last decade and are valued as field instruments, being easily portable and relatively cheap compared with mechanical double-grating spectroradiometers.[96] They are also fast, providing a spectral measurement in < 1 s compared with several minutes using a mechanical double-grating instrument. This enhanced speed of spectral acquisition opens up the possibility of new

Table 1 Guideline recommendations

Safety	A suitable assessment of risk should include the measurement of environmental UVR levels to which staff are exposed and the identification of appropriate control measures
	Environmental UVR levels should be within the maximum permissible levels proscribed in the Control of Artificial Optical Regulation at Work Regulations 2010
Phototherapy equipment	Consider uniformity of dose distribution, treatment times, control mode options and installation implications when selecting whole-body cabins
	Cabins fitted with tubes providing identical spectral output are recommended over cabins that can be switched to operate two (or more) different spectral outputs
	The use of cabins with dosimetry systems providing a biologically weighted dose are not recommended
	Regular measurements using a calibrated UV radiometer should be made in order to assess irradiance to which patients are exposed by phototherapy equipment and to check the accuracy of any dosimetry systems that are incorporated within the equipment
	An infection control and hygiene policy should be in place to ensure adequate cleaning of equipment and other surfaces in the phototherapy areas
	A lamp replacement policy should be in place to ensure that failed or low-output lamps are replaced with lamps of the correct type, and that localized areas of low or high irradiance are avoided
Patient variables	The spectral output of a source used for MED/MPD testing should be identical to that used for the treatment
UV calibration equipment	A spectroradiometer used to calibrate phototherapy sources should itself be traceably calibrated to a primary reference standard at regular intervals
	A double-grating design is recommended to ensure adequate rejection of stray light by the spectroradiometer
UV radiometer calibration certificates	Phototherapy centres should retain certificates to demonstrate traceability of calibrations for any UV radiometers used in patient dosimetry
	Recalibration of the radiometer should be performed regularly; it is good practice to do this annually
Meter calibration methodology	UV radiometers used for dosimetry in phototherapy should be calibrated annually with a calibration traceable to a national standard
	Users should ensure that calibrations are obtained from calibration laboratories that have a robust methodology in place so that the UV radiometer calibration is accurate, reproducible and appropriate for the application
Whole-body cabin measurements	The DPI in all treatment cabins should be regularly measured by a direct or indirect method, using a traceably calibrated radiometer
	All irradiance values used in the calculation of patient dose should be within 10% of the measured DPI

UV, ultraviolet; UVR, ultraviolet radiation; MED, minimal erythema dose; MPD, minimum phototoxic dose; DPI, designated patient irradiance.

applications in UV dosimetry for phototherapy, as well as time-resolved spectral measurements in research applications. However, owing to large errors that can arise from their relatively poor stray-light rejection performance, the use of array spectroradiometers for clinical UV dosimetry is not yet feasible.[24] For this reason these devices are currently used in phototherapy applications requiring only relative rather than absolute spectral measurements in clinical applications, such as assessing lamp spectra. There have been efforts to reduce stray-light errors in these instruments,[23] and manufacturers have started to implement such improvements with phototherapy applications in mind. Continued careful evaluation of new instrumentation will be required before these devices can be safely introduced to replace radiometers for clinical UV dosimetry.

Of the recent innovations in cabin design, perhaps the most significant for UV dosimetry over the last decade has been the introduction of inbuilt metering systems that are intended to provide fully automated dosimetry. The medical physics community in the U.K. has been generally sceptical about the accuracy of some of the these systems from experience in comparing the readings they provide with those from hand-held calibrated radiometers used inside the cabins; however, there is little comprehensive published evidence relating to the accuracy of different systems, although there is some evidence that dual detector systems can be accurate.[30] This is an area in which more research is needed. By supporting the improvement and development of this technological innovation in dosimetry through careful evaluation of the practical issues in the clinic with such systems, it should be possible to ensure that this technology is introduced in the safest and most effective way for the benefit of phototherapy services.

