Accuracy of Daily Fluid Intake Measurements Using a "Smart" Water Bottle

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Introduction: High fluid intake is an effective preventative strategy against recurrent kidney stones but is known to be challenging to achieve. Recently, a smart water bottle (Hidrate Spark™, Minneapolis, MN) was developed as a noninvasive fluid intake monitoring system. This device could help patients who form stones from low urine volume achieve sustainable improvements in hydration, but has yet to be validated in a clinical setting.

Methods: Hidrate Spark™ uses capacitive touch sensing via an internal sensor. It calculates volume measurements by detecting changes in water level and sends data wirelessly to users' smartphones through an application. A pilot study was conducted to assess accuracy of measured fluid intake over 24 hour periods when used in a real life setting. Subjects were provided smart bottles and given short tutorials on their use. Accuracy was determined by comparing 24-hour fluid intake measurements calculated through the smart bottle via sensor to standard volume measurements measurements calculated by the patient from hand over the same 24 hour period.

Results: Eight subjects performed 62 24-hour measurements (range 4-14). Mean hand measurement was 57.2 oz/1692 mL (21-96 oz/621-2839 mL). Corresponding mean smart bottle measurement underestimated true fluid intake by 0.5 ozs. (95% CI -1.9, 0.9). Percent difference between hand and smart bottle measurements was 0.0% (95% CI -3%, 3%). Intraclass correlation coefficient (ICC), calculated to assess consistency between hand measures and bottle measures, was 0.97 (0.95,0.98) indicating and extremely high consistency between measures.

Conclusions: 24 hour fluid intake measurements from a novel fluid monitoring system (Hidrate Spark™) are accurate to within 3%. Such technology may be useful as a behavioral aide and/or research tool particularly among recurrent stone formers with low urinary volume.

Introduction:

Urinary stone disease is one of the most common and costly diseases in medicine affecting nearly 10% of the US population.[1] Prevalence is growing rapidly with rates having more than doubled over only the past 15 years, making it the most costly urologic condition.[1,2] One of the biggest obstacles in controlling the growing incidence of stone disease is better preventative care, especially considering risk of recurrence is as high as 50% within 5 years.[2] To date, there are few treatments with strong evidence supporting their use in stone prevention. High fluid intake is perhaps the most effective preventative strategy based on a 5 year randomized control study which demonstrated a 12% recurrence rate among patients encouraged to achieve a goal of 2 liters of urine per day compared to a 27% recurrence in the group not encouraged to increase fluid intake.[3] High fluid intake is also a recommended prevention strategy by both the American Urological Association (AUA) and American College of Physicians (ACP) who advocate daily goal urine volumes of 2.5 L for all stone formers.[3,4]

Achieving significant increases in hydration and subsequently urinary volumes is a considerable clinical challenge for patients. While there is little data assessing patient compliance specifically for fluid, noncompliance with metabolic treatment of nephrolithiasis is known to be as high as 70%.[5] Recently, mobile health technology has gained attention as a potential aide in helping improve compliance with medically indicated lifestyle and dietary treatments. Early studies using “smart technology” and mobile health applications have shown implementation of such strategies can not only be beneficial in improving compliance, but also capable of facilitating sustainable behavioral change.[6] To date, studies looking at mobile health technology as it applies to increasing fluid intake is sparse, particularly among stone formers.

Recently, a novel “smart” water bottle called Hidrate Spark™ (Minneapolis, MN) was developed and brought to market. This bottle is designed to be used as a noninvasive fluid intake monitoring system, allowing users to track daily fluid intake in real-time via smartphone in order to help achieve hydration goals. Such a device may have considerable potential as a meaningful tool in the care of patients with stone disease as achieving high fluid intake is known to be difficult. We sought to assess the accuracy of this device in a preclinical setting prior to applying it towards patient care.

