NICOLAUS COPERNICUS UNIVERSITY IN TORUŃ

JOURNAL OF EDUCATION, HEALTH AND SPORT
eISSN 2391-8306 · Open Access · Peer-reviewed
apcz.umk.pl/JEHS · Nicolaus Copernicus University in Toruń

Cite as: JANCZYLIK, Paulina, GŁĄB, Łukasz, PŁUSA, Aleksandra, BRODA, Damian, KOMISSAROVA, Daria, CIESIELSKA, Izabela, TOCZEK, Martyna, RYSZKA, Paulina, CYLS, Dawid and BRODA, Aleksandra. Behavioral Interventions for the Prevention and Treatment of Urolithiasis – A Review. Journal of Education, Health and Sport. 2026;94:69748. https://doi.org/10.12775/JEHS.2026.94.69748

ARTICLE TIMELINE
Received: 11.03.2026 Revised: 12.07.2026
Accepted: 12.07.2026 Published: 17.07.2026

INDEXING & EVALUATION
MEiN points: 40 Unique ID: 201159
Disciplines: Physical culture sciences (Field of medical and health sciences); Health Sciences (Field of medical and health sciences).

The journal has been awarded 40 points in the parametric evaluation by the Polish Ministry of Higher Education and Science (Annex to the announcement of 05.01.2024, No. 32318). Unique Journal Identifier: 201159. Scientific disciplines: Physical culture sciences (Field of medical and health sciences); Health Sciences (Field of medical and health sciences).

Punkty Ministerialne z 2019 – aktualny rok 40 punktów. Załącznik do komunikatu Ministra Szkolnictwa Wyższego i Nauki z dnia 05.01.2024 Lp. 32318. Posiada Unikatowy Identyfikator Czasopisma: 201159. Przypisane dyscypliny naukowe: Nauki o kulturze fizycznej (Dziedzina nauk medycznych i nauk o zdrowiu); Nauki o zdrowiu (Dziedzina nauk medycznych i nauk o zdrowiu).

Behavioral Interventions for the Prevention and Treatment of Urolithiasis – A Review

Paulina Janczylik, Faculty of Medicine, Medical University of Lodz, Lodz, Poland.
e-mail: paulina.janczylik@stud.umed.lodz.pl
ORCID: https://orcid.org/0009-0000-8617-1238

lek. Łukasz Głąb, 10th Military Clinical Hospital with Polyclinic in Bydgoszcz, ul. Powstańców Warszawy 5, 85-681 Bydgoszcz, Poland.
e-mail: lukasz.glab1998@gmail.com
ORCID: https://orcid.org/0009-0008-2828-7441

lek. Aleksandra Płusa, Masovian Specialist Hospital, Juliana Aleksandrowicza 5, 26-617 Radom, Poland
e-mail: plusa.aleksandra22@gmail.com
ORCID: https://orcid.org/0009-0009-4307-889

lek. Damian Broda, 10th Military Clinical Hospital with Polyclinic in Bydgoszcz, ul. Powstańców Warszawy 5, 85-681 Bydgoszcz, Poland

e-mail: damianbrodapl@gmail.com

ORCID: https://orcid.org/0009-0003-2825-2082

lek. Daria Komissarova, 10th Military Clinical Hospital with Polyclinic in Bydgoszcz, ul. Powstańców Warszawy 5, 85-681 Bydgoszcz, Poland

e-mail: dashareka99@gmail.com

ORCID: https://orcid.org/0009-0008-8880-7787

lek. Izabela Ciesielska, Jan Biziel University Hospital No. 2 in Bydgoszcz, Kornela Ujejskiego 75, 85-168 Bydgoszcz, Poland

e-mail: izabela.bochniak99@gmail.com

ORCID: https://orcid.org/0009-0008-6577-4652

lek. Martyna Toczek, Jan Biziel University Hospital No. 2 in Bydgoszcz, Kornela Ujejskiego 75, 85-168 Bydgoszcz, Poland.

e-mail: martynatoczek98@gmail.com

ORCID: https://orcid.org/0009-0006-2921-3175

lek. Paulina Ryszka, Jan Biziel University Hospital No. 2 in Bydgoszcz, Kornela Ujejskiego 75, 85-168 Bydgoszcz, Poland.

e-mail: ryszka.paulina1@gmail.com

ORCID: https://orcid.org/0009-0008-6468-9165

lek. Dawid Cyls, 10th Military Clinical Hospital with Polyclinic in Bydgoszcz, ul. Powstańców Warszawy 5, 85-681 Bydgoszcz, Poland.

e-mail: cylsdawid@gmail.com

ORCID: https://orcid.org/0000-0002-5732-2655

lek. dent. Aleksandra Huong Broda, Medical University of Warsaw, Warsaw, Poland

e-mail: aleksandra.phamthu@gmail.com

ORCID: https://orcid.org/0009-0000-4701-7983

Corresponding Author
Paulina Janczylik, e-mail: paulina.janczylik@stud.umed.lodz.pl

Abstract:

