Hospitalizations and Deaths from Diarrhea and Rotavirus among Children <5 Years of Age in the United States, 1993–2003

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Recently a new rotavirus vaccine was licensed in the United States and recommended for universal immunization of American children. The impact of the vaccine on a decrease in hospitalizations will take several years to assess and will be based on the availability of good baseline data on the disease. We used the largest US hospital discharge database available, the Healthcare Cost and Utilization Project (HCUP), to study national rates, trends, and risk factors for diarrhea- and rotavirus-associated hospitalizations and deaths among children <5 years of age, to establish a baseline against which vaccine implementation can be measured. Rotavirus remained the most important cause of pediatric diarrhea throughout the study period (1993–2003). When the data were extrapolated to the US population, rotavirus was estimated to be the cause of ~60,000 hospitalizations and 37 deaths annually. Black infants had a significantly higher risk of being hospitalized with and dying from rotavirus disease early in life, compared with white infants (risk ratio [RR] for hospitalization by 12 months of age was 2.4, with a 95% confidence interval [CI] of 1.2–4.7; RR for death was 2.0, with a 95% CI of 1.7–2.5). Such racial differences in age and risk of rotavirus-associated hospitalization and death highlight the importance of timely and early rotavirus immunization of minority children. The HCUP database serves as a sensitive and robust data source for monitoring the impact of a rotavirus-immunization program in the United States.

Rotavirus is the most common cause of acute and severe diarrhea in children <5 years of age and is associated with ~600,000 deaths worldwide each year [1, 2]. Although the majority of these deaths occur in de-

veloping countries, the disease is not limited to poor settings. Rotavirus infects all children during the first few years of life and remains a common cause of physician consultations and hospital admissions in the industrialized world [1, 2]. In fact, the proportion of diarrhea-associated hospitalizations attributable to rotavirus is higher in developed countries because environmental interventions, such as sanitation and water purification, substantially prevent infection with bacterial and parasitic agents but are ineffective against rotavirus. Because of this tremendous disease burden, the development and introduction of rotavirus vaccines in global programs for childhood immunization have been a high priority for many international health agencies [3, 4]. Because of the recent licensure of a new rotavirus vaccine in the United States, prevention of the disease is possible for the next birth cohort of Amer-

Table 1. Diarrhea-coded hospitalizations among children <5 years of age, in 17 US states, 1993–2003.

Diagnostic category	ICD-9-CM code(s)	Average annual no. (%) of hospitalizations[a]		
		1993–2003	1993–1995	2001–2003
Etiology unspecified				
Presumed noninfectious	009–009.3	81,053 (59.7)	97,483 (64.5)	74,003 (57.3)
Presumed infectious	558.9, 787.91	1372 (1.0)	1799 (1.2)	1179 (.9)
Etiology specified				
Viral				
All	008.6, 008.8	46,559 (34.3)	43,280 (28.6)	48,389 (37.5)
Rotavirus	008.61	22,879 (16.9)	17,808 (11.8)	25,309 (19.6)
Bacterial				
All	001–005 (excluding 003.2), 008.0–008.5	7694 (5.7)	9192 (6.1)	6888 (5.3)
Escherichia coli	008–008.5	4096 (3.0)	4361 (2.9)	4141 (3.2)
Salmonella	002–003.9 (excluding 003.2)	2527 (1.9)	3299 (2.2)	2024 (1.6)
Parasitic	006–007.2 (excluding 006.2–006.6)	410 (.3)	656 (.4)	221 (.2)
All causes[b]	…	135,692 (11,649)	151,160 (3061)	129,190 (10,711)

**Note.** ICD-9-CM, International Classification of Diseases, 9th Revision, Clinical Modification.

[a] Data indicate proportion of total diarrhea-associated hospitalizations, per diagnostic category.

[b] Data in parentheses are SDs.

ican children [2]. Accurate projections of the benefits of a vaccine program will require robust, current data on the disease burden in the United States.

