Original Article: Clinical Investigation

Comparison between uroflowmetry and sonouroflowmetry in recording of urinary flow in healthy men

Jan Krhut,1,2 Marcel Gärtner,1 Radek Šykora,1 Petr Hurtik,4 Michal Burda,4 Libor Luňáček,1 Katarina Zvarová5 and Peter Zvara2,6

1Department of Urology, University Hospital, 2Department of Surgical Studies, Ostrava University, 3Department of Obstetrics and Gynecology, University Hospital, and 4Institute for Research and Applications of Fuzzy Modeling, Centre of Excellence IT4Innovations, Ostrava University, Ostrava, Czech Republic; 5Department of Physiology, Slovak Medical University, Bratislava, Slovakia; and 6Department of Surgery, University of Vermont, Burlington, Vermont, USA

Abbreviations & Acronyms
PCC = Pearson’s correlation coefficient
Qave = average flow rate
Qmax = maximum flow rate
SUF = sonouroflowmetry
UF = uroflowmetry

Correspondence: Jan Krhut M.D., Ph.D., Department of Urology, University Hospital, Tr. 17. listopadu 1790, 708 52 Ostrava, Czech Republic. Email: jan.krhut@fno.cz

Received 20 January 2015; accepted 22 March 2015
Online publication 18 May 2015

Objectives: To evaluate the accuracy of sonouroflowmetry in recording urinary flow parameters and voided volume.

Methods: A total of 25 healthy male volunteers (age 18–63 years) were included in the study. All participants were asked to carry out uroflowmetry synchronous with recording of the sound generated by the urine stream hitting the water level in the urine collection receptacle, using a dedicated cell phone. From 188 recordings, 34 were excluded, because of voided volume <150 mL or technical problems during recording. Sonouroflowmetry recording was visualized in a form of a trace, representing sound intensity over time. Subsequently, the matching datasets of uroflowmetry and sonouroflowmetry were compared with respect to flow time, voided volume, maximum flow rate and average flow rate. Pearson’s correlation coefficient was used to compare parameters recorded by uroflowmetry with those calculated based on sonouroflowmetry recordings.

Results: The flow pattern recorded by sonouroflowmetry showed a good correlation with the uroflowmetry trace. A strong correlation (Pearson’s correlation coefficient 0.87) was documented between uroflowmetry-recorded flow time and duration of the sound signal recorded with sonouroflowmetry. A moderate correlation was observed in voided volume (Pearson’s correlation coefficient 0.68) and average flow rate (Pearson’s correlation coefficient 0.57). A weak correlation (Pearson’s correlation coefficient 0.38) between maximum flow rate recorded using uroflowmetry and sonouroflowmetry-recorded peak sound intensity was documented.

Conclusions: The present study shows that the basic concept utilizing sound analysis for estimation of urinary flow parameters and voided volume is valid. However, further development of this technology and standardization of recording algorithm are required.

Key words: sound recording, urinary flow, voided volume, wireless data transfer.

Introduction

Voiding dysfunction is highly prevalent and has a major impact on the quality of life of a large proportion of men. UF is a widely used non-invasive test for evaluation of bladder emptying.1 It is carried out on an outpatient basis, at specified procedure areas and involves having the person urinate into the uroflowmeter often at a predetermined time. This process is unnatural and requires “on-demand” voiding often with either low or very high bladder filling. It leads to significant test-to-test variability. It has been therefore recommended that uroflowmetry should be repeated, which requires time-consuming and costly repeated clinic visits.2,3 This is the reason why the demand for smaller, more practical devices has grown and led to the emergence of portable uroflowmeters. These have not been fully adopted into routine practice, because they are costly and difficult to operate, which is especially troublesome for elderly patients.4

SUF represents a new approach to recording urinary flow patterns and measuring of urinary flow parameters. It captures the sound generated when urine stream is hitting the water level in the toilet bowl. It then uses a web-based algorithm to store the sound file in a digital form on a secure website, where it is subsequently analyzed. It uses a physical principle adopted from technologies that have been developed for estimation of the intensity of rain fall on a large body of water or the flow through turbines in hydroelectric plants.5 The literature data describing attempts
to analyze sound associated with urine flow in urology exist; however, they are sparse, with the last article dating back to 1991.6 The goal of the present pilot study was to compare the urinary flow parameters acquired using SUF with those recorded by standard uroflowmetry in healthy male volunteers in controlled settings.