Methods

Hidrate Spark™ (Figure 1) uses capacitive touch sensing via a sensor extending from the lid to the base of the bottle which calculates fluid volume measurements by detecting changes in water levels and then uploading data to the user’s smartphone via Bluetooth. Data is sent from the sensor to the app each time the bottle detects a change in water level and position through an accelerometer incorporated in the sensor. Volume measurements are reset every 24 hours and users are able to track their progress by accessing the application on their smartphone (Figure 2).

To assess the accuracy of fluid tracking in a real life fashion, 8 healthy volunteers agreed to participate in a preclinical trial. All study participants were given a Hidrate Spark™ water bottle and downloaded the associated software application on their smartphone using either Apple iOS™ or Android™. All participants underwent a step-by-step hands-on demonstration on how to appropriately set up and use the device, following the written instructions provided by the manufacturer. To ensure baseline accuracy in recordings, volunteers were asked to fill the bottles completely to 24 ozs. and place it on a flat surface for 10 seconds to allow calibration. They were then asked to drain all fluid from the bottle and ensure that an accurate measurement had been recorded to the application. All users were taught how to calibrate and recalibrate the bottle to ensure consistent readings. Users were given permission to recalibrate the bottles on their own in the event of perceived inaccuracies in fluid tracking.

Participants were then asked to use the bottle over a two-week period whereby they were asked to track the precise amount of water drank through the bottle over complete 24 hour periods on at least 3 occasions. To make these measurements, users were asked to fill the bottle to precisely 24 ozs and drink to completion then refill with 24 ozs each time. Any residual fluid at the end of the 24-hour period was then poured into a measuring cup and the residual volume subtracted from the day’s total. Volunteers were asked to only drink water through the bottle as it is specifically designated for this purpose. Fluid intake besides water was not accounted for in this study though there is a function within the application to manually add alternative fluid intake by hand.

The fluid measurements recorded both by hand and by the Hidrate Spark™bottle were summarized using descriptive statistics. The intraclass correlation coefficient (ICC) was calculated to assess the consistency between pairs of hand and bottle measures. All statistics were performed using R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna Austria. (http://www.R-project.org/). No member of the research or study team had any financial on intellectual consulting relationship with the Hidrate Spark™ company. All smart bottles were provided by the company for testing at no cost.

Results

Among eight study volunteers there were a total of 62 unique 24-hour measurements performed (range 4-14). There was one outlier that was removed from the analysis during a software update where the recorded volume from a single 24 hour measurement kept switching between ounces and milliliters.

Mean 24 hour water intake measurement by hand was 57.2 ozs (21-96 ozs). The corresponding mean 24 hour smart bottle measurement underestimated true fluid intake by a mean of 0.5 ozs. (95% CI -1.9, 0.9). Smart bottle measurements tended to underestimate true fluid intake as such measurements occurred in 52% of cases compared to overestimates in 37% and equal measurements 11% of the time. A majority of 24-hour measurements (63%) were within 5 ounces of true water intake and 72.5% of measurements were within 10% of true water intake (Figure 3). The overall percent difference between hand and smart bottle measurements was 0.0% (95% CI -3%, 3%). The ICC (95% CI) was found to be 0.97 (0.95,0.98) indicating a high degree of consistency in measurements between bottles. Manual recalibrations were performed by users on four occasions where measured and true fluid intakes were felt to be greater than expected.

All participants were asked to provide feedback via a seven question survey after they had completed their experience using the device. Questions were designed to assess attitudes, experience and general satisfaction with it. Notably, all participants shared favorable opinions regarding the bottle with zero pessimistic or negative responses towards it. (Table 1)

Discussion

We sought to determine the accuracy of the Hidrate Spark™ smart water bottle in measuring 24-hour fluid intake when used in a real life setting by an unaffiliated group of volunteers. We found that measurements taken through the bottle were within 3% of those measured by hand. Our findings, the first to focus on mobile health technology applied specifically towards the measurement of fluid intake, are both timely and relevant.