In the United States, previous studies have estimated that rotavirus leads to ~55,000–70,000 hospitalizations and ~600,000 physician visits among young children <5 years of age [5–8]. These studies have been based on analyses of data from the National Hospital Discharge Survey (NHDS), conducted by the National Center for Health Statistics (NCHS), and the Kids' Inpatient Database (KID), produced by the Healthcare Cost and Utilization Project (HCUP), both of which pose problems for interpretation. The NHDS is designed to provide national estimates of hospitalization trends, based on a 0.5%–1% sample of all hospital discharges in the United States, and results in a relatively small number of observations for analyses of subgroups or fatalities [9–11]. KID is a national sample of pediatric discharges from community hospitals in the United States. Although the number of observations in KID is much larger than that in the NHDS (~3 million vs. 270,000, respectively), KID has been produced only triannually (1997, 2000, and 2003)
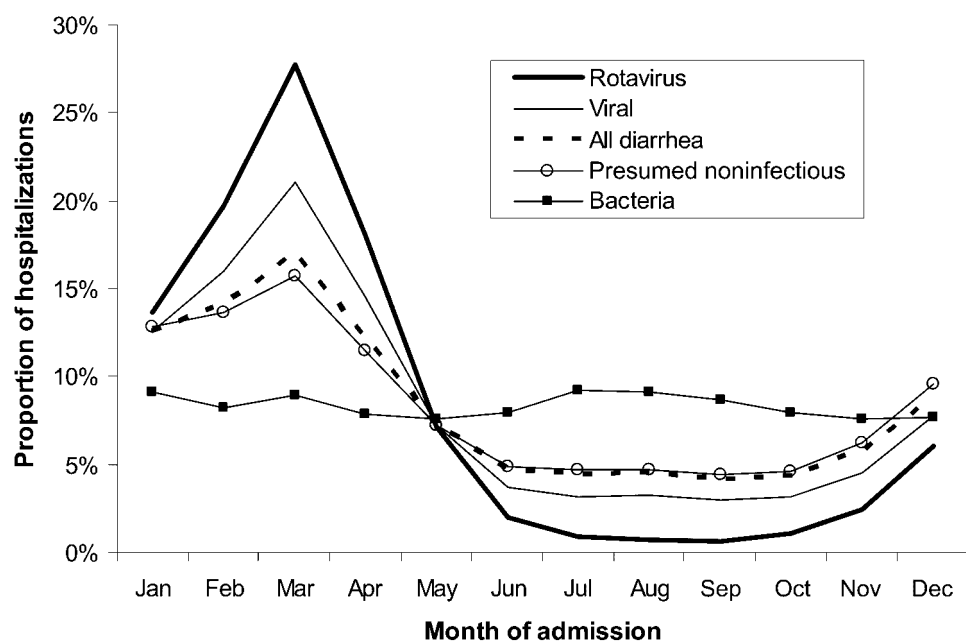
Figure 1. Seasonality of hospitalizations for diarrhea among children <5 years of age, by etiology, in 17 states, 1993–2003
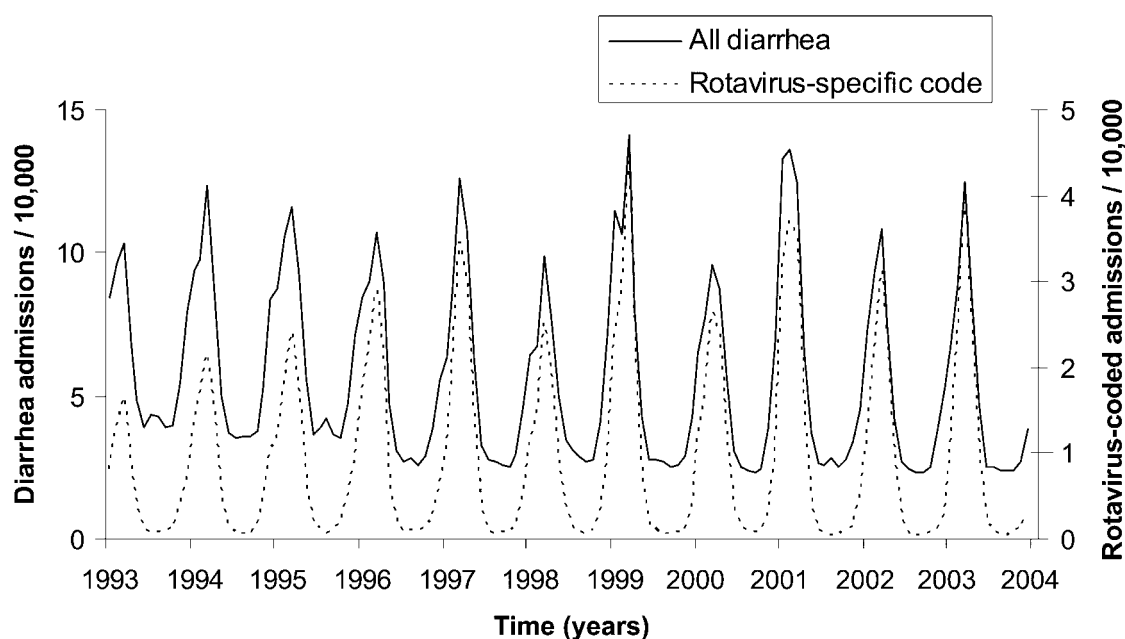
Figure 2. Monthly rates of hospitalization for diarrhea of all causes and for rotavirus-associated diarrhea (*International Classification of Diseases, 9th Revision, Clinical Modification* code 008.61) among children <5 years of age, in 16 states, 1993–2003.