**Methods**

**Preclinical testing**

In the initial preclinical experiments, we tested a number of cellular phones in order to select the type, with hardware parameters optimal for recording of the sound produced by the urinary stream falling on the water surface. We designed a set-up in which a stream with a constant flow rate was falling onto the water level in the collecting chamber filled with 3000 mL of water, and positioned on top of the gravimetric uroflowmetry device Flowmaster (MMS, Enschede, the Netherlands). Three different flow rates (6, 20, 60 mL/s) were tested. We carried out multiple synchronous UF/SUF recordings. We then compared the UF-recorded flow parameters and the pattern of the trace with a related sound, recorded with SUF. The experimental setting allowed for identification of parameters that can significantly modify the sound signal intensity. We tested the distance between the sound source and the microphone, the height of the stream, depth of the water in the receptacle, direction of the urine stream as well as the size of the room in which the recording was carried out. In addition, significant variability in the quality of the sound recording was noted between individual cell phone and smart phone types. Based on these experiments, we selected a Samsung GT-B2710 (Samsung, Seoul, Korea) for the use in the subsequent clinical trial. Trace patterns and parameters recorded using this cell phone produced the highest consistency and best correlation with UF recordings among the tested phone units.

**Clinical trial**

A total of 25 healthy male volunteers (age 18–63 years) were included in the study. All study procedures were approved by the institutional review board of the University Hospital, Ostrava, Czech Republic, and the study conformed to the provisions of the Declaration of Helsinki (as revised in Edinburgh 2000). After giving informed consent, participants were asked to carry out the uroflowmetry synchronous with sound recording using standardized conditions that included use of a cell phone that was selected in the preclinical portion of the study. A constant distance between the phone and the water level in the collecting device was used, with the phone positioned on the table next to the participant, 150 cm from the water level. All men carried out the urination in standing position when experiencing a normal desire to void. The experimental setting is shown in Figure 1.
Data analysis
From a total of 188 recordings, 34 were excluded from the final analysis, because of voided volume <150 mL, or technical problems encountered during recording. Amplitude of the sound was then recorded from the remaining SUF records and visualized in a form of a trace representing the intensity of the sound signal over time. A median convolution technique was applied to smooth the data plot and suppress sound artifacts generated during the sound signal recording. This allowed us to eliminate an artificial spike at the beginning of each SUF recording. Subsequently the matching datasets of UF and SUF were compared as follows: flow time recorded using UF was compared with the duration of the sound signal recorded by SUF; UF-recorded voided volume was compared with the calculated area under the SUF curve; and UF-recorded \( Q_{\text{ave}} \) and \( Q_{\text{max}} \) were compared with the average and peak intensity of the sound signal.

Statistical analysis
A linear model was fitted to calculate the urinary flow parameters and voided volume from data obtained by SUF. PCC was used to compare the parameters recorded by UF with those calculated based on SUF recordings. A PCC value of >0.7 was considered to be indicative of a strong correlation, 0.5–0.7 signified a moderate correlation and PCC 0.3–0.5 was indicative of a weak correlation. In addition, the error between SUF and UF was analyzed and calculated as the difference between UF-measured and SUF-estimated parameters. The standard deviation of the error was an indicator of accuracy. Approximately 68% of all UF-parameter values fell within the interval of the estimated SUF-parameter ±standard deviation of the error. A 95% confidence interval of the error specifies the interval that includes 95% of all cases.

Results
Urinary flow pattern
The flow pattern recorded by SUF showed a good visual correlation with the UF trace. The artifact (spike) at the beginning of each recording was highly reproducible and was subsequently filtered out by the median convolution filter (Fig. 2).

Correlation between the flow time, flow parameters and voided volume
A strong correlation (PCC 0.87) was documented between UF recorded flow time and duration of the sound signal recorded with SUF. A moderate correlation (PCC 0.68) was observed in voided volume measured by UF and voided volume determined by calculating the area under the SUF curve. The values calculated using SUF showed a moderate correlation to UF-recorded parameters for \( Q_{\text{ave}} \) (PCC 0.57) and a weak correlation (PCC 0.38) for \( Q_{\text{max}} \). These two values were calculated based on recorded average and peak sound intensity, respectively. The relationship between parameters obtained by either UF or SUF for each individual test are shown using scattergrams (Figs 3–6). Means and standard deviations of all recorded UF parameters as well as the PCC, standard deviation of the error and confidence intervals of the error are summarized in Table 1. Error is defined as the difference between flow parameters and voided volume measured by UF and those estimated by SUF.

![Fig 3](image-url) Scattergram representing the correlation between \( Q_{\text{max}} \) recorded by UF (y-axis) and corresponding \( Q_{\text{max}} \) estimated by SUF (x-axis).

![Fig 2](image-url) Side-by-side comparison between the recordings of a single micturition. (a) Urinoflowmetry trace. (b) Sound generated during micturition, recorded by a telephone, electronically analyzed and transformed into a trace – sonourogram.

© 2015 The Japanese Urological Association
The present pilot study documents that that intensity of the sound associated with urine stream falling on the water level in a toilet bowl could be used to estimate urinary flow parameters and voided volume. SUF therefore has a potential to become a user friendly, reliable and portable method for electronic recording of voiding pattern, voided volume and urinary flow parameters.

