

Mortality involving neuromuscular dysfunction of the bladder in the United States, 1999–2024: a serial cross-sectional analysis of national death certificate data

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Abstract

Background.

Neuromuscular dysfunction of the bladder, commonly termed neurogenic bladder, is a shared endpoint of spinal cord injury, spina bifida, multiple sclerosis, Parkinson's disease, stroke, and diabetes. Its complications, including recurrent urinary tract infection, upper urinary tract deterioration, and renal failure, are well described, but no national analysis of mortality has been reported. We examined trends in deaths involving neurogenic bladder in the United States over 26 years.

Methods.

We conducted a serial cross-sectional analysis of the CDC WONDER Multiple Cause of Death files for 1999–2024, including decedents aged ≥ 25 years for whom *International Classification of Diseases, Tenth Revision* codes N31.0–N31.9 appeared anywhere on the death certificate. Deaths from 1999 to 2020 were drawn from the standard file and deaths from 2021 to 2024 from the expanded file, with overlapping years cross-checked. Age-adjusted mortality rates (AAMR) per 100,000 were calculated using direct standardization to the 2000 US standard population. Trends were estimated using joinpoint regression, yielding annual percent change (APC) per segment and average annual percent change (AAPC) per stratum. A prespecified sensitivity analysis used a narrower definition restricted to deaths for which neurogenic bladder was recorded as the *underlying* cause.

Results.

Of the 23,982 deaths involving neurogenic bladder, 18,847 (78.6%) occurred among adults aged ≥ 65 years, and 14,169 (59.1%) occurred among men. The AAMR fell from 0.42 per 100,000 in 1999 to an inflection in 2008 (95% CI 2005–2014), declining 3.00% per year (95% CI – 5.32 to – 0.62), and then rose 3.81% per year (95% CI 3.06 to 4.56) to 0.55 per 100,000 in 2024. Rates declined and then increased in all 14 strata examined, although the initial decline was statistically significant in 10. The steepest relative increase in mortality rates occurred in younger adults, although adults aged > 65 years accounted for the most deaths and the largest absolute number of deaths. Among the adults aged 25–44 years, mortality rates rose 12.58% per year after 2014 (95% CI 9.41 to 15.85) and among those aged 45–64 years 5.69% per year after 2007, whereas the rate among adults aged 65 and older did not change materially over the full period (AAPC 0.18%, 95% CI – 0.49 to 0.86). Rates rose 7.42% per year after 2013 among non-Hispanic Black decedents (95% CI 5.08–9.81) and 4.02% per year after 2008 among non-Hispanic White decedents. In the sensitivity analysis, the trend moved in the opposite direction: deaths with neurogenic bladder as the underlying cause declined by 3.69% per year from 1999 to 2018 (95% CI – 4.88 to – 2.49), with no significant change thereafter, and their share of all deaths involving the condition halved, from 20.3% in 1999 to 9.7% in 2024. Expressed as a proportion of all deaths among adults aged ≥ 25 years, deaths involving neurogenic bladder increased by 48%, from 3.40 to 5.03 per 10,000 deaths.

Conclusions.

Deaths involving neurogenic bladder have increased since 2008, whereas deaths attributed to it have decreased. The national burden of neurogenic bladder is increasingly recorded as a comorbidity at death rather than as a cause of death. The increase is specific to this condition rather than a by-product of more complete death certification, as it is present as a proportion of all deaths. Improved urological care and changes in the recognition or recording of the neurogenic bladder cannot be distinguished using these data. The concentration of the rate increase in adults aged 25–44 years is consistent with a growing population surviving congenital and acquired neurogenic bladder into adulthood and highlights a group for whom transitional urological care may be particularly important.

Background

Neuromuscular dysfunction of the bladder, also known as neurogenic bladder, is not a single disease but a shared lower urinary tract endpoint of a wide range of neurological conditions [1]. Spinal cord injury, spina bifida, multiple sclerosis, Parkinson's disease, stroke, and diabetic neuropathy all disrupt the neural control of storage and voiding, and the site and nature of the lesion determine the pattern of dysfunction that follows [1, 2]. This heterogeneity is clinically significant because the risk of upper urinary tract damage and renal failure is generally lower in slowly progressive non-traumatic diseases than in spinal cord injury or spina bifida, and management algorithms are stratified accordingly [2], as set out in the American Urological Association and Society of Urodynamics, Female Pelvic Medicine and Urogenital Reconstruction guideline on adult neurogenic lower urinary tract dysfunction [3].

The population living with conditions that can cause neurogenic bladder is large and constantly changing. Among US adults with traumatic spinal cord injury, the prevalence of neurogenic bladder approaches 80% [4, 5]. Across the United States, the burden of neurological disorders rose substantially between 1990 and 2017, driven largely by population aging, even as spinal cord injury prevalence fell by 38.5% [6]; the global spinal cord injury burden shows a similar pattern of decline in incidence alongside growth in the prevalent population [7]. A US claims database study described the epidemiology and healthcare utilization of this population [8].

The complications of neurogenic bladder are well-characterized. A recent Delphi consensus ranked renal failure, febrile urinary tract infection, and autonomic dysreflexia as the principal complications and identified indwelling or suprapubic catheterization, detrusor leak point pressure of ≥ 40 cmH₂O, and low bladder compliance as the dominant risk factors [9]. Urinary tract infection is the most frequent complication and a major source of morbidity [10, 11, 12], and bladder cancer is a recognized long-term complication [13].

However, the mortality burden associated with neurogenic bladder remains poorly characterized. The existing mortality literature is limited, largely based on single-institution or single-cohort studies, and predominantly confined to traumatic cord injury. In a Veterans Affairs cohort, neurogenic bladder was

present in 83% of veterans with spinal cord injury and was associated with more frequent urinary tract infection, more hospitalization, and an increased risk of death [5]. Longitudinal spinal cord injury cohorts have described cause-specific mortality, including septicemia and pneumonia [14], and elevated site-specific cancer mortality [15]. None of these studies were population-based, none covered non-traumatic etiologies, and none described how mortality has changed over time. A recent bibliometric analysis of the field confirmed that epidemiological and outcome research remains a minority of neurogenic bladder publications [16].

National death certificate data offer a way to fill this gap. The CDC WONDER multiple cause of death files record every condition listed on every US death certificate, permitting analysis of conditions that contribute to death without being recorded as the underlying cause, which is likely to reflect the role neurogenic bladder occupies in many deaths [17]. Therefore, we examined mortality involving neuromuscular dysfunction of the bladder in the United States from 1999 to 2024 by age, sex, race and Hispanic origin, census region, county urbanization, and place of death and separately determined how often the condition was recorded as the underlying cause rather than as a contributing factor.

Methods

Design and data source

We conducted a serial cross-sectional analysis of national mortality data from the CDC WONDER Multiple Cause of Death databases [18, 19], which compile death certificate records for all deaths occurring in the United States and report them against the US Census Bureau population denominators. All queries were performed and exported on August 15, 2026. CDC WONDER files are periodically revised; therefore, the access date defines the data version analyzed. Because the unit of observation was the death certificate rather than an individual followed over time, the design was cross-sectional and repeated annually, and no cohort was assembled.

Case definition

A death was included if neuromuscular dysfunction of the bladder was recorded anywhere on the death certificate as the underlying cause or as any contributing cause, using ICD-10 codes N31.0 (uninhibited neuropathic bladder), N31.1 (reflex neuropathic bladder), N31.2 (flaccid neuropathic bladder), N31.8 (other neuromuscular dysfunction of the bladder), and N31.9 (neuromuscular dysfunction of the bladder, unspecified), the complete N31 three-character category. Codes were entered in the first multiple cause field with the second field left empty, so that the query returned any mention of these codes rather than a co-mention with a second condition, and the underlying cause was left unrestricted. The analysis was limited to decedents aged 25 years and older, corresponding to the seven ten-year age groups from 25–34 through 85 years and over.

Rate calculation

Age-adjusted mortality rates per 100,000 population were calculated by direct standardization to the 2000 US standard population [20], using the seven ten-year age groups from 25 years and over, renormalized to sum to unity. Confidence intervals for age-adjusted rates were calculated using the gamma method [21], which is appropriate when death counts are small. Crude rates were reported for age strata. When a subset of the standard age groups is selected, the age-adjusted rate returned by CDC WONDER is computed by weighting age-specific rates that have been rounded to one decimal place per 100,000 individuals. For strata whose age-specific rates fall below 1 per 100,000, this destroys the signal: exporting the 45–64 stratum at full numerical precision returns only three distinct age-adjusted values across seven years, identical to nine decimal places in years whose death counts differ by more than 10%, while the corresponding crude rates are distinct in every year. Therefore, the age-adjusted column is not a usable series for these strata at any export precision, and crude rates, which are unaffected, are reported instead.

