

The Impact of Body Mass Index on Quantitative 24-h Urine Chemistries in Pediatric Urolithiasis: A Systematic Review and Meta-Analysis

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Purpose: To study the effect of body mass index (BMI) on 24-h urine quantitative analysis in pediatric urolithiasis, and to explore whether obesity and overweight promote the formation of urinary calculi in children.

Materials and Methods: A comprehensive search of EMBASE, PubMed, the Cochrane Library, Web of Science, and Scopus was conducted in March 2024 and updated in October 2025 to identify all related studies. BMI was used to specify body size. Predetermined inclusion and exclusion criteria were used to screen each article. Data from appropriate studies were extracted, and a meta-analysis was performed using Stata 14.0 software.

Results: Eight studies, including 1033 children with urolithiasis who underwent 24-h urine collection for chemical analysis, were included in this meta-analysis. The BMI \geq 85th percentile group exhibited significantly higher uric acid excretion (SMD = 0.756, 95% CI = 0.092–1.420, $P = .026$). No statistically significant differences were found in calcium (SMD = -0.320, 95% CI = -0.600 to -0.050, $P = .519$), 24-h urine volume (SMD = -0.310, 95% CI = -0.790 to 0.160, $P = .555$), magnesium (SMD = -0.470, 95% CI = -0.820 to -0.120, $P = .471$), phosphate (SMD = -0.360, 95% CI = -0.610 to -0.110, $P = .805$), oxalate (SMD = -0.110, 95% CI = -0.390 to 0.170, $P = .315$), citrate (SMD = -0.190, 95% CI = -0.680 to 0.290, $P = .057$), or sodium (SMD = 0.200, 95% CI = -0.390 to 0.800, $P = .050$) excretion between the two groups. Sensitivity analyses confirmed the robustness of these findings.

Conclusion: While overweight/obese children with urolithiasis demonstrate higher urinary uric acid excretion, the absence of significant differences in other key urinary risk factors suggests that BMI alone should not be considered a separate and definitive risk factor for pediatric urolithiasis.

Keywords: pediatric urolithiasis; body mass index; pediatric obesity; 24-h urine analysis; meta-analysis

INTRODUCTION

The incidence of urinary calculi (urolithiasis) in children, defined as the presence of stones within the urinary system (kidneys, ureters, bladder, or urethra) confirmed by imaging studies or clinical symptoms, has been rising annually at an average rate of 4%–6%.⁽¹⁻³⁾ The precise cause of this trend is still unknown. It was previously theorized to be related to the increased sensitivity of imaging techniques; however, later studies have linked it to rising childhood obesity and other metabolic factors. Beyond environmental and metabolic influences, genetic predisposition also constitutes an important risk factor for urolithiasis. Specific polymorphisms in the genes encoding the vitamin D receptor (VDR) and calcitonin receptor (CTR) have been associated with altered calcium metabolism and an increased risk of renal stone formation and recurrence.^(4,5) Therefore, further research into the multifactorial causes, including metabolic, environmental, and genetic determinants, of kidney stone formation in children is warranted. Children with kidney stones face significant social and financial challenges in addition to physical

issues. It is alarming that 25% to 50% of patients experience a recurrence following their first urolithiasis episode, and over 70% of children develop secondary stones between childhood and maturity.⁽⁶⁾ Therefore, further research into the causes of kidney stone formation in children is warranted.

An increasing number of academics consider kidney stones to represent a metabolic condition.^(7,8) Current studies have demonstrated a clear correlation between adult kidney stone production and diet, climate, and obesity.^(9,10) Nevertheless, regarding the development of kidney stones in children, this association is unclear. Numerous studies have reached differing conclusions. For example, some have shown a link between childhood obesity and kidney stones, while other investigations have found no such relationship.⁽¹¹⁻¹³⁾ In adults, studies have confirmed significant abnormalities in 24-h urine parameters in obese patients, such as urinary calcium, urinary oxalate, urate, urinary sodium, and urinary pH.⁽¹⁴⁾ In children who are overweight or obese, are abnormalities in urine composition also an important factor in stone formation? Several studies

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Table 1. Parameters of abnormal 24-h urine in children

Characteristics	Abnormal values
Hypercalciuria	> 4.0 mg/kg/d[1-7]
Hyperoxaluria	> 40 mg/1.73 m ² /d[1,3,5], >45 mg/1.73 m ² /d[2,4], ≥0.57 mg/kg/d[6], >52 mg/1.73 m ² /d[7]
Hypocitraturia	< 320 mg/1.73 m ² /d[1], (<365 mg/1.73 m ² /d for males, <310 mg/1.73 m ² /d for females)[2-5], ≤400 mg/gm[6], <180 mg/gm[7]
Hyperuricosuria	> 10.7 mg/kg/d[1], >815 mg/1.73 m ² /d[2-5,7]
Low Volume	< 20 mL/kg/d[2,3,5-7]

have demonstrated a correlation between juvenile obesity and 24-h urine analysis characteristics in pediatric urolithiasis.⁽¹⁵⁻²³⁾ Notably, several research findings differ from one another. Scholars have not yet conducted a meta-analysis of the pertinent scientific evidence. To explore whether obesity and overweight contribute to the development of pediatric urolithiasis, this meta-analysis examined the findings of recent studies.

MATERIALS AND METHODS

Study Screening

A comprehensive search of PubMed, EMBASE, the Cochrane Library, Web of Science, and Scopus was conducted in March 2024. To ensure inclusion of the most recent evidence, the search was updated in October 2025, covering publications from the past approximately 14 months (from the initial search date). We conducted a comprehensive search using the following keywords and MeSH terms: [("Pediatrics"[Mesh] OR "Child"[Mesh] OR "Child, Preschool"[Mesh] OR "pediatric" OR "child" OR "children" OR "preschool" OR "toddler") AND ("Obesity"[Mesh] OR "Overweight"[Mesh] OR "Body Mass Index"[Mesh] OR "obes" OR "overweight" OR "body mass index" OR "BMI") AND ("Urinary Calculi"[Mesh] OR "Nephrolithiasis"[Mesh] OR "urolithiasis" OR "stone" OR "calculus" OR "calculi") AND ("Urine"[Mesh] OR "urine" OR "urinary")]. Every title, abstract, and full text was reviewed independently by two researchers. The prerequisites for retrieval were as follows: the paper discusses the effect of body mass index on the 24-h urine composition of children with urinary calculi, and it is written exclusively in English. Preferred Reporting Items for Systematic Reviews and Meta-Analyses

(PRISMA) standards were applied in our meta-analysis, which we carried out in March 2024 after updating the search results.⁽²⁴⁾

Inclusion and Exclusion Criteria

Studies that met all predefined criteria were included: (1) the study design was an observational study (including cohort, case-control, or cross-sectional studies); (2) the subjects were children with urolithiasis aged 1–18 years; (3) BMI was classified into two groups: below the 85th percentile (normal weight) or at/above the 85th percentile (overweight/obese) for age and sex, according to the standardized growth charts published by the U.S. Centers for Disease Control and Prevention (CDC).^(25,26) This cutoff is widely accepted in pediatric practice and research to define overweight status, which is associated with increased health risks;⁽²⁷⁾ (4) the studies compared the effects of BMI ≥85th percentile and BMI <85th percentile on the composition of 24-h urine; (5) the complete text could be accessed via the web; and (6) at least one clinical outcome of concern was reported (present in the data extraction section).

