Neonatal phototherapy – today's lights, lamps and devices

Neonatal phototherapy is a widely used and accepted form of treatment for neonatal hyperbilirubinaemia. Effective phototherapy needs to satisfy three important criteria identified in the literature: effective spectrum, sufficiently high irradiance and large effective treatment area. This article looks at how technology for delivering light therapy varies, considers the safety aspects and compares the devices available and in use in the NHS today, against the identified effective criteria.

Stephanie D.P. Wentworth
BSc(Hons), PhD, MIPEM, AMInstP, CSci
Senior Clinical Engineer, Medical Physics and Clinical Engineering Directorate, Rehabilitation Engineering Unit, Rookwood Hospital, Llandaff, Cardiff.

Keywords

neonatal phototherapy; light spectrum; irradiance; effective light field; effective surface area; phototherapy devices

Key points

Wentworth, S.D.P. (2005) Neonatal phototherapy – today's lights, lamps and devices. *Infant* 1(1): 14-19.

1. Spectrum, irradiance and effective light field area vary between devices.
2. Four basic light sources are used for phototherapy devices.
3. Not all phototherapy devices are equally effective.
4. Intensive phototherapy can be achieved using more than one phototherapy device.

Physiological jaundice is a normal process seen in 45-60% of term newborns during the first few days of life. Pathological jaundice arises from factors which alter the usual processes involved in bilirubin metabolism. Hyperbilirubinaemia needing treatment may arise from physiological or pathological causes[1]. Jaundice appearing within 24 hours of birth or after 14 days is considered to be outside the normal process and pathologic[2]. Very early jaundice may be due to blood group incompatibility and late jaundice may be a result of metabolic or endocrine disorders, for example hyperthyroidism or Criglar-Najjar disease.

Neonatal phototherapy has its origins in the observations of a nurse on the effect of sunlight on jaundiced babies' skin colour. From further experiments and observations it was found that the bilirubin molecule, responsible for the yellow skin colour of jaundiced babies, was most sensitive to light in the blue and blue-green regions of the visible spectrum[3,4]. The action of light on bilirubin is not completely understood but there are many in-depth explanations of the current understanding[5,6]. Prototype and commercial phototherapy devices followed the discovery of the effect of light on jaundiced babies and there are now many different commercial devices available. Clinical workers have identified three important criteria for effective neonatal phototherapy: effective spectrum, sufficiently high irradiance and large effective treatment area[7]. Eight of the devices commercially available and currently in use in the NHS have been evaluated by the Medicines and Healthcare products Regulatory Agency (MHRA) formerly the Medical Devices Agency (MDA). Drawing on these published evaluation reports this paper looks at the light sources used, the ways in which the devices can be used, the safety of phototherapy and how each device performs against the criteria identified by the clinical workers.

Criteria for effective phototherapy

Effective spectrum

For phototherapy to be effective photons of light from the lamp must be absorbed by the bilirubin molecule. Bilirubin appears yellow because it strongly absorbs blue and green light[6]. Blue light around 450nm is absorbed most readily if bilirubin is in a test tube. In a baby other factors, including skin penetration and albumin binding, combine causing a colour shift of the most effective light toward the blue-green region[5,8,9]. Debate over the most effective wavelengths of light to use still produces many research papers. Blue light has been investigated intensively[5,10,11] and has been shown to be effective[10]. However, Pratesi et al[12] proposed the use of blue-green light and demonstrated its effectiveness[13].

Irradiance

Once an effective waveband has been found the light available must then be sufficiently intense, that is, have a high enough irradiance, to produce an appreciable effect in reducing the neonate's bilirubin level[14]. The Department of Health (DH) recommended a minimum level of 1mW.cm^{-2} in 1992[15] but unfortunately did not specify a waveband in which to measure the irradiance. As Metherall[8] points out, it is impossible to compare published reports of irradiance because of the different wavebands and radiometers

that have been used to measure it. This problem has been discussed several times[7,16]. MHRA evaluation reports[17-23] on phototherapy devices have maintained consistency by stating measured irradiance in the waveband 400nm to 550nm, which although a little wide, includes all of the wavebands used by clinical workers in the field. It is also the waveband specified in the international standard for neonatal phototherapy devices[24].