[10–14]. KID can be used to predict associated health care expenditures, but the data do not allow for studies of yearly time trends and are not ideal for estimating disease burden for diseases such as rotavirus gastroenteritis, which exhibits a seasonal pattern with 1 epidemic season spanning 2 calendar years [14–16].

In this study, we therefore analyzed electronic databases containing all hospital discharge records from 17 states for the period 1993–2003, using the State Inpatient Database (SID) compiled by the HCUP [13, 17]. We analyzed data extracted as all diarrhea- and rotavirus-associated hospitalizations and deaths among children <5 years of age, to assess trends over time and risk factors such as race, sex, and age. Our findings include national rates of the incidence of diarrhea and rotavirus disease burden and provide data that would be useful for policy makers when considering strategies for vaccine introduction, vaccine design, and systems for monitoring the health impact of the vaccine as it is introduced.

METHODS

Data source. From the HCUP, we analyzed data from SID for 17 states for an 11-year period (1993–2003). The HCUP is a family of health care databases and related software tools and products developed through a federal-state-industry partnership and sponsored by the Agency for Health Care Research and Quality (AHRQ). HCUP databases bring together the data-collection efforts of state data organizations, hospital associations, private data organizations, and the federal government

to create a national information resource of patient-level health care data [13, 18]. Seventeen states had complete hospital discharge data for the full study period: Arizona, California, Colorado, Connecticut, Florida, Illinois, Iowa, Kansas, Maryland, Massachusetts, New Jersey, New York, Oregon, Pennsylvania, South Carolina, Washington, and Wisconsin. In 1998, these states had a combined annual birth cohort of 1,971,516 infants, which was ~50% of the US birth cohort [19, 20].

Selection of records. We extracted the records of all hospital discharges for children <5 years of age that listed any *ICD-9-CM (International Classification of Diseases, 9th Revision, Clinical Modification)* codes for diarrhea (referred to as "all-cause diarrhea"; 001–009, excluding 003.2, 558.9, and 787.91), in any position among the first 15 discharge diagnoses. The subcategories of diarrhea examined included diarrhea of determined etiology (bacterial [001–005 and 008.0–008.5, excluding 003.2], parasitic [006–007, excluding 006.3–006.6], viral [008.6–008.8], and rotavirus specific [008.61]) and diarrhea of undetermined etiology and included cases presumed to be infectious (009.0–009.3) or noninfectious (558.9 and 787.91). For each record, we noted the child's age in months and years, state, year and month of admission, length of stay, discharge status, and *ICD-9-CM* codes for all listed diagnoses and procedures. The term "diarrhea- and/or rotavirus-coded hospitalization/death" refers to an *ICD-9-CM*–coded event, as opposed to a "diarrhea- and/or rotavirus-associated event" (hospitalization or death), which refers to an estimate.

