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POSTERS

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   Dr Janelle Reyes-Goddard, Gloucestershire NHS Foundation Trust

2. Grenz Ray Treatments in Dundee: Therapeutic Outcomes and Case Reports
   Lynn Fullerton, Ninewells Hospital, Dundee

3. Dosimetry and Quality Assurance of Grenz Ray Therapy in Ninewells Hospital
   Dr Ewan Eadie, Ninewells Hospital and Medical School, Dundee

4. Fractional Laser Tissue Ablation Visualised with High Resolution Magnetic Resonance Imaging
   Dr Paul O'Mahoney, Ninewells Hospital and Medical School, University of Dundee

5. Automated Measurement of Illumination Uniformity in Phototherapy
   Jennifer Summersgill, University of Aberdeen

Organised by IPEM's Ultrasound & Non-Ionising Radiation Special Interest Group
Experiences of an in house phantom for in cabin UV dosimetry
Daniel M, Lee C
Radiological Sciences Group, Portsmouth Hospitals NHS Trust

Background
A phantom has been developed to enable dosimetry in whole body UV treatment cabinets without necessitating a member of staff to enter the treatment cabin. The phantom was designed to be small and portable allowing easy transportation between sites, but remaining broadly equivalent to a person in cabinet measurement. The evaluation of the phantom is discussed.

Methods
The phantom has been tested against the direct method with a cabin occupant (D. K. Taylor et al 2002). Irradiance was measured both on the phantom surface using a field radiometer and using the cabin on board sensors. Field radiometer measurements have been taken at waste height using an IL1400A radiometer and on board dosimetry was with the Waldmann 7001 UVA/UVB combi cabin, with both broadband UVA and broadband UVB. Seven cabin occupants each provided cabin irradiance data, taking measurements at 8 points around the cabin in 45 degree increments. Measurements account for the wearing of tight fitting lycra to better match a patient physique.

Results
Results are presented as the ratio of irradiance on the phantom surface compared to cabin displayed irradiance. The effect of BMI (range 20.2 to 25.9) and height (range 1.56m to 1.94m) of cabin occupant was investigated and showed no relationship. The average ratios of IL1400 to cabin sensor reading for the 7 volunteers were 1.00 (+/- 0.04) and 0.93 (+/- 0.03) for broadband UVA and UVB respectively. The process was repeated with the phantom in the cabinet. The ratios recorded were 1.06 (+/- 0.01) and 0.94 (+/- 0.01).

Conclusions
The Phantom provides a convenient method of performing in-cabin UV QA in the field. Results are comparable with measurements obtained with the direct method with higher precision.
Development of evidence-based clinical dosimetry in phototherapy
Rogers A, Akram P, Grocki M
Medical Physics and Clinical Engineering, Nottingham University Hospitals, UK.

**Background.** Dosimetric measurements in UV therapy cabins are required to determine the dose delivered to the patient's skin during treatment. When using an indirect method to measure cabin irradiance, a correction factor is needed to account for the shadowing effect of the patient's body.

**Method.** Measurements were made using an anatomically realistic mannequin (see photo opposite) in a Saalmann TLO1 N-line Pro cabin with a well-known tube history and a regular QA regimen. Measurements were taken with an ILT1700 radiometer, and a SED 0033 UVB sensor attached to the surface of the mannequin using Velcro. The comparison was made with measurements obtained using a tripod.

**Results.** A correction factor of $0.924 \pm 0.047$ was obtained with the paediatric mannequin; this is significantly greater than the value for adults found in previous studies $0.85 \pm 0.02$\(^2\) and the current local correction factor of $0.8188$ which was based on adult dosimetry. Dosimetry was also investigated, and it was found that the dose delivered to the forehead of the mannequin $(3.56 \pm 0.23) \times 10^4 \, J/cm^2$, was lower than that delivered to the ankles $(3.47 \pm 0.62) \times 10^5 \, J/cm^2$. Measurements with the sensor attached to the outside of the left ankle, and with the cabin floor covered with black cloth to reduce the floor scatter resulted in a drop of the average accumulated dose from $(3.47 \pm 0.62) \times 10^5 \, J/cm^2$ to $(5.08 \pm 0.71) \times 10^4 \, J/cm^2$.

**Discussion.** Although establishing average paediatric patient size is difficult the mannequin used here represents a 9-year-old which is the youngest patient visiting the Paediatric Dermatology department at NUH and would thus be expected to show the greatest variation from the adult model. From knowledge of the output distribution along the length of full body phototherapy tubes, it was expected that the mannequin’s head should receive the maximum dose. However, measurements appear to suggest that this is not the case. In addition, initial results show that in the case of paediatric patients the legs are not underexposed as is indicated in the literature \(^5\), \(^6\).

**Conclusion.** Further investigation is needed to verify the results. Future measurements should include different child phantom sizes and cabin designs. The current model used for the dosimetry takes into account the radiation reflected from the sides of the cabin. This study indicates it is also necessary to include the UV radiation scattered from the floor of the cabin.

**Key references**

2. Wulf et al.: Variables in full-body ultraviolet B treatment of skin diseases, Photodermatology, Photoimmunology & Photomedicine 26, 165–169
Handheld MED testers: An inter-comparison to inform requirements for acceptance testing and calibration

M Manley, A Stone, J McCavana

Breastcheck, Cork, Ireland

St. Vincent’s University Hospital, Medical Physics and Clinical Engineering, Dublin 4, Ireland

Background. Hand held Minimal Erythema Dose (MED) testers are designed to measure the MED for a patient receiving UVB phototherapy (Lynch et al., 2014). The devices have a series of apertures with a superimposed foil grid of varying attenuation so that 10 incremental doses of UVB are delivered to a patient simultaneously (Gourdon et al., 1998). Introducing these devices into clinical service has presented challenges from a validation and output measurement perspective because of the device’s aperture size (Otman et al., 2006), the smaller bulb size (Eadie et al., 2016), exposure geometry (device is in contact with the patient’s skin) and warm up characteristics of the bulb (Turner and Goulden, 2014). In this study an inter-comparison is performed on a number of units/models, to evaluate their performance characteristics and determine the minimum testing required before introducing such units into clinical service.

Methods. A piece of EBT3 Gafchromic film calibrated to UVB dose was placed on device exposure area and was used to measure both the absolute and relative output of the apertures of each device. A four minute exposure was acquired after the warm up time specified by the manufacturer. The output characteristics were compared to manufacturer’s specification and an inter comparison was carried out between same model devices. Warm up and spectral characteristics of each device were also measured using a spectral radiometer.