17.0 Recommended audit points

Over the last 12 months was there:

1 a log of cabin maintenance?
2 a regular log for UV irradiance measurements for all treatment equipment and that the values were within accepted ranges?
3 a log of radiometer calibration for each type of UV source, identifying the method, its traceability to known national standards and the waveband over which irradiance is measured?
4 a log of dosimeter comparisons between built-in UV dosimeters and directly measured irradiance values, and that the values were within reasonable tolerance (±10%)?
5 a log of an electrical safety standards compliance test?
6 a review of UV exposure risk assessment?

18.0 Summary

See the full article for details of evidence.

As indicated in section 6·0 'Background', undertaking clinical trials is not appropriate in this context. As the current system used for grading the strength of recommendations is directly related to the type of study, all recommendations made in this guideline can only be given a strength of recommendation of D (see Table 1 and Appendix 2).

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References

1 Bell HK, Ormerod AD. Writing a British Association of Dermatologists clinical guideline: an update on the process and guidance for authors. *Br J Dermatol* 2009; **160**:725–8.
2 Brouwers MC, Kho ME, Browman GP *et al.* AGREE II: advancing guideline development, reporting and evaluation in health care. *Can Med Assoc J* 2010; **182**:E839–42.
3 Taylor DK, Anstey AV, Coleman AJ *et al.* Guidelines for dosimetry and calibration in ultraviolet radiation therapy: a report of a British Photodermatology Group workshop. *Br J Dermatol* 2002; **146**:755–63.
4 Diffey B. The contribution of medical physics to the development of psoralen photochemotherapy (PUVA) in the UK: a personal reminiscence. *Phys Med Biol* 2006; **51**:R229–44.
5 Legislation.gov.uk. The Control of Artificial Optical Radiation at Work Regulations 2010. Available at: http://www.legislation.gov.uk/uksi/2010/1140/contents/made (last accessed 1 July 2015).
6 Department of Health. Clinical governance guidance. Available at: www.gov.uk/government/news/clinical-governance-guidance (last accessed 1 July 2015).
7 Diffey BL. Ultraviolet radiation physics and the skin. *Phys Med Biol* 1980; **25**:405–26.
8 Wolff K, Gschnait F, Hönigsmann H. Phototesting and dosimetry for photochemotherapy. *Br J Dermatol* 1977; **96**:1–10.
9 Challoner AV, Diffey BL. Problems associated with ultraviolet dosimetry in the photochemotherapy of psoriasis. *Br J Dermatol* 1977; **97**:643–8.
10 Farr PM, Diffey BL. Treatment of actinic prurigo with PUVA: mechanism of action. *Br J Dermatol* 1989; **120**:411–18.
11 Diffey BL, Harrington TR, Challoner AV. A comparison of the anatomical uniformity of irradiation in two different photochemotherapy units. *Br J Dermatol* 1978; **99**:361–3.
12 Diffey BL, Challoner AV, Key PJ. A survey of the ultraviolet radiation emissions of photochemotherapy units. *Br J Dermatol* 1980; **102**:301–6.
13 Farr PM, Diffey BL. PUVA treatment of psoriasis in the United Kingdom. *Br J Dermatol* 1991; **124**:365–7.
14 Diffey BL, Roelandts R. Status of ultraviolet A dosimetry in methoxsalen plus ultraviolet A therapy. *J Am Acad Dermatol* 1986; **15**:1209–13.
15 Roelandts R, Diffey BL, Bocquet JL. [Is accurate UVA dosimetry in photobiology and photodermatology an illusion?]. *Ann Dermatol Venereol* 1988; **115**:1261–4 (in French).
16 Dootson G, Norris PG, Gibson CJ *et al.* The practice of ultraviolet phototherapy in the United Kingdom. *Br J Dermatol* 1994; **131**:873–7.
17 Bilsland D, Dawe R, Diffey BL *et al.* An appraisal of narrowband (TL-01) UVB phototherapy. British Photodermatology