More recently, higher minimum levels of irradiance have been proposed as more realistic in order to provide effective treatment[25]. The irradiance of different phototherapy devices varies widely and is dependent on a number of factors, including the number of bulbs, tubes or light sources[11], distance of the light source from the neonate[7,26] and quality of the bulb/tube – variation has been observed.

Effective surface area

During phototherapy as much of the neonate's skin as possible should be illuminated by light of an effective waveband and sufficient irradiance[7]. When applied to devices this concept may be thought of as the 'effective light field'; 'effective surface area' is the term used by IEC[24] and DH[17]. The surface area of a full-term baby is approximately 2100cm^2, and for a 32 week premature baby approximately 1300cm^2 [27]. A planar (horizontally flat) overhead phototherapy lamp illuminates up to one third of a baby's skin surface area, ie 700cm^2 and 430cm^2 for a full term and a premature baby respectively. Illuminating as much skin surface area as possible has been shown to increase the speed of bilirubin clearance; that is increase it above the rate at which the bilirubin is produced by the infant, thereby, producing a reduction in the overall bilirubin level[7,28]. Metherall[8] also raises the important practical issue of the clothing worn by the infant during phototherapy. As much of the neonate's skin surface as possible should be exposed to the therapeutic light. Eye protection for the infant is very important but the rest of the baby's clothing should be minimal; small or transparent nappies are sometimes used.

Types of phototherapy device

Two types of phototherapy devices are currently available: the conventional phototherapy light which has been used for over 40 years and the fibreoptic phototherapy device which has been available for nearly 15 years.

FIGURE 1 Draeger Air-Shields Microlite, formerly from Hill-Rom, courtesy of Draeger Medical UK.

lights. The relationship is related to the inverse square law, that is, the intensity of light decreases as the square of the distance. For example; the irradiance at a distance of two metres will only be a quarter of the irradiance at one metre from a light source. However, the relationship in reality is more complex than this and the decrease in irradiance with distance tends to be less because the light is rarely a point source[29]. Obviously the closer the lights can be positioned to the infant the higher the irradiance, but care must be taken with the safety of such an arrangement to prevent overheating the neonate and also to ensure that as much of the infant's skin is illuminated as possible. Maisels[7] describes a system in which special blue lights were positioned to within 14cm of the mattress. He adds a cautionary note: "halogen phototherapy lamps cannot be positioned closer to the infant without incurring the risk of a burn". Close attention to the operating instructions is very important[30].

In its simplest form a conventional phototherapy device has a lamp head mounted on an adjustable, mobile stand. The lamp may then be positioned at a distance from the baby's skin. The manufacturer usually specifies a minimum

FIGURE 2 Draeger Photo-Therapy 4000 Unit courtesy of Draeger Medical UK.

Conventional phototherapy

These devices typically use one or more tungsten halogen bulb, a metal halide gas discharge tube, long or compact (or folded) fluorescent lamps, or most recently, light emitting diodes (LEDs). The light source is positioned above or below the baby and the irradiance is dependent on the distance between the baby and the distance at which a device may be used and this can vary from 25cm to 50cm. The, now obsolete, Vickers 80 is one of the oldest conventional phototherapy devices seen in use today. More recent conventional devices include the Medela Phototherapy Lamp, the Hill-Rom Micro-Lite Phototherapy System (**FIGURE 1**), the Draeger Photo-Therapy 4000 Unit (**FIGURE 2**), and

FIGURE 3 Natus neoBLUE LED, courtesy of Natus Medical Incorporated.

the Natus neoBLUE LED Phototherapy System (**FIGURE 3**). Variations on this theme of light positioned at a distance from the infant's skin include the Medela BiliBed, in which a single light source is mounted in a plastic bed frame and the baby positioned over it, and the Mediprema Cradle 360. In this latter device 16 fluorescent tubes are arranged around the inside surface of a cylinder and the neonate is placed on a hammock in the centre of the light field. Further conventional devices are now becoming available from Medestime in their Bilicrystal range.

