Community-Based Epidemiology of Hospitalized Acute Kidney Injury

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abstract

BACKGROUND: Acute kidney injury (AKI) may lead to short- and long-term consequences in children, but its epidemiology has not been well described at a population level and outside of ICU settings.

METHODS: In a large, diverse pediatric population receiving care within an integrated health care delivery system between 2008 and 2016, we calculated age- and sex-adjusted incidences of hospitalized AKI using consensus serum creatinine (SCr)–based diagnostic criteria. We also investigated the proportion of AKI detected in non-ICU settings and the rates of follow-up outpatient SCr testing after AKI hospitalization.

RESULTS: Among 1 500 546 children, the mean age was 9.8 years, 49.0% were female, and 33.1% were minorities. Age- and sex-adjusted incidence of hospitalized AKI among the entire pediatric population did not change significantly across the study period, averaging 0.70 (95% confidence interval: 0.68–0.73) cases per 1000 person-years. Among the subset of hospitalized children, the adjusted incidence of AKI increased from 6.0% of hospitalizations in 2008 to 8.8% in 2016. Approximately 66.7% of AKI episodes were not associated with an ICU stay, and 54.3% of confirmed, unresolved Stage 2 or 3 AKI episodes did not have outpatient follow-up SCr testing within 30 days postdischarge.

CONCLUSIONS: Community-based pediatric AKI incidence was ~1 per 1000 per year, with two-thirds of cases not associated with an ICU stay and more than one-half not receiving early outpatient follow-up kidney function testing. Further efforts are needed to increase the systematic recognition of AKI in all inpatient settings with appropriate, targeted postdischarge kidney function monitoring and associated management.

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Mr Parikh designed the study, analyzed the data and created the figures and tables, and drafted the manuscript; Dr Go designed the study and drafted the manuscript; Ms Tan drafted the manuscript; Drs Salyer, Auron, Kim, and Ku provided critical feedback and revised the manuscript; and all authors approved the final version of the manuscript as submitted.

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WHAT'S KNOWN ON THIS SUBJECT: Pediatric acute kidney injury (AKI) is associated with short- and long-term consequences in critically ill children, including increased mortality, hospitalizations, and progression of chronic kidney disease. However, its epidemiology has not been well described outside of critical care settings.

WHAT THIS STUDY ADDS: We describe the burden of AKI in a community-based population of children within and outside critical care inpatient settings. Importantly, there appears to be opportunity to improve follow-up outpatient kidney function testing in pediatric care after unresolved, severe hospitalized AKI.

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Acute kidney injury (AKI) is common among critically ill children, with researchers estimating, in recent studies, that 1 in 4 children admitted to ICUs experience AKI.[1–3]

Critically ill children with AKI have significantly higher short-term mortality[1,3–8] and inpatient use, including ICU and hospital lengths of stay, than children without AKI.[2–4,9,10] Longer-term outcomes associated with pediatric AKI in the ICU include increased mortality, rehospitalization, and progression to chronic kidney disease, as also observed in adults with AKI.[11–13]

Researchers have examined pediatric AKI outside of critical care settings in relatively few studies. Published estimates of AKI among hospitalized children range from 0.4% to 40%, depending on the definition of AKI used and type of patients studied.[4,7,9,14] In existing studies on non–critically ill children, researchers have reported a risk of ∼30%, but those studies are limited to high-risk samples (eg, primary renal disease, exposure to nephrotoxic medications, or undergoing cardiac procedures) or contained varying definitions of AKI.[15–20]

The etiology of pediatric AKI can be highly multifactorial.[21,22] In the absence of known preexisting kidney disease, awareness, detection and short-term monitoring of AKI episodes and their consequences may fall outside of nephrology services and into general pediatric care. Given AKI can be associated with both adverse short- and longer-term outcomes in children, earlier detection and systematic follow-up (particularly after an episode of severe AKI) may offer opportunities to improve clinical outcomes in this at-risk population.

In this study, we examine recent temporal trends in the incidence of hospitalized AKI among all children across critical and noncritical care settings and describe follow-up outpatient kidney function monitoring after AKI in a large, integrated health care delivery system.

METHODS

Source Population and Study Sample

The source population was based within Kaiser Permanente Northern California (KPNC), an integrated health care delivery system currently providing comprehensive primary through tertiary care for >4.4 million members across 21 hospitals and >245 clinics. Its membership is highly representative of the local and statewide population in terms of age, sex, and race and/or ethnicity.[23] Nearly all aspects of care are captured through KPNC's electronic medical record system that is integrated across all practice settings. Members receive essentially all their care within KPNC facilities, with a low rate of outside referral for only selected care.

We constructed calendar year cohorts of all pediatric (age 1–17 years) patients from January 2008 to December 2016. We excluded patients from yearly cohorts who had an unknown sex, previous chronic dialysis, previous organ or bone marrow transplant, or death before January 1 of each year. All eligible pediatric patients on January 1 of each year were included in the respective calendar year cohort; therefore, most patients were included in multiple calendar year cohorts. Information on receipt of renal replacement therapy was obtained from a comprehensive health plan end-stage renal disease treatment registry.[24]

The study was approved by the KPNC Institutional Review Board. Waivers of informed consent were obtained because of the nature of the study.