Group Workshop Report (April 1996). *Br J Dermatol* 1997; **137**:327–30.
18 NICE. Phototherapy (broad- or narrow-band UVB light and (PUVA). Available at: https://www.nice.org.uk/guidance/cg153/chapter/1-Guidance#phototherapy-broad–or-narrow-band-uvb-light-and-puva (last accessed 1 July 2015).
19 Burden AD, Hilton Boon M, Leman J *et al.* Diagnosis and management of psoriasis and psoriatic arthritis in adults: summary of SIGN guidance. *BMJ* 2010; **341**:c5623.
20 Moseley H. Light distribution and calibration of commercial PDT LED arrays. *Photochem Photobiol Sci* 2005; **4**:911–14.
21 Coleman AJ. A new UKAS accredited calibration system for ultraviolet radiometers. *Radiat Prot Dosimetry* 2000; **91**:153–6.
22 Moseley H. Ultraviolet A dosimetry in photopatch test centres in Europe. *J Eur Acad Dermatol Venereol* 2005; **19**:187–90.
23 Coleman A, Sarkany R, Walker S. Clinical ultraviolet dosimetry with a CCD monochromator array spectroradiometer. *Phys Med Biol* 2008; **53**:5239–55.
24 Oliver H, Moseley H. The use of diode array spectroradiometers for dosimetry in phototherapy. *Phys Med Biol* 2002; **47**: 4411–21.
25 Richard EG, Hönigsmann H. Phototherapy, psoriasis, and the age of biologics. *Photodermatol Photoimmunol Photomed* 2014; **30**:3–7.
26 Sivamani RK, Goodarzi H, Garcia MS *et al.* Biologic therapies in the treatment of psoriasis: a comprehensive evidence-based basic science and clinical review and a practical guide to tuberculosis monitoring. *Clin Rev Allergy Immunol* 2013; **44**:121–40.
27 Stern RS, Nichols KT, Väkevä LH. Malignant melanoma in patients treated for psoriasis with methoxsalen (psoralen) and ultraviolet A radiation (PUVA). The PUVA Follow-Up Study. *N Engl J Med* 1997; **336**:1041–5.
28 Lloyd JJ. Variation in calibration of hand-held ultraviolet (UV) meters for psoralen plus UVA and narrow-band UVB phototherapy. *Br J Dermatol* 2004; **150**:1162–6.
29 Coleman AJ, Collins M, Saunders JE. Traceable calibration of ultraviolet meters used with broadband, extended sources. *Phys Med Biol* 2000; **45**:185–96.
30 Amatiello H, Martin CJ. Ultraviolet phototherapy: review of options for cabin dosimetry and operation. *Phys Med Biol* 2006; **51**:299–309.
31 British Standards Institute. ISO/IEC 17025:2005. General requirements for the competence of testing and calibration laboratories. Available at: http://www.iso.org/iso/catalogue_detail.htm?csnumber=39883 (last accessed 1 July 2015).
32 Pye SD, Martin CJ. A study of the directional response of ultraviolet radiometers: I. Practical evaluation and implications for ultraviolet measurement standards. *Phys Med Biol* 2000; **45**:2701–12.
33 Martin CJ, Currie GD, Pye SD. The importance of radiometer angular response for ultraviolet phototherapy dosimetry. *Phys Med Biol* 1999; **44**:843–55.
34 Drummond A, Kane D, Bilsland D. Legal claims in Scottish National Health Service Dermatology Departments 1989–2001. *Br J Dermatol* 2003; **149**:111–14.
35 Ong S, Coulson IH. Legal claims in English dermatological practice. *Br J Dermatol* 2011; **164**:217–19.
36 Mohd Mustapa MF. Dermatology in dispute. *BAD Newsletter* 2014; **17**:28.
37 Stern RS, Lunder EJ. Risk of squamous cell carcinoma and methoxsalen (psoralen) and UV-A radiation (PUVA). A meta-analysis. *Arch Dermatol* 1998; **134**:1582–5.
38 British Association of Dermatology. Working party report on minimum standards for phototherapy services. Available at: http://www.bad.org.uk/shared/get-file.ashx?itemtype=document&id=1621 (last accessed 1 July 2015).