Results. Outputs measured were within 13% of that quoted by the manufacturer at the specified warm up time. Results also show that the measured relative outputs varied considerably from that specified by the manufacturer.

Discussion & Conclusion. Minimum acceptance testing of such units should include evaluation of warm-up characteristics; and simultaneous output measurements of all apertures over patient exposure time interval. This will allow a table of planned aperture exposures to be confirmed/determined. Periodic output measurement can then be carried out with EBT3 Gafchromic film or radiometer that has a detector with a suitable sized input optic.

Key references.

Eadie et al., 2016. Transmitted irradiance not as expected in enclosed handheld minimal erythema dose device Photodermatol Photoinmunol Photomed 32 304–6
Gordon et al., 1998. Phototesting prior to narrowband (TL-01) ultraviolet B phototherapy Br J Derm 139 811–814
Lynch et al., 2014. Comparison of a semiautomated hand-held device to test minimal erythema dose before narrowband ultraviolet B phototherapy with the conventional method using matched doses JEDAV 28(12)1696–1700
Otman et al., 2006. Validation of a semiautomated method of minimal erythema dose testing for narrowband ultraviolet B phototherapy Br J Derm 155 416–21
Turner and Goulden, 2014. Determination of the optimum operating point for a handheld minimal erythema dose device Br J Derm 170 970–1001

Figure 1: (a) Example of exposed EBT3 gafchromic film using MED tester. (b & c) Plots showing dose measured at each aperture for example (b) Durham and (c) Dr Honle MED testers.
**Hand-held UV sensitivity test devices – calibration and how to minimise inherent limitations in accuracy**

Chris Edwards, PhD, MIPEM, Department of Dermatology, Aneurin Bevan University Health Board, Newport, South Wales, UK

**Background.** The determination of start doses in UV phototherapy must take into consideration the competing aims of avoiding burning the patient on the first treatment but also ensuring that the patient has the best chance of reaching therapeutic UV doses as soon as possible. Using the common dose incrementing schedule of percentage increases attempts to match dose increases with the ability of the skin to photoadapt to UV irradiation. The higher the start dose, the higher the absolute UV increase on subsequent exposures and thus the fewer ineffective treatments needed to reach a therapeutic dose.

To account for intrinsic photosensitivity and the potential photosensitisation of patient medications, the application of test doses to determine actual patient sensitivity to the administered UV prior to starting is recommended by national guidelines. These test doses allow the determination of Minimal Erythema Dose (MED) for UVB phototherapy and Minimal Phototoxic Dose (MPD) for Psoralen-UVA (PUVA) phototherapy.

Recently hand-held MED and MPD devices have become available to simplify the determination of MED and MPD doses. However, these devices have inherent limitations which must be taken into account in everyday use. With careful calibration and an application method that closely adheres to calibration conditions, these devices can determine MED/MPD doses with clinically acceptable uncertainties.

**Methods.** Calibration of commonly available MED and MPD devices is not straightforward, and requires some specialised radiometric measurements. Warm-up and subsequent application times are critical to calibration and in-use test protocols must reflect this. Matching of handheld test device calibration and cabin dosimetry system calibration is not perfect, and varies between different models of UV cabin.

**Results.** Calibration methods will be described, and their influence in test protocols will be illustrated. Sources of uncertainty and how to minimise or quantify these will be discussed.

Practical test protocols for each phototherapy modality need the input of Medical Physics and so a working knowledge of phototherapy treatments is necessary.

**Discussion.** MED and MPD tests are recommended in nation guidelines for phototherapy. The results of these tests can ensure safe and optimally effective start doses for phototherapy, and thus have a direct and important influence on patient outcomes.

**Key references.**

Examination of a new device for MPD testing
Loan P F, McKay J
Radiation Protection Service, Belfast HSC Trust

Minimal Phototoxic Dose (MPD) testing is used to determine the starting dose for patients undergoing Psoralen-Ultraviolet A (PUVA) photochemotherapy. The MPD testing procedure has been somewhat cumbersome to date compared to the Minimal Erythemal Dose (MED) test, currently performed on Narrow Band-Ultraviolet B patients, using hand-held portable devices. Similar hand-held MPD devices have not been commercially available until now.

An investigation was undertaken into the safety and efficacy of a new hand-held MPD tester (MEDlight GmbH, supplied by Scott Medical Ltd). The investigation included measurement of the spectral emission of the lamp, analysis of the output and temperature variation of the device with time, development of traceable UV dosimetry methods and assessment of template transmission ratios. Additionally, the performance of the device was assessed clinically by comparison of patient MPD assessed using the tester against MPD assessed using established methods.
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An innovative satellite-based technology supporting public skin cancer prevention and vitamin D sufficiency

1Morelli M, 1Simeone E
2siHealth Ltd, UK.

Background.
Solar radiation has a fundamental impact on the wellness and health of the person [2]. A minimum level of UV radiation is essential to produce an optimal vitamin D level for bone calcium and for other vital organ functions [1] [5]. On the other hand, an excessive dose of UV radiation can be associated with different types of skin cancers, accelerates skin ageing and can lead to eye diseases (such as cataract) [3]. Nowadays, no "decision support system" is available for people who expose themselves to solar radiation in order to determine the most convenient radiation dose in relation to the various benefits and health risks, taking into account also the characteristics of each person.

Methods.
We present an innovative contact-less satellite-based solar radiation real-time personal dosimeter technology, simultaneously operating in different spectral bands and enabling smartphone apps that support both public skin cancer prevention (e.g. starting from preventing the personal sunburn risk) and vitamin D sufficiency support. The presented methodology has been already validated in collaboration with Public Health England (PHE) for what concerns the satellite-based real-time monitoring of erythema-effective solar dose [4], but it has now been extended also both to UV-A and to vitamin D-effective solar radiation.

Results.
The first tests of the application of this satellite-based methodology for the near real-time monitoring of UV-A and vitamin D-effective solar radiation have been performed by comparison with ground-based measurements of solar spectral radiation on the horizontal plane in UK during Summer 2018, showing good agreement both in clear-sky and in cloudy conditions. In particular we overall obtained so far a relative Mean Bias Error (rMBE) of 1.89%, a relative Standard Deviation (rSD) of 13.46%, a relative Root Mean Squared Error (rRMSE) of 13.59%, a relative Mean Absolute Error (rMAE) of 6.55%, and a Correlation Coefficient (CC) of 98.32%.

