Neonatal Phototherapy and Infantile Cancer
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OBJECTIVE: To determine whether neonatal phototherapy is associated with cancer in the first year after birth.

METHODS: We analyzed a data set from the California Office of Statewide Health Planning and Development that was created by linking birth certificates, death certificates, and hospital discharge abstracts up to age 1 year. Subjects were 5,144,849 infants born in California hospitals at \( \geq 35 \) weeks’ gestation from 1998 to 2007. We used International Classification of Diseases, Ninth Revision codes to identify phototherapy at <15 days and discharge diagnoses of cancer at 61 to 365 days. We adjusted for potential confounding variables by using traditional and propensity-adjusted logistic regression models.

RESULTS: Cancer was diagnosed in 58/178,017 infants with diagnosis codes for phototherapy and 1042/4,966,832 infants without such codes (32.6/100,000 vs 21.0/100,000; relative risk 1.6; 95% confidence interval [CI], 1.2–2.0, \( P = .002 \)). In propensity-adjusted analyses, associations were seen between phototherapy and overall cancer (adjusted odds ratio [aOR] 1.4; 95% CI, 1.1–1.9), myeloid leukemia (aOR 2.6; 95% CI, 1.3–5.0), and kidney cancer (aOR 2.5; 95% CI, 1.2–5.1). The marginal propensity-adjusted absolute risk increase for cancer after phototherapy in the total population was 9.4/100,000 (number needed to harm of 10,638). Because of the higher baseline risk of cancer in infants with Down syndrome, the number needed to harm was 1285.

CONCLUSIONS: Phototherapy may slightly increase the risk of cancer in infancy, although the absolute risk increase is small. This risk should be considered when making phototherapy treatment decisions, especially for infants with bilirubin levels below current treatment guidelines.

WHAT’S KNOWN ON THIS SUBJECT: Phototherapy is commonly used to treat neonatal jaundice. It is generally thought to be safe. However, a small number of studies have suggested an association between neonatal phototherapy and cancer.

WHAT THIS STUDY ADDS: In this study of ~5 million California births, phototherapy was associated with a small but statistically significant increased risk of some infantile cancers, specifically myeloid leukemia and kidney cancer, with ~1 additional cancer case per 10,638 treated infants.

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PEDIATRICS (ISSN Numbers: Print, 0031-4005; Online, 1098-4275).
Phototherapy is commonly used to treat neonatal jaundice. The use of phototherapy has been increasing\textsuperscript{1,2}; a recent study of term and near-term infants enrolled in a single health plan in California showed that up to 15.9% received this treatment.\textsuperscript{3} Many clinicians initiate phototherapy at levels lower than those recommended by the American Academy of Pediatrics.\textsuperscript{2,4} The rise in phototherapy use may be a result of increased identification of neonates with hyperbilirubinemia through universal screening protocols,\textsuperscript{2} fear of kernicterus,\textsuperscript{5} and general belief that phototherapy is safe.\textsuperscript{4}

Although phototherapy is thought to pose minimal risk to infants with unconjugated hyperbilirubinemia,\textsuperscript{4,6} 2 large epidemiologic studies have found phototherapy to be associated with subsequent cancer (overall leukemia and acute myelogenous leukemia).\textsuperscript{7,8} These associations have not been consistent; some studies have been reassuring,\textsuperscript{9,10} but none have been large enough to be conclusive. The potential for phototherapy to increase the incidence of cancer is supported by data from in vitro and in vivo studies.\textsuperscript{11–22}

It is important to determine whether phototherapy contributes to early childhood cancer to determine the optimal management of infants with neonatal hyperbilirubinemia. In this study, we used population-based data to investigate the association between phototherapy and cancer in the first year after birth.

**METHODS**

**Study Design and Subjects**

This study is an analysis of a historical cohort of infants born in California between January 1, 1998 and December 31, 2007. We used the linked Vital Statistics/Patient Discharge Dataset (VS/PDD) for our analyses. The VS/PDD was created for the California Office of Statewide Health Planning and Development by using probabilistic linkage of data from birth certificates, death certificates, and hospital discharge abstracts for mothers and their newborn infants up to 1 year of age.\textsuperscript{23} The VS/PDD includes all California births except those of infants born at home or in military hospitals. For our analyses, we excluded infants born at <35 weeks’ gestation and infants who died within 60 days of birth.