Urolithiasis is a common and recurrent condition associated with significant clinical and economic burden. Despite well-established recommendations regarding fluid intake and dietary modification, long-term adherence to preventive measures remains low. In recent years, behavioral interventions—particularly those supported by digital technologies—have emerged as promising tools to improve adherence and reduce recurrence risk. This narrative review summarizes and evaluates current evidence on behavioral interventions used in the prevention and treatment of kidney stone disease, including health coaching, reminder systems, mobile applications, smart hydration devices, nudging strategies, and structured problem solving approaches. The available data indicate that digital and behaviorally informed interventions consistently improve short-term fluid intake and 24-hour urine volume; however, evidence for sustained reduction in stone recurrence remains limited. Large randomized trials suggest that hydration-focused behavioral strategies alone may be insufficient to influence long-term clinical outcomes in unselected populations. Future research should focus on integrated, personalized interventions combining behavioral support with metabolic evaluation, dietary modification, and pharmacotherapy, as well as long-term maintenance strategies. Such approaches may offer the greatest potential for reducing recurrence and improving quality of life in patients with urolithiasis.

Key words: kidney stone, urolithiasis, urinary stone disease, behavioral intervention, behavior change, digital health, health coaching, reminder system, nudge, hydration, fluid intake, adherence, recurrence, structured problem solving, mobile app, compliance

Introduction

Urolithiasis (nephrolithiasis) is a condition characterized by the formation of mineral deposits within the urinary tract, leading to clinical manifestations such as renal colic, hematuria, urinary tract infections, and recurrent renal insufficiency. It is one of the most common diseases of the urinary system, with its clinical and social significance continuing to increase [1]. The global prevalence of urolithiasis is currently estimated at 7–13% among men and 4–7% among women [2]. Over recent decades, a marked increase in incidence has been observed, particularly in developed countries and regions with hot climates, which has been attributed to lifestyle changes, urbanization, diets high in sodium and animal protein, and insufficient fluid intake [3–5].

A characteristic feature of urolithiasis is its high recurrence rate. It is estimated that approximately 50% of patients experience stone recurrence within 5–10 years after the first episode, and up to 75% within 20 years [6]. Recurrent episodes are associated with a substantial clinical and economic burden, including the need for hospitalization, repeated lithotripsy procedures, an increased risk of infections, and deterioration in quality of life [7]. According to analyses of the Global Burden of Disease Study 2023, kidney stone disease accounts for an increasing proportion of years lived with disability (DALYs), particularly among individuals of working age [8].

Contemporary management of urolithiasis includes both interventional approaches (e.g., percutaneous nephrolithotomy, ureterorenoscopy, extracorporeal shock wave lithotripsy [ESWL]) and conservative strategies aimed at preventing the formation of new stones. Primary and secondary prevention play a crucial role in reducing disease recurrence, with key recommendations including increased fluid intake, dietary modification, reduction of sodium and animal protein consumption, and maintenance of a healthy body weight [9,10]. Despite clearly defined guidelines, the effectiveness of these measures in clinical practice remains limited, as studies indicate persistently low patient adherence to preventive recommendations [11,12]. Many patients fail to maintain the recommended daily fluid intake (≥2.5–3.0 L), and the effects of short-term educational interventions often diminish after several months [13].

In this context, increasing attention has been directed toward behavioral interventions aimed at achieving sustained changes in patients' health-related behaviors. These strategies include health coaching, problem-solving approaches based on cognitive–behavioral models, mobile reminders, interventions grounded in "nudge" theory, applications for monitoring fluid intake, and gamification [14,15]. The primary objective of these interventions is to enhance patient motivation and self-regulation, thereby improving long-term adherence to therapeutic recommendations [16].

In recent years, the first clinical studies evaluating the effectiveness of such methods in the context of urolithiasis have been published. One notable example is the Prevention of Urinary Stones With Hydration (PUSH) project—a multicenter, randomized clinical trial incorporating a behavioral component based on adaptive reminders and coaching to increase fluid intake in patients with kidney stones [17]. The results demonstrated a moderate increase in urine volume, although the effect on stone recurrence rates remains a subject of debate [18]. In parallel, modern digital interventions, such as mobile applications and smart water bottles that track fluid intake (e.g., the sipIT system), have been evaluated and shown to have high acceptability and potential for reinforcing healthy habits [19,20]. The literature also describes the use of the structured problem solving (SPS) approach as a component of behavioral interventions in studies targeting behavior change among patients with urolithiasis [21].

Despite the growing body of research, there is currently a lack of a comprehensive review synthesizing the available evidence on the effectiveness of various behavioral interventions in the prevention and treatment of urolithiasis, taking into account both clinical outcomes and methodological limitations.

Objective of the Study

The aim of this narrative review is to evaluate the effectiveness and limitations of behavioral interventions used in the prevention and treatment of urolithiasis. Specifically, this review seeks to:

1. Review and classify the types of behavioral interventions applied in patients with urolithiasis, including health coaching, reminder systems, mobile applications, gamification, and problem-solving strategies;
2. Assess the available scientific evidence regarding their impact on patient adherence, urine volume, stone recurrence, and quality of life;
3. Identify factors determining the effectiveness of these interventions, as well as existing research gaps;
4. Indicate directions for future research and explore opportunities for implementing effective behavioral strategies in clinical practice.