39 British Association of Dermatologists. Phototherapy service review toolkit. Available at: http://www.bad.org.uk/healthcare-professionals/clinical-services/service-standards/phototherapy (last accessed 1 July 2015).
40 Koek MB, Sigurdsson V, van Weelden H *et al.* Cost effectiveness of home ultraviolet B phototherapy for psoriasis: economic evaluation of a randomised controlled trial (PLUTO study). *BMJ* 2010; **340**: c1490.
41 Cameron H, Yule S, Moseley H *et al.* Taking treatment to the patient: development of a home TL-01 ultraviolet B phototherapy service. *Br J Dermatol* 2002; **147**:957–65.
42 Grimes DR, Robbins C, Martin CJ *et al.* Reflection modeling in ultraviolet phototherapy. *Med Phys* 2011; **38**:4312–20.
43 Grimes DR, Martin CJ, Phanco G. Investigations of cabin design in UV phototherapy. *Med Phys* 2012; **39**:3019–25.
44 Grimes DR. A computational simulation of reflector and tube effects in ultraviolet phototherapy. *Phys Med Biol* 2012; **57**:6661–70.
45 Moseley H. Scottish UV dosimetry guidelines, "ScUViDo". *Photodermatol Photoimmunol Photomed* 2001; **17**:230–3.
46 Moseley H, Thomas R, Young M. UVB lamps: a burning issue. *Br J Dermatol* 1993; **128**:704–6.
47 Martin CJ, Clouting H, Aitken A. A study of the correction factor for ultraviolet phototherapy dose measurements made by the indirect method. *Br J Dermatol* 2003; **149**:1227–31.
48 Clarkson DM, Franks L. The use of a simulated body shape for determination of patient dosimetry within whole body ultraviolet treatment cabinets. *Phys Med Biol* 2006; **51**:N51–8.
49 Medical Devices Agency. *Medical Device Alert. Reference: MDA/2003/006 Ultraviolet (UV) Phototherapy Cabinets*. London: Medical Devices Agency, 2003.
50 NHS Scotland. Safety action notice. Full-body phototherapy cabinets: risk of laceration from un-guarded UV tubes (SAN(SC)03/14). Available at: http://www.hfs.scot.nhs.uk/services/incident-reporting-and-investigation-centre-iric/safety-action-notices/safety-action-notices-issued-in-2003/ (last accessed 1 July 2015).
51 Turner D, Britton J, Tassell N *et al.* Safety of patients fitted with electronic artificial implanted devices in ultraviolet treatment cubicles. *Br J Dermatol* 2014; **171**:63.
52 Health Facilities Scotland. Estates and facilities alert. Equipment using ultraviolet (UV) tubes (EFA/2012/002). Available at: http://www.hfs.scot.nhs.uk/services/incident-reporting-and-investigation-centre-iric/estates-and-facilities-alerts/ (last accessed 1 July 2015).
53 Taylor DK. Non-coherent optical radiation sources. In: *Practical Radiation Protection in Healthcare* (Martin CJ, Sutton DG, eds). Oxford: Oxford University Press, 2005; 450–72.
54 Parrish JA, Jaenicke KF. Action spectrum for phototherapy of psoriasis. *J Invest Dermatol* 1981; **76**:359–62.
55 Fitzpatrick TB. The validity and practicality of sun-reactive skin types I through VI. *Arch Dermatol* 1988; **124**:869–71.
56 Lock-Andersen J, Wulf HC. Threshold level for measurement of UV sensitivity: reproducibility of phototest. *Photodermatol Photoimmunol Photomed* 1996; **12**:154–61.
57 Sakuntabhai A, Farr PM, Diffey BL. PUVA erythemal sensitivity depends on plasma psoralen concentration and UVA sensitivity. *Br J Dermatol* 1993; **128**:561–5.
58 McLelland J, Fisher C, Farr PM *et al.* The relationship between plasma psoralen concentration and psoralen-UVA erythema. *Br J Dermatol* 1991; **124**:585–90.

