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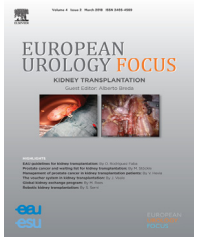

Stone Disease

Prevalence and Trends in Kidney Stone Among Adults in the USA: Analyses of National Health and Nutrition Examination Survey 2007–2018 Data

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Abstract

Background: The contemporary prevalence and trends of kidney stones are not clear.
Objective: To evaluate the gender-specific prevalence and trends in kidney stones among the US population.
Design, setting, and participants: Data on self-reported history of kidney stones from 34 749 participants aged ≥20 yr from the National Health and Nutrition Examination Survey (NHANES) were analyzed.
Intervention: Six 2-yr study cycles (2007–2008 to 2017–2018) of nationally representative series of surveys evaluated the health status of the US population.
Outcome measurements and statistical analysis: Weighted prevalence estimates of kidney stones and 95% confidence intervals (CIs) were calculated in each study cycle. Multivariable-adjusted logistic regression models were used to investigate the temporal trends.
Results and limitations: In the 2017–2018 cycle, the prevalence of kidney stones was 10.9% (CI: 9.3–12.7) in men as compared with 9.5% (CI: 8–11.2) in women. The prevalence of kidney stones increased steadily from 6.5% in the 2007–2008 cycle to 9.4% in the 2017–2018 cycle (p_{trend} = 0.001) among women but not among men (p_{trend} = 0.1). These trends remained after adjusting for sociodemographic correlates in both genders. Sensitivity analyses further adjusting for dietary information held the same results in trends (men: p_{trend} = 0.15; women: p_{trend} = 0.001). Non-Hispanic white ethnicity, obesity, gout, history of two or more pregnancies, menopause, and using female hormones were associated with a higher prevalence of kidney stones. The main limitation is the cross-sectional design of the study.

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Conclusions: Although kidney stones are more common in men than in women in the USA, the gender gap in kidney stone prevalence appears to be closing in the past decade. Kidney stones are consistently higher among non-Hispanic white and obese, and women who have had multiple pregnancies or have used female hormone therapy.
Patient summary: The prevalence of kidney stones remains higher in adult US men than in women, but the trend has been increasing only in women, closing the gender gap in kidney stone prevalence.

1. Introduction

Kidney stones are a common condition with an estimated worldwide prevalence of 7.2–7.7% [1,2]. A decade ago, results from the US nationally representative data collected as part of the National Health and Nutrition Examination Survey (NHANES) showed that approximately 10% of the adult male population in the USA had kidney stones, with a lower prevalence (7%) in women [3]. Global data also suggest that the prevalence of kidney stones has been increasing in the last quarter of the 20th century among both genders [4]. Indeed, the healthcare burden of the condition remains on the rise, as annual urolithiasis cost ranges about $2 billion in the USA alone, mostly due to renal stones [5,6].

Several risk factors have been linked to the formation of kidney stones. Some contribute to urine concentration and crystallization of solutes, and include low fluid intake levels and hot climates [4,7]. Additionally, several dietary factors were associated with a higher kidney stone risk, such as high-salt diet, diet rich in animal protein, and low-fiber diet [7]. Furthermore, gender, white race, and features of the metabolic syndrome all contribute to stone formation [8–10]. Conditions leading to elevated serum calcium levels, such as primary hyperparathyroidism, are also considered important risk factors for stone formation [11]. Some other conditions such as asthma were found to have a higher prevalence of kidney stone disease, but a causal relationship has yet to be discovered [12].

Given the rapid changes in US lifestyle and weight status over the past decade, the contemporary prevalence and trends in kidney stones among US adult population remain unclear. Therefore, we aimed to describe the recent prevalence of kidney stone disease in the USA, and evaluate gender-specific trends in kidney stones by taking into consideration a range of sociodemographic characteristics and potential risk factors from 2007 through 2018.