Discussion.
The good accuracy obtained by comparing satellite-based data and ground-based ones allows the development of mobile apps dedicated to the personal support both for skin cancer prevention and for vitamin D sufficiency, considering also the effects of any solar protection applied.

Conclusion.
The presented digital system provides a personalized ultraviolet (UV-B, UV-A) radiation dose control, maximizing benefits (e.g. vitamin D synthesis) and minimising the risks associated with solar radiation exposure (e.g. erythema and skin cancer). This system revolutionizes the relationship between the person and the sun, providing a new type of support for the proper use of photoprotective products, both in summer and in winter, for the health and a better lifestyle of each person.

Key references.
2. Lucas R M et al., International Journal of Epidemiology, 37, 654 (2008)
An investigation of different types of eyewear and face masks in protecting patients and operators from the harmful effects of Ultraviolet Radiation

1Britton J, 2Eadie E, 3Turner D
1Medical Physics Department, Leeds General Infirmary, UK.
2Photobiology department, Ninewells Hospital, Dundee, UK
3Dermatology department, Chapel Allerton Hospital, Leeds, UK

Background
Ultraviolet radiation (UVR) phototherapy and photochemotherapy are commonly used treatment modalities for a range of chronic skin conditions including psoriasis, eczema, and scleroderma [1-3]. Whilst undergoing exposure, patients wear spectacles or goggles to protect their eyes from the damaging UVR. Alternatively, face shields may also be worn to provide both skin and eye protection, if facial treatment is not required. There are a number of different types of goggles and face shields available for purchase that could be used for protecting the eyes. Some of these have clear identifications that show the levels of protection provided and the wavelengths that apply. Other makes and models may not be as clearly marked or include a medical CE mark but may still conform to specific EN standards such as EN166. To clarify which are suitable for phototherapy patients a series of transmission measurements were undertaken on a variety of face shields and other eye protection.

Methods
A series of similar experiments has been undertaken independently at two phototherapy centres - Leeds Chapel Allerton and Dundee, Ninewells Hospitals to investigate the effectiveness of different face shields and goggles at a range of price points that are currently available for purchase in the UK. Two samples, of one face shield model, were tested at both centres and another was transferred between the units to provide a means of validation.

Results
Not all the examples of the face shields and protective spectacles or goggles provided the wearer full protection between 300 nanometres (nm) and 400nm. Cost and conformance to different standards was not always a good indicator. Some of the units tested also meet BAD guidelines for use of sunglasses. Example graphs are shown in figures 1 and 2 below.

Conclusions
It is incumbent on all centres to check the properties of face shields and goggles provided to patients and operators to protect against the affects from UVR. There is no correlation between price and level of protection offered and therefore there may be opportunities for staff to make cost savings without compromising safety of patients.

References
Assessment of gaming spectacles as ocular protection in congenital erythropoietic porphyria

Aneju G., Fityan A., Fedele F., Freeman P., Sarkany R., Morley S.

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St John's Institute of Dermatology
Department of Ophthalmology
Guy's and St Thomas NHS Foundation Trust, UK.
Dermatology Department, University Hospital, Southampton NHS Foundation Trust

Background

Congenital erythropoietin porphyria (CEP) or Günthers disease is a rare hematological porphyria, which occurs due to an inherited reduction in activity of the uroporphyrinogen III synthase enzyme (UROS). This results in the accumulation of porphyrins in the skin [1] and eye epithelium. Exposure to visible light in the Soret waveband (roughly 400-410nm) leads to the development of vesicle formation, scarring and the development of symblephara. Scleral damage includes both acute scleritis and slowly progressive scleral necrosis, and may be accompanied by corneal thinning, perforation, visual loss and significant morbidity [2,3].

The protection offered by standard sunglasses might be unsuitable in that waveband, and orange-tinted lenses that do provide protection against low wavelength visible light, are considered cosmetically unacceptable for regular use. Such behavior puts patients at risk of exposure to potentially damaging levels of visible light.

In recent years there has been increasing interest in the possible role of exposure to artificial blue light. This publicity has led to the manufacture and online marketing of numerous wrap around brands of blue light protecting glasses or gaming glasses [4], as they are otherwise known. In view of these properties, such glasses may offer a potential alternative or at the very least increased choice for patients with CEP.

Methods & Results

Gaming spectacles from several brands were tested using An Abet 2000 simulator to reproduce solar light and the spectrum of light transmitted through the lenses was collected using a Bentham DMC150 monochromator (Bentham Instruments, Berkshire). The spectacles transmission was derived by comparing the filtered spectra to that of the unfiltered simulator light, as previously done for assessing protection for xeroderma pigmentosum patients [5]. This paper shows some preliminary results.

Key references.

LED Lighting Technology & ‘Blue Sky’ Research – How Hazardous is the Sky?
Haigh N R
Blueside Photonics Ltd, Preston, UK

Background: The advent of tuneable spectrum LED technology has led to the rapid growth of spectrally agile lighting products and systems capable of delivering photobiologically active levels of optical radiation, usually with multiple spectral outputs encompassing the ultraviolet, visible and near-infrared regions of the spectrum. The technology is leading to novel research and development, and light-based applications in areas such as photodynamic therapy, dermatology, horticulture and human centric lighting (HCL). Interestingly, HCL includes the possibility to entrain, via blue-green light, the human circadian rhythm and is presently being deployed in trials across certain workplaces and schools in Europe. In another application centred on room lighting, LED lighting technology has been devised for ‘artificial skylighting,’ where a room which has no access to natural daylight can be used ‘year-round’ for delivering a dose of artificial sunlight considered to be therapeutic and beneficial; a SAD lightbox can be considered a desktop version of this relatively new approach to artificial daylighting. In most of these lighting systems, there is a general desire to mimic as closely as possible, an exposure that is akin to that of natural daylight, and in many regards, the daylight spectrum represents the ‘gold-standard’ for the source to attain ahead of development towards specific modalities.

Method: This paper places the recent development of tuneable spectrum LED technology in context with photobiological safety standards such as IEC 62471, and especially within the context of the blue light photochemical retinal hazard. The exposure limits in the standard are reviewed and compared to metrologically derived radiance values for clear sky, so that the blue light hazard for artificial daylight sources can be compared with the expectations arising from daylight exposures. The paper will present a software-based methodology that shows how extant, published photometric and radiometric data can be ‘reverse engineered’ to provide insight into any collateral photobiological hazard limit data, as well as new action spectra that are increasingly better understood, such as ‘melanopic’ lighting. The paper will also describe the state-of-the-art in tuneable LED spectrum technology for a range of applications.

