Computed Tomography and Shifts to Alternate Imaging Modalities in Hospitalized Children

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BACKGROUND: Many studies have demonstrated a rise in computed tomography (CT) utilization in children’s hospitals. However, CT utilization may be declining, perhaps due to awareness of potential hazards of pediatric ionizing radiation, such as increased risk of malignancy. The objective is to assess the trend in CT utilization in hospitalized children at freestanding children’s hospitals from 2004 to 2012 and we hypothesize decreases are associated with shifts to alternate imaging modalities.

METHODS: Multicenter cross-sectional study of children admitted to 33 pediatric tertiary-care hospitals participating in the Pediatric Health Information System between January 1, 2004, and December 31, 2012. The rates of CT, ultrasound, and MRI for the top 10 All-Patient Refined Diagnosis Related Groups (APR-DRGs) for which CT was performed in 2004 were determined by billing data. Rates of each imaging modality for those top 10 APR-DRGs were followed through the study period. Odds ratios of imaging were adjusted for demographics and illness severity.

RESULTS: For all included APR-DRGs except ventricular shunt procedures and nonbacterial gastroenteritis, the number of children imaged with any modality increased. CT utilization decreased for all APR-DRGs (P values < .001). For each of the APR-DRGs except seizure and infections of upper respiratory tract, the decrease in CT was associated with a significant rise in an alternative imaging modality (P values ≤ .005).

CONCLUSIONS: For the 10 most common APR-DRGs for which children received CT in 2004, a decrease in CT utilization was found in 2012. Alternative imaging modalities for 8 of the diagnoses were used.

WHAT’S KNOWN ON THIS SUBJECT: Concern of the risk of malignancy from ionizing radiation has prompted many to advocate for judicious use of computed tomography (CT) and as low as necessary radiation doses administered per scan. Recent analysis has shown a decline in CT utilization.

WHAT THIS STUDY ADDS: We identified decreases in CT utilization between 2004 and 2012 for the 10 most common diagnostic groups receiving CT. Decreases were typically associated with increases in alternate imaging modalities. We provide a possible reason for the decrease in CT utilization.
Computed tomography (CT) is an important diagnostic imaging modality capable of quickly producing detailed information for use in medical decision-making. However, awareness of the potential adverse effects of ionizing radiation, particularly the risk of malignancy, has raised concern about its frequent use.\(^1\)\(^-\)\(^6\) Pediatric exposure to ionizing radiation in doses frequently administered by CT has been associated with 1 additional cancer per 10,000 exposed children.\(^1\) Consequently, national efforts have focused on minimizing the radiation dosage received per CT scan as well as the frequency of CT utilization in children.\(^2\)\(^-\)\(^7\)\(^-\)\(^10\) Multiple strategies have been pursued to minimize radiation dosage to children, such as reduction of dosage administered per study,\(^11\)\(^-\)\(^13\) reduction of number of CT phases,\(^11\)\(^14\) and reduced frequency of CT utilization. Reduction in frequency of CT utilization may potentially be accompanied by a shift to other imaging modalities.

Studies assessing the frequency of CT utilization in children during the past 2 decades demonstrated a large increase from the mid-1990s\(^15\)\(^-\)\(^22\) with some demonstrating either a plateau\(^16\) or decline.\(^20\)\(^-\)\(^22\) Previous studies were limited by focusing on a single institution\(^21\) or a single condition.\(^16\)\(^-\)\(^21\) Furthermore, it is unknown whether changes reflect a decrease in overall imaging or a shift to alternate imaging modalities. The objectives of this multicenter study were to assess trends in CT utilization in hospitalized children and determine whether these changes are associated with shifts to alternate imaging modalities.