Follow-up

Patients were censored in a given calendar year at initiation of chronic dialysis, organ transplant, death, health plan disenrollment, reaching the age of 18 years, or on December 31 of each year. Death was identified from administrative and hospital discharge databases, California death certificate files, and Social Security Administration vital status files.[25,26]

Identification of Hospitalized AKI

We ascertained episodes of hospitalized AKI and its severity using revised Kidney Disease: Improving Global Outcomes (KDIGO) criteria as follows: stage 1 (serum creatinine [SCr] increase of 1.5 to 1.9-fold above the baseline or an increase in SCr of ≥0.3 mg/dL within 48 hours during a hospitalization); stage 2 (SCr increase of 2.0–2.9-fold above baseline); stage 3 (SCr increase of more than threefold above the baseline, increase in SCr to ≥4.0 mg/dL, receipt of acute dialysis, or decrease in estimated glomerular filtration rate (eGFR) to <35 mL/min per 1.73m^2).[27] Urine output data were unavailable. The baseline SCr was defined as the most recent outpatient, nonemergency SCr measurement between 7 and 365 days before admission. The peak inpatient SCr was used for comparison with the baseline, and the eGFR was calculated from this value by using the modified bedside Schwartz equation.[28] Height measured during the hospitalization was used in the Schwartz equation; otherwise, the closest height measurement within 90 days of the hospitalization was used. For hospitalizations with no available baseline SCr measurement, the baseline kidney function was back-calculated through the Schwartz equation by presuming a baseline eGFR of 120 mL/min per 1.73 m^2, as previously described and validated.[1,29] All SCr measurements were made using an assay traceable to a standard isotope dilution mass spectrometry reference procedure. AKI episodes were classified as resolved if the last SCr measurement

before discharge after the qualifying AKI SCr measurement was ≤0.1 mg/dL above the baseline SCr measurement. In a sensitivity analysis, resolution of AKI was also defined as a reduction in SCr to below the AKI threshold (ie, <1.5-fold over the baseline or <0.3 mg/dL over the initial qualifying measurement).

Patient Characteristics

Demographic characteristics included age, sex, and self-reported race and/or ethnicity and were ascertained on January 1 of each year from electronic medical records. Serum creatinine concentration values were identified from comprehensive inpatient and outpatient health plan laboratory databases. Nonnetwork hospitalizations were not included because access to clinical data was unavailable.

Statistical Approach

Analyses were conducted by using SAS version 9.4 (SAS Institute, Inc, Cary, NC). We compared characteristics for patients with or without AKI and by AKI stage using analysis of variance or Kruskal-Wallis tests for continuous variables and χ^2 tests for categorical variables. Among children with AKI, we present characteristics at the time of their first hospitalization with AKI. In children with no AKI during the study period, we present characteristics at the time of their first hospitalization. Therefore, all comparisons involved categories with unique children.

We separately calculated overall and stage-specific incidence of AKI per 1000 person-years and per 100 hospitalizations per year, directly standardized to the age and sex distribution of the 2008 population. To test for a temporal trend, we performed age- and sex-adjusted Poisson regression using a generalized estimating equations approach to evaluate the significance of an ordinal calendar year term.

We calculated the proportions of AKI detected in the ICU, detected outside the ICU but with a corresponding ICU stay during the hospitalization, and detected outside the ICU with no corresponding ICU stay. AKI was determined to be detected in ICU settings if the qualifying peak inpatient SCr measurement fell within the admission and discharge times of the ICU stay. We delineated patients whose qualifying peak SCr measurement was outside the ICU but who had an ICU stay, to account for cases in which AKI or another acute illness may have prompted ICU care. We also calculated the proportions of children with follow-up outpatient, nonemergency serum creatinine testing within 30, 60, 90, and 365 days after discharge from a hospitalization with AKI per year, excluding from the denominator those who died, who initiated chronic renal replacement therapy before each end point, or whose AKI resolved before discharge.

RESULTS

Patient Characteristics

Between 2008 and 2016, we identified 1 500 546 eligible children (Supplemental Table 4). Across the study period, mean (SD) age on January 1 of each study year was 9.9 (4.9) years, and 49% were female (Table 1). From 2008 to 2016, we identified 3582 hospitalizations with AKI (7.4% of all hospitalizations), affecting 3171 children (0.2% of the pediatric population). Baseline SCr measurements were imputed for 2979 (83.2%) hospitalizations with AKI. Compared with children without AKI, children with AKI were more likely to be older, male, and Black (Table 2). Children with AKI were more likely to have a primary hospital diagnosis related to kidney disease, metabolic disease, cancer, and infectious disease; were less likely to be hospitalized for respiratory disease, musculoskeletal disease, and pregnancy; and had higher risks of in-hospital death (1.2% vs 0.0%, respectively; P <.001) and longer hospital length of stay (7.9 vs 3.8 days, respectively; P <.001; Table 2). More severe AKI was associated with younger age; female sex; being more likely to be hospitalized primarily with a kidney, infectious disease, or blood disorder-related diagnosis; longer hospital length of stay; and higher risks of inpatient and 30-day all-cause death (Table 2). Characteristics for all hospitalizations are shown in Supplemental Tables 5 and 6.