59 Otman SG, Edwards C, Gambles B *et al.* Validation of a semiautomated method of minimal erythema dose testing for narrowband ultraviolet B phototherapy. *Br J Dermatol* 2006; **155**: 416–21.
60 Alora MB, Taylor CR. Narrow-band (311 nm) UVB phototherapy: an audit of the first year's experience at the Massachusetts General Hospital. *Photodermatol Photoimmunol Photomed* 1997; **13**: 82–4.
61 Carretero-Mangolis C, Lim HW. Correlation between skin types and minimal erythema dose in narrowband UVB (TL-01) phototherapy. *Photodermatol Photoimmunol Photomed* 2001; **17**:244–5.
62 Henriksen M, Na R, Agren MS *et al.* Minimal erythema dose after multiple UV exposures depends on pre-exposure skin pigmentation. *Photodermatol Photoimmunol Photomed* 2004; **20**:163–9.
63 Ravnbak MH, Philipsen PA, Wulf HC. The minimal melanogenesis dose/minimal erythema dose ratio declines with increasing skin pigmentation using solar simulator and narrowband ultraviolet B exposure. *Photodermatol Photoimmunol Photomed* 2010; **26**:133–7.
64 Stern RS, Momtaz K. Skin typing for assessment of skin cancer risk and acute response to UV-B and oral methoxsalen photochemotherapy. *Arch Dermatol* 1984; **120**:869–73.
65 Gordon PM, Saunders PJ, Diffey BL *et al.* Phototesting prior to narrowband (TL-01) ultraviolet B phototherapy. *Br J Dermatol* 1998; **139**:811–14.
66 Cox NH, Farr PM, Diffey BL. A comparison of the dose-response relationship for psoralen-UVA erythema and UVB erythema. *Arch Dermatol* 1989; **125**:1653–7.
67 Al-Ismail D, Edwards C, Al-Ofi O *et al.* Minimal phototoxic dose (MPD) measurements for topical photochemotherapy using a semiautomated MPD tester. *Br J Dermatol* 2013; **169**:687–9.
68 Lynch M, Carroll F, Kavanagh A *et al.* Comparison of a semiautomated hand-held device to test minimal erythema dose before narrowband ultraviolet B phototherapy with the conventional method using matched doses. *J Eur Acad Dermatol Venereol* 2014; **28**:1696–700.
69 Waterston K, Naysmith L, Rees JL. Physiological variation in the erythemal response to ultraviolet radiation and photoadaptation. *J Invest Dermatol* 2004; **123**:958–64.
70 Leslie KS, Lodge E, Garioch JJ. A comparison of narrowband (TL-01) UVB-induced erythemal response at different body sites. *Clin Exp Dermatol* 2005; **30**:337–9.
71 Wulf HC, Heydenreich J, Philipsen PA. Variables in full-body ultraviolet B treatment of skin diseases. *Photodermatol Photoimmunol Photomed* 2010; **26**:165–9.
72 Diffey BL, Harrington TR, Davis A. The anatomical distribution of ultraviolet radiation in photochemotherapy. *Phys Med Biol* 1977; **22**:1014–16.
73 Langmack KA. An insight into the contributions of self-shielding and lamp reflectors to patient exposure in phototherapy units. *Phys Med Biol* 1998; **43**:207–14.
74 British Photodermatology Group. British Photodermatology Group guidelines for PUVA. *Br J Dermatol* 1994; **130**:246–55.
75 Murphy GM, McCann P, O'Leary A *et al.* Guidelines for the use of phototherapy and photochemotherapy in Ireland. *Irish J Med Sci* 1997; **166**:92–7.