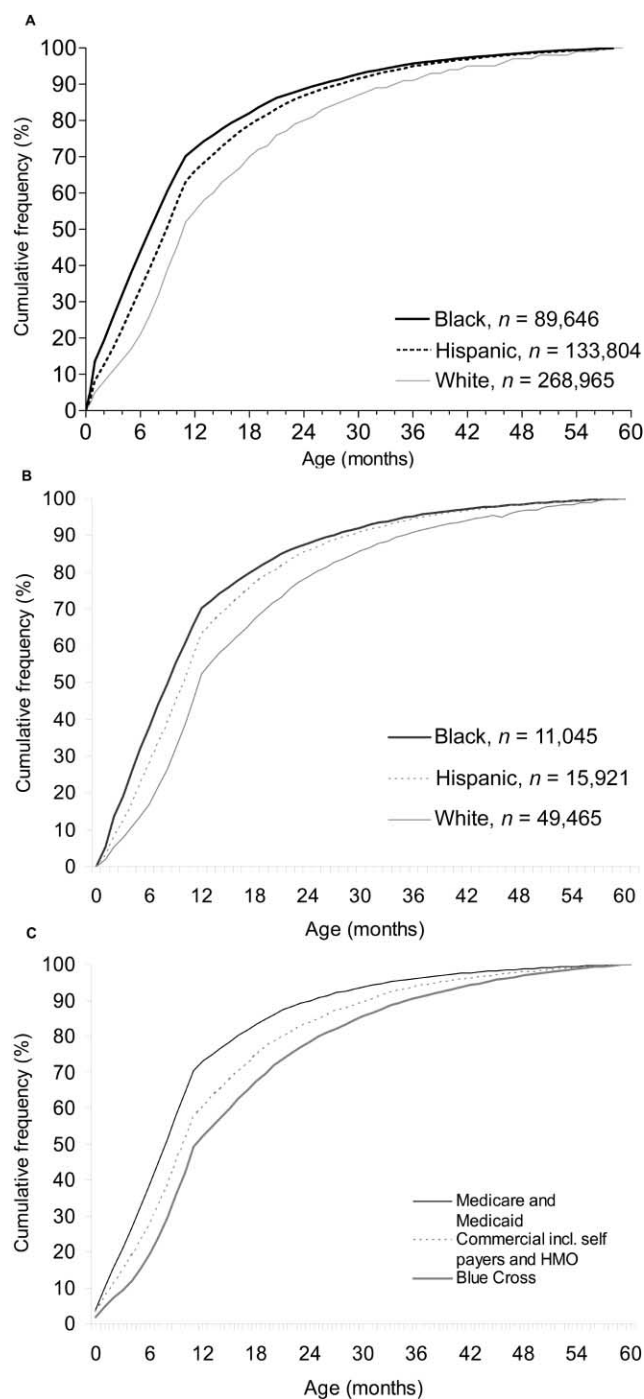***Data analyses.*** Diarrhea-coded hospitalizations were ex-

Figure 3. Cumulative frequency among children <5 years of age of diarrhea-associated hospitalizations, by race and age *(A)*; rotavirus-associated hospitalizations, by race and age *(B)*; and rotavirus-associated hospitalizations, by insurance coverage *(C)*. HMO, health maintenance organization.

amined by age group, sex, race, and month and year of discharge. National estimates of hospitalizations were calculated by extrapolating the incidence rates estimated for the 17 HCUP states to the US census population [19, 20].

Coding of race is variable across the HCUP states. We therefore limited the analyses of race to include data from 9 states (California, Connecticut, Florida, Kansas, Maryland, New Jersey, New York, South Carolina, and Wisconsin) that coded race for ≥95% of their discharge records for all study years. In 1998, data for these 9 states combined represented 16.0% of the US birth cohort [19, 20].

Average length of stay and total charges for diarrhea-coded hospitalizations were examined over time and tested for time trends. Statistical analyses were performed by use of SAS software, version 9.2, for Windows (SAS institute). Hospitalization rates were calculated as the estimated number of hospitalizations per 100,000 children, based on estimates of the resident population of children <5 years of age in the United States and estimates of live births of infants, by use of natality data for the corresponding year [19, 20].

National estimates of rotavirus-associated hospitalizations. Discharges coded as rotavirus related (*ICD-9-CM* 008.61) represent only a fraction of all rotavirus-associated hospitalizations [5–8]. To estimate the true number of rotavirus-associated hospitalizations, we modeled our data by using Serfling's harmonic regression model, which usually is used to quantify the burden of pneumonia and influenza mortality [21]. First, we compiled monthly hospital discharges for all-cause diarrhea for children <5 years of age for each of the 16 states that coded month of admission (the 17th state, Florida, was omitted because it did not code month of admission after 1997). For each state, we then fitted a linear seasonal regression model, including harmonic terms, to the monthly number of hospitalizations [21]. We used rotavirus-coded hospitalizations (*ICD-9-CM* 008.61) to identify the rotavirus seasons (10 winter seasons, from 1993–1994 to 2002–2003) and estimated the total rotavirus-specific burden of diarrhea as the number of diarrhea-coded hospitalizations that exceeded the baseline during the rotavirus winter seasons. We extrapolated estimates of seasonal burden for these 16 states to the pediatric population in the United States, to derive national estimates of the burden of rotavirus-specific diarrhea each season.

National estimates of rotavirus-associated deaths. We estimated the mean case-fatality rate for admissions that had rotavirus coded in any position among the first 15 discharge diagnoses. We then applied this case-fatality rate to our model's estimate of the total burden of rotavirus-associated hospitalizations in the United States.

