Improving Fluid Intake Behavior Among Patients With Kidney Stones: Understanding Patients' Experiences and Acceptability of Digital Health Technology

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OBJECTIVE To understand kidney stone patients' experiences with increasing fluid intake, common barriers to adherence, and technology-mediated intervention techniques that may improve adherence in this population. Increasing fluid intake to produce at least 2.5 L of urine daily is a well-established preventive strategy to reduce the risk of kidney stones. Unfortunately, adherence with this well-known and inexpensive recommendation is commonly below 50%.

MATERIALS AND METHODS Patients with a history of kidney stones were recruited to participate in semistructured focus groups about their experiences with increasing fluid intake. Inductive content analysis was used to extract themes from focus group transcripts.

RESULTS Themes from discussions with 19 patients described current fluid intake strategies, barriers to increasing fluid intake, and desirable features in a digital tool for promoting fluid intake. Common barriers to increasing fluid intake included work habits, travel, leisure activities, forgetting to drink, limited access to water, and not feeling thirsty. Patients had tried to increase fluid intake using strategies such as carrying a water bottle, identifying contextual cues for drinking, self-monitoring fluid intake, and seeking social support. Patients expressed interest in wearing sensors to improve fluid intake if the sensor was aesthetically pleasing, had guaranteed benefit and was able to connect to existing devices. The most acceptable location to wear a sensor was as a wristband or bracelet.

CONCLUSION The use of automated and semiautomated tracking technology in combination with evidence-based behavior change techniques should be explored in efforts to improve adherence to fluid intake recommendations. UROLOGY 133: 57–66, 2019. © 2019 Elsevier Inc.

Nephrolithiasis affects an estimated 8.8% of American adults with annual medical care costs in the United States exceeding $2 billion.[1] Recurrence rates are as high as 80% within 10 years.[2] Guidelines recommend increasing fluid consumption to produce at least 2.5 L of urine daily for preventing a recurrence of kidney stones.[3-8] This preventative strategy is relatively straightforward and inexpensive, yet adherence is commonly below 50%.[9,10] Technology for tracking fluid consumption may help to overcome some of the previously identified barriers to fluid consumption (eg, lack of knowledge, lack of thirst, not remembering to drink).[11] Yet little is known about patient perspectives about using technology for this purpose. This study sought to characterize the experiences that patients with nephrolithiasis have with increasing their fluid consumption and identify their needs when implementing digital tools to support their fluid consumption.

Technology has entered the field of urology with the existence of smartphone applications (apps) designed to aid in the management of kidney stones or improve fluid consumption and smart containers to monitor fluid intake.[12-14] However, the effectiveness of this technology for increasing fluid consumption among kidney stone patients has not been evaluated.[12] Wearable technology has been widely used to support a variety of health

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behaviors and outcomes.[15-18] Patients with a history of kidney stones have expressed interest in utilizing wearable sensors to improve adherence to fluid consumption recommendations.[19] Yet little is known about the needs of patients when using technology for this purpose. Any new intervention must not only be efficacious at preventing stone recurrence but must also be acceptable to patients for long-term maintenance.[20] An opportunity exists to codesign digital tools for supporting increased fluid consumption with patients.

The purpose of this study was to understand adult patients' experiences with increasing fluid consumption, common barriers to adherence, and strategies to improve and maintain this preventive behavior. Of particular interest, based on our prior work, was the acceptability of incorporating wearable sensors to provide automated lapse detection in fluid consumption.[19]

MATERIALS AND METHODS

After obtaining approval from our institutional review board, adult patients with a history of nephrolithiasis were recruited from Penn State Health Urology Clinics at Hershey Medical Center and from local family practices in State College to participate in focus groups from March to August 2017. Patients were recruited via physician referrals, fliers, a previously developed patient database and through the Penn State StudyFinder website. Patients completed a telephone screening to determine their eligibility. Eligibility requirements included being 18 or older, fluent in English, a prior diagnosis of nephrolithiasis and willing to complete all study procedures.