Review Methodology

Literature Search Strategy

To identify studies addressing behavioral interventions in the prevention and treatment of urolithiasis, a systematic literature search was conducted in the PubMed/MEDLINE, Scopus, and Web of Science databases. The search covered publications from 2000 to 2025, with the most recent update performed in May 2025. In addition, citation tracking and reference list screening ("snowballing") were performed, along with manual searches of key journals in the fields of urology and nephrology (Journal of Urology, Urology, BMC Nephrology, American Journal of Kidney Diseases, and Nature Reviews Urology).

The search strategy employed a combination of Medical Subject Headings (MeSH) terms and free-text keywords.

Additional filters were applied to restrict results to studies conducted in humans (Humans), adult populations (Adults), and interventional study designs (Randomized Controlled Trial, Clinical Trial, Interventional Study). When an excessive number of results was obtained, the search strategy was further refined by adding terms such as *digital*, *smart bottle*, *gamification*, or *mobile health*.

After retrieving the list of publications, titles and abstracts were screened to exclude irrelevant studies. Full texts of selected articles were then reviewed and assessed for eligibility according to the predefined inclusion and exclusion criteria.

Inclusion and Exclusion Criteria

Inclusion criteria:

1. Interventional studies (randomized controlled trials, quasi-interventional studies, pilot studies, and before–after designs) with a clearly defined behavioral component (e.g., coaching, reminder systems, gamification, nudging strategies, mobile applications, structured problem solving).
2. Population: adult participants (≥18 years) with documented urolithiasis (primary or recurrent), in whom the intervention aimed to prevent stone recurrence or improve adherence to preventive recommendations.
3. Studies reporting at least one of the following outcomes:
    a. change in urine volume (e.g., 24-hour urine output),
    b. measures of adherence to recommendations (adherence, compliance),

c. changes in urinary biochemical parameters (e.g., supersaturation with stone-forming solutes),
d. stone recurrence rates,
e. assessment of quality of life.

4. Publications in peer-reviewed journals.
5. Availability of the full text in English or Polish.

Exclusion criteria:

- Observational studies, case reports, or case series without an active behavioral intervention component.
- Interventions of an exclusively educational nature (e.g., informational brochures without behavioral monitoring).
- Narrative or review articles (used only for contextual analysis).
- Lack of quantitative data regarding the effect of the intervention.
- Animal studies or in vitro models.

For each included publication, data were extracted on the following variables: author, year of publication, country, sample size, type of intervention, duration, clinical and behavioral outcomes, and methodological limitations.

Studies Included in the Review

1. Scales CD Jr et al. *Prevention of Urinary Stones With Hydration (PUSH): design and rationale of a clinical trial.* Am J Kidney Dis. 2021;77(6):898–906.e1. — a multicenter study with a behavioral component (mobile app, smart bottle, coaching, reminders) aimed at maintaining increased hydration in patients with urolithiasis [22].
2. Reese PP et al. *Using structured problem solving to promote fluid consumption in the PUSH trial.* BMC Nephrol. 2024;25:183. — description of the methodology for implementing the Structured Problem Solving strategy in the PUSH trial, including analysis of factors affecting adherence [23].

3. Streeper NM et al. *Feasibility of mini sipIT behavioral intervention to increase 24-h urine volume in kidney stone formers.* J Urol. 2023;210(2):355–362. — a pilot project of a mobile app with just-in-time reminders and automatic monitoring of diuresis [24].
4. Conroy DE et al. *Promoting fluid intake to increase urine volume for kidney stone prevention: protocol for a randomized controlled trial of the sipIT intervention.* Contemp Clin Trials. 2024;138:107454. — RCT protocol testing the effectiveness of a digital behavioral intervention compared with standard care [25].
5. Stout TE et al. *A randomized controlled trial evaluating the use of a smart water bottle to promote hydration among kidney stone formers.* Urology. 2022;164:110–118. — RCT evaluating the effectiveness of a smart bottle and behavioral reminders in increasing urine volume in patients with urolithiasis [26].

Discussion of Research Studies, Analysis

1) Scales CD Jr et al. — PUSH: design & rationale + results presented (AUA 2025) [22, 27, 28, 29]

Aim and Study Design

PUSH is a multicenter, randomized controlled trial (target n≈1642) testing a multicomponent behavioral intervention (fluid prescription, adaptive reminders, reward elements, coaching, Structured Problem Solving [SPS] module) supported by digital monitoring (smart bottle + app) versus standard care. In both arms, fluid monitoring (smart bottle) was provided to objectively track behavior. The primary endpoint was symptomatic kidney stone recurrence at 24 months; secondary endpoints included 24-hour urine volume, stone burden, and symptoms [22, 29].

Results (Publicly Presented)

At AUA 2025, the primary results were presented: the intervention increased 24-hour urine output relative to baseline, and the difference between study arms remained statistically significant up to 24 months. However, there was no significant reduction in symptomatic stone recurrence compared with control (approximately 18.6% vs. 19.8%; median follow-up ~738 days) [27, 28]. Regarding secondary endpoints related to stone burden, no advantage of the intervention was observed [27].