Stratification

Rates were examined overall and by sex, ten-year age group (25–44, 45–64, 65 and over), census region, state, race and Hispanic origin, county urbanization, and place of death. State-level and place-of-death results were reported as pooled period estimates rather than annual series and were not modeled. Race and Hispanic origin were requested as crossed, not independent, groupings: race-specific queries restricted Hispanic origin to "Not Hispanic or Latino," and Hispanic decedents were obtained from a separate query spanning all race categories. For every query other than the race-specific ones, the race field was left unrestricted so that the overall series and each non-race stratum included decedents of all races, including those recorded as more than one race in the later file. Decedents of Hispanic origin recorded as "Not Stated" were uniformly excluded from every stratum. This exclusion is small: repeating the overall query without any Hispanic-origin restriction returned 18,218 deaths for 1999–2020 against 18,182 with the restriction applied, a difference of 36 deaths (0.2%), distributed across 18 of the 22 years and never exceeding four deaths in any year, and 10 deaths (0.2%) for 2021–2024, 46 deaths in total, 0.19% of the series.

Race classification changes across the file transition: the earlier file reports bridged race [22], whereas the later file reports a single race under the 1997 Office of Management and Budget standards. Asian and Native Hawaiian or Other Pacific Islander descendants were therefore combined for 2021–2024 to match the bridged Asian or Pacific Islander category. Decedents recorded as "more than one race," a category with no bridged counterpart, are retained in the overall series but assigned to no race stratum; the race strata consequently sum exactly to the overall series through 2020 and to slightly less thereafter.

CDC WONDER suppresses death counts below 10 and flags rates based on fewer than 20 deaths as being unreliable. Annual counts fell below the suppression threshold in 22 of 26 years for American

Indian or Alaska Native decedents and 13 of 26 years for Asian or Pacific Islander decedents; Hispanic counts were complete in every year but rested on fewer than 20 deaths in five years. Segmented models were therefore fitted only for non-Hispanic White and non-Hispanic Black decedents, and the remaining groups were reported as pooled counts and period rates. This restriction is consistent with published guidance that comparative mortality analyses should be limited to groups with the best-validated race and ethnicity reporting on death certificates, where detailed demographic disparity is not a primary aim [23]. The misclassification rate is approximately 40% for American Indian or Alaska Native decedents and roughly 3% for Hispanic and Asian or Pacific Islander decedents [23].

County urbanization was classified using the 2013 NCHS Urban–Rural Classification Scheme for Counties [24], with the four metropolitan levels grouped as metropolitan and the micropolitan and noncore levels grouped as nonmetropolitan. This variable is not available in the later data file; therefore, all urbanization results cover 1999–2020 only and are labeled as such throughout.

Trend analysis

Temporal trends were estimated using the Joinpoint Regression Program version 5.4.0.0 (Statistical Methodology and Applications Branch, National Cancer Institute), fitted to log-transformed rates weighted by the inverse of the squared standard error. A grid search was used, with the number of joinpoints selected by a permutation test with 4,499 permutations [25] at an overall significance level of .05, permitting a minimum of zero and a maximum of four joinpoints, and requiring at least two observations before the first joinpoint, after the last joinpoint, and between adjacent joinpoints. None of the strata reached the maximum. Confidence intervals for the APC and the AAPC were computed by the parametric method. For each stratum, we reported the annual percent change (APC) with its 95% confidence interval and significance test for every segment, and a single average annual percent change (AAPC) with confidence interval and P value. The segment P value tests the null hypothesis that the segment APC equals zero; the AAPC P value tests the null hypothesis that the duration-weighted average change across the interval equals zero; neither is the permutation P value used for model selection. A two-sided $P < .05$ was considered statistically significant.

Sensitivity analysis

The primary any-mention definition was compared with the narrower definition of neuromuscular dysfunction of the bladder recorded as the underlying cause of death, applied to the full series rather than the summary average, so that the inflection could be tested directly. We additionally report the underlying cause of death as a proportion of all deaths involving the condition, by year, as a measure that is internally standardized against changes in overall certification volume.

To distinguish a change in the occurrence of deaths involving neurogenic bladder from a general change in the completeness of death certification, we further expressed any-mention deaths as a proportion of all deaths at ages 25 years and over, extracted under an identical age and Hispanic-origin restriction.

This proportionate measure has no population denominator and is therefore unaffected by census estimation, the 2020-census blended base, or the transition between data files.

Ethics and reporting

This analysis used de-identified, publicly available aggregate data and did not constitute human subjects research; therefore, institutional review board approval and informed consent were not required. Every query specification is reported in Table S17 so that each extraction can be reproduced exactly. The reporting followed the STROBE guidelines for cross-sectional studies [26].

Results

Overall burden and trend

From 1999 to 2024, **23,982 deaths** among US adults aged ≥ 25 years involved neuromuscular dysfunction of the bladder, including 18,182 in 1999–2020 and 5,800 in 2021–2024. Annual deaths increased from 787 in 1999 to 1,511 in 2024 (Tables 1 and S1).

The age-adjusted mortality rate fell from 0.42 per 100,000 in 1999 to an inflection in 2008 (95% CI 2005–2014), declining 3.00% per year (95% CI – 5.32 to – 0.62; $P = 0.016$), and then rose 3.81% per year (95% CI 3.06 to 4.56; $P < .001$) to 0.55 per 100,000 by 2024 (Fig. 1; Tables S1, S10 and S11). The average annual percent change across the full period was 1.30% (95% CI 0.37 to 2.25; $P = .006$) (Table S12). Across most strata, Joinpoint regression identified an initial decline in mortality rates followed by a sustained increase, with a single joinpoint occurring between 2007 and 2014 across subgroups marking the change in trend; the female subgroup, however, exhibited two joinpoints, indicating an additional shift in the temporal trajectory. (Table 1)

Table 1

Deaths, age-adjusted mortality rates and joinpoint-estimated trends for neuromuscular dysfunction of the bladder as an underlying or contributing cause of death, adults aged 25 years and older, United States, 1999–2024

Characteristic	Deaths, n (%)	Rate, 1999 → 2024 [§]	Joinpoint (95% CI)	APC by segment (95% CI) [§]	AAPC (95% CI) [§]
Overall	23,982 (100.0)	0.42 → 0.55	2008 (2005–2014)	1999–2008: -3.00* (-5.32 to -0.62) 2008–2024: +3.81* (3.06 to 4.56)	+ 1.30* (0.37 to 2.25)
Sex					
Female	9,813 (40.9)	0.36 → 0.39	2007 (2001–2010) 2018 (2014–2022)	1999–2007: -4.71* (-7.60 to -1.73) 2007–2018: +1.43 (-0.53 to 3.42) 2018–2024: +6.80* (2.01 to 11.83)	+ 0.66 (-0.93 to 2.28)
Male	14,169 (59.1)	0.58 → 0.74	2006 (2005–2009)	1999–2006: -4.94* (-8.05 to -1.72) 2006–2024: +3.36* (2.81 to 3.91)	+ 0.97* (0.01 to 1.93)
Age group					
25–44 years	886 (3.7)	0.032 → 0.090 [§]	2014 (2012–2016)	1999–2014: -1.30 (-3.71 to 1.17) 2014–2024: +12.58* (9.41 to 15.85)	+ 4.03* (2.21 to 5.89)
45–64 years	4,249 (17.7)	0.174 → 0.326 [§]	2007 (2005–2009)	1999–2007: -1.58 (-4.15 to 1.06) 2007–2024: +5.69* (4.99 to 6.40)	+ 3.31* (2.38 to 4.25)

Characteristic	Deaths, n (%)	Rate, 1999 → 2024 [¶]	Joinpoint (95% CI)	APC by segment (95% CI) [¶]	AAPC (95% CI) [¶]
≥ 65 years	18,847 (78.6)	1.882 → 1.894 [¶]	2007 (2005–2009)	1999–2007: -4.20* (-5.99 to -2.37) 2007–2024: +2.31* (1.75 to 2.88)	+ 0.18 (-0.49 to 0.86)
Census region					
Northeast	4,270 (17.8)	0.38 → 0.55	2007 (2003–2009)	1999–2007: -4.07* (-7.20 to -0.83) 2007–2024: +4.23* (3.35 to 5.13)	+ 1.50* (0.35 to 2.67)
Midwest	7,025 (29.3)	0.58 → 0.62	2007 (2004–2015)	1999–2007: -3.48* (-6.40 to -0.48) 2007–2024: +2.26* (1.40 to 3.12)	+ 0.38 (-0.69 to 1.46)
South	6,981 (29.1)	0.38 → 0.48	2010 (2007–2014)	1999–2010: -4.66* (-6.55 to -2.73) 2010–2024: +5.92* (4.70 to 7.15)	+ 1.13* (0.09 to 2.18)
West	5,706 (23.8)	0.39 → 0.61	2008 (2004–2014)	1999–2008: -1.47 (-4.53 to 1.69) 2008–2024: +4.02* (3.00 to 5.05)	+ 2.01* (0.77 to 3.27)
Race and Hispanic origin					
Non-Hispanic White	20,464 (85.3)	0.43 → 0.60	2008 (2006–2009)	1999–2008: -3.18* (-4.54 to -1.80) 2008–2024: +4.02* (3.43 to 4.61)	+ 1.37* (0.77 to 1.97)
Non-Hispanic Black	1,931 (8.1)	0.41 → 0.52	2013 (2007–2017)	1999–2013: -2.61* (-4.64 to -0.53)	+ 1.68* (0.23 to 3.16)