**METHODS**

**Data Source**

This cross-sectional study used data from the Pediatric Health Information System (PHIS) (Children's Hospital Association, Overland Park, KS). The PHIS database contains de-identified administrative data detailing demographic, diagnostic, procedure, and daily charge data, including pharmacy, laboratory testing, imaging, supplies, clinical, and room/nursing, from 42 tertiary-care children’s hospitals. This database accounts for \(~\)20% of all annual pediatric hospitalizations in the United States. Data quality is ensured through a joint effort between the Children’s Hospital Association and participating hospitals, as described previously.\(^23\)

**Patient Populations**

We included patients admitted as inpatient- and observation-status to 33 participating hospitals that submitted charge data into PHIS from January 1, 2004, to December 31, 2012. The remaining 9 PHIS hospitals were excluded because these data were unavailable for the entire study period. Because previous studies show peaks in CT utilization as early as 2006,\(^20\)\(^-\)\(^22\) our study began in 2004 to best capture early changes in trends while maximizing the available data from participating hospitals. Each hospitalization was assigned an All-Patient Refined Diagnosis Related Group (APR-DRG, version 24; 3M-Corp, Minneapolis, MN) that is assigned at the time of discharge from inpatient or observation admissions, and incorporates information about diagnoses applied during hospitalization. We examined trends in CT, ultrasound, and MRI utilization (based on charge data) performed during the admission among the 10 APR-DRGs with the highest CT volume in 2004; imaging performed in the emergency department for children later admitted was included. Only imaging studies directly related to the diagnosis of the APR-DRG were included. For example, for ear, nose, and throat (ENT) conditions, head and neck images were included, whereas abdominal or chest imaging was excluded. To account for potential variability in hospital coding practices, we used the principle of including images as relevant if the imaged body part was pertinent to the APR-DRG (eg, including brain or posterior fossa MRI codes as relevant to the seizure APR-DRG). To select imaging studies for inclusion, 2 reviewers performed independent reviews for relevance of every study performed, with discrepancies resolved by group discussion. We also included codes in which the body part imaged was unspecified, because such codes could have pertained to the correct body part (eg, other unspecified MRI in seizure APR-DRG); however, these included codes tended to be lower frequency. Very low frequency images, defined as those performed in \(<\)0.5% patients within an individual APR-DRG, were excluded.

**Statistical Analysis**

Categorical variables were summarized with frequencies and percentages and compared across years (2004 vs 2012) using the \(\chi^2\) statistic. Continuous variables were summarized with means and SDs and compared across years (2004 vs 2012) using the Wilcoxon rank-sum test.

Trends in annual imaging rates were tested by using generalized estimating equations to account for hospital clustering. Rates of imaging in 2004 and 2012 also were compared by using generalized estimating equations, and adjusted by using age, gender, race (non-Hispanic white, non-Hispanic black, Hispanic, Asian, or other), insurance type (government, private, or other), disposition (home health services, home, skilled nursing facility, other), presence of a complex chronic condition (CCC)\(^24\) (eg, malignancy, sickle cell disease), admission to an ICU, receipt of mechanical ventilation, length of stay, and hospital-level case mix index (CMI). CMI in PHIS is based on APR-DRG categories and severity levels. It is calculated by Truven Health Analytics as the ratio of the...
average patient charge in a particular APR-DRG category/severity level combination to the average charge for all patients comprising the national pediatric database. All discharges in PHIS with the same APR-DRG and severity level receive the same CMI. A hospital-level CMI is then calculated as the mean of a hospital’s discharge-level CMIs. Results are presented as adjusted odds ratios (AORs) with 95% confidence intervals (CIs).

All statistical analyses were performed by using SAS version 9.3 (SAS Institute, Inc, Cary, NC), and \(P\) values < .05 were considered statistically significant. This research, using a de-identified dataset, was not considered human subjects research in accordance with the Common Rule (45 CFR 46.102[f]) and the policies of the institutional review board at Cincinnati Children’s Hospital Medical Center.

**RESULTS**

The 10 most common APR-DRGs for which patients received a CT scan in 2004 were identified across 33 children’s hospitals in the PHIS database. In descending order, these were (1) seizure; (2) ventricular shunt procedures; (3) appendectomy; (4) craniotomy except for trauma (craniotomy); (5) concussion, closed skull fracture, uncomplicated intracranial injury, coma <1 hour or no coma (concussion); (6) head trauma with coma >1 hour or hemorrhage (severe head trauma); (7) infections of upper respiratory tract; (8) nonbacterial gastroenteritis with nausea and vomiting (gastroenteritis); (9) abdominal pain; and (10) other ear, nose, mouth, throat, and craniofacial diagnoses (ENT conditions). Five of these APR-DRGs, broadly grouped as “neurological,” accounted for 5 of the top-6 reasons for imaging in 2004; 3 of the 10 can be broadly grouped as “abdominal,” most notably appendectomy. Across the 10 APR-DRGs, there were >150 000 hospitalizations in 2004 and 2012 (Table 1). Patients receiving CT tended to be younger in 2004 than 2012 (median [interquartile range]: 6 [2–12] vs 7 [2–13], \(P < .001\)).