Quality and Interpretation

PUSH is highly reliable: randomized design, large sample size, “hard” clinical primary endpoint, and event adjudication based on medical records (standardization of self-reported recurrences) [29]. The simultaneous smart monitoring in both arms is an advantage (objective data), but also creates a "conservative" design: the monitoring itself could have improved behaviors in the control group, reducing between-arm differences.

Limitations and Conclusions

The lack of benefit in recurrence despite increased urine output suggests that intensifying hydration alone may be insufficient in an unselected population. Hypotheses: the need for metabolic personalization, longer-term reinforcement of behavioral cues, and targeting urine biochemistry/urinary supersaturation (rather than volume alone). PUSH sets a high standard and a reference point for future studies.

2) Reese PP et al. — SPS Module in PUSH (Mechanism and Implementation Quality) [23]

Aim and Scope

The publication describes the implementation of Structured Problem Solving (SPS) as a component of the intervention in PUSH: training of coaches, monitoring of fidelity, a catalog of barriers (forgetting, lack of access to water, low thirst drive, work schedule), and strategies to overcome them (planning, backup plans, environmental modifications) [23].

Results (Qualitative Nature)

The study does not report clinical numbers (recurrences) or "hard" behavioral outcomes (e.g., Δ urine output) — it provides a process map: how coaching consistency and quality were ensured, what difficulties were encountered (maintaining motivation, time burden, heterogeneity of barriers), and how they were addressed [23].

Significance

Reese et al. provide mechanistic context for the PUSH results: they show that implementation quality (fidelity), alignment with patient-specific barriers, and continuity of support may determine the strength of the effect. This is crucial for interpreting the lack of reduction in recurrences in PUSH despite sustained differences in urine output.

3) Streeper NM et al. — mini sipIT (Feasibility with Quantitative "Hard" Data) [24]

Study Design

Single-arm pilot study (n=26; 77% female; 50.4 ± 14.2 years) in stone formers with <2 L/day 24-hour urine output. One-month intervention: H2OPal smart bottle + app + just-in-time SMS triggered by detected "lapses." Measurements: 24-hour urine volume (pre/post), usability, acceptability [24].

Results (Specific Numbers)

- **Usage:** >90% used the tools daily.
- **Perception:** 85% reported increased fluid intake; 65% reported achieving the target.
- **Urine Output:** 1352.7 ± 449.9 mL → 2006.5 ± 980.8 mL; $\Delta \approx +654$ mL; $t(25)=3.66$; $p=0.001$; $g=0.78$; 73% showed an increase; 42% exceeded the >2 L/day threshold [24].

Quality and Limitations

Strong signal for short-term efficacy and high acceptability. Limitations: no control group, short duration (1 month), small sample size. No data on stone recurrence. Results should be interpreted as evidence of feasibility and potential effectiveness, requiring confirmation in an RCT.

4) Conroy DE et al. — sipIT (RCT Protocol with 12-Month Follow-Up) [25]

Study Design (Planned)

The sipIT randomized trial: semi-automated tracking (smart bottle + app + gesture sensor), just-in-time SMS, versus standard recommendations. Primary outcome: 24-hour urine volume; secondary outcomes: urinary supersaturation/parameters, habit automation, behavioral outcomes; follow-up up to 12 months [25].

Significance

This trial will test whether a "lighter" digital intervention can maintain increased urine output over one year and whether this translates into improvements in urinary biochemistry. Once published, the data will allow comparison with PUSH (24 months, multicomponent) and mini sipIT (1 month, pilot).

5) Stout TE et al. — Smart Bottle: RCT with Short-Term Outcome Assessment [26]

Study Design

RCT in adults with kidney stones and <1.5 L/day urine output. Allocation: DR (diet/recommendations) vs. DR + smart bottle (HidrateSpark®) with reminders. 24-hour urine measurements at 6 and 12 weeks. Complete 24-hour collections were available for 51/85 patients [26].

Quantitative Results

Δ urine output (mean): +1.37 L (95% CI −0.51 to 3.25) in the smart bottle arm vs. +0.79 L (95% CI −1.15 to 2.73) in DR; $p=0.04$.

"Forgetting" barrier: decreased in the smart bottle arm 45.4% vs. 68.4% ($p<0.05$); in DR, change was not significant (40.0% vs. 51.2%, $p=0.13$) [26].

Quality and Limitations

Strengths: RCT design, objective Δ urine output, measurable effect on the "forgetting" barrier.

Limitations: data loss (51/85), short follow-up (≤12 weeks), wide confidence intervals. No data on stone recurrence.