2. Patients and methods

2.1. Study Population

The NHANES was designed to provide cross-sectional estimates of the prevalence of health, nutrition, and potential risk factors among the civilian noninstitutionalized US population. In this study, we included participants who have reported data on history of kidney stones (defined by responding "yes" or "no" to the question "Have you ever had kidney stones?" [3,13], with a response rate of 99%). Data on sociodemographic characteristics, body measurements, medical conditions, and lifestyle characteristics over six cycles from 2007–2008 to 2017–2018 and dietary information over five cycles from 2007–2008 to 2015–2016 (due to data availability) were extracted. Pregnant women were excluded from the analyses.

Height and weight were recorded in a mobile examination center or at the participant's home as part of the NHANES data collection procedures. Body mass index (BMI) was calculated as weight in kg/(height in meters)^2. The following standard definition for overweight and obesity classification was used to categorize BMI: underweight (<18.5 kg/m^2), normal weight (18.5–24.9 kg/m^2), overweight (25.0–29.9 kg/m^2), and obesity (≥30 kg/m^2) [14]. For analytic purposes, those who were underweight were excluded due to potential underlying health conditions.

Self-reported sociodemographic characteristics included age (grouped in 20–39, 40–59 and 60+ yr age groups), gender (men and women), race and ethnicity (non-Hispanic white, non-Hispanic black, Hispanic, and others), and annual household income (≤$25 000, $25 000–74 999, and ≥$75 000). Lifestyle characteristics included smoking status and leisure-time physical activity, where participants reported the number of days and minutes spent in moderate recreational and vigorous recreational activities in a typical week. We summarized the total number of minutes for both activities and classified participants as inactive (zero moderate-to-vigorous physical activity) and active (any moderate-to-vigorous physical activity) based on the physical activity guideline. Smoking status was classified into never smokers (did not smoke 100 cigarettes in life and do not smoke now), former smokers (smoked 100 cigarettes in life and do not smoke now), and current smokers (smoked 100 cigarettes in life and smoke now).

We extracted data on chronic conditions and dietary information that were considered potential risk factors, including history of diabetes mellitus and gout, dietary intake of total energy (kcal/d), plain water ("including plain tap water, water from a drinking fountain, water from a water cooler, bottled water, and spring water"; g/d), calcium (mg/d), and sodium (mg/d, converted to ≤2300 vs >2300 mg/d).

Furthermore, reproductive information among women was extracted, such as parity (including live births, miscarriages, stillbirths, tubal pregnancies, and abortions: 0, 1, 2, 3+), menopausal status (defined as no period in the past 12 mo due to menopause or having had hysterectomy), and history of female hormone use (estrogen and progesterone).

2.2. Analysis

All statistical analyses were performed using STATA version 14.0 (STATA Corp., College Station, TX, USA). We used survey analysis procedures to account for the sample weights, stratification, and clustering of the complex sampling design to ensure nationally representative estimates [15]. Sample characteristics were described for men and women. We calculated weighted prevalence and 95% confidence intervals (CIs) of reporting a history of kidney stones, by gender and NHANES study cycle. Gender-specific logistic regression models were used to evaluate the trend in kidney stone prevalence from 2007 to 2018, and estimated odds ratios (ORs) in crude and multivariable-adjusted models using study cycles as an independent variable. In multivariable-adjusted models, we adjusted for sociodemographic factors (age group, weight status, race/ethnicity, and annual household income), lifestyle factors (leisure-time physical activity and smoking status), chronic diseases (diabetes and

gout), and reproductive factors among women (number of pregnancies, menopausal status, and hormone use) from 2007 to 2018. Sensitivity analyses further adjusted for dietary factors (total energy intake, water intake, calcium intake, and sodium intake, all in quintiles), which were limited to 2007–2016. All statistical significance was set at $p < 0.05$.

3. Results

Between 2007 and 2018, a total of 34 796 participants responded to the question on the "history of kidney stone disease "(n = 29 200 between 2007 and 2016, of whom, 17 907 [51.5%] were men). Table 1 summarizes baseline characteristics of the study population (2017–2018) by gender. The majority of participants were non-Hispanic white (men: 62.1%; women: 62.4%), had an educational level higher than high school (men: 59.6%; women: 63.3%), were overweight (men: 34.3%; women: 28.1%) or obese (men: 43.0%; women: 42.4%), were physically active (men: 57.1%; women: 50.9%), and had no chronic conditions (men: 76.1%; women: 77.3%). The majority of women had at least two pregnancies (71.4%) and never had female hormone therapy (81.4%; Table 1).