This study was approved by the institutional review boards for the protection of human subjects at the California Health and Human Services Agency, California Department of Public Health, and the University of California, San Francisco.

### Predictor Variables

The primary predictor variable was receipt of phototherapy during a hospitalization that began within the first 2 weeks after birth. We ascertained phototherapy use by abstracting International Classification of Diseases, Ninth Revision (ICD-9)\textsuperscript{24} procedure codes for phototherapy (99.82, 99.83).

Covariates abstracted from the birth certificates included gender, birth weight, gestational age, twin birth, birth by cesarean delivery, payer source, year of birth, and maternal and paternal demographic variables (race, Hispanic ethnicity, age, and education). Covariates abstracted from discharge diagnosis ICD-9 codes included jaundice (774.0–774.4, 774.5, 774.6, 782.4), Down syndrome (758.0), other chromosomal anomalies (758.1–758.9), and nonchromosomal congenital anomalies (740.0–743.64, 743.66–749.25, 750.1–757.32, 757.39–757.9, 759.0–759.9); only congenital anomalies diagnosed during the birth hospitalization were included.

Data were missing for several of our covariates, most commonly payer source (missing in 12.1%), paternal education (9.4%), gestational age (7.1%), paternal age (7.1%), and paternal race (6.9%). We imputed missing values by using single regression imputation because of the large size of the data set. To estimate the effect of the missing data on the precision of our results, we performed multiple imputation (5 imputations) on a subset that included all cancer cases and a 1% sample of the remainder of the cohort. We included subjects with missing gestational age if their imputed gestational age (based on multiple variables including birth weight, parental race, parental age, mode of delivery, and twin status) was ≥35 weeks.

### Outcome Variables

The primary outcome was a hospital discharge diagnosis of cancer (ICD-9 codes 140.0–209.79, 230.0–234.9) in the first year after birth. We excluded cancers diagnosed at ≤60 days to reduce the likelihood of finding an association through reverse causation. In addition, it seemed less plausible that phototherapy would cause cancer in ≤60 days. We grouped cancer diagnosis ICD-9 codes by site: myeloid leukemia (205.0–205.92), lymphoid leukemia (204.0–204.92), brain or nervous system (191.0–192.9), kidney (189.0–189.9), liver (155.0–156.9), soft tissue (171.0–171.9), and other (remaining codes). If an infant had >1 type of cancer diagnosis, all were captured.

### Statistical Analysis

We used Stata 13 (Stata Corp, College Station, TX) statistical software for all analyses. We performed bivariate analyses comparing infants with and without cancer diagnoses by using $\chi^2$ tests for categorical variables and $t$ tests for continuous variables.

We computed risk ratios (RRs) and risk differences for phototherapy and each of the cancer outcomes by using the Agresti-Caffo method\textsuperscript{25} to
Because Down syndrome is such a strong risk factor for cancer, we estimated the marginal propensity-adjusted risk difference and 95% CI for cancer after phototherapy in infants with and without Down syndrome separately. For this analysis, we created a propensity score without the Down syndrome variable.

RESULTS

Our cohort consisted of 5,144,849 infants born at ≥35 weeks’ gestation who were alive >60 days after birth. A cancer diagnosis was present in 1100 of the infants, yielding an overall population incidence of 21.4/100,000. Table 1 provides a description of the cohort by cancer diagnosis status. The most common cancers were leukemia (23%), brain or nervous system cancer (16%), and eye or orbit cancer (9%).

Jaundice diagnoses were recorded in 13.9% of infants and phototherapy codes in 3.5% of the cohort. Phototherapy use increased over time, from 2.9% in 1998 to 4.4% in 2007 ($P < .001$). Of subjects who received phototherapy, 85% had a jaundice diagnosis. Jaundice itself was associated with an increased...
risk of cancer, controlling for phototherapy (RR 1.3; 95% CI, 1.1–1.5).