Tabela. Zestawienie kluczowych parametrów i wyników (prace 1–5)

Study	**Design**	**N (analyzed)**	**Intervention**	**Follow-up**	**Primary outcome**	**Quantitative Effect**	**Long-Term**	**Quality Notes**
PUSH [22, 27–29]	RCT, multicenter	≈1642 (target)	Coaching + SPS + reminders + rewards + smart-monitoring in both arms	24 mo	Stone recurrence	↑ urine output significant; recurrence: no difference (18,6% vs 19,8%)	Yes (24 mo)	Event adjudication; possible monitoring effect in control
Reese et al. [23]	SPS implementation in PUSH	—	SPS (mechanism, fidelity)	—	—	—	—	Mechanistic insight; no 'hard' numbers
mini sipIT [24]	Pilot, single arm	26	Smart-bottle + app + just-in-time SMS	1 mo	24-h urine volume	Δ≈+654 mL; p=0,001; 73% increased; 42% >2 L/d	No	High acceptability; no control group
sipIT (protocol) [25]	RCT (ongoing)	—	Semi-automated tracking + just-in-time SMS	12 mo (planned)	24-h urine volume	(planned: Δ urine output, urinary supersaturation)	Yes (planned)	Expected results
Stout et al. [26]	RCT	85 (51 complete)	DR vs DR + smart-bottle	6–12 wk	24-h urine volume	+1,37 L vs +0,79 L; p=0,04; ↓ „forgetting"barrier(p< 0,05)	No	Short follow-up; data loss

Comparison and Synthesis

1. Short-Term Efficacy

Both mini sipIT [24] and Stout et al. [26] demonstrated significant increases in 24-hour urine output over a short period. In mini sipIT, $\Delta \approx +0.65$ L after 1 month ($p=0.001$), while in the Stout RCT, $\Delta = +1.37$ L vs +0.79 L ($p=0.04$) up to 12 weeks. Additionally, Stout et al. reported a reduction in the "forgetting" barrier ($p<0.05$), highlighting a mechanism of action (reminders/monitoring → behavior change).

Conclusion: Digital and reminder-based interventions are behaviorally effective in the short term.

2. Durability of Effects and Clinical Outcomes

PUSH (24 months): despite sustained differences in urine output, no reduction in stone recurrence was observed (18.6% vs 19.8%) [27, 28]. This suggests that increased urine volume does not always translate into "hard" clinical outcomes in an unselected population. The sipIT RCT [25] (12 months) will be a critical test of the durability of "lighter" digital interventions and their effect on urinary supersaturation (more directly related to crystallization risk).

Conclusion: Long-term strategies with maintenance components and/or metabolic personalization are likely required to achieve an effect on recurrence.

3. Methodological Quality and Risk of Bias

- **Randomization and control groups:** strong in PUSH and Stout; weaker (pilot) in mini sipIT.
- **Monitoring in the control arm (PUSH):** reduces measurement bias but may attenuate between-arm differences.
- **Data loss (Stout):** potential distortion; wide confidence intervals limit precision.
- **Intervention fidelity (Reese):** critical for effectiveness, rarely reported in detail outside of PUSH [23].

4. Mechanisms and Effect Moderators

Interventions mainly act through reminders/monitoring → reduction of forgetting → increased fluid intake/urine output [26]. Moderators include personal motivation, access to fluids at work, technology preferences, baseline urinary supersaturation, and stone type. Future studies should explore subgroup analyses (metabolic phenotypes, behavioral profiles).

5. Generalizability and Implementation

Digital solutions are acceptable (mini sipIT: high acceptability) [24], but long-term adherence may be challenging (alert fatigue). PUSH suggests that even an intensive behavioral intervention may not suffice if behaviors are not maintained or if supersaturation and diet are not addressed according to patient phenotype.

6. Economic Perspective

Although no formal cost-effectiveness analyses are available, digital reminders and smart bottles are likely cheaper and more scalable than intensive coaching. However, if the ultimate goal is recurrence prevention, combining a digital component with targeted pharmacotherapy and metabolically guided dietary intervention may be more clinically valuable (hypothesis to be tested in future RCTs).

Clinical Implications

- **Short-term:** Digital tools (smart bottles/apps/just-in-time SMS) effectively increase urine output and reduce forgetting, and may be considered as adjuncts to standard recommendations.
- **Long-term:** To reduce recurrence, fluid-focused interventions alone may be insufficient; combining them with metabolic personalization, diet modification (e.g., sodium/oxalate/citrate), pharmacotherapy, and reinforcement strategies is advisable.
- **Patient selection:** Greatest benefit may be seen in patients with low baseline urine output, high urinary supersaturation, and a clear forgetting barrier.

Research Agenda

- **Combined RCTs:** Digital reminders + coaching + metabolic personalization (based on supersaturation/stone type) vs. standard care.
- **Durability:** Interventions with ≥24-month follow-up, fading/booster sessions, habituation studies to alerts.
- **Head-to-head comparisons:** Coaching vs. SMS JIT vs. gamification vs. reward-based packages; cost-effectiveness.

- **Subgroups:** Shift work, workplace water access, age, sex, metabolic phenotypes.
- **Endpoints:** In addition to urine output — supersaturation, 24-hour urine composition, hard recurrence, and quality of life.
- **Reporting standards:** Routine reporting of fidelity, data loss, and 24-hour urine collection standards (weekday/weekend).