Population- and Hospitalization-Based Incidence of AKI

Crude rates of AKI are shown in Supplemental Tables 7 through 9. Population-level age- and sex-adjusted incidence of AKI did not change significantly over time, from 0.64 (95% confidence interval [CI]: 0.58–0.71) per 1000 person-years in 2008 to 0.75 (95% CI: 0.69–0.82) per 1000 person-years in 2016, with an average of 0.70 (95% CI: 0.68–0.73) cases per 1000 person-years across the study period (Fig 1A).

Among the subset of hospitalized children, however, age- and sex-adjusted risk of AKI increased significantly from 6.0 (95% CI: 5.4–6.6) cases per 100 hospitalizations in 2008 to 8.8 (95% CI: 8.0–9.6) cases per 100 hospitalizations in 2016 (Fig 1B). This was largely driven by a significant increase in stage 1 AKI because the combined incidence of severe AKI (stages 2 and 3) remained similar at ∼1.6 cases per 100 hospitalizations per year (Fig 1B). No significant temporal trends were observed in sensitivity analyses in which stage 1 AKI ascertained with an imputed baseline were excluded (Supplemental Fig 3) or only hospitalizations with measured SCr values were included (Supplemental Fig 4).

TABLE 1 Characteristics of the Pediatric Population Aged 1 to 17 Years Old Within KPNC, 2008–2016

Characteristics	2008 (*N* = 720 131)	2009 (*N* = 715 768)	2010 (*N* = 710 451)	2011 (*N* = 722 173)	2012 (*N* = 730 261)	2013 (*N* = 727 609)	2014 (*N* = 719 901)	2015 (*N* = 739 185)	2016 (*N* = 764 549)
Age, y									
Mean (SD)	9.9 (4.9)	9.9 (4.9)	9.9 (4.9)	9.8 (4.9)	9.8 (4.9)	9.8 (4.9)	9.8 (4.9)	9.8 (4.9)	9.8 (4.9)
Median (IQR)	10.2 (5.7–14.3)	10.1 (5.6–14.2)	10.0 (5.6–14.2)	10.0 (5.6–14.1)	10.0 (5.6–14.1)	10.0 (5.7–14.1)	9.9 (5.7–14.1)	9.9 (5.7–14.0)	9.9 (5.6–14.0)
Age category, y, No. (%)									
1–5	190 914 (26.5)	192 566 (26.9)	192 256 (27.1)	195 595 (27.1)	197 650 (27.1)	195 831 (26.9)	193 068 (26.8)	198 103 (26.8)	206 506 (27.0)
6–10	204 026 (28.3)	203 663 (28.5)	203 103 (28.6)	207 902 (28.8)	211 060 (28.9)	212 621 (29.2)	213 019 (29.6)	219 665 (29.7)	227 116 (29.7)
11–17	325 191 (45.2)	319 539 (44.6)	315 092 (44.4)	318 676 (44.1)	321 551 (44.0)	319 157 (43.9)	313 814 (43.6)	321 417 (43.5)	330 927 (43.3)
Female sex, No. (%)	352 528 (49.0)	350 403 (49.0)	347 450 (48.9)	353 068 (48.9)	357 580 (49.0)	356 295 (49.0)	352 454 (49.0)	362 071 (49.0)	374 360 (49.0)
Race, No. (%)									
White	260 444 (36.2)	258 777 (36.2)	258 731 (36.4)	260 490 (36.1)	263 386 (36.1)	262 007 (36.0)	258 575 (35.9)	263 858 (35.7)	269 148 (35.2)
Black	63 341 (8.8)	62 401 (8.7)	60 983 (8.6)	60 039 (8.3)	59 421 (8.1)	57 709 (7.9)	55 661 (7.7)	55 961 (7.6)	56 272 (7.4)
Asian American and/or Pacific Islander	110 304 (15.3)	114 505 (16.0)	118 605 (16.7)	124 613 (17.3)	130 580 (17.9)	134 288 (18.5)	136 507 (19.0)	142 412 (19.3)	148 632 (19.4)
American Indian	3859 (0.5)	3852 (0.5)	3716 (0.5)	3713 (0.5)	3781 (0.5)	3599 (0.5)	3393 (0.5)	3350 (0.5)	3353 (0.4)
Multiracial	45 294 (6.3)	46 665 (6.5)	47 773 (6.7)	48 911 (6.8)	50 554 (6.9)	50 801 (7.0)	50 348 (7.0)	51 560 (7.0)	53 065 (6.9)
Other and/or unknown	236 889 (32.9)	229 568 (32.1)	220 643 (31.1)	224 407 (31.1)	222 539 (30.5)	219 205 (30.1)	215 417 (29.9)	222 044 (30.0)	234 079 (30.6)
Children with ≥1 hospitalization in Kaiser Permanente facility, No. (%)	5096 (0.7)	5315 (0.7)	5474 (0.8)	5368 (0.7)	4876 (0.7)	4347 (0.6)	3942 (0.5)	4694 (0.6)	4244 (0.5)

IQR, interquartile range.