Five focus group sessions (3-5 patients/group) were conducted between March 2017 and August 2017. After obtaining informed consent and prior to participating in the focus group, patients completed a questionnaire that collected demographic information and medical history pertaining to their kidney stone disease. Following completion of the questionnaires, a researcher reviewed the outline and guidelines for the focus group session. These guidelines included how to ensure information shared in the session would remain confidential. Patients were then led through a semistructured focus group discussion by the researcher. All focus group discussions were recorded using a digital audio recorder and later transcribed. Key topics included: experiences with different fluid consumption strategies, concerns about increasing fluid consumption, acceptability of different sensors and attachment methods, strategies for recruiting and retaining patients in a clinical trial of a fluid consumption intervention and technology design characteristics that would optimize patient engagement. Patients took turns responding to each prompt and the researcher invited open discussion and elaboration at the end of each question.

Transcripts were reviewed and analyzed for themes using inductive content analysis methods.[21,22] Unique IDs were assigned to deidentify patients. Two coders worked independently to identify meaning units within each patient's responses. The coders then compared meaning units and discussed disagreements with a third coder to achieve consensus. The 2 coders worked to group the consensus meaning units into first-order themes. A third coder challenged those themes until a consensus summary was achieved. When needed, first-order themes were grouped into higher-order themes. If a single first-order theme could not be linked to other first-order themes to create a higher-order theme, it was elevated to a stand-alone higher-order theme. After themes were identified, frequencies were determined for the number of participants and focus groups that mentioned each theme. A single quotation, or meaning unit, was selected to illustrate each first-order theme.

Descriptive statistics were calculated using IBM SPSS 24.0, summarizing patients' questionnaire responses. Categorical variables were described by their frequencies, and continuous variables were described by their mean, standard deviation, median, and range.

RESULTS

Nineteen adult patients with a history of kidney stones participated in a semistructured focus group discussion. Questionnaires were not received from 4 participants so questionnaire results below are based on $n = 15$. Patient demographics are represented in Table 1. The average age was 54.9 ± 15.0 years (range 19-72). All reported being white and not Hispanic or Latino.

Patients reported experiencing their first kidney stone episode at age 40.9 ± 16.3 years (range = 12-65). Patients reported experiencing an average of 3.9 ± 2.9 (range = 1-10) prior stone episodes. The estimated number of prior surgical interventions was 2.0 ± 1.5 (range 0-6). The onset of patients' most recent episode with a stone ranged from within the past month to 3.6 years ago, with a mean of 10.6 months (SD = 11.4). One-third of the patients reported that they currently had kidney stones.

All patients reported being very interested in preventing another kidney stone and either very or mostly willing to make lifestyle changes to prevent another kidney stone. All participants recalled that their clinician recommended increasing their fluid intake for stone prevention. Few patients were familiar with specific guidelines for recommended amount of daily urine

Table 1. Patient demographics

		n (%)
Sex		
	Female	10 (67%)
	Male	5 (33%)
Body habitus		
	Obese	9 (60%)
	Overweight	3 (20%)
	Normal weight	3 (20%)
Employment status		
	Full time	8 (53%)
	Part time	4 (27%)
	Retired	3 (20%)
Education		
	High school	1 (7%)
	Some college	5 (36%)
	Associate's degree	4 (29%)
	Bachelor's degree	2 (14%)
	Master's degree	1 (7%)
	Doctoral	1 (7%)
Income		
	$25,000-$50,000	2 (14%)
	$50,000-$75,000	4 (29%)
	$75,000-$100,000	0 (0%)
	Over $100,000	5 (36%)
	Prefer not to answer	3 (21%)

output for stone prevention, with only 27% even responding (2 reported 2 L and 2 reported 3 L). More than half of the patients (58%) did not keep track of their daily fluid intake.

Table 2 summarizes themes and illustrative quotes about patients' experiences with fluid intake for the prevention of kidney stones. All but 1 participant reported being advised to increase their fluid intake to prevent kidney stones. Most often, the participants heard this recommendation from a medical professional but a variety of sources were mentioned. Participants relied on both internal and external feedback to determine if they were drinking enough fluids. The most common internal feedback source was urine color, followed by frequency of bathroom trips, thirst, and symptoms other than thirst. Participants relied on internal feedback more than external feedback (eg, measuring fluid serving size, smartphone applications). Some reported not knowing how to tell when they were drinking enough.