Discussion / Conclusion: The advent of tuneable spectrum LED system for applications involving the blue/violet region of the visible spectrum could lead to a collateral, unexpected, optical hazards posed to both eye and skin. For the blue light hazard, it is already reasonably well understood what percentage of the blue light hazard limit value arises from exposures to daylight and conventional artificial light sources - the exposures are usually of the order of 15% of the ICNIRP published daily limit. However, a discussion now needs to be held with respect to where, via next-generation LED technology, light exposures in new application scenarios might be pushed closer to the published exposure limit values. Additional to reviewing any expected increases in exposure, there could be a need for greater clarity concerning what, if any, safety controls and documentation ought to be in place for users of these systems. This paper seeks to create a timely discussion on this subject so that the boundaries and limits can, if necessary, be defined more clearly ahead of next generation lighting technology development.

Commercial Interest
Blueside Photonics Ltd is a UK based SME working in the photonics field developing hardware and software-based LED lighting technology systems, as well as providing consultancy and training in the area of optical radiation safety. Alongside LED lighting product development, the company has an active interest in understanding where the boundaries of photobiological safety assessments lie, in order to better facilitate product development and safer working practices.
The role of Laser Protection Advisor in most health care settings is undertaken by individuals with a wide range of responsibilities and a strong understanding of appropriate Quality Assurance for medical equipment. However, there is no consensus on the required QA for medical lasers outside of the flexible guidelines provided by the MHRA, and little shared experience of suitable measurements used to investigate adverse clinical responses.

This talk is based upon a collection of my personal successes and failures in laser output measurements including the development of QA programmes for a range of medical lasers, case investigations and training workshops. By highlighting measurements that have been most valuable to me, I hope to encourage a discussion about best practices in laser output measurements.
A review of medical laser accidents: A simple burn to death by laser
Manivannan A
Medical Physics, NHS Ayrshire & Arran, Kilmarnock, Scotland, UK.

Within five years after the invention of the laser by Maiman in 1960\(^1\), the first macular laser burn was reported in 1965\(^2\). The first use of a medical laser was reported in 1963. Ophthalmology was the first medical speciality to take advantage of the sharp focusing capability of laser and reported the use of laser to replace the filament light source and improve the accuracy of photocoagulation for the treatment of diabetic retinopathy. In the past 55 years, a variety of lasers have been used in many medical specialties such as ophthalmology, gynaecology, urology, dermatology, ENT and maxillo-facial surgery. As most lasers are transmitted through a fibre, high energy laser pulses can be delivered through endoscopes and microscopes.

In 2018, sale of medical lasers crossed over $1 billion dollars\(^3\). Millions of safe laser procedures are carried out annually throughout the world. The majority of these are for beauty and aesthetic applications. Despite international guidelines, local safety measures and procedures, adverse events (also known as accidents) do happen and result in undesirable consequences\(^4\). Only recently, regulations such as EU Artificial Optical Radiation Directive 2006 have been implemented in Europe and may reduce adverse events. In recent years, due to medical lasers becoming inexpensive, there is a massive increase in their use for cosmetic applications such as skin rejuvenation, skin lightening, tattoo, hair and wrinkle removal. In many countries, use of cosmetic lasers is unregulated and is carried out mostly by non-medical personnel\(^5\).

The main cause of laser accidents is human error, particularly due to lack of knowledge, training and risk assessments and not following safety procedures. Both patients and laser users become the victims of tissue damage due to unwanted laser exposure. Most laser accidents in literature report damage to skin and eye. As lasers do not penetrate much into the skin, most injuries occur as burns leading to swelling and pain followed by scars. As the eye is transparent to visible and some invisible light (UV and near infrared), lasers can cause irreversible and permanent damage in the eye and lead to blindness. Simple laser burns are usually unreported due to the fear of being blamed for the mistake. Litigation law suits against cosmetic laser treatments such as laser hair removal and tattoo removal are on the rise. Monetary awards for damages range from $5000 to $2,145,000\(^6\). Furthermore, a few laser accidents report fire due to combustible material in the laser beam path. High voltage employed in some lasers such as CO2 and copper vapour lasers can result in electric shock. Even though rare, there are a few reported cases of laser accidents resulting in death. This presentation is a review of all reported and unreported events.

References:
The British Association of Dermatologists (BAD) have produced Service Guidance and Standards for Phototherapy Units. As of 7th March 2017 the guidelines have been accredited by the National Institute for Health and Excellence (NICE).

In an audit of Phototherapy units in the UK it was found that approximately half of the units had no access to Medical Physics expertise and 10% of units had never checked the calibration of their cabins. The introduction of the BAD service guidelines should address this issue and ensure that all phototherapy centres have appropriate facilities, equipment and access to Medical Physics expertise.

Of the eight standards, standard 5 refers to equipment and facilities. This standard is further subdivided with Standard 5A concerned with dosimetry and safety of phototherapy equipment and is the most relevant for Medical Physics departments.

The standard requires phototherapy units to have robust and accurate systems in place for UV dosimetry, regular UV risk assessment and for the control of staff UV exposure. The responsibility of frequency of measurement, tolerances and documentation has been largely left to the physicist.
The use of artificial optical radiation (AOR) sources in the medical sector is widespread and well established. Work with AOR sources includes the use of medical lasers and UV sources for both patient treatment and area sterilisation purposes. This presentation will provide an overview of these types of work and the regulatory requirements and HSE expectations associated with it; including consideration of risk assessments, restriction of exposure and servicing/maintenance. Information will also be provided on findings from inspections and common failings of the AOR Regulations in the medical sector (and other sectors). The presentation will lead to a question and answer session where questions have been pre-supplied in advance to HSE for consideration and subsequent answer/discussion.
Daylight PDT in the UK: an algorithm for accurate dosimetry, and when and where can we do it?

1,2O’Mahoney P, 3Khazova M, 4Higlett M, 4Lister T, 1,2Ibbotson S and 2Eadie E
1. University of Dundee, Dundee, UK
2. Photobiology Unit, NHS Tayside, Dundee, UK
3. Public Health England, Didcot, UK
4. Salisbury NHS, Salisbury, UK

Background.
Daylight photodynamic therapy (dPDT) is a convenient, virtually pain-free treatment for superficial pre-cancerous lesions (actinic keratosis; AK). Treatment efficacy is dependent on the patient receiving a minimum PpIX-effective dose from visible wavelengths in daylight, which will be affected by weather conditions and a number of atmospheric factors. To quantify effective light dose, a method of conveniently and accurately measuring personal daylight exposure is required. There may then exist a need to convert this measurement to effective dose, if direct measurement of PpIX-effective irradiance is not possible.