Fibreoptic phototherapy

These devices use a standard light source, usually a quartz halogen bulb. The light from the bulb may then be passed through a filter before being channelled down a fibreoptic bundle into a pad of woven optic fibres. The pad can then be placed next to the neonate's skin. Several fibreoptic devices are available worldwide, but only the Ohmeda BiliBlanket (in various versions) is available in the UK at present (**FIGURE 4**).

Light sources

In the conventional and fibreoptic phototherapy devices a variety of light sources may be used. These are summarised in **TABLE 1**.

• Fluorescent lamps
• Quartz halogen lamps
• Gas discharge tubes
• Light emitting diodes (LEDs)

TABLE 1 Light sources currently in use in phototherapy devices.

FIGURE 4 BiliBlanket Plus, courtesy of GE Healthcare.

Fluorescent tubes are the most common type of light source used. They are found in two basic forms, long tubes and folded tubes. Blue and white fluorescent tubes have been seen in use. Typical spectra from fluorescent tubes are shown in the Evaluation reports[17,20-22].

Several phototherapy devices use this type of light source: Vickers 80 (now obsolete)[17] uses 60cm long white fluorescent tubes. Mediprema Cradle 360 uses long blue tubes[20]; Draeger Photo-Therapy 4000 Unit[22], Medela BiliBed[22,31], and Medela Phototherapy Lamp[21] use folded blue fluorescent tubes.

Fluorescent tubes have the advantage of being inexpensive but their light intensity, irradiance, reduces with time[32]. Users are advised by manufacturers to change the lamps after a specified number of hours of use, which may range from 1,000 to 2,000 hours. The MHRA[15] suggest 1,500 hours.

Quartz halogen bulbs are another popular choice for phototherapy device light sources. These lamps appear white and have a broad light output including strong yellow and red components. This means that the lamps tend to get quite hot and this must be borne in mind when they are used for treatment. Various power bulbs are used: the Datex-Ohmeda Spot Phototherapy Lamp uses one 150W quartz halogen bulb and the Hill-Rom Micro Lite three 50W bulbs positioned in a row. The Ohmeda BiliBlanket also uses a single halogen bulb but the light is passed through a blue filter and channelled down the fibreoptic bundle, so the heat produced does not reach the neonate.

Quartz halogen bulbs have not been noted to reduce in intensity with age but they are quite fragile, especially when hot, and care must be taken to prolong their lifetime[17,19].

Another form of gas discharge bulb is used in the Draeger Heraeus Phototherapy Lamp[17] (**FIGURE 5**). This lamp is now obsolete, but there are still many in use in NHS hospitals. This gas discharge tube produces a broad spectrum with sharp peaks and appears a blue-white colour to the eye. The manufacturer recommends that the lamp be changed after 1,000 hours of use.

Blue LEDs have been used in prototype phototherapy devices since the 1990s[33] and in 2002 the first commercial device was launched in the UK and the USA. Very new to the market, this device uses an array of 852 Blue LEDs, 320 yellow LEDs and 13 red LEDs[23]. The manufacturer states that the blue LEDs should last at least 3,000 hours. They should not decrease in intensity with age and should not be especially fragile. They should also produce less heat because their spectrum is concentrated in the blue region of the light spectrum.

Several devices use additional white and 'gold' lights, not to improve the efficacy of the phototherapy, but to try to balance the colour of the light emitted to make it more pleasant for the users to work with. Nurses

have found that working with blue light can cause headaches and make them feel nauseous[29]. Two examples of devices with white lights are the Draeger Photo-Therapy 4000 Unit and the Natus neoBLUE. The Draeger Photo-Therapy 4000 Unit has a standard configuration of four blue folded fluorescent tubes and two white tubes. It may also be configured using six folded blue fluorescent tubes for more intensive therapy[22]. The two white tubes do not contribute to the treatment light but can be switched on separately in order to achieve a better colour balance for the users. The Natus neoBLUE LED Phototherapy System contains 320 Yellow LEDs. Again, these are designed to improve the colour balance and were incorporated following user comments that the intense blue light caused headaches[23]. Interestingly this light also includes a small section of red lights. These are designed to be used to centralise the lamp head over the neonate. They are activated by a toggle switch and are not on during treatment.