Studies were excluded if they were: (1) non-English language articles; (2) abstracts, reviews, case reports, editorials, or conference proceedings without sufficient data; or (3) studies in which the available data could not be extracted or calculated for meta-analysis.

Every title, abstract, and full text was reviewed independently by two researchers. Any discrepancies or disagreements regarding the inclusion or exclusion of studies were resolved through discussion and consensus. If consensus could not be reached, a third senior researcher was consulted to make the final decision.

Study Quality and Level of Evidence

The level of evidence for each study was rated us-

Table 2. Methodological quality and essential characteristics of included studies.

References	Nation	Study type	Study quality	Classification BMI (%)	Composition (24-h urine analysis)	Age (years) M ± SD	Sex (male:female)	Stone Location	Metabolic in Findings Overweight/Obese
Fang et al. 2021	USA	CC	7/9	<85th / ≥85th	144/99	ND	49:95/48:51	Kidney	Ho, Hc, Hoc, Hu, LV
Murphy et al. 2018	USA	C	7/9	<85th / ≥85th	41/31	13 ± 5.92 / 12 ± 3.70	ND	Kidney	ND
Cambareri et al. 2017	USA	CC	8/9	<85th / ≥85th	133/73	12.7 ± 3.8 / 12.6 ± 4.2	58:75/41:32	Not Specified	Ho, Hc, Hoc, Hu, LV
Bandari et al. 2016	USA	CC	8/9	<85th / ≥85th	81/29	14 ± 3.7 / 14 ± 4.07	22:59/15:14	Kidneys or ureters	Ho, Hc, Hoc, Hu, LV
Çaltık et al. 2015	Turkey	C	7/9	<5th / 5th-85th / ≥85th	52/20/12	6.9 ± 4.0 / 9.2 ± 4.5 / 9.4 ± 5.5	28:24/8:12/6:6	Not Specified	Ho, Hc, Hoc, Hu
Chung et al. 2012	Korea	C	8/9	≤10th / 10th-85th / ≥85th	28/71/26	8.21 ± 6.36 / 11.62 ± 5.75 / 9.81 ± 5.72	ND	Not Specified	Ho, Hc, Hoc, LV
Roddy et al. 2014	USA	CC	7/9	<85th / ≥85th	73/11	ND	23:50/9:2	Kidney	Ho, Hc, Hoc, Hu, LV
Sopifiska et al. 2019	Poland	C	7/9	<85th / ≥85th	74/35	13 ± 2.39 / 13 ± 2.63	41:33/12:23	Not Specified	ND

All the children in the studies were diagnosed with urolithiasis.

Abbreviations: BMI, body mass index; C, cohort; ND, not demonstrated; CC, case-control; %, percentile; Hc, hypercalciuria; Ho, hyperoxaluria; Hoc, hypocitraturia; Hu, hyperuricosuria; LV, low volume.

Table 3. Characteristics of 24-h urinary metabolite excretion

Items	Studies	NO. of patients <85th/≥85th	Heterogeneity P value	I ² (%)	Overall effect	P value	Higher in
Hypercalciuria	[13,15-19]	602/250	0.042	56.6	1.035 (0.529, 2.028)	0.919	–
Hyperoxaluria	[13,15-19]	602/250	0.809	0	1.749 (1.187, 2.577)	0.005	≥85th
Hypocitraturia	[13,15-19]	602/250	0.212	29.7	0.854 (0.541, 1.349)	0.5	–
Hyperuricosuria	[13,15-18]	503/224	0.217	30.7	4.59 (1.772, 11.886)	0.002	≥85th
Low Volume	[13,15,16,18,19]	530/238	0.060	55.8	2.198 (1.155, 4.182)	0.016	≥85th

ing criteria established by the Oxford Centre for Evidence-Based Medicine.⁽²⁸⁾ The methodological quality of nonrandomized studies was assessed using the Newcastle–Ottawa Scale.⁽²⁹⁾ The procedure was rotated between two reviewers. If controversy remained, consensus was sought from a third investigator.

Data Extraction

A set of predetermined criteria was utilized independently by two reviewers to extract data, which included the first author, age, year of publication, composition, classification of BMI, nation and sex ratio of children for 24-h urine collection, and outcomes of interest (the excretion of 24-h urinary urate, sodium, oxalate, phosphate, calcium, magnesium, and citrate; the volume of 24-h urine; and urine pH). For studies reporting both unadjusted (crude) and adjusted estimates for the association between BMI and urine chemistries, we prioritized the extraction of unadjusted estimates to maintain consistency and comparability across all included studies, as the adjusted estimates varied widely in their sets of confounding variables (e.g., age, sex, diet, fluid intake). This approach allows for a direct comparison of the raw physiological differences but inherently carries a risk of residual confounding, which is acknowledged as a limitation. **Table 1** displays the diagnostic criteria for abnormal 24-h urine. If a disagreement arose, the

original article was carefully reviewed again and discussed until consensus was reached.

Statistical Analysis

All meta-analyses were conducted using Stata software (version 14.0). To reduce heterogeneity and facilitate data pooling, urine solute units were standardized as follows: urine volume in milliliters per kilogram; oxalate, citrate, and urate in milligrams per 1.73 square meters; and all other solutes in milligrams per kilogram. Following Cochrane Handbook guidelines, studies reporting more than two BMI categories were pooled into two groups: BMI ≥85th percentile (overweight/obese) and BMI <85th percentile (normal weight).⁽³⁰⁾ Data reported separately by sex or region were combined to obtain a single estimate for each outcome across all studies.

For continuous outcomes, the mean difference (MD) was used as the effect measure when all studies reported the outcome in identical units. The standardized mean difference (SMD) was applied to pool outcomes reported in different units across studies. For dichotomous outcomes, odds ratios (ORs) with 95% CIs were calculated. Prior to meta-analysis, the feasibility of pooling continuous data was assessed. This included an evaluation of the normal distribution assumption for outcomes reported as means and standard deviations (SDs). As a