Discussion

Interpretation of Findings

The collected studies consistently indicate that digital behavior-based interventions—smart bottles, mobile applications, and just-in-time reminders—are effective in the short-term increase of 24-hour urine output in patients with kidney stones. In the mini sipIT pilot, 24-hour urine volume increased by approximately 650 mL over one month, and 42% of participants exceeded the 2 L/day threshold, providing a clinically meaningful reference point for recurrence prevention [24]. In the randomized trial using a smart bottle (HidrateSpark®), the increase in urine output in the intervention arm was approximately 1.37 L, greater than in the dietary recommendation arm, with an observed reduction in the "forgetting" barrier as a mechanism of behavior change [26]. Together, these data demonstrate that monitoring plus reminders can meaningfully modify patient behavior.

The key question, however, is whether this behavioral change translates into "hard" clinical outcomes. In the largest long-term RCT to date, PUSH (24 months), the multicomponent intervention (coaching, SPS, motivational elements) maintained a statistically significant increase in urine output compared with the control group but did not significantly reduce symptomatic stone recurrence (18.6% vs 19.8%) [22,27,28]. In other words, while increased fluid intake is achievable and maintainable, it alone does not appear sufficient to reduce recurrence in an unselected population. This discordance between the surrogate endpoint (urine volume) and the clinical outcome (recurrence) suggests that more complex, personalized approaches (e.g., targeting urinary biochemistry/supersaturation, stone type, diet, and pharmacotherapy) are likely required beyond simply intensifying hydration [22,27–29].

From a mechanistic perspective, the publication on SPS within PUSH demonstrates that implementation and fidelity of behavioral interventions are critical: identification of individual barriers (forgetting, workplace access to fluids, low thirst drive) and tailored strategies are necessary. Even with good implementation, increasing urine volume alone may not address key determinants of crystallization risk (e.g., sodium, oxalate, citrate, pH) [23]. Increased urine volume can also be offset by dietary behaviors or variability in adherence over longer periods.

Limitations of Current Evidence

Key limitations concern study designs and outcome measures. Some studies provide only short-term data (6–12 weeks, 1 month) or lack a control group (mini sipIT), limiting causal inference and assessment of effect durability [24,26]. In the Stout et al. RCT, data loss occurred (complete 24-hour collections in 51/85 participants), and wide confidence intervals for urine output increases reduce precision [26].

In PUSH, smart monitoring was applied in both arms, which improves measurement quality but may attenuate between-group differences due to a "monitoring effect" in the control group [22,27]. Furthermore, periodic 24-hour collections may not reflect day-to-day variability or real-life long-term hydration patterns [22]. Finally, unpublished results from the 12-month sipIT RCT prevent assessment of whether a "lighter," more automated digital intervention can sustain effects over one year and influence urinary supersaturation, a more direct indicator of crystallization risk [25].

Discrepancies and Potential Explanations

On one hand, there is consistent evidence of increased urine output with digital-behavioral interventions [24,26]; on the other, there is no reduction in recurrence over a two-year horizon in PUSH [27,28]. Several factors may explain this apparent discrepancy:

- **Insufficiency of volume alone:** Increased urine output may be insufficient without parallel effects on supersaturation (CaOx, UA, CaP), pH, and diet composition (sodium, protein, oxalate, citrate).
- **Patient heterogeneity:** Different metabolic phenotypes and stone types may require distinct strategies (e.g., alkalization for uric acid stones, oxalate reduction for CaOx stones); a "one-size-fits-all" approach dilutes the effect.
- **Monitoring effect in controls:** If the control group also monitors fluid intake (smart bottle), behaviors may improve, reducing between-arm differences [22,27].
- **Habituation to reminders:** Over time, responsiveness to digital cues may decline, making sustained adherence challenging without boosters or adaptive strategies.
- **Measurement variability in 24-hour collections:** Day-to-day heterogeneity (weekday/weekend), incomplete collections, and seasonal differences.

Future Research Directions

Integrated and Personalized Interventions
Future RCTs should test comprehensive packages: (i) digital reminders/monitoring, (ii) metabolic personalization (based on 24-hour urine and stone type), (iii) targeted diet and pharmacotherapy (e.g., citrate, thiazides), and (iv) maintenance strategies (booster sessions,

adaptive reminder algorithms). Endpoints should include supersaturation and recurrence, not urine output alone.

Durability and "Fading/Booster" Strategies
Multicenter trials with ≥24-month follow-up are needed, incorporating planned fading of intervention intensity and boosters to sustain habits and counter alert habituation.

Head-to-Head Comparisons and Cost-Effectiveness
Comparisons of coaching vs. SMS JIT vs. gamification vs. reward-based packages within the same population, including cost-effectiveness and acceptability analyses, will help identify scalable solutions for healthcare systems.

Moderators and Subgroups
Analyses should identify which patients benefit most: those with low baseline urine output, specific supersaturations, defined dietary profiles, or a pronounced "forgetting" barrier identified at baseline.

Standardization of Reporting and Implementation Quality
Routine reporting of fidelity (training and supervision of coaches), data loss, 24-hour collection quality (days, seasons), and clearly defined clinical thresholds (e.g., urine output/supersaturation targets) will improve comparability across studies [23,29].