Safety aspects of phototherapy

Phototherapy is generally considered a very safe and well-tolerated treatment for hyperbilirubinaemia. However, clinical users should be aware of the unwanted effects of using phototherapy. The biological hazard of blue light is almost entirely to the eye and in particular, the retina[29,34]. Safety precautions such as those described by Diffey and Hart[29] must be taken. Usually during therapy the neonate's eyes will be covered using commercial or in-house eye protection. Sometimes an amber headbox is used to block the blue light. Retinal hazard to staff from phototherapy devices positioned over incubators is insignificant[35]. The effect on other neonates close by, who are not receiving phototherapy has not been studied. However, Diffey and Hart's[29] irradiance measurements at 50cm from an incubator illuminated by phototherapy units, indicate a very low level of irradiance, 0.2mW.cm^{-2}. This seems to indicate that infants close by are at minimal risk.

The baby's temperature must also be carefully monitored during treatment because there may be increased heat from the phototherapy lamps and the neonate's metabolic rate may increase. Insensible water loss is another important consideration especially if the neonate is also being treated under a radiant warmer.

Unwanted ultraviolet (UV) light may be produced by some light sources used in phototherapy. Measurement with an appropriately calibrated UV meter will determine whether the built in UV shielding on the device is sufficient. UV should be reduced to very low levels or blocked completely to prevent it from reaching the infant during phototherapy. Limits have been specified in an addendum of the international standard[24].

Infrared (IR) is produced by some lamps, especially those which have a strong red and yellow component. The heating effect is particularly noticeable from the devices which use halogen lamps[18,19]. However, all lamps will produce heat since they are not 100% efficient at producing light! Many devices contain a fan to cool the lamps[22,23].

Current devices in use and compliance with accepted criteria

It has been said by Ennever[4] and Maisels[7] among others, that phototherapy devices available commercially are not as effective as they could be. Hey[36] suggests that most conventional phototherapy is only one fifth as effective as it could be. Many devices appear to have been designed more for the user than for the efficient reduction of bilirubin. To evaluate this view devices available in the UK and in use in NHS hospitals will be considered in the light of the three important criteria identified.

TABLE 2 summarises how commercially available devices meet the criteria discussed and also looks at the practical consider-ations of whether a device may be used with an incubator if the neonate needs environmental support. The table also indicates the colour of the light from each device, and whether any appreciable UV is produced.

Irradiance in the waveband 400nm to 550nm for ten devices is shown in **TABLE 2**, the waveband used in the MHRA evaluations[17] and specified by the IEC standard[24]. The irradiance values quoted are for one sample of each device – readers should be aware that there is often consid-erable variation in irradiance between identical models of device. The light from some devices is more concentrated in the blue region as their spectra and general colour demonstrate and is shown in the MHRA evaluation reports[17-23].

Irradiance at the manufacturers' minimum recommended treatment distance, as measured during technical evaluation, is shown in Table 2. As may be seen from the table, different devices have different minimum recommended treatment distances. The distances are further for halogen devices, usually because these devices also have an unwanted heating effect.

The irradiance quoted for each device is the maximum value measured at the centre of the light field. The highest irradiance at the manufacturer's minimum recommended distance was 7.75mW.cm^{-2} and the lowest 0.83mW.cm^{-2}, from the now obsolete Vickers 80.