RESULTS

For the period 1993–2003, 785,863 hospital discharge records from the 17 states were coded as cases of diarrhea, among children <5 years of age (table 1). Most cases of diarrhea-associated hospitalization (61%) were coded as unspecified etiology. Of those with specified etiology, 34% were attributed to

viral agents, 6% to bacterial agents, and <1% to parasites. Rotavirus (*ICD-9-CM* 008.61) was the single most common pathogen, coded on 16.9% of all discharge records for cases of diarrhea-associated hospitalization, and the proportion increased from 11.8% in 1993–1995, when the code was first introduced, to 19.7% in the most recent 2-year period (2001–2003) (*P* for trend, <.001; table 1). By contrast, the frequency of all-cause diarrhea declined slightly over the study period (∼1% annually; *P* = .008), from 2.8% of all hospital admissions among children <5 years of age in 1993 to 2.5% of all hospital admissions in 2003.

The seasonality of cases of diarrhea-associated hospitalization coded as unspecified viral diarrhea and those coded as rotavirus (*ICD-9-CM* 008.61) showed a very similar temporal pattern (figure 1), suggesting that cases of true rotavirus-associated hospitalization may have been underdiagnosed and nonspecifically classified as viral infections. The peak in hospitalizations from January to April and the trough from July to October were most marked for rotavirus and least apparent for diarrhea coded as bacterial. The time series for all-cause diarrhea and rotavirus admissions had very similar monthly fluctuations throughout the winter months (figure 2); however, the ratio of winter peak to summer trough was much greater for rotavirus, and all-cause diarrhea had a higher baseline during the rotavirus off-season from June to October. Rotavirus-associated admissions were most common among the youngest age groups and gradually declined as patient age increased (data not shown).

Age, sex, and ethnic differences. For the following analyses we used cumulative hospitalization data for children <5 years of age. We plotted the age distribution for children whose hospitalizations had been coded as diarrhea related, by ethnic group (figure 3). Among black and Hispanic children, the cumulative occurrence of diarrhea-coded hospitalizations was 52% and 48%, respectively, by 12 months of age but only 35% among white children (*P* < .05; figure 3*A*). The cumulative occurrence of rotavirus-coded hospitalization was 13% by 6

months of age, 41% by 1 year of age, and 75% by 2 years of age. In the 9 HCUP states that coded race, minority children were hospitalized at a younger age than were white children: among black and Hispanic children, as many as 56% and 50% of all rotavirus-coded hospitalizations, respectively, had occurred by 1 year of age, compared with 35% among white children. By 6 months of age, minority children had already experienced 26% (Hispanic) to 31% (black) of their cumulative childhood (up to 5 years of age) rotavirus-coded hospitalization burden, compared with 17% for white infants (figure 3*B*). To investigate this difference further, we studied rotavirus-coded hospitalizations by insurance coverage and found that children covered by Medicare and Medicaid were hospitalized at a younger age, compared with those covered by Blue Cross or other commercial insurance: among children covered by Blue Cross or other commercial insurance, the occurrence of diarrhea-coded hospitalizations was only 20% and 23%, respectively, by 6 months of age, compared with 46% among children who were covered by Medicare or who were self-paying (*P* < .05; figure 3*C*).

Length of stay and costs for rotavirus-coded hospitalizations. The median duration of all-cause diarrhea– and rotavirus-associated hospitalizations dropped from 3 days (interquartile range [IQR], 2–4 days) during 1993–1995 to 2 days (IQR, 2–3 days) during 1996–2003 (Wilcoxon rank sum test, *P* < .0001). During the study period, the median charge for hospitalizations coded as diarrhea increased by 38%, from $2762 in 1993 to $3586 in 2003 (*P* < .01), while the median charge for rotavirus-associated hospitalizations increased by 37%, from $2775 in 1993 to $3610 in 2003 (Wilcoxon rank sum test, *P* < .0001) (table 2).

Overall burden of diarrhea- and rotavirus-associated hospitalizations and deaths in the United States. On the basis of simple extrapolation of data for all-cause diarrhea–associated hospitalizations from the 17 HCUP states to national estimates, we found that ∼136,000 diarrhea-associated hospitalizations

Table 2. Estimates of disease burden for all types of diarrhea and for rotavirus-specific diarrhea: trends in length of stay and median cost of hospitalization and in case-fatality rate for 17 HCUP states in the United States, 1993–2003.