Methods.
A model is developed to convert illuminance to PpIX-effective irradiance. The conversion must consider multiple factors such as spectral changes in daylight, time of day and year, and location. Additionally, as most centres who offer dPDT do not undertake daylight dosimetry, there is a need to understand the optimal times of the year and conditions in which to carry out dPDT in order to be able to offer guidance and confidence to dPDT practitioners.

Results.
An algorithm, based on spectral irradiance measurements from sites in the UK, accurately converts daylight illuminance to PpIX-weighted light dose. This method is verified against true light dose values derived from measured spectral irradiance, and is found to give accurate values with a precision of ±6.8%.

Discussion.
Applying the above analysis to historic illuminance data from several sites across the UK paints a picture of PpIX-weighted light dose, and gives an indication of when viable treatment can be expected. These data can be used as guidance for other clinics considering dPDT as a treatment option.

Conclusion.
Through this work we have gained a deeper understanding of the dosimetry associated with dPDT and we are now able to accurately calculate the light dose that a patient receives during treatment.

Key references.
O’Mahoney, P. et al. (2017) Br J Dermatol, 176, 1607-16
Quantification of light dose from daylight photodynamic therapy

M Manley, A Stone, P Collins (RIP), S O’Gorman, J McCavana
1 Breastcheck,
2 The Charles Centre, Department of Dermatology, SVUH, Dublin.
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Background. Varying solar irradiance, cloud cover and altering angulation of the sun make accurate dosimetry challenging for patients undergoing daylight photodynamic therapy (dld PDT). Light dose has previously been estimated using a custom detector worn on the wrist (Wiegell et al 2011), a handheld light meter (Wiegell et al 2008) and PpIX absorption weighted spectroradiometer measurements (Rubel et al 2014). O’Mahoney et al (2017) developed a model to calculate PpIX-weighted exposure using an illuminance measurement. The aim of this study was to quantify the light dose for patients undergoing dld PDT. The study explores measurement and associated errors with a radiometer, a spectral radiometer, an illuminance meter and subsequently evaluates the use of EB3T Gafchromic film as a dosimeter.

Method. A DMc150-MDE spectroradiometer was used to measure the light spectrum at 15 minutes intervals during the patient treatment. An IL1400A radiometer with a SEL033 detector measured the integrated irradiance. A DT-8809A data logging illuminance meter logged illuminance during daylight treatments. The total effective light dose was determined by summing the time weighted irradiance spectra multiplied by normalised PpIX absorption. All measurements were carried out in the horizontal plane. The O’Mahoney model was also tested by using azimuth and declination angles as determined retrospectively from NOAA solar angle calculations (www.esrl.noaa.gov) along with measured illuminance data. EB3T Gafchromic film was placed near the treatment area for a further subgroup of patients and compared with O’Mahoney method using logged illuminance values.

Results. The effective light dose from daylight ranged from 3 ± 0.4 to 44 ± 6 J cm². The effective doses determined by the three measurement methods did not statistically agree.

<table>
<thead>
<tr>
<th>Method</th>
<th>Measurement error (%)</th>
<th>Sampling frequency (%)</th>
<th>Measurement to effective dose conversion (%)</th>
<th>Total error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O’Mahoney model</td>
<td>20</td>
<td>8.6</td>
<td>8.2</td>
<td>28</td>
</tr>
<tr>
<td>Spectral Radiometer</td>
<td>1.5</td>
<td>8.6</td>
<td>9.6</td>
<td>13</td>
</tr>
<tr>
<td>Illuminance</td>
<td>20</td>
<td>8.6</td>
<td>4 to 43</td>
<td>30 to 53</td>
</tr>
<tr>
<td>Radiometer</td>
<td>20</td>
<td>N/A</td>
<td>8 to 73</td>
<td>22 to 83</td>
</tr>
</tbody>
</table>

Table 1. Estimated errors on effective light dose calculations.

A Bland Altman plot analysis confirms statistical agreement between the effective irradiance as determined from the spectral radiometer to the O’Mahoney model for illuminance values up to 40000 lux (upper limit of calibration of the illuminance meter).

Discussion. Estimated errors associated with indirect determination of daylight effective light dose were very significant, particularly for effective light doses less than 5 J cm² (up to 83% for irradiance calculations). Between April and July, direct sunlight was incident on the detector at angles of up to 62° from vertical plane causing an underestimated effective dose of up to 50% if the treatment area is directed towards the sun on a sunny day.

Conclusion. Use of the O’Mahoney model is recommended using a calibrated logging illuminance meter with the detector in the plane of the treatment area. Preliminary results show potential for use of a postage stamp sized piece of EB3T film near treatment area facilitating a better sampling geometry while integrating dose over treatment time.

Key references.

2. Rubel D M et al 2014 Daylight PDT with methyl aminolevulinate cream as a convenient, similarly effective, nearly painless alternative to conventional PDT in actinic keratoses treatment: a randomised controlled trial Br. J. Dermatol. 171 1164–71
A patient perspective on daylight PDT


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Background. Over the last decade, the diagnosis of non-melanoma skin cancer and precancerous sun-damaged skin, known as actinic keratosis (AK), has risen. AK arise due to chronic exposure to ultraviolet radiation (UVR) from sunlight and if untreated, AK has the potential to transform into squamous cell carcinoma. There are a number of effective treatments available for AK. Typically, these include topical chemotherapeutic or immunomodulatory agents as creams, cryotherapy and photodynamic therapy (PDT); both conventional and daylight PDT (dPDT).

Although these approaches are reasonably effective, each has its advantages and disadvantages. Topical agents usually cause marked inflammation and discomfort and rely on patient adherence for application, which can result in missed treatments. Cryotherapy may be effective for isolated lesions of AK but is not appropriate for larger areas of field change AK, such as typically occurs on the face and scalp. Conventional PDT exploits a topically applied pro-drug applied to the skin that metabolises into the photosensitiser protoporphyrin IX (PpIX) and preferentially accumulates in dysplastic and neoplastic cells. Under red light illumination the PpIX combines with oxygen and light to produce toxic singlet oxygen effectively removing the AK. However, conventional PDT may cause marked pain and discomfort if treating large areas.

dPDT offers an effective and patient-preferred treatment for these larger areas of AK. Similar in procedure to conventional PDT, enabling large field cancerisation areas to be treated, it differs in PpIX application and utilises visible solar radiation rather than a red LED. dPDT yields clearance rates comparable with conventional PDT in addition to patients experiencing much less discomfort.