Growth of mobile health technology is occurring at a rapid pace and stands to challenge traditional models of care. Provider awareness of the latest technologies is increasingly important as such applications become more commonly available to patients without obligate involvement of health professionals. Smart fluid tracking technology in particular, holds high promise as a tool in the management and study of nephrolithiasis, and as such merits validation prior to considering utilization on a wider clinical scale.

Better and more effective strategies to help patients with nephrolithiasis achieve increases in fluid intake are sorely needed. High fluid intake has been associated with a reduced likelihood of stone recurrence by as much as 50%[3] and would be an extremely cost effective measure with improved compliance.[7] Nonetheless, efforts to achieve such dietary changes have historically been limited, leading to a recent call from the National Institute of Diabetes and Digestive and Kidney Diseases for more research to better assess strategies of maintaining high fluid intake in stone forming patients.[8] Notably, the potential for mobile health technology in this area was specifically mentioned.

Mobile health technology has dramatically grown in popularity over the past several years. A pubmed search for "mobile health technology" yields 74 results, 88% of which were published in the year 2013 or beyond. To date, mobile health technology has been shown to be useful in medication adherence, smoking cessation and glycemic control[9,10] and is poised to play an increasingly common role in patient care as technology evolves. Only three prior publications have explored the role of mobile health technology in nephrolithiasis. In 2015, Stevens et al. analyzed 42 different smartphone applications focusing on nephrolithiasis, a number which has almost certainly grown since the time of publication.[11] Notably, only 2 of these applications provided patients with a platform to track their daily fluid intake in an effort to reduce their overall stone risk; both of which required manual entry. One of the unique benefits of Hidrate Spark™ is the fact that fluid recording is performed automatically without the need for manual entry as the manual entry process is cumbersome and was previously found to be associated with a decrease in fluid consumption.[12] More recently, Conroy et al. identified and characterized 50 mobile applications designed to help improve fluid intake.[13] They noted that a major limitation of such applications is the tedious nature of having to continuously open and engage the applications themselves. Notably, Hidrate Spark™ syncs automatically, bypassing this cumbersome process. They also recommended that patients seek applications that facilitate self-monitoring and provide feedback on discrepancies between behavior and goals as both approaches have been proven elements of successful lifestyle behavior changes for other conditions. These are both features of Hidrate Spark™ as well.

In anticipation of the fact that Hidrate Spark™ and other fluid tracking systems like it will have considerable appeal to patients with nephrolithiasis, we believe that a measure of clinical quality assurance is necessary. The emergence of mobile health technology in clinical practice has raised some timely questions that have not previously required consideration. In particular, the role of the healthcare professional in the development and utilization of such tools remains unclear. In 2013 the U.S US Food and Drug Administration issued final guidance as to their oversight of mobile medical apps announcing that regulatory efforts would be focused on applications serving in an accessory role to registered medical devices or those that transformed the smartphone into a medical device altogether.[11] Considering the myriad of mobile health technologies that do not meet these criteria, it is no surprise that medical professional involvement in this process is relatively low. In the aforementioned study on urolithiasis applications, only one third had any identifiable involvement by health professionals.[11] As new and innovative mobile health technologies are introduced we are hopeful that similar efforts are made to test them in a clinical setting as well.

We acknowledge several limitations to our study. For one, our group had no direct involvement in the creation of this device or technology and seek only to report the accuracy of measurements obtained by use of it in a simulated clinical scenario. Second, our study was conducted in the most optimized of settings, in patients without a history of kidney stones. All volunteers had personal education from the development team regarding appropriate utilization. All devices were set up by the development team to ensure initial accuracy of measurements. Another limitation is that all 24-hour measurements were performed using only water during designated time periods where results were intended to be most accurate. As such, it is reasonable to believe that the accuracy of measurements may vary to a greater degree when used in a real life setting among patients. However, we believe that this limitation is impossible to overcome as there are currently no other methods to accurately measure true fluid intake in a non-study setting. Finally, while our study demonstrated the ability to accurately track fluid intake, the question of whether or not use of such a device actually leads to an increase in fluid intake remains unanswered. We hope to gain greater appreciation regarding the clinical and research potential of this device and technology in a separate ongoing assessment among patients with stone disease.