Characteristic	Deaths, n (%)	Rate, 1999 → 2024 [§]	Joinpoint (95% CI)	APC by segment (95% CI) [§]	AAPC (95% CI) [§]
				2013–2024: +7.42* (5.08 to 9.81)	
Hispanic or Latino	1,040 (4.3)	0.31 → 0.27	—	—	—
Non-Hispanic Asian or Pacific Islander	349 (1.5)	—	—	—	—
Non-Hispanic American Indian or Alaska Native	158 (0.7)	—	—	—	—
County urbanization, 1999–2020[§]					
Metropolitan	14,067 (77.4)	0.41 → 0.47	2007 (2004–2009)	1999–2007: -4.46* (-6.74 to -2.12) 2007–2020: +3.18* (2.33 to 4.03)	+ 0.20 (-0.78 to 1.19)
Nonmetropolitan	4,115 (22.6)	0.49 → 0.64	2010 (2005–2014)	1999–2010: -1.09 (-2.90 to 0.76) 2010–2020: +3.60* (1.64 to 5.60)	+ 1.12 (-0.12 to 2.38)

APC, annual percent change; AAPC, average annual percent change; CI, confidence interval.

The bars show the annual death counts (left axis). The line shows the age-adjusted mortality rate per 100,000, standardized to the 2000 US standard population, with a 95% confidence interval (right axis). The marker denotes the joinpoint identified by the model (2008; 95% CI: 2005–2014). The dashed vertical rule marks the transition between the Multiple Cause of Death 1999–2020 and 2018–2024 data files.

Age

Adults aged ≥ 65 years accounted for 18,847 of 23,982 deaths (78.6%); however, their crude rate was essentially unchanged across the period (1.882 to 1.894 per 100,000; AAPC 0.18%, 95% CI – 0.49 to 0.86; P = 0.592) The increase was concentrated in younger adults (Fig. 2). Rates among adults aged 25–44 years rose from 0.031 to 0.090 per 100,000, increasing 12.58% per year after 2014 (95% CI 9.41 to 15.85) the steepest increase in the analysis. Rates among adults aged 45–64 years rose from 0.174 to 0.326 per 100,000, increasing by 5.69% per year after 2007 (95% CI: 4.99 to 6.40) (Table S3).

Bars show annual death counts (left axis). The lines show crude mortality rates per 100,000 on a logarithmic scale (right axis), and the markers denote each stratum's joinpoint. Crude rather than age-adjusted rates are shown because an age-adjusted rate computed over a subset of the standard age groups and reported to two decimal places has insufficient resolution for trend estimation in these strata. A logarithmic scale is required because the rates span two orders of magnitude. The dashed vertical line marks the data file transition.

Sex

Men accounted for 14,169 deaths (59.1%) and women for 9,813 (40.9%). The age-adjusted rate rose from 0.58 to 0.74 per 100,000 in men (AAPC 0.97%; $P = .047$) and from 0.36 to 0.39 in women (AAPC 0.66%; $P = 0.41$). The null average in women should not be interpreted as an absence of change; it comprises a significant decline of 4.71% per year until 2007 (95% CI - 7.60 to - 1.73), a decade of no significant change, and a significant increase of 6.80% per year from 2018 (95% CI 2.01 to 11.83) (Fig. 3 and Table S2).

Bars show annual death counts (left axis); lines show age-adjusted mortality rates per 100,000 with 95% confidence intervals (right axis). The markers denote each joinpoint. The average annual percent change in women does not differ from zero because a significant decline and a significant subsequent increase offset one another; the segment estimates in Table 1 should be read in preference to the summary value. The dashed vertical line marks the data file transition.

Race and Hispanic origin

Non-Hispanic White decedents accounted for 20,464 deaths (85.3%), and non-Hispanic Black decedents accounted for 1,931 (8.1%). Rates rose 4.02% per year after 2008 in the former (95% CI 3.43 to 4.61) and 7.42% per year after 2013 in the latter (95% CI 5.08 to 9.81), which was the steepest race-specific increase observed (Fig. 4, Table S5). Hispanic or Latino decedents accounted for 1,040 deaths (4.3%). Their age-adjusted rate did not increase, standing at 0.31 per 100,000 in 1999 and 0.27 in 2024, although annual deaths rose from 25 to 88 and the crude rate rose from 0.14 to 0.22, reflecting growth and aging of the Hispanic population. No segmented model was fitted for this group because rates in five years rested on fewer than 20 deaths (Table 1, Fig. 4).

Bars show annual death counts (left axis); lines show age-adjusted mortality rates per 100,000 with 95% confidence intervals (right axis). Race categories were restricted to non-Hispanic decedents, and Hispanic decedents were obtained from a separate query spanning all races. No joinpoint marker is shown for Hispanic decedents because rates in five years rested on fewer than 20 deaths, and no segmented model was fitted. Non-Hispanic Asian or Pacific Islander and American Indian or Alaska Native decedents are not shown because the counts fell below the disclosure threshold in most individual years. The dashed vertical rule marks the data-file transition, at which the race classification changes from bridged to a single race.

Hispanic decedents accounted for 1,040 deaths (4.3% of total deaths). Although deaths rose from 25 in 1999 to 88 in 2024, the Hispanic population aged ≥ 25 years grew 2.31-fold over the same interval, and the age-adjusted rate fell from 0.310 per 100,000 in 1999 to 0.266 in 2024. An exploratory segmented fit, restricted to the 21 of 26 years for which an age-adjusted rate is reported, placed an inflection at 2010, with a decline of 6.61% per year before it and an increase of 5.43% per year after (average annual change – 0.05%). This estimate is exploratory rather than confirmatory: five of the nine years preceding the inflection are missing because the rate rested on fewer than 20 deaths, and in strata with complete data, omitting the same five years moved the corresponding segment estimate by up to 0.4 percentage points per year. The counts of non-Hispanic Asian or Pacific Islander (349 deaths, 1.5%) and non-Hispanic American Indian or Alaska Native (158 deaths, 0.7%) fell below the disclosure threshold in most individual years. Trends were not modeled for any of these three groups; pooled counts were complete and are reported in Table S6.

Geography and urbanization

The absolute rates were the highest in the Midwest. The steepest late increase was in the South (5.92% per year after 2010) and the largest full-period change in the West (AAPC 2.01%; $P < .001$); the Midwest average did not differ from zero despite both segments being significant (Table 1; Fig. 5; Tables S4 and S12). From 1999 to 2020, non-metropolitan rates exceeded metropolitan rates throughout and rose more steeply after their respective inflections (Fig. 6, Table S7). Pooled state-level rates varied by approximately ten-fold in both periods (Table S9).

Bars show annual death counts (left axis); lines show age-adjusted mortality rates per 100,000 with 95% confidence intervals (right axis). The markers denote each joinpoint. The dashed vertical line marks the data file transition.

Bars show annual death counts (left axis); lines show age-adjusted mortality rates per 100,000 with 95% confidence intervals (right axis). Counties were classified using the 2013 NCHS Urban–Rural Classification Scheme, with the four metropolitan levels combined as metropolitan and the micropolitan and noncore levels as nonmetropolitan. This variable is not available in the Multiple Cause of Death 2018–2024 file; therefore, this figure covers 1999–2020 only.

Place of death

Deaths occurring in nursing homes or long-term care facilities fell from 7,038 (38.7%) in 1999–2020 to 1,592 (27.5%) in 2021–2024, while deaths at the decedent's home rose from 3,712 (20.4%) to 1,568 (27.1%), and deaths in hospice facilities from 543 (3.0%) to 379 (6.5%) (Table S8).

Sensitivity analysis: underlying versus contributing cause

Neuromuscular dysfunction of the bladder was recorded as the underlying cause of death in 3,167 of 23,982 deaths (13.2%). This series moved in the opposite direction of the primary analysis. The underlying cause age-adjusted rate fell from 0.081 per 100,000 in 1999 to 0.052 in 2024, and annual underlying cause deaths were essentially flat (160 in 1999; 147 in 2024), while deaths involving the

condition nearly doubled. Joinpoint regression placed a single inflection at 2018, although with a wide confidence interval (95% CI 2008–2022): the rate declined 3.69% per year from 1999 to 2018 (95% CI – 4.88 to – 2.49; $P < .001$), and the subsequent segment did not differ significantly from zero (5.71% per year, 95% CI – 0.83 to 12.68; $P = .08$). The average annual percent change across the full period also did not differ significantly from zero (– 1.52%, 95% CI – 3.17 to 0.17; $P = .08$) (Table S14).