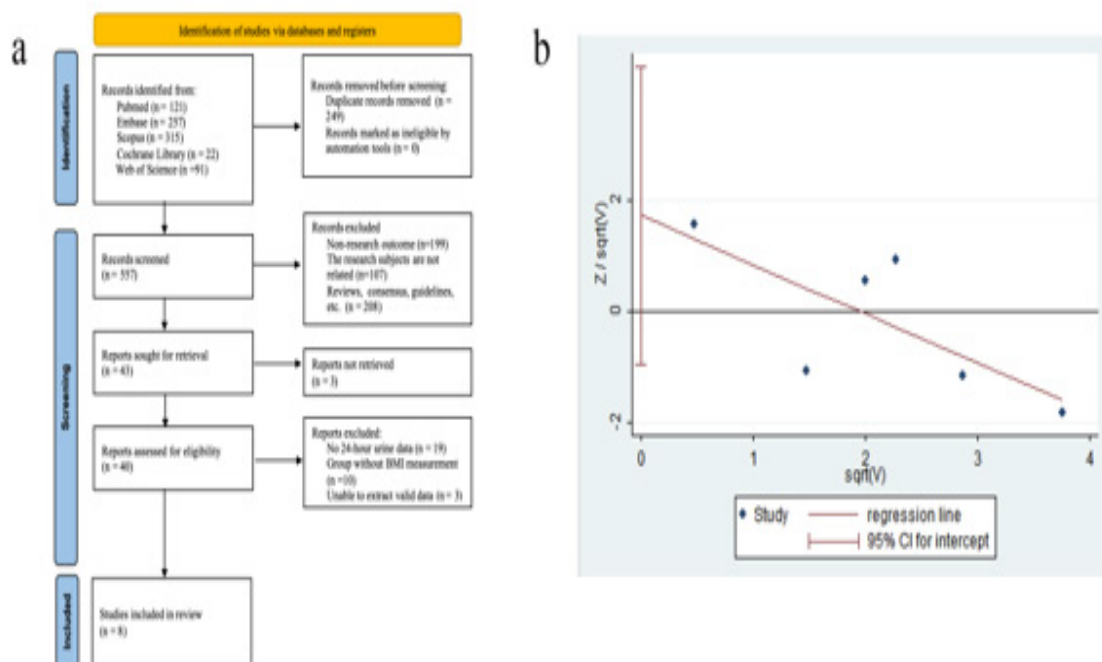


Figure 1. (a) Flowchart for search and screening of target studies. (b) The Egger test of urine pH.

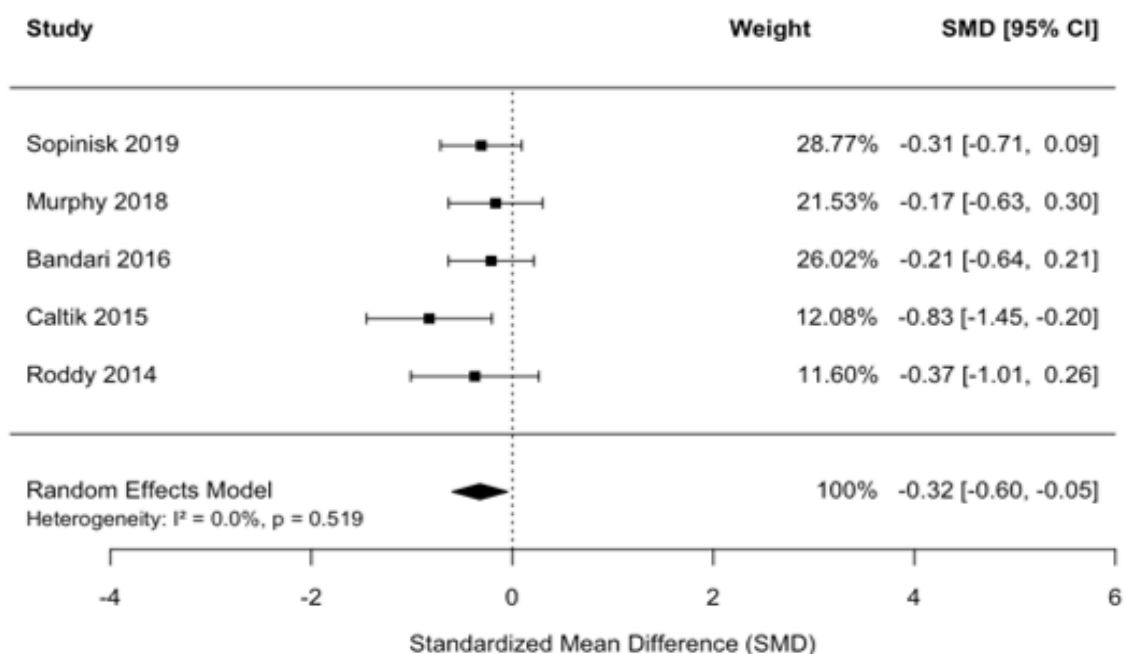


Figure 2. Forest plot of 24-h calcium levels in children.

screening tool for potential skewness, we applied the criterion that a mean/SD ratio of less than 2 for positive-valued data suggests a non-normal distribution. All studies contributing to the final pooled estimates presented mean/SD ratios above this threshold for their respective outcomes, supporting the use of parametric meta-analytic methods. For all meta-analyses involving a small number of studies ($n \leq 10$), the random-effects

model was fitted using the restricted maximum likelihood (REML) estimator for the between-study variance (τ^2). To account for the uncertainty in the estimation of τ^2 when the number of studies is small, the Knapp–Hartung (KH) adjustment was applied to the standard errors of the pooled effect, and the corresponding P values and confidence intervals were derived from a t-distribution with $k-2$ degrees of freedom (where k is the number

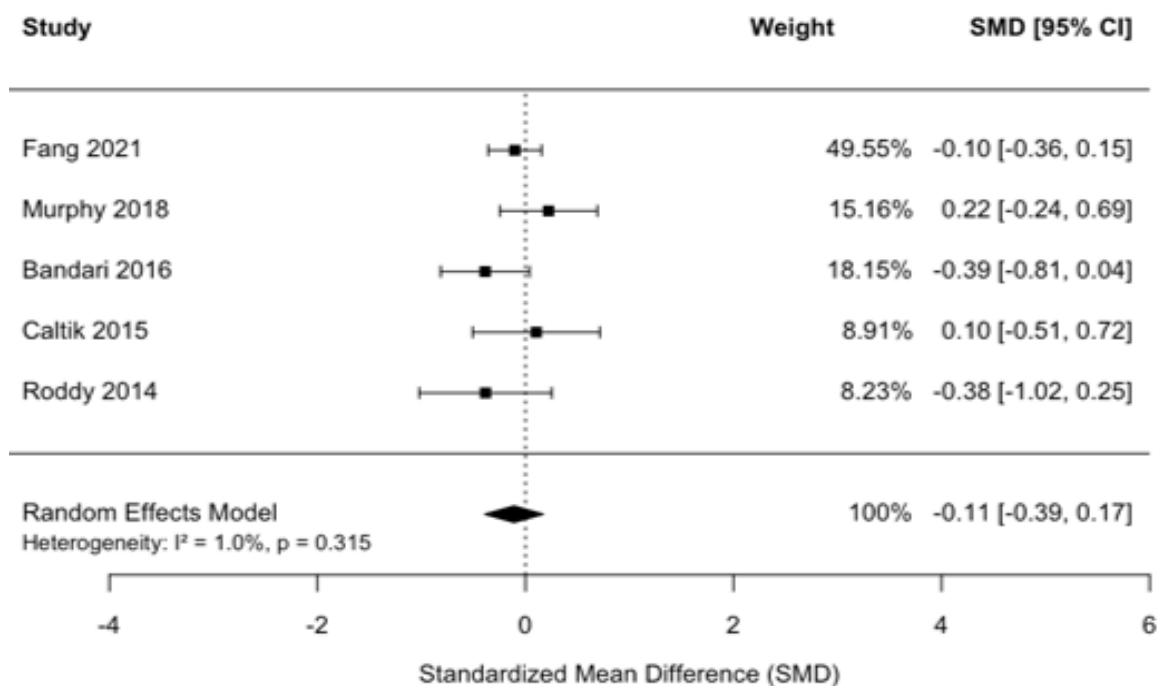


Figure 3. Forest plot of 24-h oxalate levels in children.