Conclusions:

Hidrate Spark™ is a noninvasive fluid tracker that demonstrates accuracy of true fluid intake to within 3% in a research setting. This device has considerable potential as a behavioral aide to help patients with nephrolithiasis achieve high fluid intake and decrease stone risk. Future studies testing this device in a clinical setting are warranted and underway.

Works Cited

1. Scales CD, Jr., Smith AC, Hanley JM, Saigal CS, Urologic Diseases in America P. Prevalence of kidney stones in the United States. *European urology.* Jul 2012;62(1):160-165.
2. Kirkali Z, Rasooly R, Star RA, Rodgers GP. Urinary Stone Disease: Progress, Status, and Needs. *Urology.* Oct 2015;86(4):651-653.
3. Borghi L, Meschi T, Amato F, Briganti A, Novarini A, Giannini A. Urinary volume, water and recurrences in idiopathic calcium nephrolithiasis: a 5-year randomized prospective study. *The Journal of urology.* Mar 1996;155(3):839-843.
4. Qaseem A, Dallas P, Forciea MA, Starkey M, Denberg TD, Clinical Guidelines Committee of the American College of P. Dietary and pharmacologic management to prevent recurrent nephrolithiasis in adults: a clinical practice guideline from the American College of Physicians. *Annals of internal medicine.* Nov 4 2014;161(9):659-667.
5. Dauw CA, Yi Y, Bierlein MJ, et al. Factors Associated With Preventive Pharmacological Therapy Adherence Among Patients With Kidney Stones. *Urology.* Jul 2016;93:45-49.
6. Bassi N, Karagodin I, Wang S, et al. Lifestyle modification for metabolic syndrome: a systematic review. *The American journal of medicine.* Dec 2014;127(12):1242 e1241-1210.
7. Lotan Y, Buendia Jimenez I, Lenoir-Wijnkoop I, et al. Increased water intake as a prevention strategy for recurrent urolithiasis: major impact of compliance on cost-effectiveness. *The Journal of urology.* Mar 2013;189(3):935-939.
8. Scales CD, Jr., Tasian GE, Schwaderer AL, Goldfarb DS, Star RA, Kirkali Z. Urinary Stone Disease: Advancing Knowledge, Patient Care, and Population Health. *Clinical journal of the American Society of Nephrology : CJASN.* Jul 07 2016;11(7):1305-1312.
9. Free C, Phillips G, Watson L, et al. The effectiveness of mobile-health technologies to improve health care service delivery processes: a systematic review and meta-analysis. *PLoS medicine.* 2013;10(1):e1001363.
10. Hou C, Carter B, Hewitt J, Francisa T, Mayor S. Do Mobile Phone Applications Improve Glycemic Control (HbA1c) in the Self-management of Diabetes? A Systematic Review, Meta-analysis, and GRADE of 14 Randomized Trials. *Diabetes care.* Nov 2016;39(11):2089-2095.
11. Stevens DJ, McKenzie K, Cui HW, Noble JG, Turney BW. Smartphone apps for urolithiasis. *Urolithiasis.* Feb 2015;43(1):13-19.
12. Smith LP, Hua J, Seto E, et al. Development and validity of a 3-day smartphone assisted 24-hour recall to assess beverage consumption in a Chinese population: a randomized cross-over study. *Asia Pacific journal of clinical nutrition.* 2014;23(4):678-690.
13. Conroy DE, Dubansky A, Remillard J, et al. Using Behavior Change Techniques to Guide Selections of Mobile Applications to Promote Fluid Consumption. *Urology.* Jan 2017;99:33-37.