The idea of using sound analysis in the diagnosis of voiding dysfunction is not new. It was anecdotally mentioned a long time ago that urologists attempted to detect lower urinary tract dysfunction simply by listening to the patient voiding. Attempts to quantify the relationship between the sound of the urine flow and the urinary flow pattern have been described previously.

Koiso et al. used a sensor positioned on the surface of the perineum of 25 men to record the sound of urine flowing through the urethra. Using spectral analysis, they detected the flow turbulence in patients who were believed to have a bladder outflow obstruction and no such turbulence in healthy individuals. Although authors studied this technique in a comprehensive manner and published several communications, this technique had never become a part of routine practice. A major limitation of the present study was an absence of objective verification of bladder outflow obstruction.

The present results show a strong correlation between UF and SUF in flow time, and a moderate correlation with respect to estimation of the voided volume and \( Q_{\text{ave}} \). The correlation in \( Q_{\max} \) was weak. The standard deviation in the error (differences between the UF-measured and SUF-estimated voided volume and \( Q_{\max} \)) was approximately 25–30%.

We acknowledge that at this stage of the development of this method, the level of accuracy is clearly inferior to that obtained by UF. We, however, suggest that the portability and ease of use of this technique leads to substantial advantages. It allows for multiple recordings at home, under natural conditions, reducing intra-individual test-to-test variability and limiting the need for hospital visits. At this time, we believe that SUF could benefit patients in several clinical situations. Those include a possibility of remote evaluation of men undergoing the trial without catheter after acute urinary retention, and in the treatment follow up of patients receiving medical treatment for lower urinary tract symptoms. Even in the absence of the

**Table 1** Correlation between the flow time, flow parameters and voided volume

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>PCC</th>
<th>Error St. Dev</th>
<th>Error Conf Int95</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Q_{\text{ave}} )</td>
<td>3.43</td>
<td>8.61</td>
<td>0.38</td>
<td>7.97</td>
<td>±15.754</td>
</tr>
<tr>
<td>( Q_{\max} )</td>
<td>16.29</td>
<td>5.10</td>
<td>0.57</td>
<td>4.18</td>
<td>±8.258</td>
</tr>
<tr>
<td>Voided volume</td>
<td>315.16</td>
<td>126.84</td>
<td>0.68</td>
<td>9.24</td>
<td>±182.573</td>
</tr>
<tr>
<td>Flow time</td>
<td>18.15</td>
<td>4.87</td>
<td>0.87</td>
<td>2.39</td>
<td>±4.726</td>
</tr>
</tbody>
</table>

© 2015 The Japanese Urological Association
exact quantification of the urinary flow parameters, the SUF-determined flow pattern combined with the estimated voided volume could identify patients in need of additional detailed evaluation and treatment.

The present trial identified several technical problems that could lead to improvements of SUF accuracy if solved. The most fundamental are related to the cell phone microphone technology and variation in quality of mobile network reception. The majority of recently released cell phones are equipped with a noise cancellation system. This feature is designed to filter out the background noise that does not resemble a human voice. This feature proved to have a detrimental effect on the accuracy of the parameters recorded with SUF. The laboratory part of this trial showed that more advanced cell phone technology (especially that used in latest generations of smart phones) is associated with an unacceptably high degree of signal processing, making these devices unsuitable for SUF. Use of cell phone technology makes this method dependent on the availability of the mobile signal (reception). Reduced signal quality led to generation of random artifacts in the course of SUF recording. We believe that both these limitations necessitate changing the platform used for recording to a specialized recording device using a designated microphone without artificial sound signal modulation.

The sound that SUF records and analyzes is the result of complex physical events that take place during the contact of urine with the water surface. The majority of the sound is attributed to oscillations of air bubbles, which form just below the water surface. This splashing phenomenon is generated by a large number of various size bubbles, resulting in wide acoustic spectra. The algorithm used accounts for this complexity. This is the reason why the SUF data could not have been expressed in decibels, but rather arbitrary units had to be used. Findings from the acoustic literature as well as the present data show that flow rate is a dominant parameter determining the sound intensity; however, we recognize that SUF accuracy and repeatability is dependent on a number of factors. The most important proved to be the microphone distance from the sound source and the height of the stream. A modality allowing standardization of these parameters would need to be developed as well, before SUF could be used as a standard diagnostic tool.

The present study supports the feasibility of the basic concept of using sound analysis for estimation of urinary flow parameters and voided volume. However, it also identifies areas in which this technology needs improvement.

Acknowledgments

The authors thank Dr Jerry Blavias for valuable input, Travis Mann-Gow for critical review and editorial assistance, and Jiri Krhat for supplying the schematic drawing. The work of Petr Huntik and Michal Burda was supported by the European Regional Development Fund, Project of IT4Innovations Centre of Excellence (CZ.1.05/1.1.00/02.0070, VP6).

Conflict of interest

P Zvara and K Zvarova are partners in the commercial enterprise that developed and patented this technology. The remaining authors declare no conflict of interest.

References