ICU-Based Incidence of AKI

The community-level incidence of AKI in each care setting did not significantly change over time (Fig 1C). However, among the subset of hospitalized children, the incidence of AKI in all care settings increased significantly across the study period (Fig 1D). Among hospitalizations with AKI, the proportion with AKI detected in ICU settings averaged 12.3% each year from 2008 to 2018 (Fig 2A). AKI with no ICU stay contributed 66.7% of all AKI episodes (Fig 2A). Among AKI episodes detected in the ICU, the onset of AKI started before ICU admission in 28.6% of episodes. Among AKI detected outside of the ICU but with transfer to the ICU, the SCr remained elevated above AKI levels in 26.3% of episodes. Thus, the overall proportion of AKI episodes with SCr elevation meeting AKI criteria in ICU settings was 18.3%.

Among 2393 AKI hospitalizations not associated with an ICU stay, 418 (17.7%) were classified as severe (Fig 2B).

Resolution of AKI and Follow-up Kidney Function Testing

Among 3582 hospitalized AKI episodes, 26.0% were discharged with SCr levels that returned to baseline, 28.2% were discharged with elevated SCr compared with baseline, and 45.7% did not have any inpatient SCr measurements after the value used to define AKI.

Follow-up SCr testing rates within 30, 60, 90, and 365 days postdischarge from a hospitalization with unresolved AKI did not change significantly from 2008 to 2016. On average, follow-up testing increased from 15.8% at 30 days to 28.5% at 365 days as well as across AKI stages (Table 3). Thirty-day follow-up testing was higher among severe, confirmed unresolved AKIs (45.7%) compared to severe resolved AKIs (33.0%), although more than one-half of these episodes did not receive a follow-up test (Table 3).

In sensitivity analyses using a less stringent definition of AKI resolution, 41.7% of AKI were resolved and 12.6% were unresolved before discharge. However, 30-day follow-up testing was only 53.1% among severe, confirmed unresolved AKIs by using this revised definition (Supplemental Table 10).

DISCUSSION

In a diverse cohort of >1.5 million children receiving care across 21 medical centers in an integrated health care delivery system, we characterized the community-level and hospitalization-based incidences

TABLE 2 Characteristics of Children Hospitalized Within KPNC, 2008–2016, by AKI Status and AKI Severity