Hospital length of stay was notably longer in 2004 compared with 2012 (2 days [1–5] vs 2 days [1–4], \(P < .001\)), whereas patient complexity measured by CMI was higher in 2012 (1.5 [0.8–2.2] vs 1.4 [0.8–2.2], \(P < .001\)). The 10 most common APR-DRGs comprised 31.4% of all patients receiving CT in 2004 and 30.8% in 2012.

In both 2004 and 2012, seizure was the highest-volume APR-DRG associated with imaging, whereas volume for severe head trauma was the 10th most common APR-DRG (Table 2). Imaging utilization varied greatly across APR-DRGs, years, and imaging modalities. The APR-DRGs of seizure, concussion, severe head trauma, infections of the upper respiratory tract, and ENT conditions had an overall decrease in percentage of patients imaged in 2012 vs 2004. The decrease was most noted for patients with an APR-DRG of seizure where CT utilization decreased by almost 50%, and MRI utilization decreased by >10%. Net imaging increased for ventricular shunt procedures, appendectomy, craniotomy, gastroenteritis, and abdominal pain, with the most notable increase in patients with gastroenteritis. Within this APR-DRG, although CT use marginally increased, there was an almost 300% increase in ultrasound utilization.

Figure 1 depicts the trend of imaging utilization over our study period. Statistically significant reductions in CT utilization were noted across all

### Table 1 Demographics 2004–2012 Inpatient and Observation-Status Patients With One of the Top 10 APR-DRGs

<table>
<thead>
<tr>
<th>APR-DRGs</th>
<th>Overall</th>
<th>2004</th>
<th>2012</th>
<th>(P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;1</td>
<td>26 392</td>
<td>13 463 (20.3)</td>
<td>14 929 (17.4)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>1–5</td>
<td>52 895</td>
<td>23 913 (36)</td>
<td>28 982 (33.8)</td>
<td></td>
</tr>
<tr>
<td>6–12</td>
<td>42 180</td>
<td>17 598 (26.5)</td>
<td>24 582 (28.7)</td>
<td></td>
</tr>
<tr>
<td>&gt;12</td>
<td>28 711</td>
<td>11 459 (17.2)</td>
<td>17 252 (20.1)</td>
<td></td>
</tr>
<tr>
<td>Boys</td>
<td>85 195</td>
<td>37 236 (56.1)</td>
<td>47 959 (56)</td>
<td>&gt;.9358</td>
</tr>
<tr>
<td>Race</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Hispanic white</td>
<td>76 882 (50.5)</td>
<td>33 584 (50.6)</td>
<td>43 298 (50.5)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Non-Hispanic black</td>
<td>27 882 (18.3)</td>
<td>12 884 (19.4)</td>
<td>14 988 (17.5)</td>
<td></td>
</tr>
<tr>
<td>Hispanic</td>
<td>26 030</td>
<td>11 421 (17.2)</td>
<td>15 382 (17.9)</td>
<td></td>
</tr>
<tr>
<td>Asian</td>
<td>2669 (1.8)</td>
<td>1066 (1.6)</td>
<td>1603 (1.9)</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>17 942</td>
<td>7478 (11.3)</td>
<td>10 464 (12.2)</td>
<td></td>
</tr>
<tr>
<td>Insurance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Government</td>
<td>76 467 (50.2)</td>
<td>27 755 (41.8)</td>
<td>48 712 (56.8)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Private</td>
<td>56 761</td>
<td>23 932 (36)</td>
<td>32 829 (38.3)</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>18 950</td>
<td>14 746 (22.2)</td>
<td>4204 (4.9)</td>
<td></td>
</tr>
<tr>
<td>Disposition</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Home health services</td>
<td>1808 (1.1)</td>
<td>606 (0.9)</td>
<td>999 (1.2)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Home</td>
<td>14 6459 (96.2)</td>
<td>64 994 (97.8)</td>
<td>81 465 (95)</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>3468 (2.3)</td>
<td>520 (0.8)</td>
<td>2986 (3.5)</td>
<td></td>
</tr>
<tr>
<td>Skilled</td>
<td>622 (0.4)</td>
<td>310 (0.5)</td>
<td>312 (0.4)</td>
<td></td>
</tr>
<tr>
<td>CCC</td>
<td>57 055</td>
<td>22 054 (35.2)</td>
<td>35 001 (40.9)</td>
<td>0.0587</td>
</tr>
<tr>
<td>ICU</td>
<td>18 541</td>
<td>9122 (15.7)</td>
<td>9419 (11)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Mechanical ventilation</td>
<td>6780 (4.5)</td>
<td>3307 (5.5)</td>
<td>3473 (4.1)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Length of stay, d</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0–1</td>
<td>71 610</td>
<td>29 054 (43.7)</td>
<td>42 556 (49.8)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>2–4</td>
<td>59 630</td>
<td>27 300 (41.2)</td>
<td>32 240 (37.8)</td>
<td></td>
</tr>
<tr>
<td>5–7</td>
<td>11 318</td>
<td>5272 (7.9)</td>
<td>6048 (7.1)</td>
<td></td>
</tr>
<tr>
<td>&gt;7</td>
<td>9620 (6.3)</td>
<td>4717 (7.1)</td>
<td>4903 (5.7)</td>
<td></td>
</tr>
</tbody>
</table>