Often phototherapy devices are positioned over an incubator, in which case the device can be brought no closer than the incubator canopy. Incubator canopy to mattress distance has been taken as a standard 40cm. This standardisation allows a direct comparison of device irradiance in the 400nm to 550nm waveband for those devices, which may be positioned at 40cm for treatment. **TABLE 2** shows a variation in irradiance between 0.58mW.cm^{-2} and 11.71mW.cm^{-2}. The very high irradiance device, the Datex-Ohmeda Spot Photo-therapy Lamp, is recommended for use at 50cm, and at 40cm may warm the neonate too much. The other five devices that may be used at 40cm produce an irradiance between 1.86mW.cm^{-2} and 3.30mW.cm^{-2}, which is acceptable since it is above the minimum criterion level of 1mW.cm^{-2}.

Most devices are able to illuminate an area greater than 700cm^2 (one third of the surface area of a full term neonate) at an irradiance level of 1mW.cm^{-2} or greater. However, light fields are rarely uniform and the irradiance will decrease towards the edge of the light field[37,38]. A high central field irradiance is usual. The area in which the irradiance is greater than 1mW.cm^{-2} has been used as an acceptance criterion, but it does not indicate the field profile. Three devices do not achieve this effective field criterion of 1mW.cm^{-2}:

- The Vickers 80, because of its low irradiance
- The Ohmeda BiliBlanket Plus because the pad used for treatment is only 176cm^2 [17]
- The Datex-Ohmeda Spot Phototherapy Lamp because the effective light field is only approximately 415cm^2, even though it has a very high irradiance within that light field[19]

The UV output of the devices is gener-ally very low, but those which produce a measurable UV level should be compared against the limits specified in the standard[24].

All of the devices in **TABLE 2** could be

Device	Colour of light	Lamp type	Manufacturer's minimum recommended distance between the lamp head and the neonate (cm)	Irradiance at manufacturer's minimum recommended treatment distance ($mW.cm^{-2}$)	Irradiance at standard 40cm distance (approximate incubator canopy to mattress distance) ($mW.cm^{-2}$)	Is the effective light field >700cm^2?	UVA 320nm to 400nm at the manufacturer's minimum recommended distance ($mW.cm^{-2}$)	Can the device be used with a baby incubator?
Draeger Photo-Therapy 4000 Unit	Blue & white options	Folded fluorescent tubes(6)	30cm	3.39 (4 blue tubes and 2 white tubes) 4.07 (6 blue tubes)	2.16 (4 blue 2 white) 2.64 (6 blue)	Yes	0.009	Yes
Draeger Heraeus Phototherapy Lamp	White	Gas discharge bulb (1)	30cm	5.03	3.30	Yes	0.12	Yes
Medela Phototherapy Lamp	Blue	Folded fluorescent tubes (4)	25cm	4.66	2.08	Yes	0.016	Yes
Medela BiliBed	Blue	Folded fluorescent tube (1)	On frame (~6cm)	5.56	Not applicable	Yes	0.000	No
Ohmeda BiliBlanket Plus	Blue	Halogen bulb (1)	In contact	4.83	Not applicable	No	0.025	Yes
Datex-Ohmeda Spot Phototherapy Lamp	White	Halogen bulb (1)	50cm	7.75*	11.71*	No	0.120	Yes
Hill-Rom Micro-Lite Phototherapy System	White	Halogen bulbs (3)	42cm	2.50	As for manufacturer's recommended distance	Yes	0.002	Yes
Natus neoBLUE LED **Phototherapy System**	Blue (yellow & red)	LEDs 852 Blue 320 Yellow 13 Red	30cm	2.29	1.86	Yes	0.000	Yes
Mediprema Cradle 360	Blue	Long fluorescent tubes (16)	On gauze hammock ~20cm	5.25	Not applicable	Yes	0.005	No
Vickers 80	White	Long fluorescent tubes (4)	None specified	0.83 @ 30cm	0.58	No	0.04	Yes

* Manufacturer states irradiance at 50.8cm (but this was not explicit in the manual and was not known prior to measurement)
Note: 40cm is a standard distance used to approximate the distance of the lamp head from the mattress when the phototherapy device is used over an incubator. There are several models of incubator in use in the UK, all with different canopy heights. None of the manufacturers recommend using their device at 40cm.