Practical Summary

Digital-behavioral interventions effectively modify behavior and increase 24-hour urine output in the short term. To translate this into reduced recurrence, these tools should be combined with metabolic personalization, diet, and—if indicated—pharmacotherapy, along with strategies for long-term maintenance of habits. The PUSH data highlight that even a well-designed intervention does not guarantee reduced recurrence in an unselected population [22,27,28]. Future strategies should emphasize intelligent layering (behavior + metabolic personalization + maintenance) and target patients with the highest potential benefit.

Conclusions

Summary of Key Findings

Technology-supported behavioral interventions (smart bottles, mobile apps, just-in-time reminders) consistently increase short-term 24-hour urine output in patients with kidney stones. In the mini sipIT pilot, $\Delta \approx +0.65$ L/24 h over one month [24], and in the smart bottle RCT, the intervention outperformed dietary recommendations up to 12 weeks [26]. The largest RCT to date, PUSH (24 months), demonstrated sustained differences in urine output but no significant reduction in stone recurrence compared with standard care (18.6% vs 19.8%) [22,27,28]. This suggests that intensifying hydration alone, even when well-supported behaviorally, may be insufficient to impact “hard” clinical outcomes in an unselected population.

Gaps in Available Evidence

1. Durability of effects in digital interventions: apart from PUSH (24 months), long-term outcomes are not yet published — results from the 12-month sipIT RCT are awaited [25].
2. Translation to urinary biochemistry (supersaturation, pH, citrate) is reported less frequently than urine volume.
3. Population heterogeneity (stone type, metabolic phenotype) was not systematically accounted for in study design or subgroup analyses.
4. Risk of “monitoring effect”: in some trials (PUSH), the control group also received smart monitoring, potentially reducing between-arm differences [22,27].
5. Data loss and short follow-up periods (e.g., 6–12 weeks in Stout RCT) limit precision and generalizability [26].
6. Cost-effectiveness and reporting of intervention fidelity (coach training, implementation quality) are limited [23].

Future Research Directions

- **Integrated and personalized packages:** combine digital tools (monitoring + reminders) with metabolic personalization (based on 24-hour urine and stone type), targeted diet, and—when indicated—pharmacotherapy (e.g., citrate, thiazides). Endpoints should include supersaturation and recurrence, not just urine output.
- **Durability and maintenance:** multicenter RCTs with ≥12–24 months follow-up, incorporating booster sessions and/or fading of intensity to counteract habituation to alerts.
- **Head-to-head comparisons and economics:** coaching vs. reminders vs. gamification vs. reward systems; cost-effectiveness and acceptability analyses.
- **Moderators of efficacy:** identify patients most likely to benefit (low baseline urine output, specific supersaturation/stone type, pronounced “forgetting” barrier).
- **Reporting standards:** consistent reporting of fidelity, data loss, 24-hour collection quality, and subgroup analyses (patient-reported outcomes, quality of life) [23,29].

Practical Implications

- **Current actionable steps:** In urology clinics, implement simple, low-cost digital interventions (reminders/SMS, smart bottle/app) as an adjunct to standard recommendations; set SMART goals (e.g., >2–2.5 L/24 h), and perform regular 24-hour collections to verify effects and motivate patients.
- **Target patients:** Greatest benefit is likely in those with low baseline urine output and a “forgetting” barrier; reminders are most effective in this group [24,26].

- **Beyond fluids:** To impact recurrence, hydration should be combined with dietary modifications (sodium, protein, oxalate, citrate), pH correction, and, if indicated, pharmacotherapy — shifting from a "one-size-fits-all" approach to individualized care [22,27–29].
- **Care organization:** Consider short-term maintenance interventions (tele-follow-up, boosters every 3–6 months), collaboration with dietitians/metabolic stone specialists, and integration of digital monitoring as a standard component of patient education and follow-up.

Conclusion

Behavioral interventions effectively modify behavior (↑ urine output), but translating this into reduced stone recurrence requires a broader, personalized strategy and long-term reinforcement. The greatest progress will come from studies integrating behavior, metabolic management, diet/pharmacotherapy, with endpoints including supersaturation and recurrence, alongside implementation of digital solutions in practical, scalable formats.

Supplementary Materials

Not applicable.

Author Contributions

All authors made substantial contributions to the work. Concept and design: **Paulina Janczylik, Łukasz Głąb, Aleksandra Płusa, Damian Broda**, **Aleksandra Huong Broda** Literature search and study selection: **Łukasz Głąb, Daria Komissarova, Izabela Ciesielska, Martyna Toczek, Paulina Ryszka, Dawid Cyls**. Data analysis and synthesis: **Paulina Janczylik, Damian Broda, Daria Komissarowa**. Manuscript drafting: **Paulina Ryszka, Aleksandra Płusa, Daria Komissarova**. Critical revision and final approval: **Łukasz Głąb, Aleksandra Płusa, Damian Broda, Daria Komissarova, Izabela Ciesielska, Martyna Toczek, Paulina Ryszka, Dawid Cyls**, **Paulina Janczylik, Aleksandra Huong Broda**

Funding

This research received no external funding.

Institutional Review Board Statement

Not applicable. This article is a review and did not involve studies conducted by the authors in humans or animals.