Trend estimate	All diarrhea				Rotavirus (*ICD-9-CM* coded)			
	1993–2003 (*n* = 785,863)	1993–1996 (*n* = 238,757)	2001–2003 (*n* = 204,056)	Annual change (SE)	1993–2003 (*n* = 132,505)	1993–1996 (*n* = 28,128)	2001–2003 (*n* = 39,975)	Annual change (SE)
Hospitalization								
Mean duration, days	3.2	3.7	2.9	−.09 (.02)[a]	3.5	4.0	3.2	−.10 (.02)[a]
Median cost, $	3200	2800	3900	142 (25)[a]	3200	2800	3900	144 (27)[a]
Case-fatality rate (per 100,000 hospitalizations)	109.2	138.5	102.0	−4.2 (1.7)[b]	61.4	113.0	48.4	−7.7 (2.2)[c]

Note. HCUP, Healthcare Cost and Utilization Project; *ICD-9-CM*, International Classification of Diseases, 9th Revision, Clinical Modification.
[a] *P* < .001.
[b] *P* < .05.
[c] *P* < .01.

Table 3. Comparison of national estimates of acute gastroenteritis (AGE)– and rotavirus-associated hospitalizations among children <5 years of age.

| | Data source | | | |
	NCHS, 1979–1992 [6]	NHDS, 1993–1995 [5]	NHDS, 2000–2002 [22]	HCUP, 1993–2003
Variable				
AGE				
Estimated no. of annual hospitalizations	185,700	162,500	179,600	135,692
Annual incidence, no. of hospitalizations/10,000 (range)	97	83	95	71 (64–80)
Cumulative incidence[a]	1 in 20	1 in 25	1 in 20	1 in 26
Proportion of all annual pediatric admissions, %	12.0	13.5	12.5	10.2
Rotavirus				
Estimated no. of annual hospitalizations (% of AGE-associated hospitalizations)				
ICD-9-CM coded	NA[b]	26,800 (17)	33,800 (18)	22,900 (17)
Brandt indirect estimate[c]	54,100 (29)	NA	58,600 (32)	56,300 (39)
Residual indirect estimate[d]	55,100 (30)	NA	70,100 (38)	59,800 (48)
Cumulative incidence[a]	…	1 in 145	1 in 115	1 in 170
ICD-9-CM coded				
Brandt indirect estimate[c]	1 in 70	…	1 in 65	1 in 70
Residual indirect estimate[d]	1 in 70	…	1 in 55	1 in 65

Note. HCUP, Healthcare Cost and Utilization Project; *ICD-9-CM, International Classification of Diseases, 9th Revision, Clinical Modification;* NA, not available; NCHS, National Center for Health Statistics; NHDS, National Hospital Discharge Survey.

[a] The risk of a child having the outcome by 5 years of age.
[b] Rotavirus-specific *ICD-9-CM* code not yet introduced at the time of this study [1].
[c] Obtained by summing the monthly products of the number of diarrhea-associated hospitalizations, multiplied by the proportion of those hospitalizations attributable to rotavirus, using data from Brandt et al. [23].
[d] Calculated by subtracting the number of diarrhea-associated hospitalizations occurring in winter (November through April) from those occurring in summer (May through October). For the present study, these values were estimated by use of a Serfling regression model and a cyclical winter seasonal baseline, instead of data for summer months.

occur annually among children <5 years of age in the United States (table 3). Estimates of rotavirus-associated hospitalizations were created by use of modeling techniques in which the months with almost no rotavirus activity served as a baseline for estimates of the proportion of cases of all-cause diarrhea that could be attributed to rotavirus during the annual rotavirus season [5, 6, 8, 23–28]. We estimated that, of the 136,000 diarrhea-associated hospitalizations, ~59,600 (43.8%; 95% confidence interval [CI], 52,300–66,800) are due to rotavirus.

During the 11-year study period, we identified a total of 858 deaths among the 785,863 diarrhea-associated hospitalizations among children <5 years of age, which corresponds to a case-fatality rate of 1 death per 915 diarrhea-associated hospitalizations. Of these 858 deaths, 82 (9.6%) occurred among 132,505 cases of rotavirus-coded hospitalizations, which corresponds to a case-fatality rate of ~1 death per 1616 rotavirus-coded hospitalizations. The case-fatality rate for both diarrhea- and rotavirus-associated hospitalizations declined gradually during the study period (figure 4).

To estimate the average annual mortality burden attributable to rotavirus in the United States, we applied the estimated case-fatality rate for rotavirus-specific diarrhea (62 deaths per 100,000 rotavirus-coded hospitalizations [95% CI, 48.5–75.3]) to the annual estimate of 59,600 rotavirus-associated hospital-

izations (95% CI, 52,300–66,800) and found that the average annual mortality burden attributable to rotavirus was 37 deaths (95% CI, 25–50) in the United States during the study period. Case fatality was associated with racial disparities, since black children had a significantly higher risk of dying during rotavirus-associated hospitalization, compared with white children (risk ratio for death, 2.4 [95% CI, 1.2–4.7]).