TABLE 2 Phototherapy device data.

physically used in the post-delivery ward over a bassinet, or with the baby positioned on or in them. Only those on stands and the fibreoptic device could be used with an infant radiant warmer or with a baby incubator. This may or may not be important when users are considering purchasing a new device.

The Ohmeda BiliBlanket and the Ohmeda BiliBlanket Plus versions have a high irradiance but only a small effective light field area. However, the design allows a greater flexibility of use; they may be used in an incubator, radiant warmer, bassinet or at home, and can be used while the baby is cuddled or fed.

The Medela Cradle 360 is the only device that can provide illumination to all of the baby's skin, but it cannot be used with an incubator and does not provide controlled thermal support. So-called 'double' phototherapy, the use of two (or more) phototherapy devices to treat one neonate, significantly increases the surface area illuminated and decreases treatment time[39]. The actual physical size of a phototherapy device can be very important if at least two of them need to be positioned around an incubator. Often an Ohmeda Biliblanket and an overhead device will be used together.

Factors which affect the dose and efficacy of phototherapy and recommendations for clinical application are covered in detail in the American Academy of Pediatrics clinical practice guidelines[37].

Conclusion/Discussion

Many phototherapy devices are available commercially and are in use in the UK today. Phototherapy devices are generally robust and have few parts to go wrong. For this reason many currently in use are old technology, but as long as the light bulbs or tubes are still available they continue to be used. Newer devices may not necessarily be more effective than older ones but all should meet the minimum criteria for effectiveness. Of all the devices tested and seen, only the Vickers 80 fails to provide sufficient irradiance.

For a baby requiring an incubator the Medela Phototherapy Lamp, the Draeger Photo-Therapy 4000 Unit, the Draeger Heraeus Phototherapy Lamp and the Natus neoBLUE LED Phototherapy System all meet the above criteria (irradiance, waveband and effective surface area).

For babies not needing thermal support, the Medela BiliBed and the Mediprema Cradle 360 also meet the criteria. The

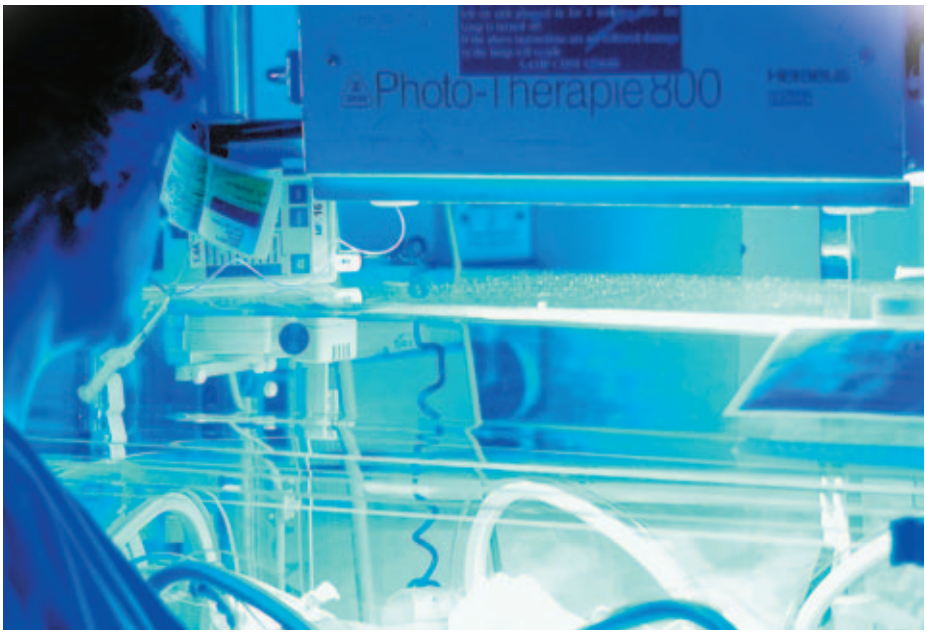

FIGURE 5 Draeger Heraeus phototherapy lamp.