The proportion of deaths involving neurogenic bladder as the underlying cause halved over the study period, from 20.3% in 1999 to 9.7% in 2024 (Fig. 7) (Table S15); unlike the modeled estimates, this measure is arithmetic and carries no distributional assumptions. Therefore, the narrower definition does not reproduce the primary result: the inflection sits a decade later, the full-period direction is opposite, and the terminal increase that is unambiguous in the primary series is not statistically supported here.

Bars show annual death counts (left axis); lines show age-adjusted mortality rates per 100,000 with 95% confidence intervals (right axis). Any mention denotes the condition recorded anywhere on the death certificate, and underlying cause denotes the condition recorded as the underlying cause. Underlying-cause deaths accounted for 20.3% and 9.7% of deaths involving the condition in 1999 and 2024, respectively. The dashed vertical line marks the data file transition.

Expressed as a proportion of all deaths at ages 25 years and over, deaths involving neurogenic bladder rose from 3.40 per 10,000 deaths in 1999 to a nadir of 2.60 in 2008 and then to 5.03 in 2024, a 48% increase across the period and a 1.94-fold increase from the nadir (Fig. 8, Table S16). Over the same interval, deaths involving neurogenic bladder rose by 92%, while all deaths at these ages rose by 30%. The proportionate series reached its minimum in 2008, the same year as the age-adjusted series did. The proportion fell during 2020 and 2021 to 3.98 and 3.86, respectively, before rising to its maximum in 2024.

Any-mention deaths per 10,000 deaths at age 25 years and over, with a 95% confidence interval. The denominator was extracted under identical age and Hispanic origin restrictions. This measure has no population denominator and is therefore unaffected by census estimation, the 2020-census blended base, or the transition between data files, which the dashed vertical rule marks. The proportion reached its minimum in 2008, which was the same year as the age-adjusted rate.

Discussion

In this national analysis spanning 26 years, deaths involving neuromuscular dysfunction of the bladder declined until 2008 and then rose steadily, reaching 0.55 per 100,000 by 2024. The headline finding, however, is not the rise itself but its composition. Deaths for which neurogenic bladder was recorded as the underlying cause declined significantly through 2018 and showed no significant change thereafter, while the proportion of deaths involving it halved. Therefore, the increase in the primary series reflects deaths in which neurogenic bladder was recorded as a contributing condition rather than the underlying cause of death.

Two explanations are consistent with this pattern, and these data cannot distinguish between them.

The first is clinical progress. The classical terminal pathway in the neurogenic bladder runs through upper tract deterioration, recurrent infection, and renal failure [9], and obstructive uropathy from the neurogenic bladder remains a recognized cause of renal failure in older adults [27]. Systematic bladder management, intermittent catheterization in preference to indwelling drainage, and surveillance of the upper tracts are all directed at preventing this pathway [1, 2, 3, 9]. Bladder management is the principal modifiable factor associated with that pathway: in a multicenter series of 849 patients with chronic spinal cord injury, intermittent catheterization was associated with significantly fewer urological complications than indwelling catheterization, and indwelling drainage carried a markedly higher risk of urinary stones [28]. Chronic kidney disease nonetheless remains more than three times as prevalent in this population as in the general population, and is associated with comorbid diabetes, recurrent urinary tract infection and reduced bladder volume [29]. A decline in deaths attributed to neurogenic bladder alongside an increase in deaths involving the condition is consistent with successful prevention of this terminal pathway: neurogenic bladder may increasingly be carried as a chronic comorbidity to the end of life rather than serving as the underlying cause of death.

The second is certification drift. The number of conditions recorded per death certificate has increased over this period with the adoption of electronic death registration and the 2003 revision of the US Standard Certificate of Death; therefore, part of the increase in recorded involvement could reflect more complete certification rather than a true change in mortality involving neurogenic bladder. However, two observations constrain this explanation. First, if the increase were driven solely by a general increase in the completeness of death certification, this proportion would be expected to remain relatively stable. However, deaths involving neurogenic bladder increased as a proportion of all deaths at these ages, from 3.40 to 5.03 per 10,000, suggesting that the observed increase is unlikely to be driven by a general rise in the number of conditions recorded. Second, if the observed increase reflected more complete recording of comorbid conditions on death certificates during the COVID-19 pandemic, the proportion would be expected to increase rather than decline; the decrease observed in 2020 and 2021 therefore does not support general certification drift as the sole explanation for this trend. It remains possible that recognition and recording of neurogenic bladder specifically improved over the period through wider documentation of chronic urological conditions or the use of structured problem lists, and these data cannot rule that out.

Taken together, these analyses considerably narrow the range of possible interpretations. A generalized increase in the completeness of death certification is unlikely to fully account for this trend. What cannot be separated is a genuine increase in the number of people dying with neurogenic bladder from an increase in the reliability of recognition and recording of the condition when present. The national mortality burden of neurogenic bladder appears to increasingly reflect its presence as a comorbidity at death rather than as the underlying cause, and studies that count only underlying-cause deaths may underestimate the number of deaths involving the condition.

The concentration in younger adults

The most striking stratum-level finding is that adults aged 65 and over, who account for 79% of the deaths, showed relatively little net change in mortality rates, while rates in adults aged 25–44 years rose 12.58% per year after 2014.

This finding requires careful interpretation. The denominator here is the entire US population aged 25 to 44 years, not the population living with a neurogenic bladder, whose size is not recorded in these data. Therefore, a rising population mortality rate is fully compatible with falling case fatality; if more people survive congenital and acquired neurogenic bladder into adulthood, more deaths will occur among people with the condition, even if the risk to each individual falls. These data cannot estimate case fatality because the prevalence is unknown, and the increase reported here should not be interpreted as evidence that the care of young adults with neurogenic bladder has deteriorated. Two mechanisms may contribute to this pattern.

The first may be the growth of the population surviving congenital neurogenic bladder into adulthood. Infant mortality associated with spina bifida in high-income countries has fallen by approximately 4.76% per year over recent decades, attributed to advances in treatment and mandatory folic acid fortification [30]. One possible consequence is a growing adult population with congenital urological disease, a group whose care needs are now recognized as a distinct field, transitional urology, and for whom failed transition from pediatric to adult services carries documented consequences [31]. We note explicitly that the cited evidence concerns infant survival; the inference that improved infant survival produces a larger young adult population at risk of death with neurogenic bladder is ours, and it is an inference rather than a demonstrated chain.

The second may be diabetic bladder dysfunction, which affects close to half of patients with diabetes mellitus and remains under-recognized [32], against the background of a substantially rising diabetes prevalence [33]. Multiple sclerosis, with a US prevalence of approximately 682 per 100,000 adults and a marked female predominance [34], also contributes to the younger strata. These etiologies differ in prognosis: the risk of upper tract damage is much lower in slowly progressive non-traumatic disease than in spinal cord injury or spina bifida [2]; therefore, a shift in the etiological mix toward non-traumatic causes could potentially lower attributable mortality while raising recorded involvement, a pattern that is consistent with the one observed here.

Disparities

Rates rose fastest among non-Hispanic Black decedents, at 7.42% per year after 2013, compared to 4.02% per year after 2008 among non-Hispanic White decedents. The two inflections fall in different years; therefore, the estimates describe overlapping but not identical intervals and should not be read as a single ratio. We are not aware of any prior study examining racial disparities in neurogenic bladder outcomes; therefore, this finding has no direct precedent in the literature. It should be regarded as

hypothesis-generating and warrants dedicated investigation with data capable of distinguishing incidence, access to urological care, bladder management strategies, and competing causes of death.

The urbanization gradient invites an access-related explanation, although these data cannot establish one. Nonmetropolitan rates exceeded metropolitan rates throughout 1999–2020 and increased more steeply. Neurogenic bladder requires sustained specialist follow-up, including urodynamic assessment, upper tract surveillance, and management of catheter-associated complications, and access to that care is unevenly distributed. The US urological workforce is projected to fall short of demand, with the shortage concentrated outside metropolitan areas [35], and rural providers identify specialty care access, geographic dispersion, and workforce shortage as the principal barriers [36]. An equally consistent explanation is case mix: nonmetropolitan populations are older and have a higher prevalence of diabetes and of traumatic injury, each of which raises the burden of neurogenic bladder without any contribution from access to care. Rates were adjusted for age but for no other characteristic, and these data cannot distinguish the two. Nonetheless, the variation in state-level rates — approximately eight-fold in 1999–2020 and tenfold in 2021–2024 — should be interpreted cautiously: variation of that magnitude may reflect differences in certification practice, disease occurrence, or other factors, and the same caution applies to geographical variation in the measured neurological disease burden [37].

The shift in place of death

The near-halving of the nursing home share of deaths, alongside increases in home and hospice deaths, is consistent with the broader national movement of end-of-life care out of institutions in the US. We note that the two periods compared differ in length and that the later period spans the COVID-19 pandemic, during which the place of death shifted across all causes; this finding should not be attributed to changes in neurogenic bladder care specifically.