Commonly reported barriers to drinking included work demands, participation in leisure activities, and traveling. Other times in which participants tended not to drink were when access to water was limited or when quality of water was questionable. Others reported that they limited their fluid consumption based on their activities that day. Five participants reported drinking too little because they did not remember to drink or did not find themselves thirsty enough. Three participants did not identify any barriers to drinking. Strategies that patients used to increase fluid consumption included carrying a water bottle, contextual cues, feedback from self-monitoring or automated reminders, and social support. Four participants reported not having a specific strategy to increase fluid intake (Table 2).

Table 3 summarizes themes and illustrative quotes related to patients' concerns about increasing fluid consumption. Common concerns included frequent bathroom trips, satiety, and water dissatisfaction. Participants expressed an intimidation factor in reference to the sheer volume of water they needed to consume daily to reach recommended intake as well as an unpleasant bloating feeling from drinking a lot of water. Dissatisfaction with water was related to the mineral content and the unappealing taste. Other concerns included water not being a priority, not being effective, or having a negative effect on the environment. Few participants reported no specific concerns with increasing fluid consumption. To avoid frequent bathroom trips participants reported intentionally avoiding fluid intake at night, during travel or leisure activities, or at work. Most participants did not have suggestions for addressing those concerns although 2 suggested that making fluid consumption a more delightful experience by flavoring the water or obtaining an aesthetically pleasing drinking container.

Table 4 summarizes themes and illustrative quotes about the acceptability of different sensors and attachment methods. The majority of patients were receptive to wearing a sensor to improve fluid intake behavior. The most important features of a wearable sensor included aesthetics, efficacy, and compatibility with existing digital devices. A wristband was the most acceptable location to wear a sensor (63%), followed by a necklace (26%). Few patients (11%) reported not being willing to wear a wristband sensor. Patients were generally not willing to wear sensors attached to their torso or with adhesives, earbud sensors, or ingestible sensors.

Incorporating technology, like text, email, or wrist-worn sensors, was acceptable for notifying participants about their drinking behavior. Only 4 participants preferred not to get notifications and 1 participant did not care. Participants said they would like to receive reminders at regularly scheduled intervals ranging from every half hour to once a day. Some participants only wanted reminders if a lapse in drinking was detected. Three participants were uncertain either because they did not want to receive too many, were not sure how many was enough, or felt that the optimal frequency of reminders depended on their activities for the day. In terms of feedback on their drinking behavior, the majority of participants wanted text message or email feedback on their success in meeting their fluid intake goal at regular intervals, ranging from daily to monthly. Two expressed interest in receiving feedback only if their goal was not met. Lastly, participants were asked what was a reasonable cost for a device to detect lapses in their drinking. Most were either uncertain or suggested a price less than $100. One participant was willing to pay $1,000 while another had no limit to the device cost if it proved to be efficacious for improving fluid consumption.

To promote clinical trial recruitment, patients suggested the following strategies including: recruitment via clinicians, targeting those with a history of kidney stones, social media advertisements, and emphasizing incentives as education or personal gain. Retention strategies that were discussed included providing tools for prevention, education, and monetary incentives (eg, "Keep the session short and pay the people").

Finally, the most desired outcomes from a new fluid intake intervention included stone prevention, pain reduction, reduce duration of episode, and reduce emotional distress/inconvenience ("Just the pain and discomfort of them. I would drink more water any day to eliminate that").

DISCUSSION

Increasing fluid intake is the behavioral cornerstone of nephrolithiasis prevention and is the preventative strategy that patients are most willing to perform.[11] It is also the least expensive intervention and has been shown to be a cost-effective strategy for kidney stone prevention.[23] Despite these advantages, adherence with fluid consumption guidelines remains poor and new tools are needed to improve fluid consumption behavior.[9,10] There is a paucity of knowledge on patient perspectives about using technology for this purpose. An opportunity exists to codesign acceptable digital tools with patient input so this study characterized patient perspectives on increasing fluid consumption to prevent the recurrence of kidney stones and identified their needs when implementing digital tools to support their fluid consumption.