Methods. After completion of treatment 56 patients (with 35 responding) were mailed a 19 question survey based on their dPDT experience, its comparison to other treatments, and how it could be implemented as a home therapy. Patient responses were evaluated. Furthermore, a public engagement event was held, at which 5 patients who also undertook the survey, attended (out of 9 invited). The survey was discussed further at this event, enquiring on improvements that could be made to the current service and what could be done to bring dPDT closer to home.

Results. Patient responses confirmed that dPDT is the preferred treatment for AK, however, some improvements were highlighted, which could improve the patient experience of dPDT. These included improved weather forecasts as well as there being a choice as to where treatment is administered; either at home, GP clinic or at local hospitals. The survey structure also allowed an intuitive patient pain measurement, directly compared this (and disease clearance) to other treatments used and patient satisfaction rates were recorded. This led on to enquiring about receiving dPDT as a primary care treatment then gathering information for designing patient support for self-administration of the treatment.

Conclusion. From the patient surveys and the engagement event it is apparent that dPDT is a well-tolerated and patient-preferred treatment. It is associated with very little pain or discomfort and is combined with high disease clearance rates and flexibility of use making it attractive for both patients and doctors. However, further improvements could be made to improve the use of dPDT as a home-based therapy. Our findings highlight the importance to patients of availability of well-tolerated, effective and convenient treatment for AK.

Key references.
Uniform light distribution as a design criterion in artificial daylight photodynamic therapy

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2. The Scottish Photodynamic Therapy Centre, Dundee, U.K.
3. University of Dundee, Dundee, U.K.
4. Blueside Photonics Ltd, Preston, U.K.

Background.
Daylight photodynamic therapy (dPDT) is an effective and well tolerated treatment for field-change actinic keratoses. One drawback in advocacy of dPDT is relatively unpredictable weather conditions, and hence less reliable treatment outcomes. Light sources with low irradiances have been used in artificial dPDT in order to provide comparable and more reliable treatment indoors. For large treatment areas, such as the scalp or lower leg, uniform light distribution is imperative in ensuring effective treatment across the whole field. In order to address this challenge, we have developed a novel artificial dPDT light source with tuneable direction of light emission.

Methods.
Control over the output of seven individual wavebands allows the artificial dPDT light source to replicate the protoporphyrin-IX (PpIX)-weighted spectrum of daylight. Light distribution across three test surfaces - a flat surface, model head and model leg - is characterised alongside that of a typical PDT lamp.

Results.
The artificial dPDT light source is capable of delivering 5.6 J cm⁻² PpIX-weighted daylight dose at a distance of 240 mm for a 2-hour treatment. The uniformity of light distribution on curved surfaces is improved four-fold for a 50 x 100 mm treatment area and two-fold for larger treatment areas.

Discussion.
A comparison of both PpIX-weighted spectra from the artificial dPDT light source and of daylight shows a good match, with a PpIX-effective dose sufficient for effective dPDT. Significant improvements can be made in the uniformity of the light distribution - by optimising the direction of light emission larger areas may be reliably treated.

Conclusion.
This light source innovates in approaches to uniform multiwavelength light distribution, meeting the challenges often associated with artificial dPDT.

Key references.
O’Mahoney, P. et al. Photodiagnostics and Photodynamic Therapy. 23 (2018) 144-150
Developing Quality Control Methodologies & Tolerances for Blue Light and Photodynamic Therapy Units

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Background: There is currently limited guidance on methodologies for routine Quality Control (QC) measurements on clinical Blue Light (BL) (for treatment of neonatal jaundice) and Photodynamic Therapy (PDT) units. There is also little data on what constitutes acceptable results of such testing. For BL therapy it has been demonstrated that treatment is more effective with higher irradiances up to a plateau of 2mW/cm² [1], giving an irradiance level below which lamp replacement could be considered. However it has also been demonstrated that BL units can have considerable variation in irradiance across their treatment area [2], which may result in an insufficient area being covered for effective treatment. IPEM guidance [3] for both BL and PDT units indicates that uniformity is therefore an important consideration. The aim of this work was to make irradiance and uniformity measurements on a set of BL and PDT units and monitor the consistency of these over repeated visits. This data could then be used to inform QC measurements and generate tolerances based on what is achievable by units in clinical use.

Methods: Sets of irradiance measurements were made using a grid pattern at typical treatment distances from the phototherapy units. This work included 7 BL units (2 Draeger Babytherm 8010, 3 Medela overhead units and 2 Medela Bilibeds) and 3 PDT units (all Aktilite CL128). QC tests were performed based on availability of the units, so results are included for annual measurements on the BL units over a period of 3-4 years and on the PDT units for quarterly measurements over a period of 1 year. For PDT units, the central 4x10cm area of the unit was considered because using this area was found to limit the influence of setup errors. For all units, an average irradiance and Coefficient of Variation (CoV) were calculated as indicators of overall irradiance for the patient and uniformity respectively. These were then monitored over time.

Results: The results indicated that all of the BL units were capable of producing average irradiances in excess of 2mW/cm². However, as would be expected, a gradual decline is observed over several years as the lamps age so some units are observed to fall below this irradiance threshold. For PDT units the average irradiance was very stable, and typically varied within 3% over the period of this work. It was noted that the PDT units delivered radiant exposures which are 20-50% higher than that stated. The uniformity was also found to be very stable; with the CoV of all units varying by less than 5% (as an absolute measure) between measurements. Typical CoVs were ~25-35% for Draeger Babytherm 8010 and Medela overhead units, 45-55% for Medela Bilibed Units and <10% for Aktilite CL128 Units.

Discussion & Conclusions: The average irradiance for the BL units indicate that they are capable of delivering adequate irradiance, but are susceptible to irradiance falling below the threshold as lamps age. This is now used as a trigger to advise nursing staff to monitor outcomes and replace the lamps if there are any concerns. The over-dose of PDT units is monitored for consistency, but no further action has been taken because strict dose control is not critical in PDT [3]. The uniformity data confirms that the BL units do indeed suffer from considerable variation in irradiance, but provided the average irradiance exceeds 2mW/cm² this should not be a major cause for concern. The PDT units tested here appear to give quite uniform irradiances, but this is influenced by the measurement being made over the central region of the unit. The CoV itself is consistent between units of the same type and between measurements, meaning that the values presented here could be used to guide what would be expected from measurements and inform a tolerance. For units made up of multiple lamps, a change in the uniformity could indicate a fault with individual lamps allowing them to be identified and replaced.