76 Ibbotson SH, Bilsland D, Cox NH *et al.* An update and guidance on narrowband ultraviolet B phototherapy: a British Photodermatology Group Workshop Report. *Br J Dermatol* 2004; **151**:283–97.
77 Diffey BL. Sources and measurement of ultraviolet radiation. *Methods* 2002; **28**:4–13.
78 Diffey BL, Taylor DK, Hart GC *et al.* *Phototherapy Physics: Principles, Dosimetry, Sources and Safety*. York: Institute of Physics and Engineering in Medicine, 2010.
79 Reed NG, Wengraitis S, Sliney DH. Intercomparison of instruments used for safety and performance measurements of ultraviolet germicidal irradiation lamps. *J Occup Environ Hyg* 2009; **6**:289–97.
80 Mountford PJ, Pepper MG, Goldin D. A UVA meter for monitoring the irradiance within a photochemotherapy unit. *Phys Med Biol* 1983; **28**:177–84.
81 Diffey BL, Challoner AV. Absolute radiation dosimetry in photochemotherapy. *Phys Med Biol* 1978; **23**:1124–9.
82 Mountford PJ, Davies VJ. Ultraviolet radiometry of clinical sources with a miniature multijunction thermopile. *Clin Phys Physiol Meas* 1987; **8**:325–35.
83 ISO. ISO/CIE 19476:2014 (CIE S 023/E:2013). Characterization of the performance of illuminance meters and luminance meters. Available at: http://www.iso.org/iso/catalogue_detail.htm?csnumber=65048 (last accessed 1 July 2015).
84 Martin CJ, Pye SD. A study of the directional response of ultraviolet radiometers: II. Implications for ultraviolet phototherapy derived from computer simulations. *Phys Med Biol* 2000; **45**:2713–29.
85 Foy T. The use of clinical broadband UV radiometers for optical radiation hazard measurements. *J Radiol Prot* 2011; **31**:453–65.
86 Diffey BL. Spectroradiometry. *Photodermatol* 1985; **2**:44–7.
87 Kostkowski H. *Reliable Spectroradiometry*. La Plata, MD: Spectroradiometer Consulting, 1997.
88 Walker JH, Saunders RD, Jackson JK *et al.* Results of a CCPR intercomparison of spectral irradiance measurements by national laboratories. *J Res Natl Inst Stand Technol* 1991; **96**:647–68.
89 Moseley H. Phototest equipment. In: *Photodermatology* (Ferguson J, Dover JS, eds). London: Manson Publishing, 2006; 14–20.
90 Kane R, Sell H. *Revolution in Lamps: A Chronicle of 50 Years of Progress*. Lilburn, GA: Fairmont Press, 2001.
91 Anderson RR, Parrish JA. *Science of Photomedicine*. New York: Plenum Press, 1982.
92 Currie GD, Evans AL, Smith D *et al.* An automated dosimetry system for testing whole-body ultraviolet phototherapy cabinets. *Phys Med Biol* 2001; **46**:333–46.
93 Fulljames CA, Welsh AD. Measurement of patient dose in ultraviolet therapy using a phantom. *Br J Dermatol* 2000; **142**:748–51.
94 Barbagallo J, Spann CT, Tutrone WD *et al.* Narrowband UVB phototherapy for the treatment of psoriasis: a review and update. *Cutis* 2001; **68**:345–7.
95 Veith W, Deleo V, Silverberg N. Medical phototherapy in childhood skin diseases. *Minerva Pediatr* 2011; **63**:327–33.
96 Ylianttila L, Visuri R, Huurto L *et al.* Evaluation of a single-monochromator diode array spectroradiometer for sunbed UV-radiation measurements. *Photochem Photobiol* 2005; **81**:333–41.

Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's website:

Appendix S1. Literature search strategy.

Appendix 1

Table A1 Glossary

Broadband UVB (BB-UVB) therapy	Ultraviolet (UV)B radiation from sources that emit a range of wavelengths between 280 and 315 nm used for the treatment of skin diseases
Cosine response	The UV energy incident on the skin per unit area varies as the cosine of the angle of incidence. UV detectors for measurement of irradiance need to have a similar angular response to reproduce the correct irradiance; this is referred to as a cosine response
Cumulative dose	The UV dose accumulated by a patient usually assessed over a complete treatment programme or over all treatments administered during their lifetime
Designated patient irradiance	UV irradiance at the patient's skin during treatment from a particular phototherapy unit; derived from radiometer measurements with appropriate adjustment factors
Diffuse reflectance	The fraction of UVR that is reflected from the skin surface and not absorbed. For skin, the reflection occurs in multiple directions and is termed diffuse, unlike a mirror, which gives specular reflection in a single direction
Diffuser	Input optic of a radiometer detector commonly consisting of a disc of translucent material designed to collect UVR incident from all directions in order to mimic a cosine angular response
Dose	UVR energy incident on the skin during a treatment or a series of treatments. UVR dose = irradiance × treatment time
Internal detectors	Internal detectors sited within the UV phototherapy cabin to record irradiance during treatment in real time, provided in many cabins. If calibrated, these can be used for setting treatment dose
Irradiance	Radiant power incident on a surface from all forward angles, per unit area. It is expressed in watts or milliwatts per square centimetre or nanometer (W m^{-2} or mW cm^{-2} nm^{-1}, respectively) in a specified wavelength range
Nanometre (nm)	Unit of length, equal to 10^{-9} metre
Narrowband UVB (NB-UVB) therapy	A narrow waveband of UVR, 311–312 nm, emitted by certain fluorescent lamp phosphors (e.g. TL-01 lamps) and found to be more effective than BB-UVB in the treatment of psoriasis
PUVA therapy	Administration of the drug psoralen combined with UVA phototherapy. Used for treatment of psoriasis and other conditions. Psoralen, which can be administered orally or topically, sensitizes the skin to UV
Radiometer	A radiometer comprises a detector and meter for measuring the irradiance of optical radiations. For UV measurement the detector incorporates filters to allow selective measurement of UV irradiance, and these instruments are often referred to as UV meters. Such meters require calibration for each type of source
Responsivity	The input–output gain of a photodetector, which is measured in terms of the electrical signal per unit optical power or for a radiometer per unit irradiance
Spectral irradiance	Irradiance defined as a function of wavelength and expressed in watts or milliwatts per square metre or centimetre per nanometre (W m^{-2} nm^{-1} or mW cm^{-2} nm^{-1})
Spectroradiometer	An instrument that measures irradiances of optical radiations per unit wavelength in W cm^{-2} nm^{-1}, employed in calibration of sources for UVA or UVB
Ultraviolet radiation (UVR)	UVR belongs to the nonionizing part of the electromagnetic spectrum and ranges between 100 nm and 400 nm. It is conventionally categorized into three regions UVA, UVB and UVC
UVA	UVR with wavelengths of 315–400 nm. This may be split into two regions, UVA1 and UVA2
UVA1	UVR with wavelengths of 340–400 nm
UVA2	UVR with wavelengths of 315–340 nm
UVB	UVR with wavelengths of 280–315 nm
Wavelength	A fundamental descriptor of electromagnetic radiation, including light. It is the distance between corresponding points of a propagated wave, measured in nanometres

Appendix 2

Table A2 Levels of evidence

Level of evidence[a]	Type of evidence
1++	High-quality meta-analyses, systematic reviews of RCTs or RCTs with a very low risk of bias
1+	Well-conducted meta-analyses, systematic reviews of RCTs or RCTs with a low risk of bias
1–	Meta-analyses, systematic reviews of RCTs or RCTs with a high risk of bias
2++	High-quality systematic reviews of case–control or cohort studies High-quality case–control or cohort studies with a very low risk of confounding, bias or chance, and a high probability that the relationship is causal
2+	Well-conducted case–control or cohort studies with a low risk of confounding, bias or chance, and a moderate probability that the relationship is causal
2–	Case–control or cohort studies with a high risk of confounding, bias or chance, and a significant risk that the relationship is not causal
3	Nonanalytical studies (e.g. case reports, case series)
4	Expert opinion, formal consensus

RCT, randomized controlled trial. [a]Studies with a level of evidence '–' should not be used as a basis for making a recommendation.

Appendix 3

Table A3 Strength of recommendation

Class	Evidence
A	At least one meta-analysis, systematic review or RCT rated as 1++, and directly applicable to the target population, or A systematic review of RCTs or a body of evidence consisting principally of studies rated as 1+, directly applicable to the target population and demonstrating overall consistency of results Evidence drawn from a NICE technology appraisal
B	A body of evidence including studies rated as 2++, directly applicable to the target population and demonstrating overall consistency of results, or Extrapolated evidence from studies rated as 1++ or 1+
C	A body of evidence including studies rated as 2+, directly applicable to the target population and demonstrating overall consistency of results, or Extrapolated evidence from studies rated as 2++
D	Evidence level 3 or 4, or Extrapolated evidence from studies rated as 2+, or Formal consensus
D (GPP)	A good practice point is a recommendation for best practice based on the experience of the guideline development group

RCT, randomized controlled trial; NICE, National Institute for Health and Care Excellence.