Datex-Ohmeda Spot Phototherapy Lamp provides a very high irradiance but only over a small area[19,31] and the Hill-Rom Micro-Lite Phototherapy System provides a medium irradiance but over a limited area. Ohmeda BiliBlankets have a high irradiance but small effective treatment area, but this disadvantage is offset by the versatility of the device.

We can conclude that not all phototherapy devices are equally effective. When their characteristics are compared to the three important criteria identified more informed decisions can be made about the device chosen to administer phototherapy. Care must be taken in choosing a device which will be effective and also be easy to use and acceptable to the clinical users and parents.

Acknowledgements

I would like to thank the MHRA for funding much of the phototherapy work and Dr Diane Crawford and the team in CEDAR. DH evaluation reports can be downloaded by NHS staff from www.medical-devices.gov.uk or ordered directly from MHRA on 020 7972 8181. I would also like to thank Dr Colin Gibson, Dr John Mecklenburgh, Mr David Taylor and Dr Maurice Wentworth for their support and helpful discussions.

References

1. **Blackburn S.** Hyperbilirubinaemia and neonatal jaundice. *Neonatal Network* 1995; **14**(7): 15-25.
2. **Valman H. B.** The first year of life. In: Jaundice in the newborn. 4th edition BMJ Publishing Group. 1995.
3. **Cremer R. J., Perryman P. W., Richards D. H.** Influence of light on the hyperbilirubinaemia of infants. *Lancet* 1958; 1094-97.
4. **Ennever J. F.** Blue light, green light, white light, more light. Treatment of neonatal jaundice. *Clin Perinat* 1990; **17**: 467-81.
5. **Ennever J. F.** Phototherapy for neonatal jaundice. In: Polin RA and Fox WW, eds. Fetal and Neonatal Physiology 1992; 112: 1165-73. Philadelphia: W B Saunders.
6. **Maisels M. J.** Neonatology - Pathophysiology and Management of the Newborn. Avery G B, Fletcher M A, MacDonald M H, eds. 1994: 38.
7. **Maisels M. J.** Why use homeopathic doses of phototherapy? *Pediatrics* 1996; **98**: 283-87.
8. **Metherall J.** Phototherapy for neonatal hyperbilirubinaemia: Delivering an adequate dose. *JNN* 2003; **9**(6): 183-86.
9. **Ives N. K.** Neonatal jaundice. In: Rennie, J. and Robertson, N., eds. Textbook of Neonatology 3rd edition. Edinburgh: Churchill Livingstone. 1999.
10. **Tan K. L.** Efficacy of fluorescent daylight, blue and green lamps in the management of nonhemolytic hyperbilirubinaemia. *J Pediatrics* 1989; **114**: 132-37.
11. **Tan K. L., Lim G. C., Boey K. W.** Efficacy of "high intensity" blue light and "standard" daylight phototherapy for non-haemolytic hyperbilirubinaemia. *Acta Paediatr* 1992; **81**: 870-74.
12. **Pratesi R. Agati G., Fusi F.** Phototherapy for neonatal hyperbilirubinaemia. Photodermatology 1989; **6**: 244-57.
13. **Donzelli G. P., Pratesi S., Rapisardi G., Agati G., Fusi F., Pratesi R.** 1 day phototherapy of neonatal jaundice with blue-green lamp. *Lancet* 1995; **346**: 184-85.
14. **Tan K. L.** The nature of the dose response relationship of phototherapy for neonatal hyperbilirubinaemia. *J Pediatrics* 1977; **90**: 448.
15. **DH**. The application of phototherapy. Health Equipment Information (HEI) No. 202 September 1992.
16. **Health Devices**. Fibreoptic phototherapy systems. *Health Devices* 1994; **24**: 132-53.
17. **DH.** Neonatal phototherapy. A review including evaluations of Ohmeda BiliBlanket Plus and Medela BiliBed. Evaluation 391. London: Medical Devices Agency (MDA). 2000.