References

**Background.** UVC decontamination units are now being used in the hospitals as an adjunct to Hydrogen Peroxide Vapours. The aim of this work is to review implementation of a safe system of work for these units.

**Methods.** The process for introducing a safe working system involves engagement from a variety of stakeholders. These include: Procurement, Infection Control, Suppliers, LPAs. In different hospitals additional persons may be included in the Stakeholders.

Ideally the process should begin with procurement, where the LPA can offer advice as the process begins; provide a prior risk assessment; and help comply with the Trust Radiation Safety Policy.

During commissioning the documentation required are Local Rules and a System of work. At this point the prior Risk assessment can be changed to become the current risk assessment. The Local Rules, System of Work and Risk Assessment should be read by all members of staff using the system. Signing the Local Rules is confirmation that the user understands and will abide by them. All users need to be trained and evidence of Training provided.

After an agreed period of time the UVC system should have a Safety Audit done.

**Results.** The results from the first UVC safety audit at GHNHSFT showed: minor changes were required in all three documents; the UVC warning sign needed amending; overall the system was being used safely.

**Discussion.** Some Infection Control and Procurement Departments are still unaware of the hazard posed by UVC and so prior engagement with Medical Physic is not always possible. However, with proper plenary meetings the safety requirements can be discussed and actioned. Proper auditing of the system is an excellent way to self-assess and to identify areas for improvement.

**Conclusion.** Prior engagement of all stakeholders, efficient plenary meeting and timely safety audit are all useful processes to allow for the implementation of UVC decontamination systems.

The Photodermatology Unit has been administering grenz rays for the treatment of some inflammatory skin conditions since 2008. Grenz can be translated as ‘border’ in German and Grenz Rays can be found in the boundary between ionising radiation and UV radiation. Grenz ray treatment is only administered for conditions that have been resistant to other treatments. From 2008-2017 a total of 149 patients have received 213 treatment courses for conditions including, scalp psoriasis (49 patients, 74 courses), nail dystrophy (27 patients, 37 courses) and palmoplantar pustulosis (12 patients, 16 courses). Patients are reviewed following a course of treatment and if necessary additional courses can be prescribed. Comparing the outcomes for patients who received either one or two courses for treatment of their scalp showed 10.7% cleared after one course (28 patients), increasing to 22.2% following a second course (18 patients). The outcomes of all courses administered showed, 9.4% cleared, 32.9% marked improvement, 35.7% slight improvement, 19.2% no change and 2.8% were lost to follow-up.

Case 1: Female, aged 73. Palmoplantar pustulosis affecting the soles of both feet received a total of 40Gy administered weekly over 8 weeks between September and October 2015. Sustained marked improvement was reported 11 months following treatment and the patient commented how pleased she was to be able to walk in comfort a gain.

Case 2: Male, aged 41. Localised plaque psoriasis affecting the left lower leg received a total of 53Gy administered over two courses between November 2015 and November 2016. The area still remains clear 12 months following treatment.

Case 3: Male, aged 54. Localised plantar psoriasis affecting the left sole received a total of 52Gy administered over two courses between August 2012 and February 2015. Sustained marked improvement was reported 14 months following treatment.

Case 4: Female, aged 52. Darier’s disease affecting her upper back received a total of 8.5Gy administered weekly over 4 weeks between December 2016 and January 2017. No benefit was noted.

In this group of patients with disease that has failed previous treatments, less than half reached complete clearance or marked improvement. However as illustrated by the cases, it is highly beneficial for some.
**Background.** The Dermatology department in Ninewells Hospital offer Grenz Ray Therapy for a range of skin conditions such as eczema, psoriasis and other inflammatory skin conditions that have not improved with other suitable treatments [1]. Grenz Rays are a form of electromagnetic radiation falling at the border between ultraviolet rays and X-rays, and share some of the biological properties of both [2]. They are relatively superficial in terms of penetration, with negligible radiation reaching beneath 2mm depth [2].

The Grenz Ray Unit (Progressus Medica AB, Sweden) operates at 10kV and 10mA, and has a range of circular applicators of different diameters to vary the size of the treatment field. The selected applicator is placed in contact with the patient’s skin and a “Dose-Time Chart” is used to determine the exposure time based on the required treatment dose. It is an outpatient procedure, with a course of treatment typically delivered in 4-10 weekly sessions.

**Methods.** The Grenz Ray Unit’s output is measured following the IPEMB Code of Practice and the Addendum [3, 4], giving dose measurements which are traceable to a primary standard at the National Physical Laboratory. A 0.2cc thin window soft x-ray ionisation chamber is used at the surface of a solid water phantom for these measurements.

There is a quality assurance programme in place for the Grenz Ray Unit involving a 6-monthly cycle of quality control (QC) tests, with one test plus an output measurement performed each month. This was established based on guidance for Kilovoltage X-ray units in IPEM Report 81 [5].

**Results.**

<table>
<thead>
<tr>
<th>Month</th>
<th>QC Test</th>
<th>Expected Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>Output</td>
<td>Output = 0.134 Gy/sec ± 5%</td>
</tr>
<tr>
<td>January, July</td>
<td>Timer Linearity</td>
<td>Ratio of measurements at different exposure times within ± 5% of exposure time ratio</td>
</tr>
<tr>
<td>February, August</td>
<td>Applicator Factor</td>
<td>Outputs for all applicators within ± 3% of 5cm diameter reference applicator</td>
</tr>
<tr>
<td>March, September</td>
<td>Field Uniformity</td>
<td>Uniform – assessed visually using Gafchromic film</td>
</tr>
<tr>
<td>April, October</td>
<td>Half Value Layer</td>
<td>HVL = 0.040 mmAl</td>
</tr>
<tr>
<td>May, November</td>
<td>Filament Integrity</td>
<td>Consistency with previous pin-hole image</td>
</tr>
<tr>
<td>June, December</td>
<td>Chamber Calibration</td>
<td>Combined calibration factor = 23.21</td>
</tr>
</tbody>
</table>

**Table 1: Summary of Grenz Ray Unit quality assurance schedule**

**Discussion.** Previous investigations have shown that the output decreases with continued use of the Grenz Ray Unit, and returns to the expected value after a period of inactivity. The quality assurance schedule and QC tests have been designed to minimise the effect of this. The falling output is also accounted for during patient treatments; for example varying the order of treatment for multiple sites.