Characteristics	No AKI (*N* = 35 084)	AKI (*N* = 3171)	*P*	AKI Stage 1 (*N* = 2741)	AKI Stage 2 (*N* = 488)	AKI Stage 3 (*N* = 360)	*P*
Age, y			<.001				<.001
Mean (SD)	10.2 (5.5)	12.7 (4.9)		13.2 (4.7)	11.5 (5.1)	10.7 (5.3)	
Median (IQR)	11.4 (4.8–15.3)	14.9 (10.1–16.4)		15.2 (11.4–16.5)	13.2 (7.5–16.0)	12.2 (5.6–15.4)	
Age category, y, No. (%)			<.001				<.001
1–5	10 502 (29.9)	469 (14.8)		315 (12.8)	81 (19.1)	73 (25.8)	
6–10	6421 (18.3)	410 (12.9)		276 (11.2)	84 (19.8)	50 (17.7)	
11–17	18 161 (51.8)	2292 (72.3)		1872 (76.0)	260 (61.2)	160 (56.5)	
Female sex, No. (%)	18 299 (52.2)	1259 (39.7)	<.001	936 (38.0)	182 (42.8)	141 (49.8)	<.001
Race, No. (%)			<.001				.10
White	14 007 (39.9)	1290 (40.7)		1005 (40.8)	164 (38.6)	121 (42.8)	
Black	3122 (8.9)	464 (14.6)		354 (14.4)	80 (18.8)	30 (10.6)	
Asian American and/or Pacific Islander	4900 (14.0)	482 (15.2)		370 (15.0)	61 (14.4)	51 (18.0)	
American Indian	187 (0.5)	11 (0.4)		9 (0.4)	2 (0.5)	0 (0.0)	
Multiracial	3321 (9.5)	309 (9.7)		247 (10.0)	31 (7.3)	31 (11.0)	
Other and/or unknown	9547 (27.2)	615 (19.4)		478 (19.4)	87 (20.5)	50 (17.7)	
Year of first hospitalization, No. (%)			<.001				.77
2008	4684 (13.4)	334 (10.5)		250 (10.2)	50 (11.8)	34 (12.0)	
2009	4533 (12.9)	374 (11.8)		288 (11.7)	54 (12.7)	32 (11.3)	
2010	4506 (12.8)	402 (12.7)		305 (12.4)	58 (13.7)	39 (13.8)	
2011	4335 (12.4)	365 (11.5)		284 (11.5)	51 (12.0)	31 (11.0)	
2012	3838 (10.9)	315 (9.9)		248 (10.1)	34 (8.0)	31 (11.0)	
2013	3348 (9.5)	324 (10.2)		259 (10.5)	33 (7.8)	32 (11.3)	
2014	3054 (8.7)	312 (9.8)		252 (10.2)	40 (9.4)	20 (7.1)	
2015	3610 (10.3)	366 (11.5)		287 (11.7)	49 (11.5)	29 (10.3)	
2016	3181 (9.1)	381 (12.0)		290 (11.8)	56 (13.2)	35 (12.4)	
Primary hospitalization diagnosis group, No. (%)			<.001				<.001
Gastrointestinal	6393 (18.2)	519 (16.4)		430 (17.5)	57 (13.4)	32 (11.3)	
Psychiatric	4956 (14.1)	529 (16.7)		497 (20.2)	27 (6.4)	5 (1.8)	
Respiratory	4804 (13.7)	174 (5.5)		135 (5.5)	29 (6.8)	10 (3.5)	
Musculoskeletal	4054 (11.6)	147 (4.6)		119 (4.8)	14 (3.3)	14 (5.0)	
Nervous system	2754 (7.9)	226 (7.1)		194 (7.9)	16 (3.8)	16 (5.7)	
Pregnancy	2150 (6.1)	52 (1.6)		41 (1.7)	9 (2.1)	2 (0.7)	
Metabolic	1417 (4.0)	428 (13.5)		292 (11.9)	106 (24.9)	30 (10.6)	
Infectious	817 (2.3)	194 (6.1)		108 (4.4)	50 (11.8)	36 (12.7)	
Kidney	569 (1.6)	185 (5.8)		90 (3.7)	29 (6.8)	66 (23.3)	
Hematologic	464 (1.3)	74 (2.3)		37 (1.5)	12 (2.8)	25 (8.8)	
Circulatory	321 (0.9)	77 (2.4)		60 (2.4)	12 (2.8)	5 (1.8)	
Cancer	256 (0.7)	120 (3.8)		83 (3.4)	20 (4.7)	17 (6.0)	
Rehabilitation	66 (0.2)	24 (0.8)		15 (0.6)	5 (1.2)	4 (1.4)	
Other	6063 (17.3)	422 (13.3)		362 (14.7)	39 (9.2)	21 (7.4)	
Hospitalization length of stay, d							
Mean (SD)	3.8 (5.9)	7.9 (15.6)	<.001	6.9 (14.0)	9.5 (19.1)	14.7 (20.6)	<.001
Median (IQR)	2 (1–4)	4 (2–8)	<.001	4.0 (2.0–7.0)	4.0 (2.0–9.0)	8.0 (3.0–16.0)	<.001
Deaths within hospitalization, No. (%)	15 (0.0)	36 (1.1)	<.001	11 (0.5)	6 (1.4)	19 (6.7)	<.001
Deaths within 30 d of discharge, No. (%)	4 (0.0)	11 (0.4)	<.001	7 (0.3)	0 (0.0)	4 (1.4)	.004

For those with no AKI during the study period, characteristics at first hospitalization are presented. For those with AKI at any point, characteristics at the first hospitalization with AKI are presented. IQR, interquartile range.

of AKI as defined using KDIGO SCr-based criteria. Our overall pediatric and hospitalized populations are highly similar to the US national population with a median age of 10 years, 49% female, a median hospital length of stay of 3.8 days, and similar hospital diagnoses in comparison to the 2012 Kids' Inpatient Database.[30,31] From 2008 to 2016, the incidence of hospitalized AKI in the pediatric population was stable at 0.70 cases per 1000 person-years; in contrast, the subset of pediatric hospitalizations affected by AKI increased from 6.0 per 100 hospitalizations to 8.8 per 100 hospitalizations. This increase may be explained by secular trends in managing more care outside the hospital to reduce the risk of hospital-related complications given our integrated care delivery structure, leading to more severe illness among