Similar to a study by Tarplin et al, participants were generally familiar with recommendations to increase their fluid consumption.[24] However, few participants in the present study were able to recall the volume of fluid intake (or urine production) required. In addition, Tarplin et al reported that patients who were successful used a strategy (ie, cues/prompts) to remind themselves to drink (typically carrying a water bottle) whereas unsuccessful patients typically tried to remember without using a specific cue or prompt.[24] Patients in the present study also identified common strategies to increase fluid intake including: carrying a water bottle, contextual cues, feedback from self-monitoring or automated reminders, and

Table 2. Experiences with fluid consumption strategies

First-Order Theme	Second-Order Theme	Quote
*Frequency (No. of focus groups/no. of participants)		
Have you been told that increasing fluid intake can prevent kidney stones?		
Yes (5/18)		
	Yes (5/16)	"Yes, I've been told that many times" (P#17)
	Drink water (2/3)	"I was told to increase my water consumption" (P#8)
Different sources (2/5)		
	Recommended by medical professional (2/4)	"He (urologist) said stay hydrated but I don't remember him giving me a specific amount for kidney stone prevention" (P#12)
	Medical profession who did not recommend (1/1)	"There was actually no information from my OBGYN about kidney stones" (P#11)
	Recommended by nonmedical professional (1/1)	"Weight watchers instructor always tells me to drink more water" (P#12)
Specific volume recommended (3/3)		"Doctors say somewhere around a gallon" (P#10)
How do you know you have been drinking enough during the day?		
Internal feedback (5/13)		
	Urine color (3/6)	"Watching the color of my urine" (P#8)
	Frequency of bathroom trips (4/5)	"Keep track how many times I've used the restroom" (P#11)
	Symptoms other than thirst (3/3)	"Sometimes I feel a headache" (P#9)
	Thirst (2/2)	"Thirst is how I know if I'm drinking enough during the day" (P#12)
External feedback (3/4)		
	Measuring servings of bottles (3/3)	"I count the number of bottles to keep track" (P#12)
	Apps (1/2)	"App on my phone but I am not very good at keeping track" (P#2)
Don't know how to tell (3/4)		"I don't really. . .my body doesn't tell me when I've had enough" (P#10)
Are there certain situations when you tend not to drink enough?		
Contexts (5/14)		
	At work (4/7)	"I don't have time when I'm at work to make sure my water bottle is filled with fresh water" (P#11)
	Leisure activities (4/5)	"When I'm out and about" (P#10)
	Travel (car) (4/4)	"I know when we travel before I would stop drinking around 7 pm the night before so we didn't have to stop" (P#14)
	No days are the same (1/2)	"Depends, no days are ever the same" (P#4)
	Access to water (quantity and quality) (2/4)	"It's a matter of effort to ensure a supply of good water is available" (P#12)
No cues to drink (3/5)		
	Forget (3/4)	"I just don't think about drinking" (P#17)
	Not thirsty (1/3)	"I'm never really thirsty" (P#17)
I don't avoid drinking in any situations (3/3)		"I really have no excuses" (P#5)
What do you do to try to drink regularly?		
Access to water bottle with known volume (4/9)		"I have a big 32 oz Yeti and I have it sitting on my desk and I fill it with ice every morning" (P#10)
Contextual cues (3/5)		"When I walk out into the kitchen I will drink" (P#14)
Social support (2/3)		"I have a bunch of coworkers who don't want to do my work while I'm out with kidney stones so they remind me daily" (P#17)
Tailoring drinks to preferences (2/2)		"I have to put water flavoring in mine" (P#18)

Continued

Table 2. Continued

First-Order Theme	Second-Order Theme	Quote
Get feedback (4/5)		
	Self-monitoring (3/4)	"I've tried monitoring it on my Fitbit which doesn't work well because you have to put it in and there's no reminder" (P#11)
	Automated reminders via technology (2/2)	"I have a water bottle that beeps at me if I'm not drinking enough" (P#17)
No strategy (2/4)		"I do not know if I am really trying enough to drink regularly" (P#9)