**Note:** Interquartile range.
APR-DRGs. Severe head trauma had the largest reduction in CT utilization. There were no ultrasound studies meeting inclusion criteria for seizures, concussion, or severe head trauma. Ultrasound use increased during the study period for all other APR-DRGs, with the greatest increase noted in appendectomy and gastroenteritis. MRI utilization could not be evaluated for appendectomy, gastroenteritis, or infections of the upper respiratory tract because of limited study volume. Statistically significant changes in MRI use were noted across the remaining APR-DRGs, with marked increases for ventricular shunt procedures. For all included patients and APR-DRGs, the preferred modality of imaging substitution across the study duration was ultrasound, a finding primarily influenced by the abdominal diagnosis categories (Fig 2). To understand the reason for decreases in CT for severe head trauma, we performed analyses with and without the exclusion of patients transferred to PHIS hospitals, but found no difference in trends. We also reviewed a list of the 20 most frequently included codes in the APR-DRG in 2004 compared with 2012, and noted no apparent shifts in coding practices that might account for our findings.

AORs comparing 2004 with 2012 imaging utilization were calculated for each modality and APR-DRG combination (Fig 3, Supplemental Table 3). The adjusted odds of CT imaging declined across all APR-DRGs. The odds of CT in 2012 compared with 2004 decreased by 40% for appendectomy (AOR 0.6; 95% CI 0.5–0.6; P < .001), 40% for abdominal pain (AOR 0.6; 95% CI 0.5–0.7; P < .001) and 10% for gastroenteritis (AOR 0.9; 95% CI 0.8–0.99; P < .019). Additionally, there was a concomitant increase in ultrasound for those 3 APR-DRGs, with appendectomy having an AOR of 3.0 (95% CI 2.8–3.2; P < .001), abdominal pain having an AOR of 2.4 (95% CI 2.1–2.6; P < .001), and gastroenteritis having an AOR of 3.5 (95% CI 3.2–3.9; P < .001). Seizure, concussion, infections of the upper respiratory tract, and head trauma did not have increased odds of ultrasound utilization. AOR for ultrasound were all >1 for the remaining APR-DRGs (ventricular shunt procedures, craniotomy, and ENT conditions). Limited MRI utilization data did not allow for calculation of AOR for appendectomy, infections of the upper respiratory tract, and gastroenteritis. For seizure and ENT conditions, AORs were not >1. For all other conditions, the AOR for MRI exceeded 1.