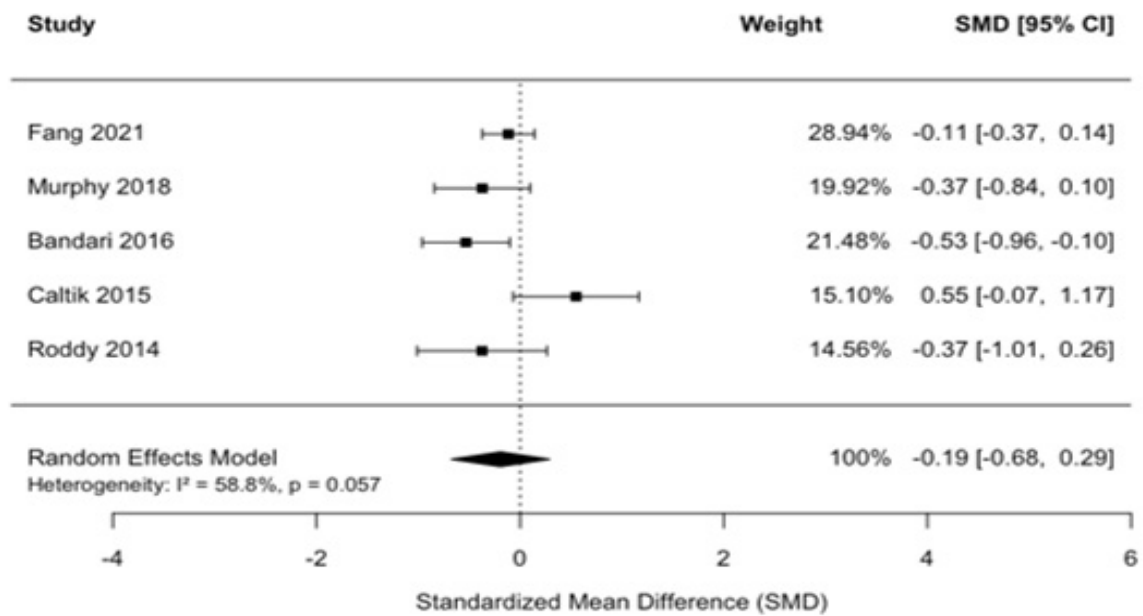


Figure 4. Forest plot of 24-h citrate levels in children.

of studies). This approach provides more conservative and reliable inference compared with the standard DerSimonian–Laird method under these conditions. Heterogeneity among included studies was quantitatively assessed using the I^2 statistic and Cochran Q test (chi-square test). Significant heterogeneity was considered present when the I^2 value exceeded 50%. The statistical model for meta-analysis was selected based on the degree of heterogeneity. When heterogeneity was not significant ($I^2 \leq 50\%$), a fixed-effects model (Mantel–Haenszel method) was used; when significant heterogeneity was present ($I^2 > 50\%$), a random-effects model (DerSimonian and Laird method) was employed to provide more conservative and generalizable estimates.

The Z-test was used to determine the statistical significance of the pooled effect size, with a two-tailed P value $< .05$ considered statistically significant. The Egger test was used to assess publication bias (only for results involving ten or more studies). To test the robustness of the results, we conducted a sensitivity analysis by sequentially excluding each study to observe its impact on the overall pooled estimate. Additionally, to explore potential sources of heterogeneity ($I^2 > 50\%$) observed for certain outcomes, univariate meta-regression analyses were conducted using a random-effects model. The study-specific effect estimate served as the dependent variable, with categorical moderators (geographic region; study design) as independent variables. The

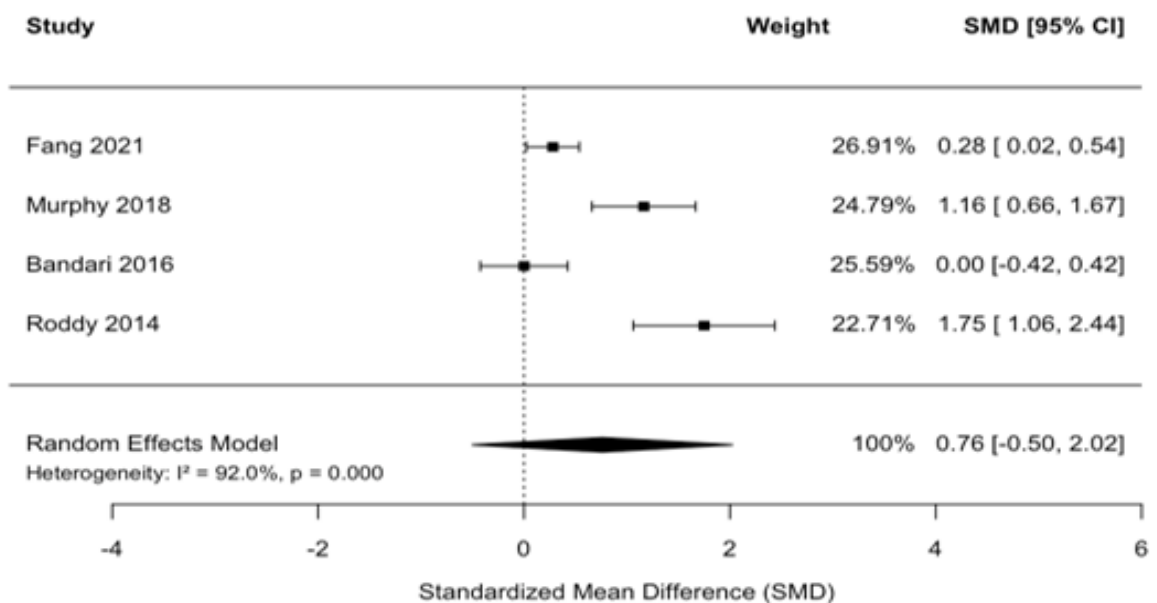


Figure 5. Forest plot of 24-h urate levels in children.

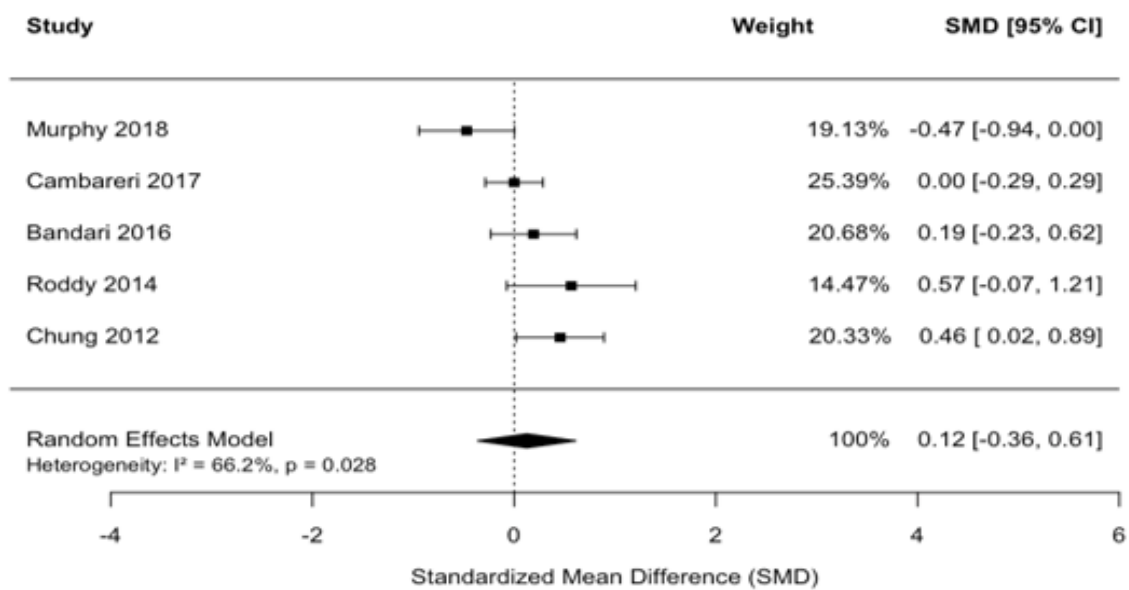


Figure 6. Forest plot of 24-h urine pH in children.