In 2017–2018, the estimated prevalence of kidney stone was 11.9% (95% CI: 9.3–14.5%) in men aged 20 yr and older. The prevalence of kidney stones was stable among men from 2007 through 2018 in the overall sample (p_{trend} = 0.1) as well as in each age group (20–39 yr: p_{trend} = 0.62; 40–59 yr: p_{trend} = 0.18; ≥60 yr: p_{trend} = 0.66). Among women, the prevalence of kidney stones increased from 6.5% (95% CI: 5.3–7.7%) to 9.4% (95% CI: 7.3–11.4%) from 2007 through 2018 (difference = 2.8%, 95% CI: 0.6–5.1%, p_{trend} = 0.001). This trend was observed among women younger than 60 yr (20–39 yr: difference = 3.0%, 95% CI: 0.6–5.5%, p_{trend} = 0.002; 40–59 yr: difference = 3.0%, 95% CI: −1.2 to 7.2%, p_{trend} = 0.032), but not in women aged 60 yr and older (difference = 2.1%, 95% CI: −1.3 to 5.4%, p_{trend} = 0.261; Table 2). Figure 1 shows

Table 1 – Characteristics of US adults aged ≥20 yr by gender from the NHANES 2017–2018 data[a,b].

	Men				Women			
	Overall	20–39 yr	40–59 yr	≥60 yr	Overall	20–39 yr	40–59 yr	≥60 yr
No.	2541	742	777	1022	2681	807	878	996
Weighted (N)	114 910 970	42 884 662	40 385 444	31 640 874	121 691 245	41 514 019	42 222 352	37 954 874
Ever had kidney stones								
Never	88.1	95.1	86.1	81.3	90.6	93.2	89.6	89.1
Ever	11.9	4.9	13.9	18.7	9.4	6.8	10.4	10.9
Race/ethnicity (%)								
Non-Hispanic white	62.1	55.5	59.87	73.9	62.4	54.1	60.6	72.9
Non-Hispanic black	10.8	12.3	10.74	8.6	12.1	13.7	12.5	10.1
Hispanic	16.2	21.5	16.57	8.7	15.4	20.1	16.0	9.7
Other[c]	10.9	10.7	12.81	8.8	10.2	12.2	10.9	7.3
Family poverty ratio (%)								
<1.3	18.1	24.2	15.9	12.4	22.1	29.3	20.6	15.9
1.3–<3.5	36.1	36.8	32.59	39.7	35.9	35.4	31.9	40.6
≥3.5	45.9	39.1	51.52	47.9	42.1	35.3	47.5	43.5
Educational attainment (%)								
<High school	11.9	10.1	12.5	13.7	10.8	9.7	10.3	12.4
High school	28.5	32.0	25.87	27.0	26	23.6	24.6	29.9
>High school	59.6	57.9	61.62	59.3	63.3	66.7	65.2	57.8
Weight status (%)					0			
<25 kg/m^2	22.7	30.7	16.62	19.5	29.5	36.2	28.5	23.6
25–<30 kg/m^2	34.4	29.1	36.94	38.3	28.1	24.1	28.3	32.2
≥30 kg/m^2	43	40.3	46.44	42.2	42.4	39.7	43.3	44.3
Leisure-time physical activity[d] (%)								
Inactive	42.9	38.3	42.69	49.4	49.1	38.4	49.5	59.7
Active	57.1	61.7	57.31	50.6	50.9	61.6	50.6	40.3
Smoke status (%)								
Never	48.1	54.1	50.93	36.2	66.8	69.1	65.3	66.0
Past	32.6	21.6	29.87	50.8	17.6	11.4	17.7	23.9
Current	19.4	24.3	19.2	13.0	15.6	19.5	17.0	10.1
Chronic diseases[e] (%)								
No	76.1	95.6	80.55	43.9	77.3	94.2	79.7	57.3
Any	23.9	4.4	19.45	56.1	22.7	5.8	20.3	42.7
History of pregnancies								
0					17.8	38.3	8.8	6.6
1					10.8	14.4	9.3	8.8
2					21.8	14.2	23.5	27.7
3+					49.6	33.0	58.4	56.9
Female hormone therapy (%)								
Never					81.4	95.0	84.0	64.7
Ever					18.7	5.0	16.0	35.3
Menopause[f] (%)								
No					46.12	91.3	41.3	5.6
Yes					53.88	8.7	58.7	94.4
History of diabetes								