**DISCUSSION**

In this multicenter cross-sectional study, we identified a decline in CT imaging between 2004 and 2012 for the 10 most common diagnostic groups for which CT is performed. This decrease occurred with a concomitant increase in alternate imaging modalities in 8 studied diagnostic groups, supporting the hypothesis that previously noted declines in CT utilization are associated with shifts to alternate modalities. Decreases in CT utilization have public health implications.
decreasing exposure to hazardous ionizing radiation. Longitudinal studies assessing subsequent cancer development identify an increased malignancy risk, with precise estimates difficult to calculate based on wide variability in radiation doses delivered by CT scans and by uncertainties inherent in radiation risk estimates. Therefore, the substitution of an imaging modality that does not confer ionizing radiation may affect lifetime cancer risk in children who receive diagnostic imaging.

We believe that the decrease in CT utilization is multifactorial. In 2006, the Alliance for Radiation Safety in Pediatric Imaging, which represents collaboration between dozens of national and international organizations, began as an effort within the Society for Pediatric Radiology. The initial focus, due to the frequency of pediatric CT scans performed in the United States and the use of adult dose protocols in pediatric imaging, was to raise awareness of radiation exposure and the opportunity to use lower doses when imaging children. Although not directly targeted at decreasing the number of CT scans performed on children, it is possible the increased awareness of the harms of ionizing radiation influenced physician selection of imaging modality. Additionally, since 2006, published studies defined circumstances in which CT use was unnecessary, such as children at very low risk of clinically important brain injuries, new-onset seizure disorder, or validation of clinical scoring to evaluate children with suspected appendicitis. It also is possible that advances in technology (ie, compact disc read/write functionality) and the spreading use of electronic health records and health information exchanges may have facilitated the sharing of existing images from referring hospitals, which may reduce or eliminate the need for additional imaging.
However, the trends persisted even after excluding patients transferred to PHIS hospitals from analyses. The increased use of alternate imaging modalities may be primarily related to a desire of health care providers to address clinical concerns without exposure to ionizing radiation. Contributory factors supporting this shift may include advances in diagnostic imaging quality for nonradiation modalities and increased availability of staff needed to perform the studies, such as sedation teams, which may be needed for MRI. We also hypothesize that the emergence of evidence that provides support for choosing nonradiation modalities may have played a role in the shift to alternate imaging. In particular, we noted striking shifts to ultrasound for the APR-DRGs of appendectomy, gastroenteritis, and abdominal pain, with ultrasound the preferred modality in all 3 groups. Because the APR-DRG is applied after discharge, it is possible the shift in this grouping of codes represents a shift favoring ultrasound as the modality of choice in the evaluation of suspected acute appendicitis. Some of these ultrasounds also may have been performed to evaluate for intussusception as a cause of abdominal pain, as the validation of ultrasound as a first-line examination occurred during the study period.

The preference toward ultrasound for all included patients is notable, and also may be affected by factors such as timeliness of the study and the lack of need for sedation. Concerted efforts have been made to assess and increase awareness of imaging-related radiation exposure among ordering physicians, medical students, and families. Half of the APR-DRGs were associated with an increase in alternate imaging that exceeded decreases in CT. One possible explanation is that growing confidence or ability to perform ultrasound or MRI emboldened providers to perform more imaging. Also possible is that larger increases in alternate imaging were disproportionately represented by certain patient populations, such as those with CCC who were more prevalent by the end of our study. The remaining half of the APR-DRGs were associated with a decrease in CT that exceeded increases in ultrasound/MRI, suggesting that it was not only a desire to avoid ionizing radiation that drove the decision to not use CT, but a general decline in imaging volume. Other factors also may be at play, such as new or updated national guidelines discouraging routine use of CT for simple febrile or first nonfebrile seizure or the growing use of imaging appropriateness criteria and clinical pathways in emergency department and inpatient settings that provide guidance and evidence base for the use or nonuse of certain diagnostic approaches.