DISCUSSION

We present updated estimates and describe temporal trends for diarrhea- and rotavirus-associated hospitalizations and deaths among children <5 years of age in the US population, using the most complete state-level hospital discharge database available to date [11, 16]. In addition, this study of 11 years of continuous surveillance data provides a robust baseline platform from which to assess the impact of the new rotavirus immunization program being rolled out in the United States.

In terms of overall burden to the pediatric population in the United States, 1 in 26 US children suffered a diarrhea-associated hospitalization during their first 5 years of life. Our national estimate of ~60,000 annual hospitalizations attributable to rotavirus infection corresponds to ~1 in 60 US infants hospitalized for rotavirus-specific diarrhea. Our findings demonstrate
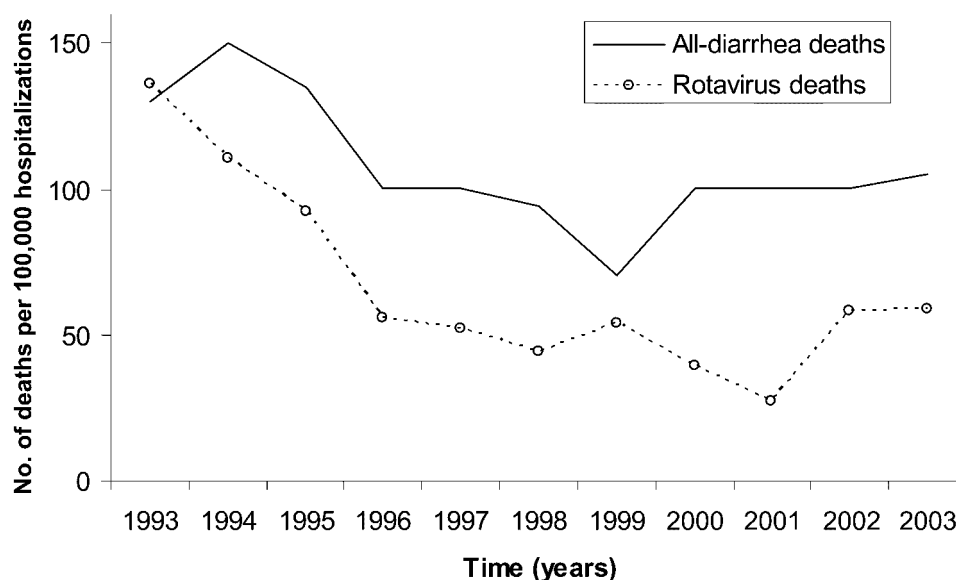
Figure 4. Trends in case-fatality rates for diarrhea- and rotavirus-associated hospitalizations among children <5 years of age, 1993–2003

that rotavirus-specific diarrhea is common and remains a substantial burden on pediatric departments (in terms of beds, days of hospitalization, and dollars) during the rotavirus seasonal months in winter and early spring. We estimate that each rotavirus-associated hospitalization has a 2-day length of stay and incurs charges of ~$3600. In theory, a fully implemented (90% coverage) national immunization program using a highly efficacious rotavirus vaccine (90% efficacy against severe outcomes) would prevent ~80% of the total seasonal burden of 60,000 rotavirus-associated hospitalizations and 35–40 deaths—that is, ~48,000 hospitalizations and 30 deaths could be prevented annually once a national vaccine program has been in place for several years.

Although the incidence of hospitalizations coded with the rotavirus-specific *ICD-9-CM* code (008.61) increased steadily over time, our model analysis of the total burden of rotavirus-specific diarrhea demonstrated that, even today, only a fraction of all true rotavirus-associated hospitalizations appear to be coded as *ICD-9-CM* 008.61. Thus, tabulations based on this *ICD-9-CM* code represent only the "tip of the iceberg," compared with the total rotavirus-associated disease burden [5, 6, 8, 23–28]. Using our model-derived estimate of ~60,000 annual rotavirus-associated hospitalizations as the best measure of the true total disease burden, we estimate that the fraction of *ICD-9-CM*–coded rotavirus-associated hospitalizations has increased from ~1/4 to ~1/3 of all actual cases, over the decade studied. No clear guidelines exist for diagnostic testing of rotavirus infection, and, as long as no specific treatment is available for rotavirus disease, there is no obvious reason for a doctor to screen for rotavirus during the care of a patient. A child with watery diarrhea can be rehydrated without knowledge of

the pathogen; thus, performing a diagnostic assay only increases the cost of care but does not really change the treatment provided. Testing is mainly conducted to (1) exclude the presence of bacterial and/or parasitic pathogens that effect potential treatment, (2) document the presence of an outbreak, or (3) establish cause of death. Therefore, the observed increase in rotavirus-coded hospitalizations likely reflects an increase in testing practice due to enhanced awareness of the disease, combined with improved coding procedures, rather than a true increase in disease occurrence.