Table 1 (*Continued*)

	Men				Women			
	Overall	20–39 yr	40–59 yr	≥60 yr	Overall	20–39 yr	40–59 yr	≥60 yr
No	87.0	98.2	87.1	71.7	89.8	97.4	90.4	81.4
Yes	13.0	1.8	12.9	28.3	10.2	2.6	9.6	18.6
History of gout								
No	92.9	98.7	98.7	84.6	96.8	99.6	97.5	93.0
Yes	7.1	1.4	1.4	15.4	3.3	0.4	2.5	7.1

COPD = chronic obstructive pulmonary disease; NHANES = National Health and Nutrition Examination Survey.
[a] Participant characteristics were presented by age group: all age, 20–39 yr, 40–59 yr, and 60 yr or older. All estimates were weighted to be nationally representative.
[b] No. of participants within each age group may not sum up to equal the unweighted number due to missing data. Weighted percentage may not sum up to 100% due to missing data.
[c] "Other" includes race/ethnicity other than non-Hispanic white, non-Hispanic black, and Hispanic, including multiracial.
[d] Leisure-time physical activity level was defined by engaging in no (inactive) or any (active) moderate or vigorous recreational physical activity over the past 30 d (2005–2006) or in a typical week (2007–2018).
[e] Chronic diseases included cardiovascular diseases, cancer, COPD, and diabetes.
[f] Menopause was defined as no period in the past 12 mo due to menopause or having had a hysterectomy.

the crude weighted trends in kidney stones according to race/ethnicity and weight status.

From 2007 through 2018, the stable trend in men and the increasing trend in women remained similar in multivariable adjusted models (men: p_{trend} = 0.18; women: p_{trend} = 0.001; Table 3). Across both genders, a lower prevalence of kidney stone was observed among non-Hispanic black (men: OR = 0.40, 95% CI: 0.33–0.49; women: OR = 0.46, 95% CI: 0.36–0.59) and Hispanic (men: OR = 0.72, 95% CI: 0.61–0.85; women: OR = 0.74, 95% CI: 0.58–0.94) race/ethnicities. Meanwhile, both obesity (men: OR = 1.74, 95% CI: 1.43–2.13; women: OR = 1.62, 95% CI: 1.35–1.95) and a history of gout (men: OR = 1.32, 95% CI: 1.04–1.67; women: OR = 1.94, 95% CI: 1.31–2.86) were associated with a higher prevalence of kidney stones. Specific to reproductive factors in women, having had two (OR = 1.64, 95% CI: 1.21–2.23) or three or more (OR = 2.17, 95% CI: 1.63–2.88) pregnancies, a history of menopause (OR = 1.61, 95% CI: 1.21–2.15), and a history of female hormone use (OR = 1.38, 95% CI: 1.15–1.65) were associated with a higher prevalence of kidney stones (Table 3).

Sensitivity analyses further adjusting for dietary behavior were limited to 2007 through 2016, as NHANES provided data on dietary information only up to 2016

Table 2 – Weighted trends in kidney stone prevalence among US adults, NHANES 2007–2018[a].