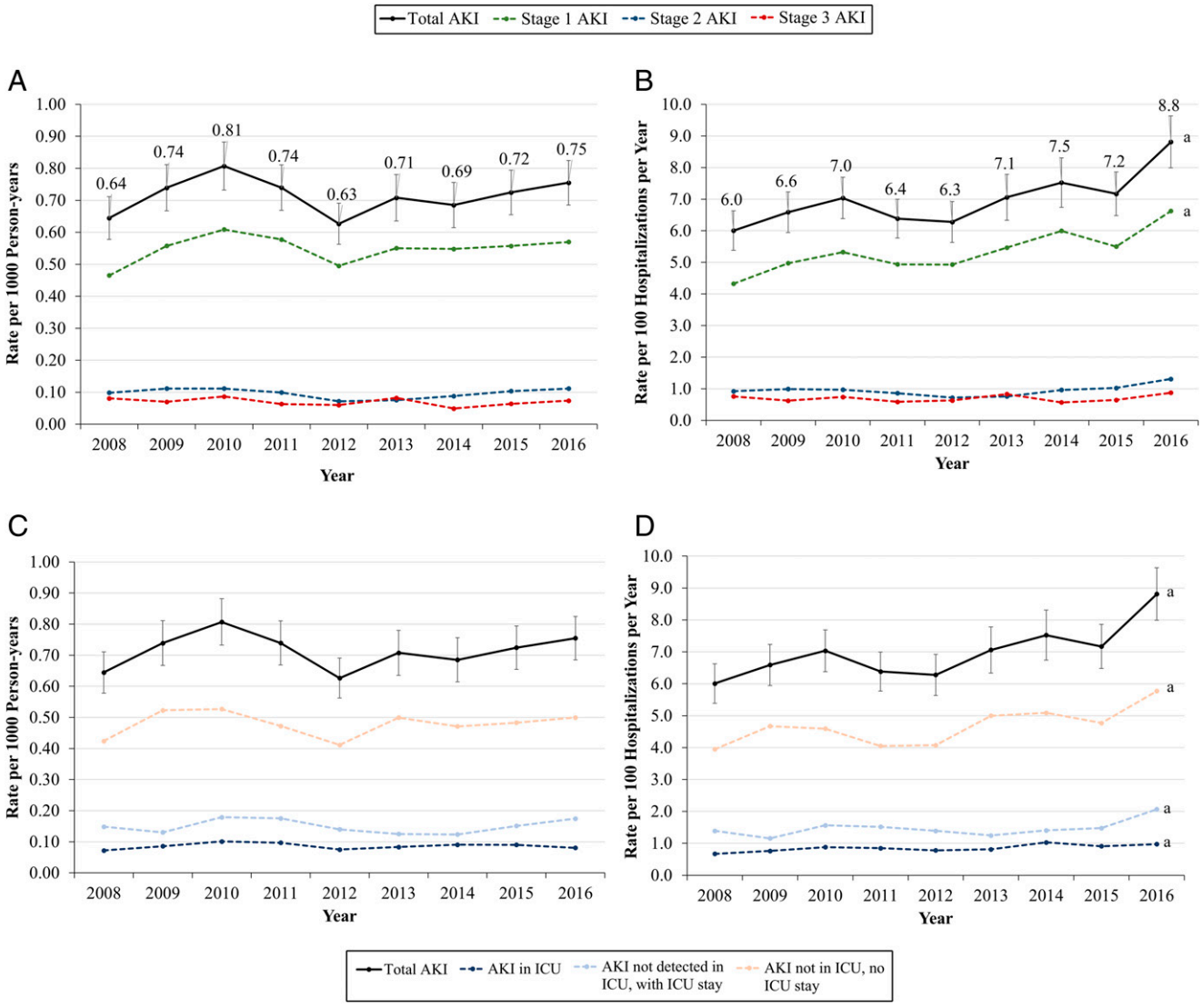

FIGURE 1

Age- and sex-adjusted incidence of AKI, 2008–2016. A, Rate among all children, per 1000 person-years, by severity. B, Rate among hospitalized children, per 100 hospitalizations per year, by severity. C, Rate among all children, per 1000 person-years, by ICU status. D, Rate among hospitalized children, per hospitalizations per year, by ICU status. [a] Denotes trend $P < .05$.

children hospitalized in later years. The lower overall hospitalization rate in 2016 (0.5%) compared to 2008 (0.7%) accompanied by an increase in the proportion of hospitalizations with SCr measurements (55.6% to 68.4%) supports this hypothesis, given that SCr testing may be indicative of more severe illnesses. Furthermore, the incidence of AKI did not change among the subset of hospitalizations with SCr measurements over the study period, suggesting that the apparent increase in AKI is due to shifts in the underlying population of hospitalized children.

In several studies, researchers have reported on the incidence of pediatric AKI. Holmes et al[19] reported an AKI incidence (using KDIGO criteria) among Welsh children of 1.37 per 1000 person-years. However, the authors included potential nonhospitalized AKI in this estimate, which accounted for ~30% of AKI episodes among nonneonates in the study. Sutherland et al[9] estimated the rate of AKI to be 0.39 per 100 hospitalizations among hospitalized children but relied on administrative diagnosis codes to identify AKI, which are known to have suboptimal accuracy compared to more objective SCr-based criteria. Among 13 914 noncritical hospitalized children, McGregor et al[15] identified AKI by KDIGO criteria in 5% of all hospitalizations and 30% of hospitalizations with SCr measurements. This estimate is more consistent with our estimate of 7.0% and is expected to be slightly lower