Limitations

Cause-of-death ascertainment depends on the completion of death certificates, which is imperfect. The expected net direction is under-ascertainment, since chronic contributing conditions are more often omitted from a certificate than recorded in error; therefore, the burden reported here may be underestimated. As discussed above, certification practice is time-varying, which is the principal threat to the interpretation of the primary trend.

Race and Hispanic origin in the numerator are reported by the funeral director from an informant, whereas the denominator is self-reported census data; misclassification is concentrated in specific groups, approximately 40% for American Indian or Alaska Native decedents against roughly 3% for Hispanic and Asian or Pacific Islander decedents [23]. Small annual counts meant that trends could only be estimated for non-Hispanic White and non-Hispanic Black decedents. For non-Hispanic Asian or Pacific Islander decedents, a pooled 2021–2024 estimate is reportable because selecting the Asian and Native Hawaiian or Other Pacific Islander categories together returns counts above the disclosure threshold, but the earlier series remains suppressed in 9 of 22 years, and no long-run trend can be

estimated. Rates for smaller strata should be read as approximate, even when pooled counts are complete.

Race classification also changes across data file transitions. Deaths through 2020 are reported against bridged-race population estimates, in which decedents recorded as more than one race are reallocated to single-race categories, whereas deaths from 2021 are reported under the 1997 Office of Management and Budget single-race standard [22]. We combined the Asian and Native Hawaiian or Other Pacific Islander categories from 2021 to match the bridged Asian or Pacific Islander category, and decedents recorded as more than one race, for whom no bridged counterpart existed, were retained in the overall series but assigned to no race stratum. Therefore, the race strata sum exactly to the overall series through 2020 and slightly less thereafter. Three considerations limit the implications of the findings reported here. First, bridging alters the denominators of the two strata we modeled the least: bridged population counts exceed single-race counts by approximately 0.5% for the White population and 2.5% for the Black population, against 12.0% for American Indian or Alaska Native and 5.0% for Asian or Pacific Islander populations [22]. Second, the inflections estimated for both modeled race strata — 2008 for non-Hispanic White and 2013 for non-Hispanic Black decedents — fall well before the transition, and no stratum in the analysis placed a joinpoint at 2020 or 2021; therefore, the segmented structure is not an artifact of the change in classification. Third, the terminal segments span the transition continuously without a step. Nonetheless, this change means that race-specific rates before and after 2021 are not defined for identical populations, and comparisons across that boundary should be made with that in mind.

A death certificate records which conditions were present, but not the order in which they developed. Therefore, deaths involving the neurogenic bladder are a marker of documented multimorbidity at death, not of a causal sequence. This is the reason why the underlying cause analysis is reported alongside, rather than instead of, the primary series.

Rates and their standard errors were obtained from CDC WONDER as exported rather than recomputed from age-specific deaths and populations. The exported rate columns are rounded to two decimal places, and for a rate of this magnitude, the exported standard error resolves to two distinct values across the study period. This limits the precision of the inverse-variance weights used in the trend models and is a likely contributor to the wide confidence intervals around some of the estimated joinpoint years. It did not affect death counts, population denominators, crude rates reported for age strata, or the proportion of deaths for which neurogenic bladder was the underlying cause.

The design was cross-sectional and ecological; it described population-level rates over time and supported no inference about individual decedents. Etiology is not recorded in a way that permits separating spinal cord injury, spina bifida, multiple sclerosis, and diabetic causes; therefore, the mechanistic account offered above is inferential. County urbanization data are unavailable after 2020, restricting the comparison to 1999–2020. Finally, non-resident deaths are excluded, and residents

undercounted in census denominators still contribute deaths to the numerator, which could inflate rates in affected groups.

Conclusions

Deaths involving neuromuscular dysfunction of the bladder in the United States fell until 2008 and have risen since, while deaths attributed to the condition declined and now account for fewer than one in ten involved deaths, down from one in five in 1999. Neurogenic bladder is increasingly recorded as a comorbidity at the time of death rather than as the cause of death.

The increase was also present when deaths involving neurogenic bladder were expressed as a proportion of all deaths, suggesting that it may not be fully explained by a generalized increase in the completeness of death certification. Improved recognition of the neurogenic bladder cannot be excluded. The increase was steepest in adults aged 25 to 44 years and in non-Hispanic Black decedents, although most deaths remained in adults aged 65 and over, and rates were consistently higher outside metropolitan counties through 2020. These patterns highlight an increasing burden of deaths involving neurogenic bladder among young adults, a population whose long-term urological care cannot be evaluated from mortality data alone and warrants a dedicated investigation.

Declarations

Ethics approval. This study used de-identified, publicly available aggregate data (CDC WONDER) and was exempt from institutional review board review.

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Conflicts of interest. The authors declare no conflict of interest.

Data availability. All data are publicly available from the CDC WONDER (<https://wonder.cdc.gov>). The supplementary file contain the analyzed data.

Author contributions.

KA: Conceptualization; Methodology; Software; Validation; Visualization; Writing – original draft.

EA: Software; Validation; Data curation; Visualization; Writing – original draft.

MO: Investigation; Data extraction; Formal analysis; Resources; Writing – review & editing.

SP: Investigation; Data curation; Validation; Writing – review & editing.

SQ: Methodology; Validation; Supervision; Writing – review & editing.

MAM: Validation; Resources; Writing – review & editing.

AAZ: Investigation; Resources; Supervision; Writing – review & editing.

GN: Supervision; Project administration; Writing – review & editing. (Corresponding author). All authors read and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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Figures

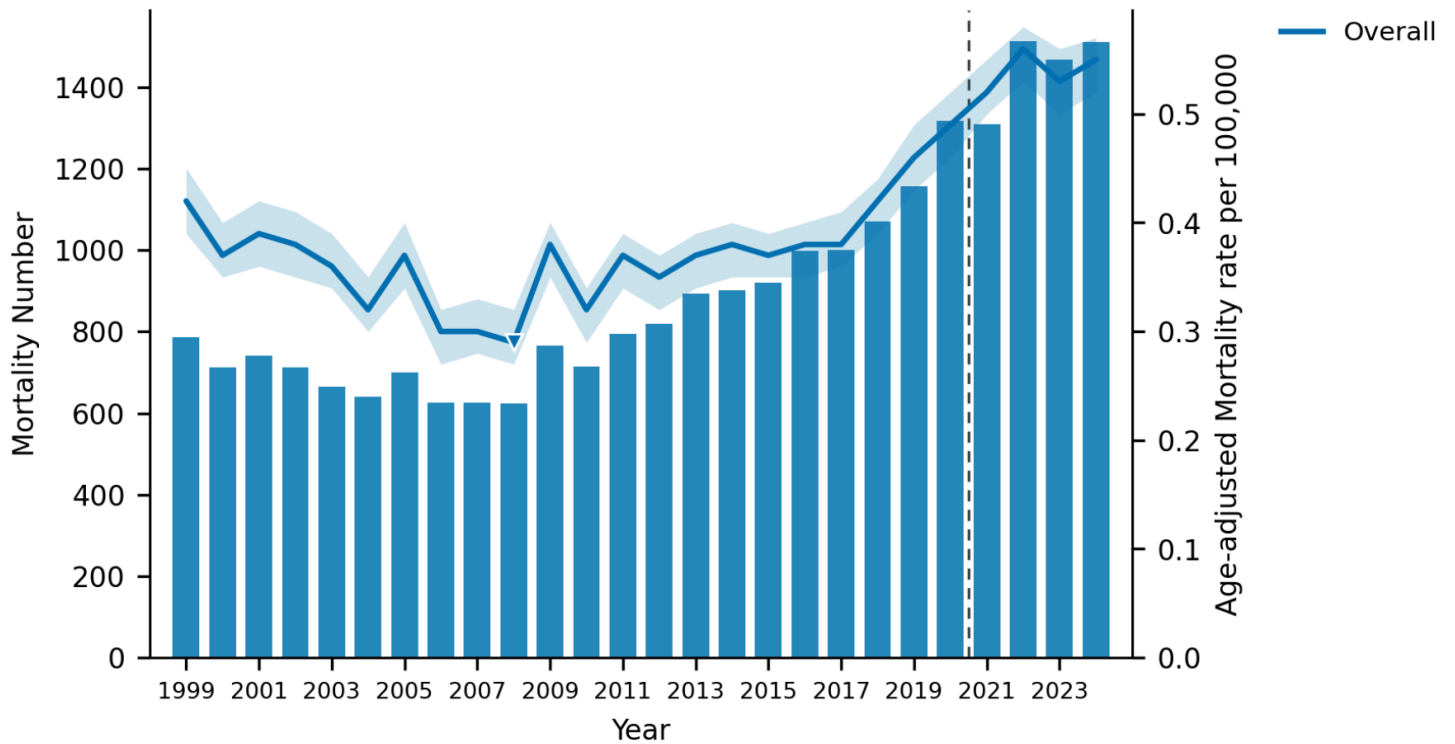


Figure 1

Deaths and age-adjusted mortality rate involving neuromuscular dysfunction of the bladder in the United States from 1999 to 2024.