Age (yr)	Trends in kidney stone prevalence						β (95% CI) [b]	p for trend[b]	2017–2018 vs 2007–2008
	2007–2008	2009–2010	2011–2012	2013–2014	2015–2016	2017–2018			Difference (95% CI)[c]
Men, weighted % (95% CI)									
Overall	11.6	10	8.4	10.9	13.3	11.9	0.4	0.1	0.3
	(9.6–13.6)	(8.3–11.7)	(6.7–10.2)	(9.1–12.7)	(11.9–14.7)	(9.3–14.5)	(−0.1 to 0.9)		(−2.9 to 3.4)
20–39	5.5	5	3.7	4.5	7	4.9	0.1	0.62	−0.6
	(3.2–7.8)	(3.7–6.4)	(2.1–5.3)	(2.3–6.8)	(5.1–8.9)	(3–6.9)	(−0.3 to 0.6)		(−3.5 to 2.3)
40–59	12.9	10.3	8.6	12.6	14	13.9	0.6	0.18	1.0
	(10.1–15.7)	(6.9–13.7)	(5.5–11.8)	(9.4–15.8)	(10.4–17.6)	(9.1–18.7)	(−0.3 to 1.4)		(−4.3 to 6.3)
≥60	20.4	17.8	15.4	17.8	21.2	18.7	0.2	0.66	−1.6
	(17.9–22.8)	(14.5–21.2)	(11.8–18.9)	(13.9–21.6)	(16–26.4)	(14.5–23)	(−0.7 to 1.0)		(−6.3 to 3.1)
Women, weighted % (95% CI)									
Overall	6.5	7.7	8.7	9.4	10	9.4	0.6	0.001	2.8
	(5.3–7.7)	(6.7–8.7)	(6.6–10.8)	(7.6–11.1)	(8.2–11.8)	(7.3–11.4)	(0.3–1.0)		(0.6–5.1)
20–39	3.8	5.2	6.5	7.5	7.8	6.8	0.7	0.002	3.0
	(2.5–5)	(3.3–7.1)	(4–9)	(5.9–9.2)	(5.4–10.2)	(4.6–9)	(0.2–1.1)		(0.6–5.5)
40–59	7.4	8.3	10	11	12.3	10.4	0.8	0.032	3.0
	(5.1–9.7)	(6.3–10.4)	(7.1–13)	(8.1–13.9)	(7.6–16.9)	(6.7–14.2)	(0.1–1.5)		(−1.2 to 7.2)
≥60	8.8	9.8	9.5	9.5	9.9	10.9	0.3	0.261	2.1
	(6.3–11.4)	(7.7–12)	(6.4–12.7)	(7–12.1)	(8–11.7)	(8.6–13.2)	(−0.2 to 0.8)		(−1.3 to 5.4)

CI = confidence interval; NHANES = National Health and Nutrition Examination Survey.
[a] Weighted estimates and 95% CIs were estimated for each survey cycle. All estimates were weighted to be nationally representative.
[b] The estimate β, 95% CI, and p for trend were calculated using linear regression that included the NHANES 2-yr cycle as a continuous variable. The estimate β can be interpreted as the average percentage point change in prevalence every 2 yr.
[c] A decrease corresponds to difference below zero.