In unadjusted analyses, subjects who received phototherapy were at higher risk of overall cancer (RR 1.6; 95% CI, 1.2–2.0), myeloid leukemia (RR 2.7; 95% CI, 1.4–5.2), kidney cancer (RR 2.7; 95% CI, 1.3–5.6), and other cancer (RR 1.7; 95% CI, 1.1–2.5), although the risk differences were small (Tables 2 and 3). The associations between phototherapy and overall cancer, myeloid leukemia, kidney cancer, and other cancer persisted in propensity-adjusted models (Table 3). Propensity-adjusted models, traditional multivariable-adjusted models, and models with and without multiple imputation gave similar results. In a complete case analysis (n = 3 717 503), we found similar propensity-adjusted associations between phototherapy and overall cancer (odds ratio [OR] 1.5; 95% CI, 1.1–2.1), myeloid leukemia (OR 2.2; 95% CI, 1.0–4.9), kidney cancer (OR 3.4; 95% CI, 1.6–7.3), and other cancer (OR 1.7; 95% CI, 1.1–2.7). After adjustment for jaundice alone, the association between phototherapy and myeloid leukemia was similar (OR 2.6; 95% CI, 1.2–5.6), the associations between phototherapy and overall cancer (OR 1.3; 95% CI, 1.0–1.8) and other cancer (OR 1.5; 95% CI, 1.0–2.4) were slightly diminished, and the association between phototherapy and kidney cancer (OR 1.6; 95% CI, 0.7–3.5) was diminished further. The marginal propensity-adjusted absolute risk increase for cancer after phototherapy in the total population was 9.4/100 000 (95% CI, 1.4/100 000–17.4/100 000), with a number needed to harm of 10 638.

Down syndrome was diagnosed in 7812 subjects (0.2% of the cohort). In the subgroup of infants with Down syndrome, 19% received phototherapy. Cancer was diagnosed in 18 infants with Down syndrome (lymphoid leukemia in 4, myeloid leukemia in 10, other leukemia in 2, brain or nervous system cancer in 1, and other cancer in 1). The marginal propensity-adjusted absolute risk increase for cancer after phototherapy was much higher for infants with Down syndrome (77.8/100 000; 95% CI, -1.2/100 000–156.8/100 000, number needed to harm of 1285) than for infants without Down syndrome (8.1/100 000, 95% CI 0.4/100 000–15.8/100 000, number needed to harm of 12 346). This difference was caused by the higher baseline risk of cancer in infants with Down syndrome; the propensity-adjusted ORs for cancer after

### Table 2 Incidence of Cancer by Whether Infants Received Phototherapy, by Cancer Site

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<th>Propensity-Adjusted Analyses</th>
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### Table 3 RRs and Propensity-Adjusted ORs for the Association Between Phototherapy and Cancer, by Cancer Site

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phototherapy were similar: 1.2 for infants with Down syndrome and 1.4 for infants without Down syndrome (P for interaction = .79).

**DISCUSSION**

In this study, we found that neonatal phototherapy was associated with an increased risk of cancer in the first year after birth; these associations persisted in adjusted analyses. Specifically, we found associations between phototherapy and overall cancer (adjusted odds ratio [aOR] 1.4), myeloid leukemia (aOR 2.6), kidney cancer (aOR 2.5), and other cancer (aOR 1.6). Based on our findings, 10,638 infants would need to be treated with neonatal phototherapy to cause 1 excess case of infantile cancer.

With epidemiologic studies, it is important to consider whether associations found are biologically plausible. The potential for phototherapy to increase the incidence of cancer is supported by evidence dating from the 1970s that blue light is mutagenic in vitro. Additionally, in vivo experiments on human newborns have demonstrated DNA damage, alterations in cytokine levels, and evidence of oxidative stress after treatment with phototherapy. This is concerning because all these conditions have been implicated in the pathogenesis of cancer. Although the clinical importance of these alterations remains to be elucidated, they present a potential mechanism whereby phototherapy could be related to childhood cancer.

The association between phototherapy and leukemia reported here has been previously suggested in other large epidemiologic studies. A population-based case–control study from the state of Washington found neonatal jaundice to be associated with an increased risk of leukemia (OR 1.5; 95% CI, 1.1–2.1). In a subgroup analysis, the risk of leukemia was higher in jaundiced infants who received phototherapy (OR 2.2; 95% CI, 1.0–4.9). A Swedish case–control study found increased odds of myeloid leukemia in infants with physiologic jaundice (OR 2.5; 95% CI, 1.2–5), which again was more pronounced in those treated with phototherapy (OR 7.5; 95% CI, 1.8–31.9). As in the current study, the Swedish group did not find an association between phototherapy and lymphoid leukemia (OR 1.0; 95% CI, 0.5–1.8).