Table 3. Concerns about increasing fluid consumption

First-Order Theme	Second-Order Theme	Quote
*Frequency (No. of focus groups/no. of participants)		
What concerns do you have about increasing your fluid intake?		
Frequent trips to bathroom (2/4)		"The more I drink the more I go to the bathroom, it's just disruptive to my day" (P#17)
Volume (4/6)		
	Bloated feeling (2/4)	"At times I feel full and I do not want to drink any more water" (P#7)
	Quantity excessive (2/2)	"I can barely get through 5 bottles and that's a lot" (P#10)
Water dissatisfaction (2/4)		
	Water mineral content (1/2)	"For me to drink tap water is huge because I feel like the water around here, you can taste something in it" (P#10)
	Water unappealing (ie, flavor) (2/3)	"I think water is gross and boring" (P#8)
No concerns (3/3)		"I don't have any real concerns. It is a matter of you have to do it" (P#6)
Water not a priority (1/1)		"I have got other things occupying my mind and getting a glass of water is not one of them" (P#3)
Not effective for preventing (1/1)		"Drinking more and still have stones" (P#2)
Environmental concerns (1/1)		"I don't like buying bottled water. So it's an environmental concern for me also" (P#11)
Are there particular times when you would not want to increase your fluid intake or when you intentionally dehydrate yourself to avoid bathroom trips?		
At night (3/6)		"I don't like to drink after 8 at night because then I'm up all night going to the bathroom and then I get no sleep" (P#17)
During travel/leisure (2/6)		"If I wanted to go to the beach or drive for a couple hours, I would slow down or else at bed time I would be up several times during the night" (P#16)
At work (2/2)		"I'm a pilot by trade and when I fly personally or employed, I don't have the accommodations" (P#19)
No (2/2)		"I don't think I do that" (P#9)
Don't know (1/2)		"I really don't know" (P#6)
Other (1/2)		"When I do not feel good I don't feel like drinking" (P#4)
Is there anything you think can be done to relieve those concerns?		
Don't know (4/7)		"For me, I don't think. What I drink now is what I'm going to drink" (P#10)
Make it delightful (1/2)		
	Flavoring of water (1/1)	"The flavored water without any calories are okay to drink I guess" (P#12)
	Aesthetically pleasing drinking container (1/1)	"A nice vessel to drink out of. . .something that's aesthetically pleasing" (P#11)

Table 4. Acceptability of different sensors and attachment methods

First-Order Theme	Second-Order Theme	Quote
*Frequency (No. of focus groups/no. of participants)		
How could we interest you in wearing sensors to increase your fluid intake?		
Aesthetics (3/3)		"Comfortable and not visible" (P#7)
Guaranteed accuracy/benefits (2/3)		"I would need a reasonable guarantee of accuracy that it's actually measuring what it's supposed to" (P#12)
Connect to existing devices (1/1)		"It would be nice if it was linked to my Fitbit since that's already a habit I have" (P#11)
Curiosity (2/2)		"I would be into that as long as you showed me what I have to do" (P#14)
Not interested (2/2)		"Probably wouldn't interest me unless it was something that would avoid life threatening situations" (P#19)
What sensors would you not be willing to wear to increase your fluid intake?		
Not on torso (5/6)		
	Not on clothes (4/4)	"Things that you would wear on the outside that other people would see, that is hard to do" (P#11)
	Not on chest (2/2)	"Probably not the chest sensor" (P#18)
No accessories (3/6)		
	No earbuds (2/3)	"The ear buds, I wear them to listen to music when I'm walking but otherwise I don't think I'd be motivated to wear an ear bud" (P#12)
	No necklace (2/2)	"I don't think I would do anything on the neck" (P#11)
	Nothing extra on wrists or hands (1/2)	"I wear a watch so wearing something like a Fitbit would bother me" (P#18)
No adhesives (3/3)		"The patch thing, I'm not sure because sometimes the adhesive makes me itch" (P#18)
No ingestibles (3/3)		"I don't know if I would ingest something though" (P#14)
Need more info (2/2)		"As long as I'm able to drink like I am free to. If I was not able to do that then I would not be interested" (P#6)
No sensors at all (1/2)		"Anything that was attached. . .do not want to do that" (P#6)
No limitations (1/2)		"I don't have a problem with anything" (P#14)
Where would you mostly likely wear sensors on your body?		
Under clothes (2/3)		"Somewhere under my clothes, not on them" (P#17)
Phone (1/3)		"Use an app on my phone" (P#1)
Patch (1/2)		"I would try a patch if I could hide it" (P#11)
Jewelry/accessories (5/15)		
	Wristband/bracelet (5/12)	"I could do a wristband because I have a Fitbit" (P#2)
	Necklace (3/5)	"If it was an attractive enough necklace I would probably wear it" (P#12)
	Ring (1/1)	"If you could have a sensor ring" (P#11)
	Earring (1/1)	"An earring maybe" (P#12)
Anything (1/2)		" I wouldn't have a problem with anything. . .... I'm game for anything." (P#15)
How would you like to see notifications about your progress with fluid consumption?		
Tech (5/12)		
	Text/email (4/11)	"Text or anything on the smartphone would be fine" (P#9)
	Via Fitbit (2/2)	"I think it would be really nice, again, coming through my Fitbit" (P#11)
Prefer not to get notifications (3/4)		
	No tech (2/3)	"I don't think I would want an electronic message of my progress" (P#8)
	No email (1/1)	"For me personally anything but email" (P#2)
Don't care (1/1)		"I'm indifferent" (P#19)
How often would you like to receive reminders to drink?		