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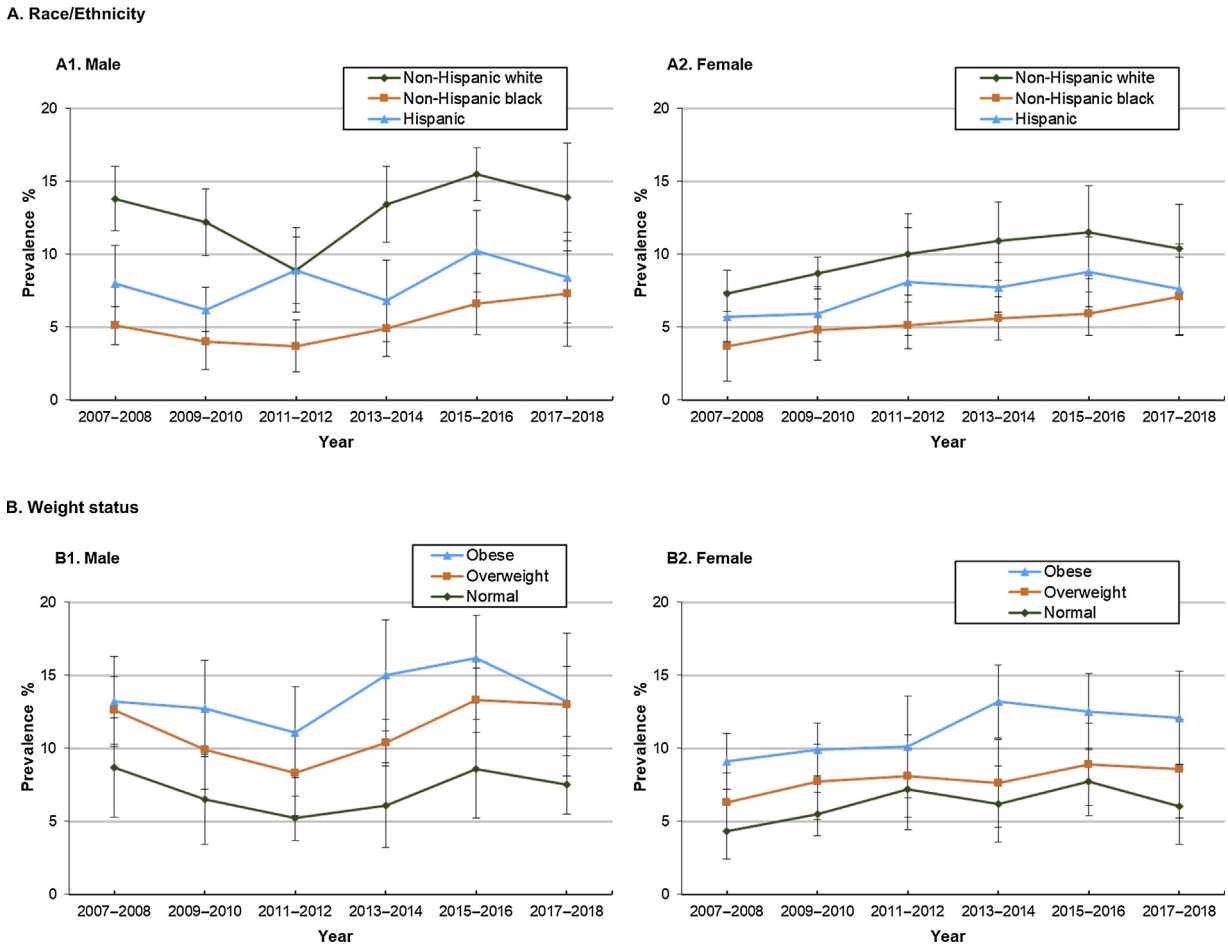

Fig. 1 – Crude weighted trends in kidney stones according to (A) race/ethnicity and (B) weight status, NHANES 2007–2018. Data were weighted to be nationally representative. Error bars indicated 95% CIs.
CI = confidence interval; NHANES = National Health and Nutrition Examination Survey.

(Supplementary Table 1). Nevertheless, the crude (men: p_{trend} = 0.09; women: $p_{trend} \leq 0.001$) and adjusted (men: p_{trend} = 0.15; women: p_{trend} = 0.001) trends remained the same (Supplementary Table 2). Furthermore, disparities in ethnicity, weight, history of gout, and female reproductive factors remained similar after adjusting for dietary behavior (Supplementary Table 3).

4. Discussion

In this representative sample of the US adult population, around 12% of men and 10% of women reported a history of kidney stones. Despite a higher overall prevalence of kidney stones among men, the disease trend remained stable over the past decade. Conversely, a rising trend of kidney stone prevalence was observed among adult women, particularly those younger than 60 yr, closing the gender gap in kidney stone disease. We also observed a racial disparity, such that kidney stones were more common among non-Hispanic whites than among non-Hispanic blacks or Hispanics. Moreover, being overweight or obese or having a history of gout was significantly associated with a higher prevalence of kidney stones in both genders. Regarding women's reproductive factors, kidney stones were more commonly reported among women who had two or more pregnancies or had used female hormone therapy.