model incorporated the inverse of the study-specific variances as weights and estimated the between-study variance component (τ^2) using the restricted maximum likelihood (REML) method. The statistical significance of each moderator was assessed using a z-test with a significance threshold of $P < .05$.

RESULTS

Characteristics and Quality of Qualified Studies

The literature search and selection process are detailed in the PRISMA flowchart (Figure 1a). Initially, 806 records were identified through database searching. After removal of 249 duplicates, 557 records underwent title and abstract screening, of which 514 were excluded.

The full text of 43 articles was sought for retrieval, with 40 assessed for eligibility. Of these, 32 studies were excluded with reasons (primarily due to lack of 24-h urine data [$n = 19$] or no BMI-based group comparison [$n = 10$]). Ultimately, 8 studies met all inclusion criteria and were included in the qualitative and quantitative synthesis. These 8 studies, encompassing a total of 1033 children with urolithiasis who underwent 24-h urine collection for chemical analysis, formed the basis of the present meta-analysis.

Table 2 shows the basic characteristics of the eight included studies; four were case-control studies and four were cohort studies. According to the Newcastle–Ottawa Scale, a study can receive up to nine stars for

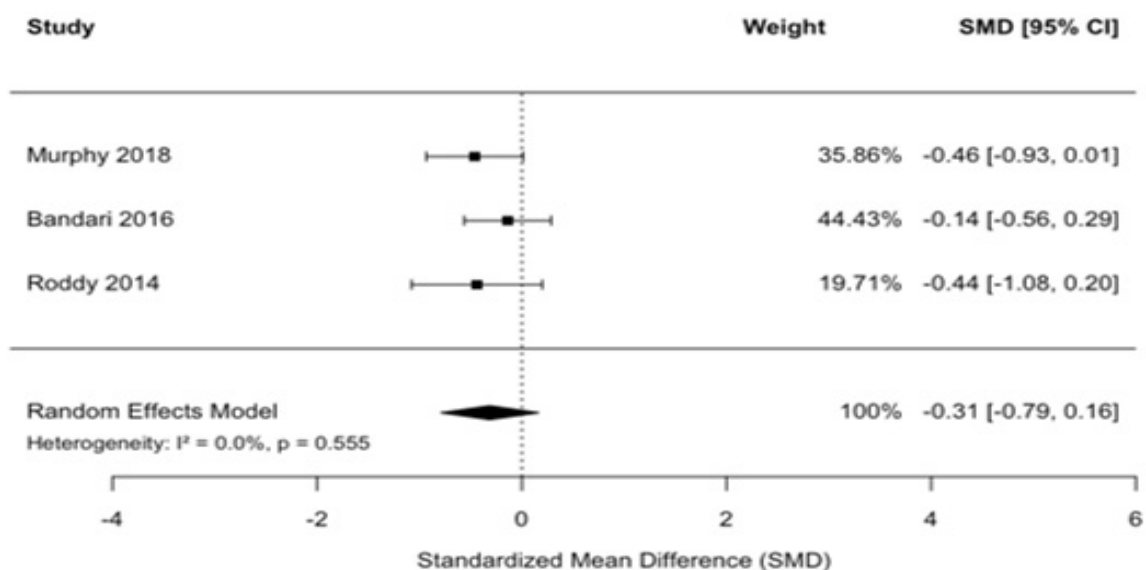


Figure 7. Forest plot of 24-h urine volume in children.

methodological quality. Of the four case-control studies, three were deducted one star because of failure to specify whether the case group and the control group managed the confounding factors influencing urine metabolism, such as diet and drinking water.^(15,17,18,20) One study was deducted two stars because of a lack of standardization in the 24-h urine analysis measurement and failure to identify the confounding factors affecting urine metabolism.⁽¹⁵⁾ Of the four cohort studies, three were docked two stars for failing to explain follow-up^(16,19,31) and one was docked one star for failing to describe the outcome assessment.⁽²¹⁾ Studies with a score of ≥ 7 were deemed to be of high methodological quality. **Table 2** also lists basic characteristics such as first author, country, composition, age, classification of BMI, sex ratio, NOS score, and abnormal values of patients' 24-h urine analysis.

Publication Bias

Publication bias was explored by the Egger test. As shown in Figure 1b, the Egger test of urine pH, which included most of the studies, appeared to be within the 95% confidence interval ($P = .607$), suggesting that this meta-analysis did not have a significant publication bias.

Calcium

The BMI ≥ 85 th percentile group excreted less calcium in 24 h than the BMI < 85 th percentile group (SMD = -0.320 , 95% CI = -0.600 to -0.050 , $P = .519$; **Figure 2**). However, the difference was not statistically significant.

Oxalate

There was no statistical difference in 24-h oxalate excretion between the BMI ≥ 85 th percentile group and the BMI < 85 th percentile group (SMD = -0.110 , 95% CI = -0.390 to 0.170 , $P = .315$; **Figure 3**).

Citrate

There was no statistical difference in 24-h citrate excretion between the BMI ≥ 85 th percentile group and the BMI < 85 th percentile group (SMD = -0.190 , 95% CI = -0.680 to 0.290 , $P = .057$; **Figure 4**).

Urate

The BMI ≥ 85 th percentile group excreted more urate in 24 h than the BMI < 85 th percentile group (SMD = 0.760 , 95% CI = -0.50 to 2.020 , $P < .0001$; **Figure 5**).

pH

There was no statistical difference in the pH of urine between the BMI ≥ 85 th percentile group and the BMI < 85 th percentile group (SMD = 0.120 , 95% CI = -0.360 to 0.61 , $P = .028$; **Figure 6**).

Urine Volume

Our analysis revealed that the 24-h urine volume in the BMI ≥ 85 th percentile group was less than that in the BMI < 85 th percentile group (SMD = -0.310 , 95% CI = -0.790 to 0.160 , $P = .555$; **Figure 7**). However, the difference was not statistically significant.