After exclusion of images unrelated to the APR-DRGs, several diagnoses had no utilization of some alternate imaging modalities. For example, hospitalizations for seizure, concussion, and head trauma were not associated with ultrasound utilization, and appendectomy and gastroenteritis were not associated with MRI. These absences of data we feel intuitively fit with logical clinical decision-making. This study has several limitations. First, although the study included a large number of children’s hospitals, utilization patterns may differ in other institutions not included in the study. However, previously published data using a national dataset that did incorporate nonchildren’s hospitals similarly found a decrease in CT utilization for suspected appendicitis. Second, utilization from referring hospitals would not have been captured in our data. Because referring adult hospitals may more commonly perform CT scanning, this limitation would cause us to underestimate the magnitude of CT use, although the effect on trends is uncertain. Third, APR-DRGs do not reflect the

![Figure 3](https://example.com/figure3.png)

**Figure 3**
Adjusted odds of imaging for each APR-DRG in 2012 compared with 2004. Odds ratios are adjusted for age, gender, race, insurance, disposition, CCC, ICU, mechanical ventilation, length of stay, and charge weight CMI. * denotes the upper limit of the CI as 9.
indication for or appropriateness of the imaging study but rather the final diagnosis. For example, patients within the gastroenteritis APR-DRG may have presented with signs concerning for appendicitis and received imaging as part of the diagnostic evaluation ultimately leading to the diagnosis of gastroenteritis. Therefore, these data cannot serve to evaluate appropriateness of diagnostic testing and do not imply unnecessary utilization. Given the complexity of factors affecting clinical outcomes, we cannot draw conclusions on whether shifts in imaging may affect quality of care. Additionally, it is possible that changes in imaging may alter final diagnoses, leading to decreased detection of some conditions and thus alternate classification by APR-DRG in some circumstances. However, we are unable to determine whether this occurred or the extent to which it might occur. We expect that such misclassification would result in underrepresentation of some diagnoses, which might cause us to underestimate the magnitude of shift to alternate imaging. Fourth, administrative data may not fully account for interinstitutional variability in coding practices. We addressed this limitation by reviewing any imaging study performed on >0.5% of eligible children; therefore, we believe the impact of this limitation is minimal. One finding that is challenging to explain is the marked decrease in CT utilization for the APR-DRG of severe head trauma, which includes coma >1 hour or hemorrhage. To clarify these findings, we conducted additional analyses, such as exclusion of patients transferred in, as well as examination of coding practices. It is possible that there has been a shift in the classification of this APR-DRG. Published literature has questioned the accuracy of APR-DRG codes’ reflection of clinically significant measures in neurotrauma,48,49 which has potentially affected coding practices. Last, point-of-care ultrasounds are increasingly used in the emergency department setting, but in most scenarios function more as an extension of the physical examination rather than as a billable diagnostic procedure, and so would not be captured in the data. The use of point-of-care ultrasounds could, therefore, potentially underestimate the magnitude of shift to other modalities, in particular the abdominal APR-DRGs.

CONCLUSIONS

Our study demonstrated a decrease in CT utilization from 2004 to 2012, and an increase in ultrasound or MRI in 8 of 10 studied common diagnostic groups, supporting the hypothesis of shifts from CT to alternate imaging. In addition to less overall imaging for some conditions, we hypothesize that concerns over ionizing radiation may be influencing providers’ choice in imaging, which may affect lifetime cancer risks for pediatric patients. Physicians should continue to be vigilant in their decision-making, choosing imaging evaluations that maximize immediate patient benefit while minimizing financial and potential long-term biological costs.

ABBREVIATIONS

AOR: adjusted odds ratio
APR-DRG: All-Patient Refined Diagnosis Related Groups
CCC: complex chronic condition
CI: confidence interval
CMI: case mix index
CT: computed tomography
ENT: ear, nose, and throat
PHIS: Pediatric Health Information System

FINANCIAL DISCLOSURE: The authors have indicated they have no financial relationships relevant to this article to disclose.

FUNDING: No external funding.

POTENTIAL CONFLICT OF INTEREST: The authors have indicated they have no potential conflicts of interest to disclose.

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*Pediatrics* 2015;136;e573; originally published online August 24, 2015;
DOI: 10.1542/peds.2015-0995

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/content/136/3/e573.full.html