Continued

Table 4. Continued

First-Order Theme	Second-Order Theme	Quote
As often as needed (3/6)		"I would like them when you think I'm not drinking enough" (P#13)
Regular schedule (4/8)		
	Every half hour (1/1)	"Probably every half hour" (P#14)
	10 min before each hour (1/1)	"I know my app reminds you 10 minutes before the hour. . .something like that would work" (P#2)
	2-3×/day (2/3)	"Maybe like have a 3 times a day alert" (P#4)
	Every couple hours (2/3)	"It would be fine every two hours" (P#10)
	Daily (1/2)	"Daily would work" (P#18)
Uncertain (3/3)		
	Don't want too many (2/2)	"Since my episode I kind of remind myself a lot so getting more reminders I don't need that" (P#8)
	Don't know (1/1)	"I don't know" (P#16)
	Depends on the day (1/1)	"It depends on the kind of day I am having" (P#3)
Never (1/1)		"Never" (P#6)
How often would you like to receive feedback on your overall progress?		
Whenever you haven't drank enough (1/2)		"When it's showing that you didn't drink enough" (P#16)
Regular intervals (5/16)		
	Once a day (2/6)	"I would like it at night so I know what I did and what I need to do tomorrow" (P#3)
	Every couple days (1/1)	"Every couple days" (P#1)
	Every 3-4 days (1/1)	"If I would be having a problem for like 3-4 days, the sensor would pick up that I was off" (P#13)
	Once a week (5/8)	"I agree with what everyone else said. Maybe once a week" (P#17)
	Occasionally (2/3)	"I think the periodic feedback would work better for me" (P#12)
	Monthly (2/2)	"Monthly would be fine" (P#13)
What would be a reasonable cost for a device to detect lapses in your drinking?		
Uncertain (3/8)		
	Unsure (3/4)	"I would have no clue" (P#18)
	Depends on what you get (2/2)	"It would depend if there was a continuing cost on top of it, and if it was something that I can stand wearing, something discrete" (P#19)
	Depends on insurance (1/2)	"Hopefully Medicare or some type of insurance would help me pay for it" (P#14)
Less than $100 (3/8)		
	Cost of a Fitbit (1/4)	"I would say the cost of a Fitbit" (P#3)
	$20-30 (1/1)	"I wouldn't be opposed to paying $20-30" (P#1)
	$40 (1/1)	"I would go $40" (P#8)
	$75 (1/1)	"I'd spend $75 on that" (P#11)
	$100 or less (1/2)	"I would say a $100 or less" (P#9)
A lot (2/2)		
	No more than $1000 (1/1)	"If it had to be out of pocket hopefully no more than $1000" (P#13)
	No limit (1/1)	"If I was lapsing, and getting back it would be worth whatever cost to make sure that I am drinking" (P#6)

social support. Rather than just telling patients to increase fluid consumption, physicians should specifically review fluid volume goals tailored to the individual patient and review possible strategies to identify one that may best fit for the patient's lifestyle.