**Conclusion.** The Grenz Ray Unit has been in use in Ninewells Hospital since 2007 and to date has treated 178 patients for a range of skin conditions. Over this time the equipment has demonstrated consistent performance based on results from regular quality assurance testing.

**Key references.**

[1] NICE. *Treating inflammatory skin conditions with low energy X-rays (Grenz rays)* (2007)
POSTER: Fractional Laser Tissue Ablation Visualised with High Resolution Magnetic Resonance Imaging

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2Photobiology Unit, Ninewells Hospital and Medical School, University of Dundee, UK.  
3Clinical Radiology, Ninewells Hospital and Medical School, NHS Tayside  
4Photobiology Unit, Ninewells Hospital and Medical School, NHS Tayside

Background. MR imaging provides excellent contrast between soft tissues and is routinely used to assist in the diagnosis and monitoring of several clinical conditions. However there is little published literature regarding dedicated imaging of the skin. Fractional Laser Tissue Ablation is used for enhancing drug penetration and cosmetic resurfacing by creating small holes in the skin by irradiation with a laser. The purpose of this project was to develop imaging sequences capable of acquiring high resolution skin images and to explore the research and clinical use of these sequences.

Methods. High resolution clinical imaging sequences (up to 90 µm pixel size) using a dedicated small field-of-view loop coil were created. These were tested on a 3T Siemens Prisma MRI scanner using phantoms and healthy volunteers. An investigation was conducted to determine whether clinical MRI could be employed to investigate the penetration depth achieved by a fractionated ablative laser. Initial work involved irradiating gelatine-based phantoms with a CO2 laser. Subsequently a healthy volunteer was also irradiated with the fractional laser and imaged.

Results. In healthy volunteers, T1 and T2-weighted spin echo and gradient echo imaging sequences were created, showing the epidermis (~0.3 mm thick), dermis (~1.5 mm thick) and subcutaneous fat (~1 cm thick). The ablative depths of the laser holes on the gelatine phantoms were measured on the acquired images, showing an increase in penetration depth as laser energy increases (Figure 1). Results were highly dependent on the water content of the phantom. Resulting images from the healthy volunteer clearly show the effects of the fractional laser (Figure 2).

Conclusion. This work has resulted in extremely high resolution skin imaging and to our knowledge the first in-vivo MR images of ablative fractional laser effects on skin. Further patient experience is required to optimise non-laser procedures and determine clinical relevance. Future work with ex-vivo tissue is planned to investigate ablative laser-tissue interactions.

Key references.
**POSTER: Automated Measurement of Illumination Uniformity in Phototherapy**

1Jennifer Summersgill 1Medical Physics, University of Aberdeen, UK.

**Introduction**

Photodynamic therapy (PDT) involves the combination of light, exogenous photosensitiser and oxygen to kill malignant cells. Homogenous light distribution is key to preventing under-treatment of the disease area. Current light measurement techniques for PDT lamps involve manually placing a detector at 1 cm increments across the treatment field of view of the source and plotting the irradiance map to visualise the illumination uniformity. This is a time-consuming activity, involving two people that is performed in a darkened room. To overcome these obstacles and achieve more efficient data collection this project aimed to develop an automated path-following measurement robot.

**Methods**

An automated, Arduino Uno controlled, three-wheel, line-following, light measurement robot was developed, (Figure 1). Three pairs of infrared (IR) sensors and emitters, mounted to the undercarriage of the vehicle, enable the robot to follow any route where there is contrast in IR absorbance between path and surrounding surface. Video of the robot following a path under a PDT light source (Aktlite CL 128 LED lamp, Galderma, UK) can be accessed here: https://youtu.be/Rf27RoGmoKA.

**Results**

Light measurement is performed by two photodiodes, located on the top surface of the vehicle, which acquire data as the vehicle travels underneath the light source at a relevant treatment distance (Figure 2). Data is acquired in 100 ms intervals using two photodiodes. The automated system was used to measure the light distribution of common PDT sources and compared to the current standard measurement technique.

![Figure 1: The robot viewed from top down.](image1)

![Figure 2: Plots of the uniformity of illumination of the Aktlite LED lamp of A: the laser detector, B: the robot.](image2)

<table>
<thead>
<tr>
<th>Aktlite LED lamp</th>
<th>Laser detector</th>
<th>Robot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data acquisition time</td>
<td>16 minutes</td>
<td>45 seconds</td>
</tr>
<tr>
<td>Distance between lines</td>
<td>2.5 cm</td>
<td>1 cm</td>
</tr>
<tr>
<td>Number of measurements per line</td>
<td>10</td>
<td>28</td>
</tr>
<tr>
<td>Total number of measurements</td>
<td>60</td>
<td>148</td>
</tr>
<tr>
<td>Field of view of measurements</td>
<td>22.5 cm x 22.5 cm</td>
<td>13.5 cm x 13.5 cm</td>
</tr>
<tr>
<td>Area showing 90% – 130% of intensity</td>
<td>16 cm x 16 cm</td>
<td>5 cm x 5 cm</td>
</tr>
<tr>
<td>Average percentage of intensity over 10 x 10 cm effective treatment area</td>
<td>85.67%</td>
<td>90%</td>
</tr>
<tr>
<td>Coefficient of variance over 10 x 10 cm effective treatment area</td>
<td>21.83</td>
<td>5.56</td>
</tr>
</tbody>
</table>

Table 1: Table comparing different parameters of the laser detector and robot over the Figure 3 experiment.

**Discussion**

Figure 1 shows the robot does not provide as detailed a uniformity plot due to the poorer sensitivity, slower response time and smaller dynamic range of the photodiodes used. Table 1 demonstrates the large time saving that can be achieved by the robot (45 seconds vs 16 minutes) and the higher resolution (148 vs 60 measurements). The robot can be produced cheaply (approx. £55), the procedure requires only one operator and is more comfortable to perform. Average uniformity is similar between methods, however the robot’s low coefficient of variation is likely artificial due to poor sensitivity of the photodiodes and does not represent a true reflection of the light field.

**Conclusions**

A prototype flexible automated light measurement system has been developed and demonstrated operational. The system requires improvement which could be achieved by:

1. More, smaller IR emitters and sensors to improve line-following accuracy and allow more complex manoeuvres.
2. Better quality photodiodes with higher sensitivity and wider dynamic range.
3. Better motor components that allow for slower rotation to enable higher measurement resolution as a result of more measurements and increased time for the photodiodes to respond to changes in intensity.

Although these improvements would make the system more expensive and increase the procedure time, it is my opinion that the robot would remain more cost and time efficient compared with current measurement techniques.