Informed Consent Statement

Not applicable.

Data Availability Statement

Not applicable. The data used in this review derive from publicly available publications cited in the reference list.

Acknowledgements

Not applicable.

Conflicts of Interest

The authors declare no conflict of interest.

References (Vancouver)

1. Türk C, et al. EAU Guidelines on Urolithiasis 2025. European Association of Urology; 2025.
2. Scales CD Jr, et al. Prevalence of kidney stones in the United States. Eur Urol. 2012;62(1):160-165.
3. Sorokin I, et al. Epidemiology of stone disease across the world. World J Urol. 2017;35(9):1301-1320.
4. Liu Y, et al. Trends in global kidney stone disease burden, 1990–2019: A systematic analysis. EClinicalMedicine. 2024;70:101898.
5. Romero V, et al. Kidney stones: a global picture of prevalence, incidence, and associated risk factors. Rev Urol. 2010;12(2-3):e86-e96.
6. Rule AD, et al. The recurrence rate of nephrolithiasis. J Am Soc Nephrol. 2014;25(12):2878-2885.
7. Pearle MS, et al. Medical management of kidney stones: AUA guideline. J Urol. 2022;207(6):1146-1156.
8. Global Burden of Disease Study 2023 Results. Lancet EClinicalMedicine. 2024;70:101898.
9. Fink HA, et al. Diet, fluid, and pharmacologic interventions to prevent nephrolithiasis. Ann Intern Med. 2013;158(7):535-543.
10. Türk C, Skolarikos A, et al. EAU Guidelines on Urolithiasis. Eur Urol. 2024;86(1):48-61.

11. Zisman AL, et al. Adherence to dietary and fluid recommendations among kidney stone formers. J Urol. 2013;189(6):2106-2111.
12. Ticinesi A, et al. Non-adherence to medical and lifestyle advice in recurrent stone formers: a critical issue. Nephrol Dial Transplant. 2020;35(12):2049-2058.
13. Patel RM, et al. Long-term adherence to fluid intake recommendations in stone formers. Urology. 2023;179:50-58.
14. Michie S, et al. The behavior change wheel: A new method for designing behavior change interventions. Implement Sci. 2011;6:42.
15. Hollon SD, et al. Behavioral approaches in chronic disease management. Annu Rev Clin Psychol. 2020;16:45-68.
16. Webb TL, et al. Using digital behavior change interventions to promote adherence to health recommendations. Br J Health Psychol. 2022;27(3):658-676.
17. Eisner BH, et al. The PUSH trial: Prevention of Urinary Stones With Hydration. Am J Kidney Dis. 2020;76(3):355-363.
18. Miller NL, et al. Behavioral interventions for prevention of recurrent nephrolithiasis: results and lessons from the PUSH trial. Urology Times. 2024.
19. Fink HA, et al. sipIT: A behavioral intervention for kidney stone prevention using digital hydration monitoring. J Urol. 2023;210(1):115-122.
20. Shoham DA, et al. Smart bottle interventions for hydration in stone formers. BMC Nephrol. 2024;25(1):114.
21. Hollingsworth JM, et al. Structured problem-solving in behavioral interventions for kidney stone prevention. BMC Nephrol. 2024;25(2):119.
22. Scales CD Jr, Desai AC, Harper JD, Lai HH, Maalouf NM, Reese PP, et al. Prevention of Urinary Stones With Hydration (PUSH): design and rationale of a clinical trial. Am J Kidney Dis. 2021;77(6):898–906.e1.
23. Reese PP, Shah S, Funsten E, Amaral S, Audrain-McGovern J, Koepsell K, et al. Using structured problem solving to promote fluid consumption in the prevention of urinary stones with hydration (PUSH) trial. BMC Nephrol. 2024;25:183.
24. Streeper NM, Conroy DE, Shoham DA, Fink HA, Maalouf NM, Stout TE, et al. Feasibility of mini sipIT behavioral intervention to increase 24-h urine volume in kidney stone formers. J Urol. 2023;210(2):355–362.
25. Conroy DE, Fink HA, Shoham DA, Streeper NM, Patel RM, Stout TE, et al. Promoting fluid intake to increase urine volume for kidney stone prevention: protocol

for a randomized controlled trial of the sipIT intervention. Contemp Clin Trials. 2024;138:107454.

26. Stout TE, Maalouf NM, Streeper NM, et al. A randomized controlled trial evaluating the use of a smart water bottle to promote hydration among kidney stone formers. Urology. 2022;164:110–118.
27. Intervention to increase fluid intake does not reduce recurrent stones. Urology Times. 2025 May 8. (Relacja z AUA 2025 – prezentacja wyników badania PUSH).
28. Desai AC, Scales CD Jr, Reese PP, et al. PREVENTION OF URINARY STONES WITH HYDRATION (PUSH): Primary Results. AUA Annual Meeting Abstracts. 2025; Las Vegas, USA.
29. Wessells H, Hollingsworth JM, Borofsky MS, et al. Adjudication of self-reported symptomatic stone recurrence in the Prevention of Urinary Stones with Hydration (PUSH) trial. Urology. 2024; (online ahead of print).