Previously, the prevalence of kidney stones in both genders was reported to have had increased from 1988 to 1994, as compared with the late 1970s and early 1980s [8]. Additionally, a previous assessment of kidney stones using the NHANES data (2007–2010) confirmed a higher prevalence in men than in women [3]. The present study, to the best of our knowledge, is the first to comprehensively describe the epidemiology and systematically evaluate the contemporary trends of this disease across men and women, taking into consideration a range of standard and gender-specific risk factors.

The rising trend of kidney stone disease among US women can be multifactorial. First, previous NHANES data show that obesity and metabolic syndrome rates rose significantly among US women [16,17]. Obesity and metabolic syndrome are linked to an increased risk of several types of kidney stones such as calcium oxalate, calcium phosphate, and uric acid stones [18]. Another type of stones, struvite, is mostly caused by urinary tract infections, which are more common among women, and the frequency of infections is

Table 3 – Weighted logistic regression models of kidney stone among US adults, adjusted for sociodemographic and lifestyle characteristics, NHANES 2007–2018[a].

	Odds ratio (95% CI)	
	Men (n = 14 339)	Women (n = 13 355)
Age	1.03 (1.02–1.03)	0.98 (0.97–0.99)
Race/ethnicity		
Non-Hispanic white	1 (Reference)	1 (Reference)
Non-Hispanic black	0.40 (0.33–0.49)	0.46 (0.36–0.59)
Hispanic	0.72 (0.61–0.85)	0.74 (0.59–0.94)
Other[b]	0.73 (0.53–1.01)	0.77 (0.55–1.07)
Family poverty ratio		
<1.3	1 (Reference)	1 (Reference)
1.3–<3.5	1.16 (0.96–1.41)	0.98 (0.82–1.16)
≥3.5	1.00 (0.79–1.27)	0.97 (0.77–1.22)
p for trend	0.83	0.58
Educational attainment		
<High school	1 (Reference)	1 (Reference)
High school	1.01 (0.81–1.25)	0.98 (0.74–1.28)
>High school	0.98 (0.79–1.23)	1.17 (0.95–1.44)
p for trend	0.78	0.08
Weight status		
<25 kg/m^2	1 (Reference)	1 (Reference)
25–<30 kg/m^2	1.41 (1.14–1.74)	1.19 (0.97–1.48)
≥30 kg/m^2	1.74 (1.42–2.13)	1.6 (1.33–1.92)
p for trend	< 0.001	< 0.001
Leisure-time physical activity[c]		
Inactive	1 (Reference)	1 (Reference)
Active	0.95 (0.83–1.08)	0.73 (0.61–0.88)
Smoking status		
Never	1 (Reference)	1 (Reference)
Past	0.86 (0.73–1.02)	1.15 (0.89–1.5)
Current	1.08 (0.89–1.30)	1.08 (0.87–1.35)
Chronic diseases[d]		
No	1 (Reference)	1 (Reference)
Any	1.02 (0.8–1.29)	1.45 (1.12–1.87)
History of pregnancies		
0		1 (Reference)
1		1.42 (0.98–2.04)
2		1.64 (1.21–2.23)
3+		2.18 (1.64–2.91)
p for trend		<0.001
Female hormone therapy		
Never		1 (Reference)
Ever		1.28 (1.05–1.55)
Menopause[e] (%)		
No		1 (Reference)
Yes		1.61 (1.21–2.15)
History of diabetes		
No	1 (Reference)	1 (Reference)
Yes	1.48 (1.17–1.88)	1.26 (0.97–1.65)
History of gout		
No	1 (Reference)	1 (Reference)
Yes	1.32 (1.04–1.67)	1.92 (1.31–2.82)
Cycle		
2007–2008	1 (Reference)	1 (Reference)
2009–2010	0.85 (0.68–1.06)	1.21 (0.96–1.53)
2011–2012	0.65 (0.49–0.85)	1.37 (1.01–1.87)
2013–2014	0.94 (0.72–1.22)	1.37 (1.03–1.83)
2015–2016	1.10 (0.88–1.38)	1.59 (1.20–2.12)
2017–2018	1.00 (0.74–1.34)	1.41 (1.06–1.88)
p for trend	0.18	0.004