The bars show the annual death counts (left axis). The line shows the age-adjusted mortality rate per 100,000, standardized to the 2000 US standard population, with a 95% confidence interval (right axis). The marker denotes the joinpoint identified by the model (2008; 95% CI: 2005–2014). The dashed vertical rule marks the transition between the Multiple Cause of Death 1999–2020 and 2018–2024 data files.

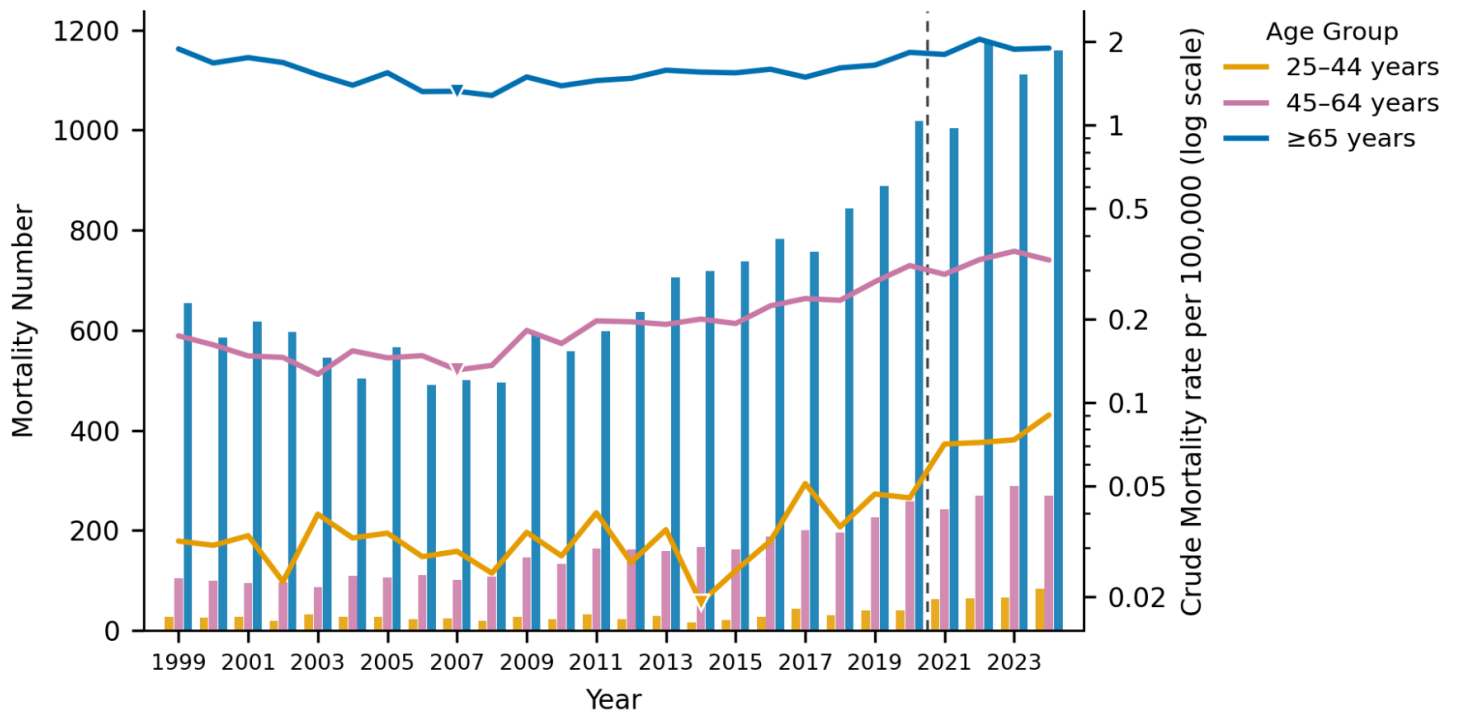


Figure 2

Deaths and crude mortality rate of neuromuscular dysfunction of the bladder by age group, United States, 1999–2024.

Bars show annual death counts (left axis). The lines show crude mortality rates per 100,000 on a logarithmic scale (right axis), and the markers denote each stratum's joinpoint. Crude rather than age-adjusted rates are shown because an age-adjusted rate computed over a subset of the standard age groups and reported to two decimal places has insufficient resolution for trend estimation in these strata. A logarithmic scale is required because the rates span two orders of magnitude. The dashed vertical line marks the data file transition.

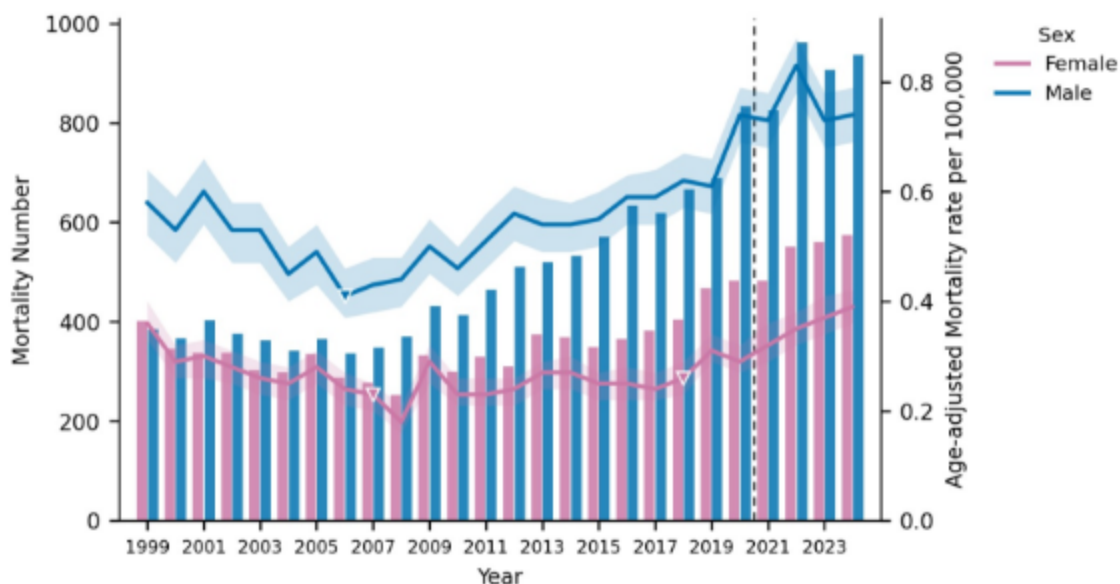


Figure 3

Deaths and age-adjusted mortality rate of neuromuscular dysfunction of the bladder by sex, United States, 1999–2024.

Bars show annual death counts (left axis); lines show age-adjusted mortality rates per 100,000 with 95% confidence intervals (right axis). The markers denote each joinpoint. The average annual percent change in women does not differ from zero because a significant decline and a significant subsequent increase offset one another; the segment estimates in Table 1 should be read in preference to the summary value. The dashed vertical line marks the data file transition.