Sodium, Magnesium, and Phosphate

There was no statistical difference in 24-h sodium excretion between the two groups (SMD = 0.200 , 95% CI = -0.390 to 0.800 , $P = .050$; **Supplementary Figure 1**). The 24-h urinary magnesium excretion in the group with BMI ≥ 85 th percentile was lower than that in the group with BMI < 85 th percentile, but the difference was not statistically significant (SMD = -0.470 , 95%

CI = -0.820 to -0.120 , $P = .471$; **Supplementary Figure 2**). There was no statistically significant difference in the 24-h urine phosphorus excretion between the two groups (SMD = -0.360 , 95% CI = -0.610 to -0.110 , $P = .805$; **Supplementary Figure 3**).

Urinary Metabolic Abnormalities

Based on 24-h urinalysis results, several studies have reported differences in hypercalciuria, hyperoxaluria, hypocitraturia, hyperuricosuria, and lower urine volume between the two groups.^(13,15-19) The outcomes of the meta-analysis are shown in **Table 3**. The BMI ≥ 85 th percentile group showed greater odds of having hyperoxaluria (OR = 1.749 mg/ 1.73 m², 95% CI = 1.187 – 2.577 , $P = .005$), hyperuricosuria (OR = 4.59 mg/ 1.73 m²/d, 95% CI = 1.772 – 11.886 , $P = .002$), and lower urine volume (OR = 2.198 mL/kg, 95% CI = 1.155 – 4.182 , $P = .016$) than the < 85 th percentile group. Nevertheless, there was no statistical difference in hypocitraturia (OR = 0.854 mg/ 1.73 m², 95% CI = 0.541 – 1.349 , $P = .5$) and hypercalciuria (OR = 1.035 mg/kg, 95% CI = 0.529 – 2.028) between the two groups.

Heterogeneity Evaluation

The I^2 value determined heterogeneity. Pooled estimates of citrate ($I^2 = 57.2\%$), hypercalciuria ($I^2 = 56.6\%$), and lower urine volume ($I^2 = 55.8\%$) yielded an I^2 value of more than 50%, whereas the remaining I^2 values were less than 50%. The Cochrane Collaboration states that the heterogeneity reflected by the I^2 statistic can be accepted as long as it is less than 50%. This investigation used a random-effects model. Eight studies, including four cohort studies and four case-control studies—four from the United States and one each from Turkey, Korea, and Poland—were included. A meta-regression was used to assess whether country and study type contributed to heterogeneity. The results showed that countries and study types were not sources of heterogeneity for citrate, oxalate, pH, urate, urine volume, calcium, sodium, phosphate, and magnesium ($P > .05$; **Supplementary Table 1**).

Sensitivity Analysis

When the effect model was switched from the random-effects model to the fixed-effects model, the outcomes remained mostly unchanged, suggesting that the model was stable and the small-sample study had minimal impact on the pooled effect. We used metaninf to explore the impact of individual studies on outcomes; all the outcomes including calcium, oxalate, urate, urine volume, pH, citrate, sodium, phosphate, and magnesium were stable (**Supplementary Figure 4**).

DISCUSSION

Children are becoming more affected by urolithiasis each year. Accurately understanding the risk factors for urolithiasis can aid in developing innovative treatment and preventative strategies as well as a deeper understanding of the disease's origin and pathology. Overweight and obesity in children are becoming increasingly problematic as living standards rise. Hypertension, diabetes, kidney stones, and chronic renal disease are closely associated with high BMI in adults.⁽³²⁾ In children, there is no consensus on whether overweight and obesity increase the risk factors for kidney calculus formation.

There is evidence demonstrating a link between kidney stone production and fat and overweight. It is thought

that the endocrine activity of adipose tissue produces the hormones adiponectin, resistin, and leptin, which may directly harm the kidney and encourage the development of stones. These pathophysiological processes are concurrently influenced by oxidative stress, insulin resistance, renin-angiotensin-aldosterone system activation, aberrant lipid metabolism, and inflammation.⁽³³⁾ In addition to examining how being overweight or obese may contribute to the development of urolithiasis, this paper is the first comprehensive study of the influence of BMI on the 24-h urine composition in children with urolithiasis. The findings of this meta-analysis revealed that among the multiple 24-h urine parameters examined, only uric acid excretion demonstrated a statistically significant difference between BMI groups, with overweight/obese children (BMI \geq 85th percentile) exhibiting higher uric acid levels. Notably, other crucial lithogenic factors including calcium, oxalate, citrate, sodium, magnesium, phosphate, and urine pH showed no statistically significant differences between groups. This pattern suggests that while BMI may influence certain metabolic pathways related to uric acid handling, it does not appear to broadly alter the urinary lithogenic profile in children with urolithiasis.⁽³⁴⁾

Calcium oxalate calculus is the most prevalent kind of kidney stone, accounting for about 80% of all kidney stones. While previous research in adults has suggested that obesity may influence calcium excretion, our meta-analysis found no statistically significant difference in 24-h urinary calcium excretion between BMI groups in pediatric stone formers. This discrepancy highlights potential age-related differences in the metabolic effects of obesity on urinary chemistry.⁽³⁵⁾ This finding might be attributed to either increased intestinal absorption or endogenous oxalate synthesis linked to elevated insulin levels, which ultimately leads to decreased calcium excretion.

For children's growth, calcium is an essential nutrient. According to earlier research, patients who consume a high-calcium diet had a decreased incidence of stones.⁽³⁶⁾ According to some academics, body fat has little impact on calcium excretion, which is linked to dietary consumption of protein and salt.⁽¹²⁾ Meanwhile, we found no difference in the prevalence of hypercalciuria between the BMI \geq 85th percentile group and the BMI $<$ 85th percentile group. In addition, research on adults has demonstrated that a diet rich in sodium can enhance the exchange of calcium and sodium in the renal tubules, resulting in hypercalciuria and increasing the risk of stone formation.⁽³⁷⁾ However, our study found no difference in urinary sodium in children with urolithiasis in the BMI \geq 85th percentile group and the BMI $<$ 85th percentile group, but studies are showing that a low-sodium diet can effectively prevent calculus recurrence in patients with hypercalciuria.⁽³⁸⁾ Consequently, we hypothesize that obesity is neither a significant factor in children's 24-h calcium and sodium levels nor a risk factor or sole cause of kidney stones in children.

Our meta-analysis confirmed that obese children exhibit significantly higher 24-h urate excretion compared with normal-weight children, a finding consistent with observations in adult populations.^(15,18,20,21) However, contrary to some previous reports, we did not find statistically significant differences in urine volume between BMI groups. Fang and Cambareri et al. conducted a multicenter retrospective study and found that obese children had lower urine volume and higher urate

levels, with no regional differences.^(15,17) Duan et al. also found that urate levels are associated with obesity.⁽³⁹⁾ Kuroczyka-Saniutycz found that hyperuricemia was not associated with increased urate excretion, while increased urate excretion was related to increased calculus risk.⁽⁴⁰⁾ Interestingly, a Turkish study found that those with higher BMI had lower urate levels,⁽¹⁹⁾ and Chung et al. did not find that lower urine volume was a risk factor for developing stones.^(16,21) Combined with previous research, we believe urate likely plays a minimal role in pediatric stone formation because children have a higher urine pH at baseline. In addition, there are huge differences in children's dietary structure, and this study did not stratify studies by different age groups; together with the small meta-sample size and regional differences and other factors, the conclusion should be interpreted cautiously.