Perceived barriers to fluid intake also require attention. Tasian et al identified unique barriers for adolescents, including unawareness of water intake volume and low responsiveness to the perceived need to drink more.[25] Education may be necessary for some patients but it is unlikely to be sufficient in adult populations. In our sample, common barriers to meeting fluid intake guidelines included work demands, participation in leisure activities, traveling, forgetting to drink, limited access to fluids, and

not being thirsty. McCauley et al identified related barriers to fluid intake in adult patients, including (1) not knowing the benefits of fluid or not remembering to drink, (2) disliking the taste of water, lack of thirst, and lack of availability, and (3) needing to void frequently and related issues at work or school.[11] Behavioral interventions for increasing fluid consumption should target these barriers by making fluid consumption less burdensome, recognizing that some barriers will be more difficult to overcome than others. Different behavioral interventions may be necessary to target the needs of specific subpopulations. For now, physicians should discuss their patients' barriers to increasing fluid consumption and collaborate in identifying possibly solutions. Digital tools could be used to support fluid intake tracking and provide behavioral feedback.

Overall poor adherence with fluid intake recommendations highlights the need for new tools to address disease-specific barriers and to provide reminders to patients to increase fluid consumption.[9,10] Digital tools, such as connected water bottles, smartphone applications and wearable sensors, are emerging to support fluid intake behavior change; however, little is known about their acceptability or efficacy.[14,19] Behavior change techniques can be implemented in smartphone apps to support self-monitoring, goal setting, and prompt drinking behavior.[12] Apps can also be paired with connected devices to track and provide regular feedback on fluid intake.[13,26-28] Connected water bottles can address a number of barriers described by participants by providing an external cue, accessibility, automated reminders to drink, and feedback on fluid intake progress via a companion smartphone application. Connected bottles reduce the burden of manually tracking fluid intake but are limited because patients need to consume from the container in order for them to be tracked (and often only able to track water). Thus, connected water bottles may not be ideal for daily use and in certain social situations. Developing algorithms for processing data from wearable sensors to track fluid intake may help to overcome these limitations (and complement the value of connected bottles).

Our focus groups revealed that a wristband was the most acceptable location to wear a sensor. Wristbands with inertial sensors (ie, accelerometers, gyroscopes) have been used to classify drinking behavior.[29] Wearable sensors may be best suited for patients who struggle to remember to drink throughout the day, because they can be used to trigger reminders when lapses in drinking behavior are detected (eg, if a patient has not had a drink within the past hour). These sensors tend to be minimally obtrusive and acceptable to wear at social gatherings, especially if made to be aesthetically pleasing which was an important feature reported from our sample.

The majority of patients wanted reminders to increase fluid intake. However, preferences for the type and frequency of reminders and progress reports varied widely. Patient preferences should be taken into consideration during the design of digital tools. Although participants may not have had personal experience with all of the digital tools discussed, patient attitudes and expectations are important drivers of decision-making and behavioral choice. These beliefs should be incorporated into the development of new technology.[30] A universal solution is unlikely to exist so device selection may need to be matched to the needs and preferences of individual patients. Intervention technology should be adaptable to accommodate patient preferences, expectations, and attitudes.[30] Such tailoring will likely increase engagement and enhance effects.[30] For some patients, wearable sensors may be sufficient; for others, those wearables may need to be combined with other tools (eg, connected water bottles). Clinical trials will be necessary with a larger sample size, objective measurement from 24-hour urine or imaging, and suitable comparison groups to determine which digital tools are efficacious for stone prevention with different subpopulations of patients.

This study was based on a relatively homogeneous sample of patients from central Pennsylvania. Conclusions may not generalize to populations with greater racial, ethnic, educational, or geographic diversity. Patients who participated in focus groups may be more motivated and responses about acceptability may not predict actual adoption and engagement across a more general population. Neither daily fluid consumption nor urine output was collected. Not all patients in this study necessarily struggled with adherence to fluid intake recommendations. Furthermore, data were collected from focus group discussions and it is possible that participants influenced each other's responses; either inflating the level of agreement or restricting discussions.