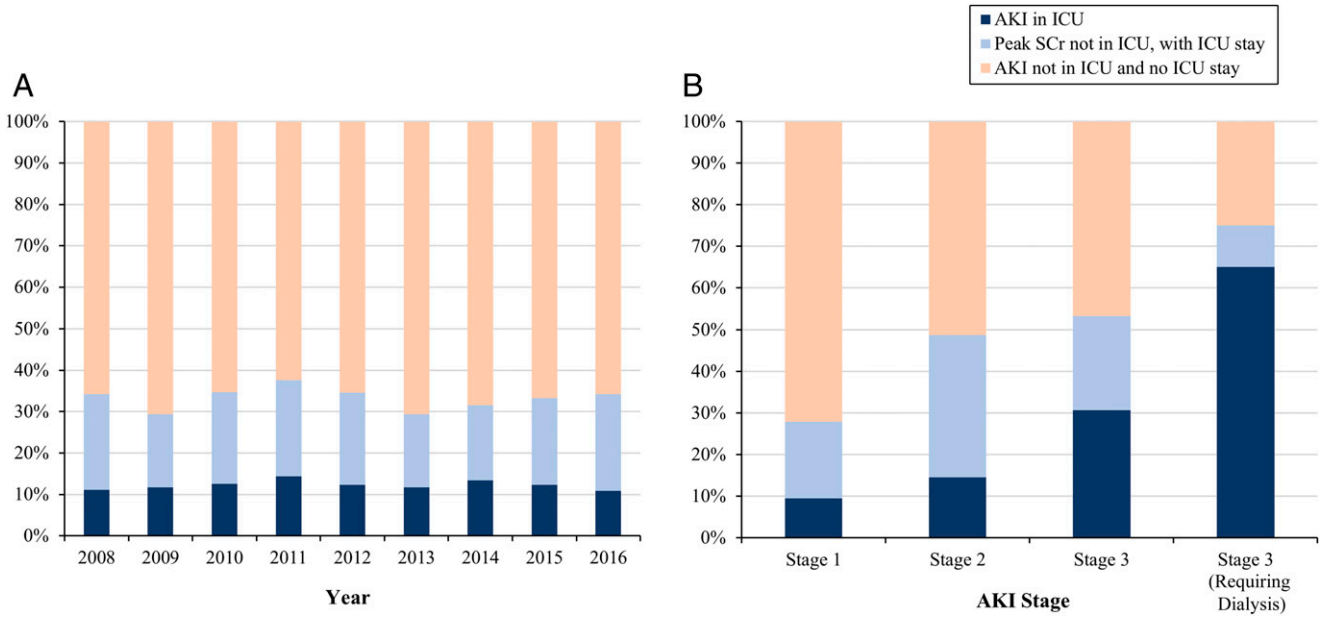

FIGURE 2
Distribution of AKI detection within ICU versus non-ICU settings among 3582 pediatric hospitalizations with AKI in KPNC, by year and AKI stage, 2008–2016. A, By year. B, By AKI severity.

because of its focus on only non–critically ill patients.

Importantly, we found that 67% of AKI episodes were not associated with an ICU stay, representing a substantial proportion of hospitalized AKI that has not been the focus of previous studies of AKI in children.[1–3,6,11,32] This proportion is consistent with the percentage of AKI not occurring in the ICU observed in the Kids' Inpatient Database

TABLE 3 Follow-up SCr Testing After 3582 Pediatric Hospitalizations With AKI, by Year, AKI Stage, and Resolution of AKI, 2008–2016

Strata	*n*	First Outpatient SCr Measurement After Discharge, No. (%)			
		≤30 d	≤60 d	≤90 d	≤365 d
Unresolved or unknown resolution of AKI, by year	2651				
2008	251	41 (16.3)	50 (19.9)	56 (22.3)	77 (30.7)
2009	308	41 (13.3)	52 (16.9)	54 (17.5)	85 (27.6)
2010	337	58 (17.2)	68 (20.2)	70 (20.8)	96 (28.5)
2011	319	51 (16.0)	64 (20.1)	66 (20.7)	95 (29.8)
2012	265	48 (18.1)	58 (21.9)	61 (23.0)	79 (29.8)
2013	264	47 (17.8)	54 (20.5)	62 (23.5)	78 (29.6)
2014	279	39 (14.0)	46 (16.5)	54 (19.4)	82 (29.4)
2015	296	41 (13.9)	46 (15.5)	48 (16.2)	75 (25.3)
2016	332	52 (15.7)	63 (19.0)	70 (21.1)	89 (26.8)
Unresolved or unknown resolution of AKI, by stage	2651				
Stage 1	2099	206 (9.8)	266 (12.7)	293 (14.0)	455 (21.7)
Stage 2	306	77 (25.2)	90 (29.4)	97 (31.7)	134 (43.8)
Stage 3	246	135 (54.9)	145 (58.9)	151 (61.4)	167 (67.9)
Resolved AKI, by stage	931				
Stage 1	640	183 (28.6)	211 (33.0)	222 (34.7)	285 (44.5)
Stage 2	182	45 (24.7)	55 (30.2)	59 (32.4)	71 (39.0)
Stage 3	109	51 (46.8)	57 (52.3)	61 (56.0)	70 (64.2)
Confirmed unresolved AKI, by stage	1013				
Stage 1	639	108 (16.9)	137 (21.4)	148 (23.2)	205 (32.1)
Stage 2	203	65 (32.0)	76 (37.4)	79 (38.9)	103 (50.7)
Stage 3	171	106 (62.0)	111 (64.9)	114 (66.7)	121 (70.8)
Unknown resolution of AKI, by stage	1638				
Stage 1	1460	98 (6.7)	129 (8.8)	145 (9.9)	250 (17.1)
Stage 2	103	12 (11.7)	14 (13.6)	18 (17.5)	31 (30.1)
Stage 3	75	29 (38.7)	34 (45.3)	37 (49.3)	46 (61.3)