The relationship between urolithiasis and urine pH is well studied. For example, we know that calcium phosphate calculi will only form in more alkaline urine, while uric acid calculi and cystine stones form in low urine pH. Lower urinary pH has been found in adult studies of obese patients, but no association between BMI and urinary pH was found in this meta-study. In adult studies, it has been suggested that obesity and metabolic syndrome lead to reduced urine pH, rather than hyperuricemia or increased uric acid excretion.⁽⁴¹⁻⁴³⁾ It is also believed to be related to hyperinsulinemia and insulin resistance in obese patients.⁽⁴⁴⁾ Although Eisner et al. examined the BMI and urinary metabolic profile of children with kidney calculi and found that higher BMI was related to lower urine pH,⁽²²⁾ the sample size was small and single-center, so this conclusion needs more basic research to further confirm.

In adults, it has been shown that obese patients have elevated levels of oxalate and low levels of citrate. However, no variations between the two groups' 24-h urine oxalate and citrate contents were found in this study. Interestingly, the prevalence of hyperoxaluria in the BMI \geq 85th percentile group was higher than that in the BMI $<$ 85th percentile group, with a statistical difference. Perhaps lithogenic biochemistry itself is not outside the normal range and does not seem to stand alone as a significant risk factor. Some studies have suggested increased oxalate excretion in obese children,^(16,19) while other studies have concluded the opposite.^(15,18,20) For example, Eisner et al. suggested that obese children eat more foods with low oxalate content.⁽²²⁾ This conclusion may also be influenced by different urine collection and detection methods, diet, culture, geography, or underlying hormones.

While point estimates suggested trends toward lower magnesium and phosphate excretion in overweight/obese children, these differences did not reach statistical significance in our analysis. The clinical relevance of these trends remains uncertain given the lack of statistical significance and the limited sample size available for these analyses. Future studies with larger sample sizes are needed to determine whether these trends represent true physiological differences.

The most consistent finding across studies was the significantly higher uric acid excretion in overweight and obese children, which aligns with established physiological mechanisms linking adiposity to purine metabolism and uric acid production. However, it is important to note that despite this biochemical difference, the clinical significance in pediatric stone formation may be at-

tenuated by children's typically higher baseline urinary pH, which favors uric acid solubility.

The study we conducted has several limitations. The primary limitation of this study lies in our strict adherence to the U.S. CDC BMI standards to maintain consistency in weight status classifications across included studies. While this methodological choice enhances internal comparability, it may exclude studies employing other authoritative standards (such as the World Health Organization [WHO] criteria or the International Obesity Task Force [IOTF] criteria). This could potentially limit the generalizability of our findings and exert a potential influence on the final pooled effect size. Second, 24-h urine was only collected once in all trials. Because multiple urine collections may differ greatly, a single 24-h urine collection may not be sufficient to thoroughly examine individuals before metabolic treatment to prevent stones. Third, the concentration of each urine component is not well known, which is problematic for determining the likelihood of stone development. Fourth, we acknowledge an important methodological limitation regarding the estimation of heterogeneity. As correctly noted, with the small number of studies included in our meta-analyses (typically ≤ 5 studies per outcome), the estimates of between-study variance (τ^2) and the I^2 statistic are inherently imprecise and should be interpreted with caution. While we employed the Knapp–Hartung adjustment to provide more conservative confidence intervals for the overall effect, the uncertainty in heterogeneity estimation remains a constraint. This limitation is common in meta-analyses with few studies but important to consider when interpreting the consistency of effects across the included studies. Furthermore, due to the lack of subgroup analyses for different stone types, different age groups, and different genders, the reliability of the research findings and conclusions remains to be tested. In addition, as noted, we primarily relied on unadjusted estimates to ensure uniformity. Consequently, the pooled effects are susceptible to confounding bias, as factors such as dietary habits, fluid intake, and other metabolic parameters that influence both BMI and urine composition could not be accounted for. The sets of confounding variables adjusted for, when reported, were inconsistent across studies, precluding the use of adjusted estimates or the application of external methods to correct for confounding bias, as suggested in advanced methodological literature.⁽⁴³⁾ This residual confounding should be considered when interpreting our findings. Lastly, our restriction to studies published in the English language may have introduced selection bias, as relevant studies published in other languages might have been missed. This decision was made due to constraints in resources and translation capabilities. However, it is noteworthy that our comprehensive search across multiple international databases did not yield a substantial number of non-English articles that met our other inclusion criteria based on their titles and abstracts, which may mitigate the potential impact of this limitation.

To address these limitations, future studies should prioritize the development of large-scale, prospective cohorts with sufficient statistical power to conduct meaningful subgroup analyses stratified by age, sex, and stone composition. Methodologically, such studies should employ repeated 24-h urine collections using standardized protocols to better define individual lithogenic risk profiles

over time. Comprehensive adjustment for key confounders—particularly detailed dietary intake and fluid consumption—is essential to isolate the true effect of adiposity. Beyond these methodological improvements, research should explore more precise adiposity metrics that account for body composition and fat distribution, rather than relying solely on BMI. Finally, integrating novel approaches such as metabolomic profiling could help elucidate the underlying pathophysiological mechanisms connecting obesity, metabolic syndrome, and pediatric stone formation, ultimately paving the way for more effective, personalized prevention strategies.

CONCLUSIONS

In conclusion, this meta-analysis demonstrates that among pediatric stone formers, overweight and obese children (BMI ≥ 85 th percentile) exhibit significantly higher urinary uric acid excretion compared with normal-weight children. However, no statistically significant differences were observed in other key urinary risk factors including calcium, oxalate, citrate, sodium, magnesium, phosphate, urine pH, or volume. The isolated finding of hyperuricosuria, in the absence of other lithogenic abnormalities, suggests that BMI alone does not substantially alter the overall urinary risk profile for stone formation in children. Therefore, BMI by itself should not be regarded as an independent and definitive risk factor for pediatric urolithiasis. Future research should focus on elucidating the complex interplay between adiposity, metabolic syndrome components, and stone risk through larger, longitudinal studies with comprehensive adjustment for potential confounders.

SUMMARY

Overweight/obese children with urolithiasis show higher urinary uric acid, but no other urine differences, suggesting BMI alone is not a definitive pediatric stone risk factor.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

1. Sas D, Becton L, Tutman J, et al. Clinical, demographic, and laboratory characteristics of children with nephrolithiasis. *Urolithiasis*. 2016;44:241-6.
2. Dwyer M, Krambeck A, Bergstralh E, et al. Temporal trends in incidence of kidney stones among children: a 25-year population-based study. *J Urol*. 2012;188:247-52.
3. Sas DJ, Huffman T, Shatat IF, et al. Incidence of kidney stones in children evaluated in the ER is increasing. *J Pediatr*. 2016;157:132-7.
4. Basiri A, Shakhssalim N, Houshmand M, et al. Coding region analysis of vitamin D receptor gene and its association with active calcium stone disease. *Urol Res*. 2012;40:35-40.
5. Shakhssalim N, Basiri A, Houshmand M, et al. Genetic polymorphisms in calcitonin receptor gene and risk for recurrent kidney calcium stone disease. *Urol Int*. 2014;92:356-62.
6. Kocvara R, Plasgura P, Petrik A, et al. A prospective study of nonmedical prophylaxis after a first kidney stone. *BJU Int*. 1999;84:393-8.
7. Ramaswamy K, Shah O. Metabolic syndrome