Two other studies did not find an association between phototherapy and cancer. A case–control study from the United Kingdom with 143 leukemia cases found no statistically significant association between phototherapy and leukemia (OR 0.5; 95% CI, 0.1–2.3); in this study, none of the 15 subjects with myeloid leukemia received phototherapy (OR 0; 95% CI, 0–11.7). A Danish study of 55,120 children with neonatal hyperbilirubinemia found no association between hyperbilirubinemia and overall cancer (standardized incidence ratio [SIR] 1.0; 95% CI, 0.8–1.3) or any subtype, including leukemia (SIR 1.2; 95% CI, 0.8–1.7) and kidney cancer (SIR 1.0; 95% CI, 0.4–2.2). The authors of that study estimated that 85% to 90% of the children with hyperbilirubinemia received phototherapy, but they were unable to specifically evaluate the association between phototherapy and cancer.

In this study, we also found an association between phototherapy and other cancer. The “other cancer” group included an excess of bone cancer, which is extremely rare in infancy, suggesting that this group consists, at least in part, of metastases and misclassified cancers. Nonetheless, we found a persistent association between phototherapy and these other cancers. Our study has the advantage of a large cohort, with >5 million infants and 1100 cancer cases. The incidence of cancer in our study is similar to what is reported from US Cancer Registries, which suggests that our ascertainment of cancer cases was reasonably complete.

Because we used a large statewide data set, this study has a few limitations. We were unable to adjust for potential confounding variables not included in the data set. As an example, because serum bilirubin levels were not available, we cannot exclude the possibility that the association between phototherapy and cancer could be caused by elevated bilirubin levels (not captured by a discharge diagnosis of jaundice). The association between phototherapy and cancer persisted in analyses adjusted for a discharge diagnosis of jaundice, although a diagnosis of jaundice is admittedly a crude indicator of hyperbilirubinemia.

Because data on phototherapy intensity and duration were not available, we could not investigate the effect of phototherapy dosage. We did not have data on home phototherapy; we hypothesize that misclassification of subjects who received home phototherapy as unexposed would attenuate the observed association between phototherapy and cancer. Our ascertainment of phototherapy and of cancer diagnoses was probably incomplete, but it is unlikely that the completeness or accuracy of cancer coding differed between those who did and did not receive phototherapy or that the accuracy of phototherapy coding differed depending on subsequent risk of cancer. Such nondifferential misclassification, if present, would have biased our ORs toward 1. Also, the data set we used is limited to the first year after birth. In a companion study, Newman et al looked at the association between neonatal phototherapy and childhood cancer in a cohort of almost 500,000 children born over a
17-year period in Kaiser Permanente Northern California hospitals. In that study, phototherapy was associated with an increased risk of overall cancer and nonlymphocytic leukemia in unadjusted models, but these associations were no longer statistically significant after researchers adjusted for potential confounders. These results could reflect the ability to adjust for additional potential confounders that were not available in our data set (eg, bilirubin levels). However, the 95% CI reported in that study did not exclude adjusted differences of the magnitude reported here.

Although we found an increased risk of cancer in infants who received phototherapy, the absolute risk increase among those who received phototherapy was low. However, for infants with Down syndrome, the absolute risk increase was almost 10 times higher because of their higher baseline risk for cancer.

Therefore, especially in infants with bilirubin levels below recommended treatment thresholds and in infants with Down syndrome, the risks of phototherapy may exceed the benefits.

CONCLUSIONS
Phototherapy is a valuable treatment for infants with neonatal hyperbilirubinemia. Our results support the need for health care providers to consider phototherapy as they do most other treatments (ie, as having both benefits and potential risks) and to limit the use of phototherapy to infants for whom the benefit/risk balance is most likely to be favorable.

ACKNOWLEDGMENTS
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ABBREVIATIONS
aOR: adjusted odds ratio
CI: confidence interval
ICD-9: International Classification of Diseases, Ninth Revision
OR: odds ratio
RR: risk ratio
SIR: standardized incidence ratio
VS/PDD: Vital Statistics/Patient Discharge Dataset

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