CONCLUSION

Increasing fluid consumption is a well-known and accepted prevention strategy but few patients currently make consistent efforts to monitor their fluid intake. In light of evidence that thirst and memory are insufficient for increasing fluid consumption, wearable sensors may help support patients' adherence with prevention guidelines. Incorporating components that address patient-identified barriers to adherence and are acceptable to patients will increase the long-term use of wearable sensors for promoting fluid consumption. This study identified a number of viable components that should be considered when designing digital tools to support adherence. Sensors can provide automated lapse detection in fluid intake and remind patients to drink. Combining wearable sensors with evidence-based behavior change techniques should be explored in efforts to improve adherence to fluid intake recommendations.

SUPPLEMENTARY MATERIALS

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.urology.2019.05.056.

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EDITORIAL COMMENT

This is a well-designed study that explores the challenge we face in improving fluid intake for our kidney stone patients. The authors offer a patient-centric vantage in defining the barriers to adherence and strategies that might improve them. Various approaches have been used in the past with limited success, but herein lies a unique opportunity to improve behavior by amalgamating input from the patient perspective with currently available technology. As discussed in the paper, external cues or prompts have proven benefit in helping patients improve their fluid intake. However, currently used devices for this purpose such as smart water bottles, have several limitations that preclude consistent use. Perhaps rightfully so, the idea that a wearable device can trigger appropriate fluid intake based on behavioral cues or preprogrammed goals is more appealing, as it gives 1 more freedom and flexibility while providing a more robust platform that can incorporate intake from multiple sources. An important caveat to consider, based on our own ongoing work in this area, is that while digital technology might be appealing, stand-alone devices independent of requisite smartphones might prove to be more inclusive—as we have found many patients such as the elderly do not own or use smartphones. Nonetheless, it is incumbent on the clinician to encourage the use of whatever evidence-based device or tool that can improve adherence and potentially reduce risk of stone recurrence. Some caution should be used in extrapolating data from this specific focus group as participation bias might overlook socioeconomic, age, and cultural barriers; accordingly, it might be helpful to expand this focus group model across sites to capture more diverse perspectives. The main takeaway from this study is that patients are initially motivated, however, currently available resources for kidney stone formers are not sufficient to yield sustainable behavioral modification. Accordingly harnessing smart technology with patient-specific feedback is a logical next step and further development in this area must be encouraged.

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AUTHOR REPLY

We thank you for the positive comments regarding the findings of our study. Education to drink more, thirst, and memory are not enough to improve fluid intake for kidney stone prevention. New digital tools are needed to identify and initiate behavior change on a just-in-time basis when lapses in drinking behavior are detected. As you noted, it is also important for health behavior changes to be maintained. Incorporating patients in the design process should increase the value of new technology for them; this study offered a foundation for the field to consider as new technology for promoting fluid consumption is developed.

In addition to patient-specific feedback, opportunities exist to incorporate other contextual features (eg, location [work vs home]; day of week [weekend vs weekday]; time of day; environmental conditions [temperature]) and to personalize decision rules for selecting and timing notifications when lapses are detected.[1] A one-size-fits-all, universal solution may not exist, so technology should be (1) adaptable to accommodate the preferences and needs expressed by patients, and (2) adaptive in learning the idiosyncratic patterns and responses outside of patients' awareness. Such personalization will likely increase engagement and improve sustainable behavioral modification.

We agree that new technology might not be immediately suitable for all of today's patients; however, we note that technology adoption, particularly smartphones, continues to increase. Across all adults, smartphone ownership exceeds 80%.[2] Among adults age 65 years and older, smartphone ownership increased from 18% to 53% from 2013 to 2019. Developing and evaluating evidence-based digital tools takes considerable time. During that time, younger cohorts will join the ranks of older adults, bringing their experience with technology into the older cohorts. Thus, the process of developing new health technology needs to begin today to be ready for the patients of tomorrow.

We agree with the point about limited generalizability and realize that responses about acceptability may not predict actual adoption and engagement across a more general population. In technology development it is common to have an early-stage design in small groups, which often limits diversity. However, the goal of this study was to open the door for patient input in the development process and we hope the field will remain open to input from more diverse populations as this work progresses. Ultimately, there can be no substitute for rigorous clinical trials with diverse patient populations to determine which digital tools are effective for stone prevention among different subpopulations of patients.

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