18. **DH.** Neonatal Phototherapy: Hill-Rom Micro-Lite Phototherapy System. Evaluation 00091. London: MDA. 2001a.
19. **DH.** Neonatal Phototherapy: Datex-Ohmeda Spot Phototherapy Lamp. Evaluation 00092. London: MDA. 2001b.
20. **DH.** Neonatal phototherapy: Mediprema Cradle 360. Evaluation 01160. London: MDA. 2001c.
21. **DH.** Neonatal phototherapy: Medela Phototherapy Lamp. Evaluation 01161. London: MDA. 2001d.
22. **DH.** Neonatal phototherapy: Draeger Photo-Therapy 4000 Unit. Evaluation 01162. London: MDA. 2001e.
23. **DH.** Neonatal phototherapy: Natus neoBLUE LED Phototherapy System. Evaluation 04143. London: Medicines and Healthcare products Regulatory Agency (MHRA). 2004.
24. **International Electrotechnical Commission (IEC).** Medical Electrical equipment part 2-50: Particular requirements for the safety of infant phototherapy equipment. 2003.
25. **Dicken P., Grant L. J., Jones S.** An evaluation of the characteristics and performance of neonatal phototherapy equipment. *Physiological Measurements* 2000; **21**: 493-503.
26. **Modi N., Keay A. J.** Phototherapy for neonatal hyperbilirubinaemia. *Arch Dis Child* 1983; **58**: 406-09.
27. **International Commission on Radiological Protection (ICRP)**. Report of the task group on reference man. ICRP publication 23. 1975.
28. **Tan K. L.** Comparison of the efficacy of fiberoptic and conventional phototherapy for neonatal hyperbilirubinaemia. *J Pediatrics* 1994; **125**: 607-12.
29. **Diffey B., Hart G.** Ultraviolet and blue-light phototherapy – principles, sources, dosimetry and safety. IPEM Report 76, York. 1997.
30. **DH**. Phototherapy devices for the treatment of neonates and infants. Hazard warning HN9606 1996. www.medical-devices.gov.uk (last accessed 13.12.04).
31. **Wentworth S. D. P.** A study of neonatal phototherapy devices. Proceedings of the Sixth Annual Scientific Conference of the Institute of Physics and Engineering in Medicine. York, IPEM. 2000. www.medphys.soton.ac.uk/IPEM2000 (last accessed 14.12.04).
32. **Tan K. L.** Phototherapy for neonatal jaundice. *Clin Perinat* 1991; **18**: 423-39.
33. **Vreman H. J., Wong R. J., Stevenson D.K. et al.** Light-emitting diodes: A novel light source for phototherapy. *Pediatric Research* 1998; **44**(5): 804-09.
34. **Abramov I, Hainline L, Lemerise E, Brown A.** Changes in visual functions of children exposed as infants to prolonged illumination. *J Am Optometric Assoc* 1985; **56**: 614-19.
35. **Hart G., Day C., Hainsworth A.** Phototherapy for neonates. *JNN* 1997; **3**(4): centre insert.
36. **Hey E.N.** Phototherapy: Fresh light on a murky subject. *MIDIRS Midwifery Digest* 1995; **5**(3): 256-260.
37. **American Academy of Pediatrics.** Clinical practice guidelines subcommittee on hyperbilirubinaemia. Management of hyperbilirubinaemia in the newborn infant. *Pediatrics* 2004; **114**(1): 297-316.
38. **Wentworth S. D. P.** Neonatal phototherapy: Which device is best for your babies? A review of nine devices. Poster presentation at IPEM scientific meeting 'Output and safety of optical devices' October 2002. Poster and oral presentation at the Annual National Neonatal Nurses Conference, Nottingham, September 2002.
39. **Newman T. B., Maisels M. J.** Evaluation and treatment of jaundice in the term newborn: A kinder, gentler approach. *Pediatrics* 1992; **89**(5): 809-18.