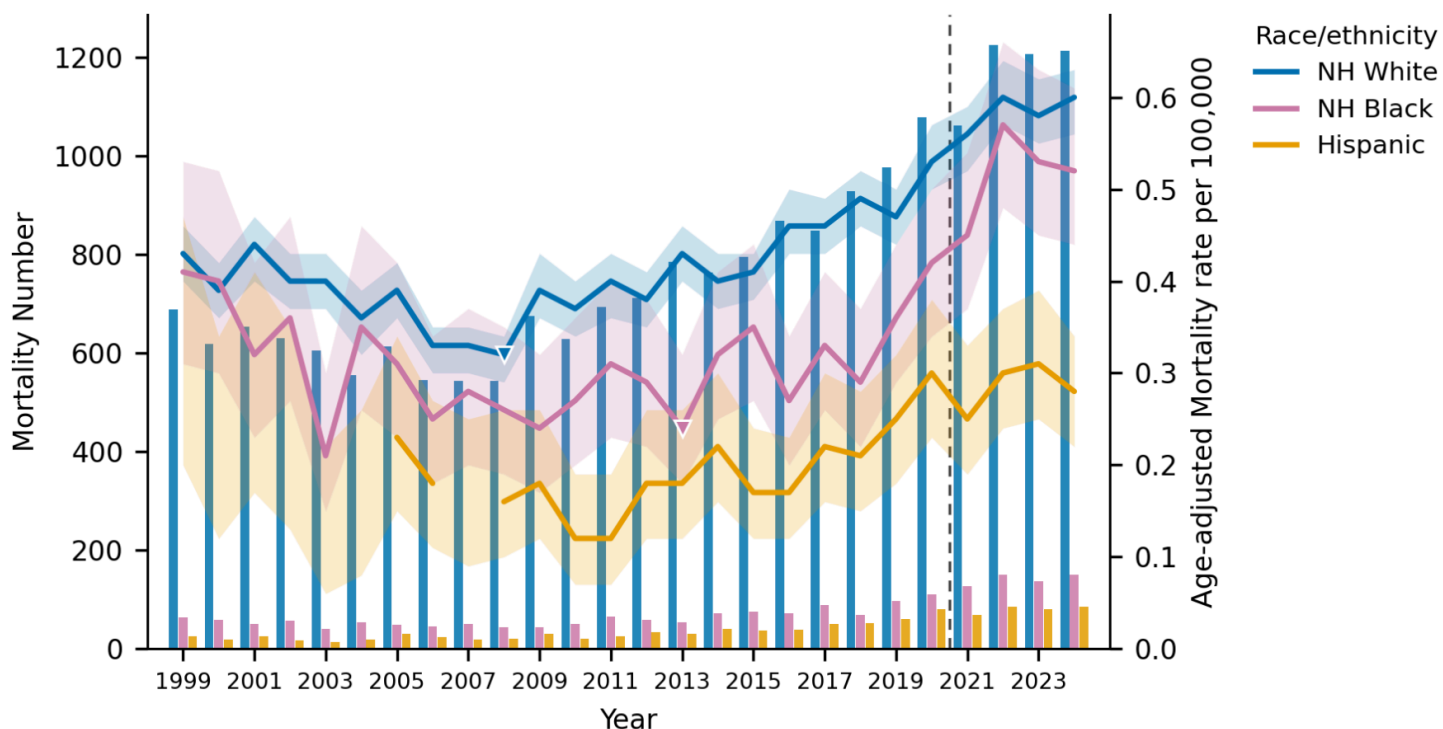


Figure 4

Deaths and age-adjusted mortality rate of neuromuscular dysfunction of the bladder by race and Hispanic origin, United States, 1999–2024.

Bars show annual death counts (left axis); lines show age-adjusted mortality rates per 100,000 with 95% confidence intervals (right axis). Race categories were restricted to non-Hispanic decedents, and Hispanic decedents were obtained from a separate query spanning all races. No joinpoint marker is shown for Hispanic decedents because rates in five years rested on fewer than 20 deaths, and no segmented model was fitted. Non-Hispanic Asian or Pacific Islander and American Indian or Alaska Native decedents are not shown because the counts fell below the disclosure threshold in most individual years. The dashed vertical rule marks the data-file transition, at which the race classification changes from bridged to a single race.

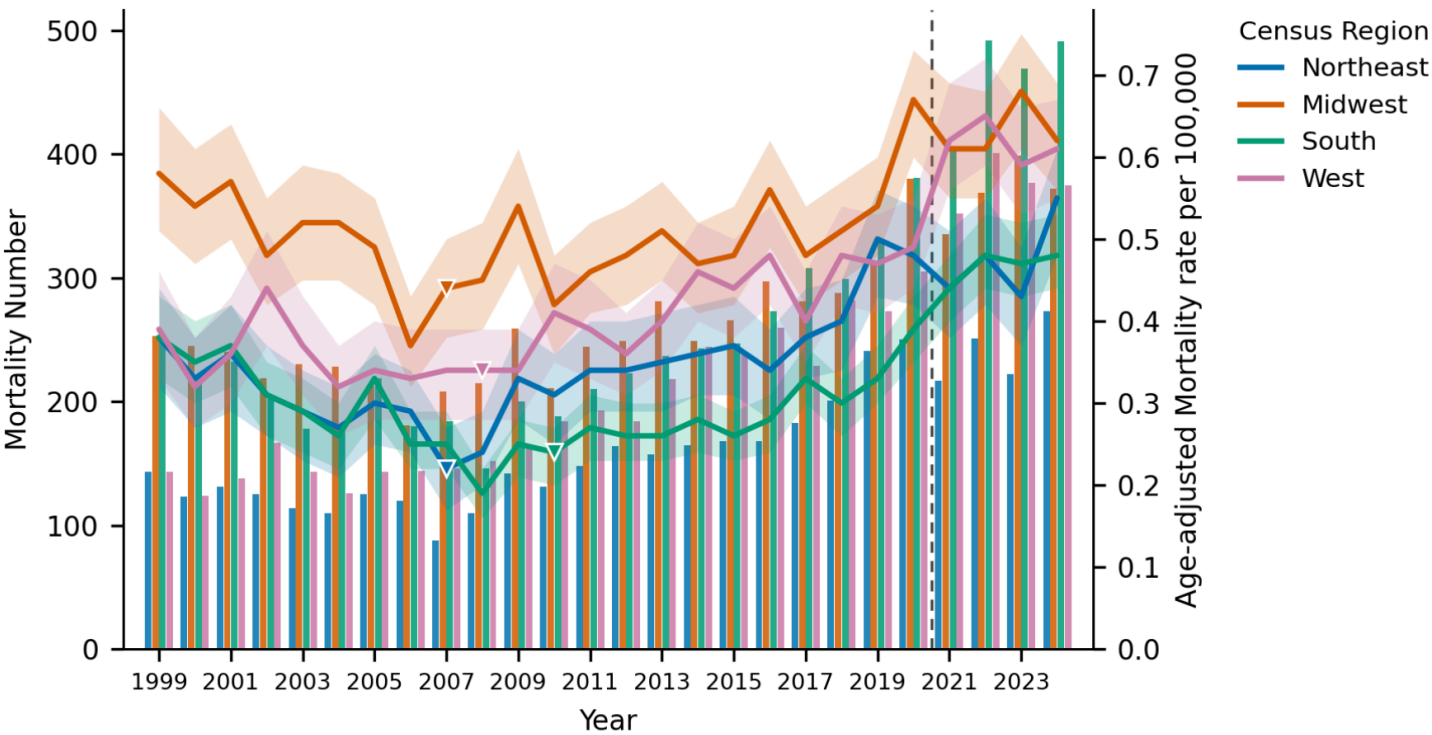


Figure 5

Deaths and age-adjusted mortality rate of neuromuscular dysfunction of the bladder by census region, United States, 1999–2024.

Bars show annual death counts (left axis); lines show age-adjusted mortality rates per 100,000 with 95% confidence intervals (right axis). The markers denote each joinpoint. The dashed vertical line marks the data file transition.

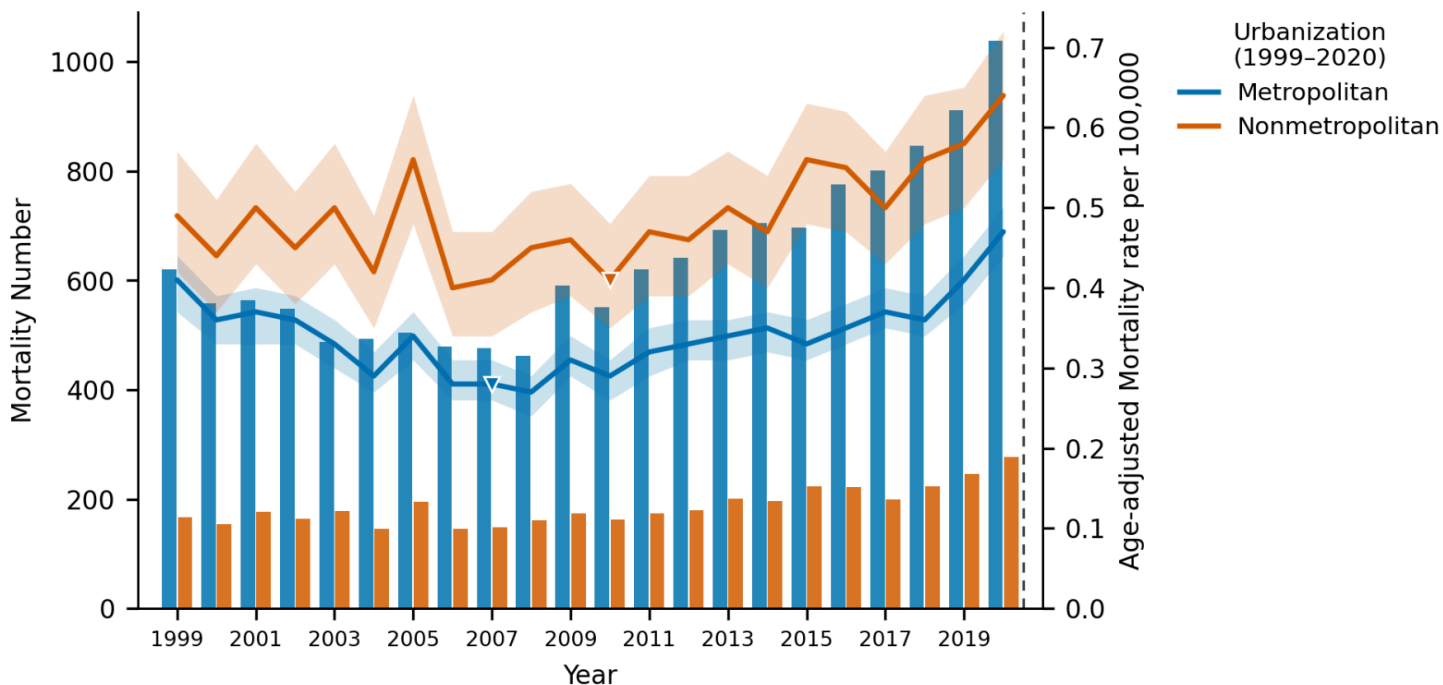


Figure 6

Deaths and age-adjusted mortality rate of neuromuscular dysfunction of the bladder by county urbanization, United States, 1999–2020.