Of note, the national estimate of all-cause diarrhea, based on 11 years of HCUP data, is considerably lower (136,000 cases) than the most recent estimates calculated by analyses of data from the NCHS (179,600 cases) and KID (157,000 cases; average of data for 1997 and 2000) [8, 22]. We do not know the reason for this discrepancy but consider HCUP data, which is based on 100% of hospital discharges in 17 states over an 11-year period, to be highly reliable and less vulnerable to annual changes. Our model-based estimates of the national numbers of rotavirus-associated hospitalizations and deaths were generated with a model commonly applied to assessments of national disease burden of influenza [21]. The cyclical regression model generated a baseline of expected hospitalizations and attributed the seasonal winter increase to rotavirus infection. The resulting national estimates, 60,000 hospitalizations and 37 deaths, correspond well with results from different studies, such as the recent estimate of 47,000–60,000 hospitalizations and 20 deaths based on data from KID and an analysis using different methods [8]. The unique advantage of the Serfling model is that it allows for refined subgroup analyses, as well as estimates of total disease burden, that are free of coding bias

associated with differences in the use of laboratory testing for diagnostic purposes or variations in *ICD-9-CM*–coding practices. Furthermore, our Serfling model is similar to the residual method used by Ho et al. [24], who calculated the burden of rotavirus-associated hospitalizations as the difference between the number of winter (November through April) minus the number of summer (May through October) hospitalizations. In our study, we modeled overall burden of rotavirus-associated hospitalizations by using a seasonal regression approach to the time series of all-cause diarrhea. In this approach, a seasonal baseline mirrors the expected level of diarrhea-associated hospitalizations caused by a variety of non-rotavirus pathogens cocirculating in winter, and the rotavirus-specific disease burden is calculated as the excess above the baseline during epidemic periods of rotavirus infection. Because of the strong geographic/temporal sweep pattern in the all-cause diarrhea peaks across states [29] and because rotavirus-coded hospitalizations closely mirror this sweep pattern, rotavirus most likely contributes the majority of the observed excess disease burden during winter. If other, yet-to-be-identified viruses contribute to the disease burden, these other viruses would have to be circulating in a pattern that closely resembles the sweep pattern of rotavirus, which we consider to be less likely. The national estimates that we derived are quite robust and fairly similar when determined by use of all methods applied to date (table 3).

Our analyses of data from the 9 HCUP states that consistently coded race demonstrated that early rotavirus vaccination (at age 2, 4, and 6 months) would be beneficial for minority groups in particular, because infants in these groups had a higher risk of dying from rotavirus disease and because a substantial proportion of rotavirus-associated hospitalizations among black and Hispanic infants occurred by 6 months of age, whereas white infants tended to be hospitalized later during childhood [8, 23]. This earlier age at rotavirus-associated hospitalization is also a feature of the hospitalization of children in developing countries, where up to 70% of rotavirus-associated hospitalizations occur during the first year of life.

Looking at rotavirus-associated hospitalizations by patient age and payment method suggests that, in general, children covered by the more expensive insurance plans and private payers are hospitalized at an older age, compared with children covered by low-cost insurance plans. However, our study design did not enable us to assess what sociobehavioral factors may explain the observed racial differences in the age patterns for rotavirus-associated hospitalizations.

Our study has some limitations related to the lack of procedures to validate diagnoses and to changes in the categorization of racial groups during the study period. We consider these limitations to have had little influence on our results, since a study done in New York by Chang et al. [28] found that, for >90% of hospital discharges coded as rotavirus, a positive laboratory result had been recorded in the patients' charts. Unfortunately, the 2-year lag time between hospitalization and data release for the HCUP (as for other major registries of discharge data, such as KID and the NCHS) diminishes the usefulness of these sources in assessing the immediate impact of a national immunization program.

Our updated assessment of rotavirus disease burden demonstrates that gastrointestinal illness and rotavirus disease specifically remain a major cause of severe pediatric morbidity in the United States and underscores the potential benefits of prevention through immunization. This study also provides a solid basis for future assessment of the impact of rotavirus immunization in the United States. For the purpose of rapid assessment, we suggest prospective surveillance of a representative sample of hospitals from 4 geographic regions (west, midwest, south, and northeast) and recommend that this initiative be supplemented with annual analyses of updated HCUP data, to monitor long-term trends in disease impact.

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