of 65.5%.[9] Although the large majority of non-ICU AKIs in our study were low severity as expected, 18% were severe AKIs. Many of these AKI episodes could reflect clinically undetected AKI; however, up to nearly 1 in 5 cases of potentially undetected AKI were of presumed high AKI severity and may reflect a need for increased surveillance in selected hospitalized children. Further studies are necessary to determine any differences in etiology or outcomes of severe AKI episodes among non–critically ill patients.

Overall, postdischarge outpatient SCr testing after an episode of AKI was moderate in our cohort. On average, 15.8% of patients with a presumed unresolved AKI received a follow-up SCr test within 30 days after discharge and 28.5% within 365 days. This may be due, in part, to the discrepancy between AKI defined by using an imputed baseline SCr and clinically recognized AKI. Thirty-day follow-up testing rates across all AKI cases were much higher among those with a measured baseline SCr (57.7%) compared with those with an imputed baseline SCr (11.7%) (Supplemental Table 11). However, it is likely that children with a measured baseline may already be in the care of outpatient nephrology services and reflect a particularly high-risk population. In addition, many providers may choose not to test children in situations in which the child appears fully recovered clinically or performing a blood test is contraindicated. As expected, the proportion of patients with follow-up tests was significantly higher with increasing severity of AKI. However, even at one year after discharge, a follow-up SCr test was not found in more than one-third of severe AKI patients who did not appear resolved before discharge, regardless of the definition of AKI resolution used. In pediatric patients, previous studies and guidelines have suggested that AKI may contribute to long-term incidence or worsening chronic kidney disease, highlighting the need to consider more systematic follow-up kidney function testing and disease monitoring after episodes of AKI by pediatricians and other primary care providers, with potential referral to specialty care.[12,27,33]

Our study has several strengths. To our knowledge, ours is the first study of the community-level incidence of hospitalized AKI using KDIGO SCr-based criteria and an isotope dilution mass spectrometry-traceable SCr data over a contemporary study period. This is a distinct advantage over studies using diagnostic codes to identify AKI episodes because it allows for ascertainment of both clinically detected and uncoded AKI by using a standardized definition. Importantly, we were also able to characterize the location of the onset and peak of the AKI within a hospitalization and estimate AKI resolution using serial SCr measurements. Additional strengths include our large, demographically diverse population and our ability to systematically follow-up with patients to evaluate kidney function testing patterns during the first-year postdischarge.

Our findings should also be placed in the context of several limitations. Because our source population received care through an integrated health care delivery system, we were unable to capture clinical data for nonnetwork hospitalizations. Although these accounted for ~20% of hospitalizations among the pediatric population over the study period, the vast majority of those patients are routinely transferred to KPNC facilities shortly after admission to complete their care. We lacked data on urine output, which would lead to an underestimate of AKI episodes.[1,34] A measured baseline SCr was unavailable for 76% of all hospitalizations (83% of hospitalizations with AKI), as is expected among children; however, in children with a measured baseline SCr, the imputed SCr value was similar (median difference: −0.03 [interquartile range: −0.12 to 0.05] mg/dL), supporting the validity of the imputation approach. We were also unable to characterize the occurrence of AKI episodes occurring outside the hospital. Finally, our results may not be fully generalizable to uninsured patients, other geographic areas, or to all practice settings, because AKI incidence may be influenced by network-specific practice patterns.

CONCLUSIONS

We observed a community-based incidence of hospitalized AKI of 0.7 per 1000 person-years among children, with two-thirds of AKI episodes occurring outside critical care settings and approximately one-half of children with presumed severe AKI not receiving follow-up SCr testing within 90 days of discharge. To reduce the potentially longer-term consequences of AKI in children, further efforts should be made for the systematic recognition and awareness of AKI in all inpatient settings with appropriate, risk-based postdischarge follow-up kidney function monitoring by pediatricians and other pediatric primary care providers. Studies are also needed to examine the etiologies, long-term clinical outcomes, and more effective preventive and therapeutic strategies for pediatric AKI, especially in non–critically ill children.

ABBREVIATIONS

AKI: acute kidney injury
CI: confidence interval
eGFR: estimated glomerular filtration rate
KDIGO: Kidney Disease: Improving Global Outcomes
KPNC: Kaiser Permanente Northern California
SCr: serum creatinine

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