Photodosimeter Badge System

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The Committee on Phototherapy in the Newborn of the National Academy of Sciences has recommended development of a compact system to continuously measure radiant energy exposure of infants treated with phototherapy. A small bilirubin-impregnated photodosimeter film badge was developed by the Beckman Instrument Company for this purpose and was used during the National Institute of Child Health and Human Development (NICHD) phototherapy study. This report summarizes the results of data obtained with this measurement device and briefly describes the performance of this system.

METHODS

The film badge dosimeter system consists of a 5.2×2.6-cm plastic badge composed of an imbedded disk of bilirubin cast in a polymeric substrate and sandwiched between two layers of clear plastic. Before exposure to light, the badge exhibits a high optical density at 460 nm due to a relatively high concentration of bilirubin. The optical density of the badge at 400 to 500 nm decreases as a function of the total dose of light within the action spectrum for the photodecomposition of bilirubin to which the badge has been exposed. Initial optical density at 460 nm is measured by a densitometer designed and dedicated specifically for this purpose. After exposure, the optical density is again measured by insertion into the densitometer; the total dosage, which is the time-integrated irradiance received by the badge during the photodecomposition process, is derived from the difference in optical density between the two readings. (A description of the calibration of the badge is available on request from Biometry Branch, Epidemiology and Biometry Research Program, National Institute of Child Health and Human Development, Bethesda, Maryland.)

For use in the NICHD phototherapy study, the badge was taped to the exposed surface of the unclad thorax of infants receiving phototherapy; for control infants the badge was either affixed to the trunk external to any covering or attached horizontally to the bassinet near the infant. Optical density was determined and recorded for each badge at 24-hour intervals. As a result of experience gained during the study, the formulation of the badge was changed twice, and the dosimeter badges were provided in three separate consecutive batches: A, B, and C.

During the study, dosimeter light exposure readings were taken for 1,010 infants with 840 infants receiving four or more measurements. The photodensitometer badge was relatively easy for the staff to apply and use, and it did not appear to interfere with patient care. Problems with inoperability of the photodensitometers and with supply of the dosimeter badges did occur, and these were attributed to the developmental stage of the system.

The mean radiant exposures measured by the badge in joules per square centimeter (J/cm²) per 24-hour period were tabulated by batch, by birth weight group, by phototherapy versus control group, by center, by day in study, and by time of year. Multivariate analysis of variance techniques were also performed testing the dependent variable of light reading (in joules per square centimeter) for significant differences in independent variables of
batches, phototherapy vs control group, and institutions.

RESULTS

The photodosimeter badge readings for the phototherapy group during 0 to 96 hours were greater than those for the control group by a factor of 2.6 (batch C at 48 hours, 51 J vs 19 J) to 8.0 (batch A at 48 hours, 80 J vs 10 J) ($P < .0001$ by Student's $t$ test for phototherapy vs control group for each batch). When readings were analyzed by batches, batch A produced higher readings than either of the subsequent batches at exposures greater than 40 J/cm$^2$ (batches A vs B, $P < .003$ for 24 to 96 hours, A vs C, $P < .001$ for 48 and 72 hours). By multivariate analysis, 1% of the variation in light readings was due to differences in batches alone. Analysis of mean radiant exposure by calendar month in the study revealed that for badges A and B exposed to phototherapy, the reading decreased over time. Thus it was concluded that all subsequent analyses should be conducted both by separate badge batches and for all batches combined.

To examine the relationship between measured light exposure and bilirubin degradation (dose response), the change in serum bilirubin level over each 24-hour period for each infant in the study was determined and designated as $\Delta$ bilirubin. Linear regression analyses of $\Delta$ bilirubin vs badge reading were performed for the infants with birth weight of 2,000 g or more and those with birth weight less than 2,000 g for each day of the study, for all dosimeter batches combined, and for each batch separately. Because of the possible deterioration in responses by badge batches A and B, the regression analyses were performed first using the entire study population with dosimeter data and a second time excluding all dosimeter readings after the apparent decrease in sensitivity for batches A and B. A relationship of decreasing serum bilirubin level with increasing light exposure was consistently observed during the first 72 study hours for each batch and infant group. The correlation coefficients were .36 and .27 for infants with birth weight less than 2,000 g and for infants with birth weight 2,000 g or more, respectively, and correlation coefficient was $\leq .25$ for all subsequent periods of treatment. For the first 24 hours of treatment, the slopes of the linear regressions for light exposures vs bilirubin level were $-0.0146$ mg of bilirubin and $-0.0217$ mg of bilirubin per deciliter per joule per square centimeter for infants with birth weight less than 2,000 g and for infants with birth weight 2,000 g or more, respectively.

DISCUSSION

The previously described photodosimeter badge system enabled efficient collection of exposure data for a large number of study infants. This system was able to distinguish clearly between control and phototherapy groups with regard to the amount of light exposure.

As mentioned above, the measurement data provided by the photodosimeter system were used to determine the dose response of phototherapy applied in this study. Although clear-cut differences in serum bilirubin levels were observed between study and control infants, change in bilirubin level correlated poorly with the light exposure measured by the photodosimeter system. This suggests that either the dosimeter badge system did not accurately detect this relationship or that such a relationship was masked by other variables. Erratic performance of the photodosimeters, as previously reported,

Comparison between the photodosimeter system and conventional radiometry was performed using measurements taken at each center in the study as described by Landry et al. Measurements of mean radiant exposure for each dosimeter badge batch combined for the four days of treatment for the phototherapy group were converted to irradiance as a constant exposure over a 24-hour period. Given that 1 J/cm$^2$ equals 1 Ws, and 1 J/cm$^2$ equals 11.574 $\mu$W/cm$^2$ as a constant exposure over a 24-hour period, calculated exposures per 24 hours by batches are as follows: batch A, 59.50 J/cm$^2$ = 688.65 $\mu$W/cm$^2$ as a constant exposure $\times$ 24 hours; batch B, 37.84 J/cm$^2$ = 437.96 $\mu$W/cm$^2$ as a constant exposure $\times$ 24 hours; and batch C, 38.39 J/cm$^2$ = 444.33 $\mu$W/cm$^2$ as a constant exposure $\times$ 24 hours. Measured irradiances of phototherapy units by conventional radiometry for the wavelength range 400 to 500 nm varied from a low of 597 $\mu$W/cm$^2$ to a high of 934 $\mu$W/cm$^2$ with a mean of 714 $\mu$W/cm$^2$. These comparisons show the badge measurement to be somewhat lower in magnitude (3.5% batch A, 38.7% batch B, and 37.8% batch C) compared with the mean conventional radiometric measurements combined for all centers. This difference may be a result of differences in performance of the measurement systems, inconsistent use of the badges, withdrawal of phototherapy for part of the treatment period, or other factors. Given the number of variables that could affect these different measurements and the developmental stage of the photodosimeter system, we considered differences of 3.5% to 38.7% to be remarkably small.

In summary, the photodosimeter badge system...
used in the clinical trial of phototherapy demonstrated potential for efficiently obtaining light exposure data integrated over time for a large number of infants. However, because of variation in performance of the badge and probable deterioration in some badges over time, the system cannot yet be considered reliable. Problems such as these must be resolved before the photodosimeter system could reach widespread clinical usefulness.

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