- and nephrolithiasis. *Transl Androl Urol*. 2014;3:285-95.
8. Sakhaee K. Nephrolithiasis as a systemic disorder. *Curr Opin Nephrol Hypertens*. 2008;17:304-9.
 9. Taylor E, Stampfer M, Curhan G. Obesity, weight gain, and the risk of kidney stones. *JAMA*. 2005;293:455-62.
 10. Aune D, Mahamat-Saleh Y, Norat T, et al. Body fatness, diabetes, physical activity and risk of kidney stones: a systematic review and meta-analysis of cohort studies. *Eur J Epidemiol*. 2018;33:1033-47.
 11. Issler N, Dufek S, Kleta R, et al. Epidemiology of pediatric renal stone disease: a 22-year single center experience in the UK. *BMC Nephrol*. 2017;18:136.
 12. Alfandary H, Haskin O, Davidovits M, et al. Increasing prevalence of nephrolithiasis in association with increased body mass index in children: a population-based study. *J Urol*. 2018;199:1044-9.
 13. Wang Q, Hu W, Lu Y, et al. The impact of body mass index on quantitative 24-h urine chemistries in stone forming patients: a systematic review and meta-analysis. *Urolithiasis*. 2018;46:523-33.
 14. Fang AM, Gibson E, Oster RA, et al. Effect of age, BMI, and gender on urinary risk factors in pediatric idiopathic stone formers. *J Pediatr Urol*. 2021;17:477-85.
 15. Murphy MO, Erpelding SG, Chishti AS, et al. Influence of BMI in nephrolithiasis in an Appalachian pediatric population: a single-center experience. *J Pediatr Urol*. 2018;14:330-7.
 16. Cambareri GM, Giel DW, Bayne AP, et al. Do overweight and obese pediatric stone formers have differences in metabolic abnormalities compared with normal-weight stone formers? *Urology*. 2017;101:26-30.
 17. Bandari J, Dangle PP, Lyon TD, et al. 24-h urinary parameters in overweight and obese children with urolithiasis. *J Urol*. 2016;196:526-30.
 18. Caltik Yilmaz A, Buyukkaragoz B, Oguz U, et al. Influence of body mass index on pediatric urolithiasis. *J Pediatr Urol*. 2015;11:350-5.
 19. Roddy JT, Ghousheh AI, Christensen MA, et al. Metabolic evaluation of urolithiasis and obesity in a midwestern pediatric population. *J Urol*. 2014;191:771-6.
 20. Chung JD, Kim TH, Myung SC, et al. Influence of overweight on 24-h urine chemistry studies and recurrent urolithiasis in children. *Korean J Urol*. 2012;53:268-74.
 21. Eisner BH, Eisenberg ML, Stoller ML. Influence of body mass index on quantitative 24-h urine chemistry studies in children with nephrolithiasis. *J Urol*. 2009;182:1142-5.
 22. Vieira MS, Francisco PC, Hallal A, et al. Association between dietary pattern and metabolic disorders in children and adolescents with urolithiasis. *J Pediatr*. 2020;96:333-40.
 23. Knobloch K, Yoon U, Vogt PM. Preferred reporting items for systematic reviews and meta-analyses (PRISMA) statement and publication bias. *J Craniomaxillofac Surg*. 2011;39:91-2.
 24. Kuczmarski RJ, Ogden CL, Grummer-Strawn LM, et al. CDC growth charts: United States. *Adv Data*. 2000;314:1-27.
 25. Barlow SE; Expert Committee. Expert committee recommendations regarding the prevention, assessment, and treatment of child and adolescent overweight and obesity: summary report. *Pediatrics*. 2007;120:S164-92.
 26. Ogden CL, Flegal KM. Changes in terminology for childhood overweight and obesity. *Natl Health Stat Report*. 2010;25:1-5.
 27. Phillips B, Ball C, Sackett D. Oxford Centre for evidence-based medicine 2011 levels of evidence. 2011. Accessed 24 Nov 2017.
 28. Wells G, Shea B, O'Connell D, et al. The Newcastle–Ottawa Scale (NOS) for assessing the quality of nonrandomized studies in meta-analyses. 2012. Accessed 24 Nov 2017.
 29. Higgins JPT, Green S. *Cochrane Handbook for Systematic Reviews of Interventions* Version 5.1.0 [updated March 2011]. The Cochrane Collaboration; 2011.
 30. Sopinska M, Wawrzyniak A, Jobs K, et al. Urolithiasis in patients with a normal and high body mass: a single-center study. *Pediatr Med Rodz*. 2019;15:145-51.
 31. Afshin A, Forouzanfar M, Reitsma M, et al. Health effects of overweight and obesity in 195 countries over 25 years. *N Engl J Med*. 2017;377:13-27.
 32. Wollin DA, Skolarikos A, Preminger GM. Obesity and metabolic stone disease. *Curr Opin Urol*. 2017;27:422-7.
 33. Kim S, Luan X, Canning D, et al. Association between body mass index and urolithiasis in children. *J Urol*. 2011;186:1734-9.
 34. Shi L, Berkemeyer S, Buyken AE, et al. Glucocorticoids and body fat associated with renal uric acid and oxalate, but not calcium excretion, in healthy children. *Metabolism*. 2010;59:134-9.
 35. Panzarino V. Urolithiasis in children. *Adv Pediatr*. 2020;67:105-12.
 36. Nouvenne A, Meschi T, Prati B, et al. Effects of a low-salt diet on idiopathic hypercalciuria in calcium-oxalate stone formers: a 3-mo randomized controlled trial. *Am J Clin Nutr*. 2010;91:565-70.
 37. 2015–2020 dietary guidelines for Americans. Washington, DC: US Department of Health and Human Services; US Department of Agriculture; 2015.
 38. Yao Y, Duan Y, Liang W, et al. Association between serum uric acid levels and obesity among university students (China). *Nutr Hosp*. 2015;31:2407-11.
 39. Kuroczycka-Saniutycz E, Porowski T, Protas PT, et al. Does obesity or hyperuricemia influence lithogenic risk profile in children with urolithiasis? *Pediatr Nephrol*. 2015;30:797-803.
 40. Sarica K, Eryildirim B, Yencilek F, et al.

- Role of overweight status on stone-forming risk factors in children: a prospective study. *Urology*. 2009;73:1003-7.
41. Sakhaee K, Maalouf NM. Metabolic syndrome and uric acid nephrolithiasis. *Semin Nephrol*. 2008;28:174-80.
 42. Semins MJ, Shore AD, Makary MA, et al. The association of increasing body mass index and kidney stone disease. *J Urol*. 2010;183:571-5.
 43. Shavit L, Ferraro PM, Johri N, et al. Effect of being overweight on urinary metabolic risk factors for kidney stone formation. *Nephrol Dial Transplant*. 2015;30:607-13.
 44. Greenland S, O'Rourke K. Meta-Analysis. In: Rothman KJ, Greenland S, Lash T, editors. *Modern Epidemiology*. 3rd ed. Philadelphia: Lippincott Williams & Wilkins; 2008. p. 660-2.