Bars show annual death counts (left axis); lines show age-adjusted mortality rates per 100,000 with 95% confidence intervals (right axis). Counties were classified using the 2013 NCHS Urban–Rural Classification Scheme, with the four metropolitan levels combined as metropolitan and the micropolitan and noncore levels as nonmetropolitan. This variable is not available in the Multiple Cause of Death 2018–2024 file; therefore, this figure covers 1999–2020 only.

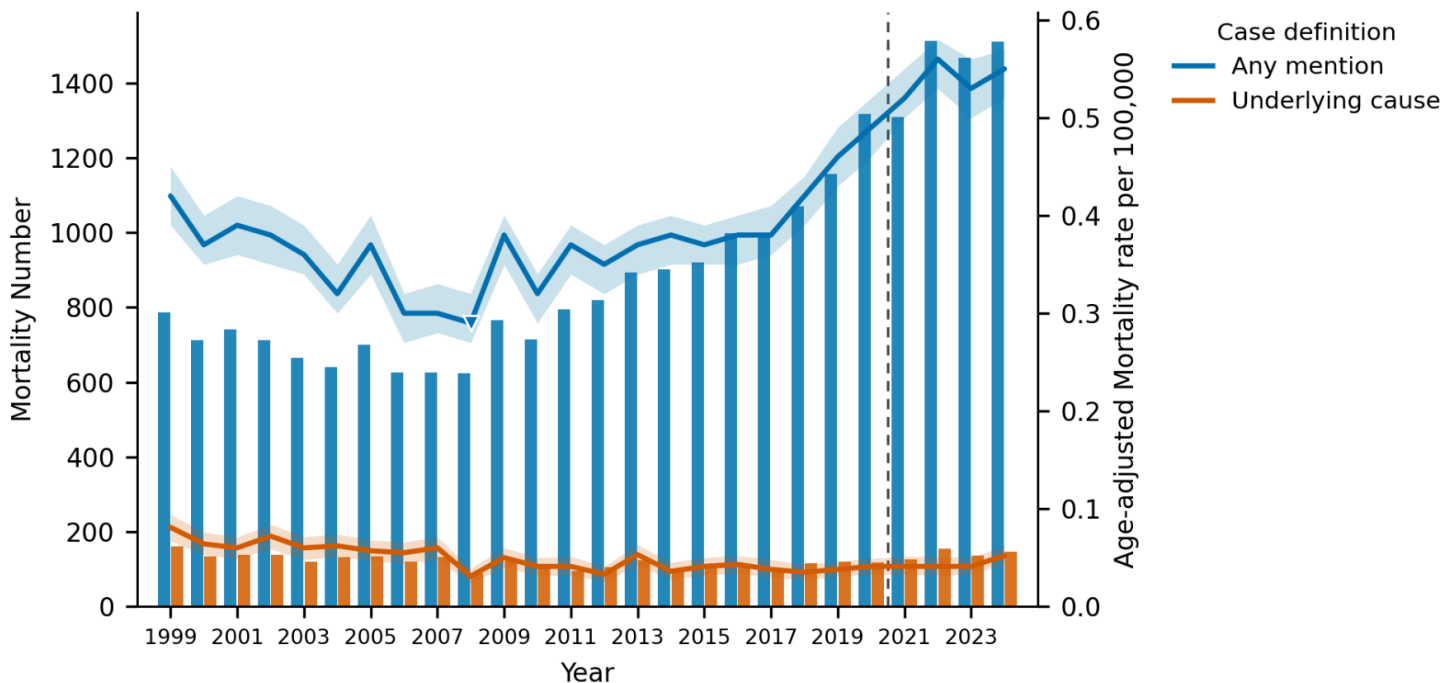


Figure 7

Deaths and age-adjusted mortality rate involving neuromuscular dysfunction of the bladder by case definition, United States, 1999–2024.

Bars show annual death counts (left axis); lines show age-adjusted mortality rates per 100,000 with 95% confidence intervals (right axis). Any mention denotes the condition recorded anywhere on the death certificate, and underlying cause denotes the condition recorded as the underlying cause. Underlying-cause deaths accounted for 20.3% and 9.7% of deaths involving the condition in 1999 and 2024, respectively. The dashed vertical line marks the data file transition.

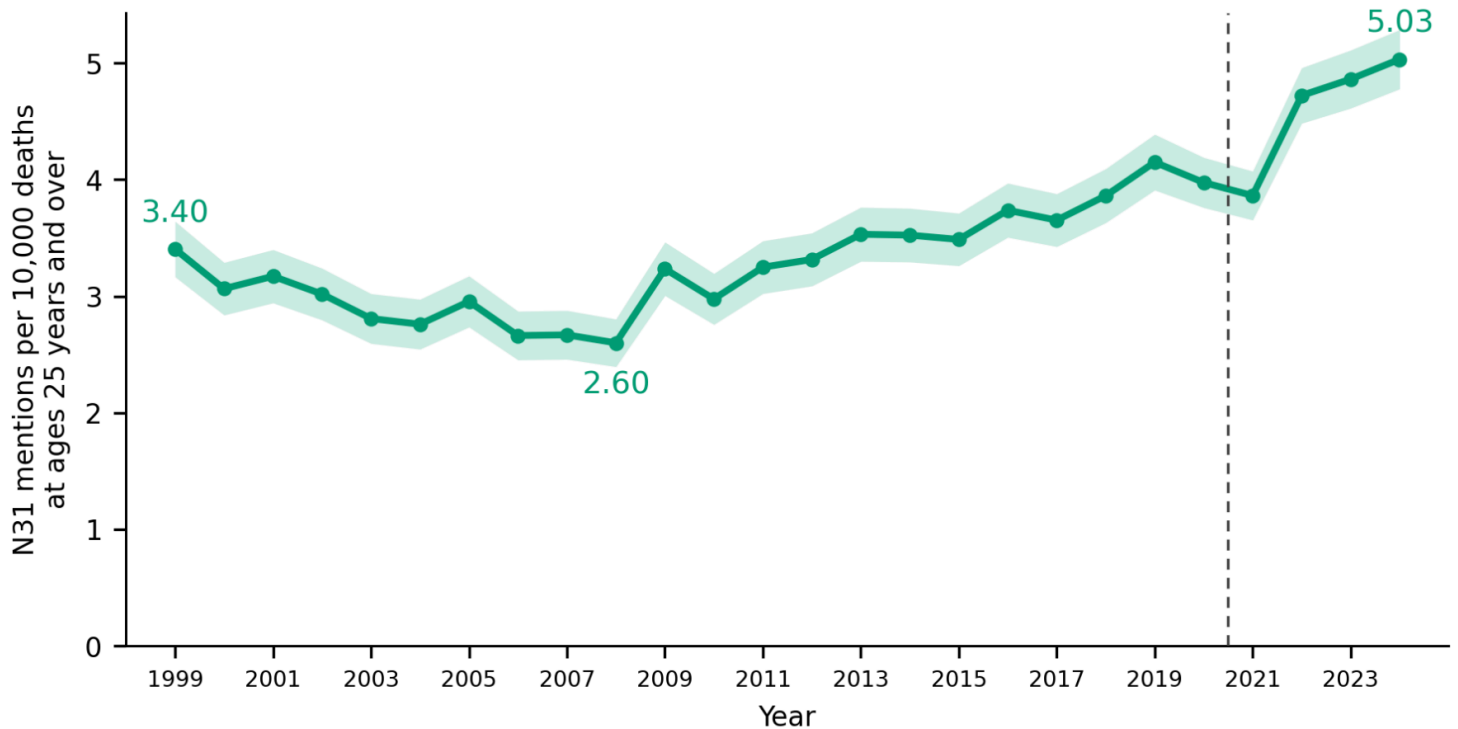


Figure 8

Deaths involving neuromuscular dysfunction of the bladder as a proportion of all deaths at age ≥ 25 years, United States, 1999–2024.

Any-mention deaths per 10,000 deaths at age 25 years and over, with a 95% confidence interval. The denominator was extracted under identical age and Hispanic origin restrictions. This measure has no population denominator and is therefore unaffected by census estimation, the 2020-census blended base, or the transition between data files, which the dashed vertical rule marks. The proportion reached its minimum in 2008, which was the same year as the age-adjusted rate.

Supplementary Files

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- [2SepSupplementaryTablesN31S1S172.docx](#)