CI = confidence interval; COPD = chronic obstructive pulmonary disease; NHANES = National Health and Nutrition Examination Survey.
[a] All estimates were weighted to be nationally representative.
[b] "Other" includes race/ethnicity other than non-Hispanic white, non-Hispanic black, and Hispanic, including multiracial.
[c] Leisure-time physical activity level was defined by engaging in no (inactive) or any (active) moderate or vigorous recreational physical activity in a typical week.
[d] Chronic diseases included cardiovascular diseases, cancer, COPD, and diabetes.
[e] Menopause was defined as no period in the past 12 mo due to menopause or having had a hysterectomy.

well known to increase with age [19]. Other inflammatory conditions such as inflammatory bowel disease, which increase oxalate absorption stone formation, are more prevalent in women, and the overall incidence is increasing [20,21].

The evident non-Hispanic white predominance of kidney stones is in line with previous literature [3,4]. No conclusive evidence fully explains the inter-racial disparities, and it is proposed that genetics alone cannot be the sole culprit [22]. Several studies have shown that non-Hispanic blacks, of both genders, excrete less calcium and oxalate in urine as compared with their white counterparts [23,24]. Possible explanations may include inter-racial differences in gastrointestinal oxalate absorption, endogenous oxalate synthesis, urinary citrate excretion, and relative sensitivity to parathyroid hormone action [22–25].

Obesity plays an essential role in kidney stone formation. A higher BMI promotes urinary excretion of calcium, oxalate, and uric acid [9], thereby participating in kidney stone formation [26]. Obesity is also associated with insulin resistance [27], which, if persists for long enough, might lead to diabetes, a well-known risk factor for stone formation [10]. Data from the Nurses' Health Study I and II and Health Professional Follow-up Study confirmed that higher BMI (≥30 kg/m^2) increased the risk of symptomatic kidney stones [9,11,28]. Moreover, weight gain and a high waist circumference were associated with an increased kidney stone risk, with a more pronounced effect of this association among women than among men [28].

A higher prevalence of kidney stones in women among those who had two or more pregnancies or who used female hormone therapy could be attributed to alterations in the hormonal milieu. Estrogen has a protective effect against stone formation, which may also explain the higher kidney stone prevalence in men [29]. Moreover, estrogen deprivation "in postmenopausal women" may be accompanied by changes in bone metabolism, which translate into a higher risk of stone formation [30].

Our study has several limitations. First, the cross-sectional design of the study precludes drawing cause-effect conclusions and is subjected to selection as well as response biases. Second, since the data were self-reported, there lies the risk of several biases, such as recall bias. In addition, having to recall a history of kidney stones is not accurate, owing to the exclusion of asymptomatic stones in many cases and the omission of ureteric and bladder stones. That we did not have information on the type of kidney stones represents another limitation, precluding further analyses addressing the different etiologies and their contribution to the increase in kidney stone prevalence observed among women. Last, common essential risk factors, including family history and sun exposure levels, were not analyzed, which may have affected our results. Nevertheless, our data provide an important observation about the epidemiology of kidney stones and the underlying factors.

5. Conclusions

In the US adult population, the estimated prevalence of kidney stones was stable in men from 2007 to 2018. Meanwhile, this prevalence increased significantly in women, particularly among women younger than 60 yr. Although men still have a higher prevalence of kidney stones, the gender gap in kidney stone prevalence appears to have been closing over the past decade. Kidney stone disease disparities are observed in racial groups, as well as by weight status and female reproductive factors. Further studies are needed to identify the drivers of the observed upward trends in the prevalence of kidney stones in women.

Author contributions: Mohammad Abufaraj had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.
Study concept and design: Abufaraj, Yang, Shariat.
Acquisition of data: Xu, Cao, D'andrea, Yang.
Analysis and interpretation of data: Waldhoer, Seitz, Schernhammer, Fajkovic.
Drafting of the manuscript: Abufaraj, Siyam, Tarawneh, D'andrea.
Critical revision of the manuscript for important intellectual content: All authors.
Statistical analysis: Yang, Waldhoer, Seitz, Schernhammer, Fajkovic.
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Appendix A. Supplementary data

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