Urophonographic Studies of the Lower Urinary Tract: A New Approach to Urodynamics

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*Department of Urology, Institute of Clinical Medicine, University of Tsukuba, Ibaraki 305, †Department of Urology, the University of Gunma, Gunma 371 and ‡Research Laboratory of Precision Machinery and Electronics, Tokyo Institute of Technology, Yokohama 227

Koiso, K., Kanoh, S., Rinsho, K., Nemoto, R., Ishikawa, H., Ishikawa, S., Ohtani, M., Nemoto, S., Takeshima, H., Uchida, K., Kondo, F., Shimazui, T., Kikuchi, K., Kaneko, S., Yoshii, S., Noguchi, R., Umeyama, T. and Kosugi, Y. Urophonographic Studies of the Lower Urinary Tract: A New Approach to Urodynamics. Tohoku J. exp. Med., 1987, 151 (1), 57–64 — The detection and recording systems for urethral sounds during micturition were developed. This procedure was termed as “urophonography” and its recording as “urophonogram”. Classification of urophonograms was undertaken on the basis of analyzing normal healthy male volunteers, and patients with benign prostatic hyperplasia. Four types of urophonogram were demonstrated. Urophonography was useful for investigation of dysfunctional voiding, and lower urinary tract obstruction. Urophonography will be a new approach to urodynamic investigations.

Recently we have developed the method of sonic detection of lower urinary tract disorders in order to identify the disturbances in the urinary stream. Analysis of these sounds generated by the urinary flow at the posterior urethra during voiding is thought to be a new method in urodynamic studies, which we now call “urophonography”.

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Patients and Methods

Patients

Twenty-five patients with benign prostatic hyperplasia (BPH) underwent urophonography before surgery. Average age of the patients was 67.8±6.6 (mean ± s.d.) years. As controls 10 healthy male volunteers were examined with their informed consent. Their average age was 66.3±4.0 (mean ± s.d.) years. Urophonography with simultaneous uroflowmetry was undertaken. Its parameters included time to maximum flow (Tmax) (sec), maximum flow rate (MFR) (ml/sec), average flow rate (AFR) (ml/sec), and flow time during micturition (Mt) (sec) (Abrams et al. 1983).

Methods

Block diagram of the sound-recording system is shown in Fig. 1a.

In the system three detectors are available. However, in practice it is enough for one to detect the sounds. The microphone built in a steel detector case (30 mm in diameter and 17 mm in thickness) is commercially available. This "Capra"-type microphone (Model TA-501-TA, Nihon Kohden Co., Tokyo) was designed to pick up the sounds. For perfect contract and fixation a jelly for ultrasound examination and bandage were used. The detection system we used had a gain of 40-50 dB greater than that of an ordinary stethoscope.

The detected sounds were amplified by a PSC-4100 low noise amplifier and recorded in a data recorder (Sony FE-39A, Sony Magnescale Inc., Tokyo). The sounds were also brought into bandpass filters (up to 2 kHz) and monitored using stereoheadphones.

The hardware configuration of the data analyzing system is presented in Fig. 1b. The recorded data was carefully examined with the aid of a graphic equalizer (Yamaha Q1027, Yamaha Electrics, Tokyo), then the playback speed was reduced to 1/500 using two data recorders (Sony A-109 and FR-3125); and the chart recording was obtained on a thermal pen recorder (WX-4404, Watanabe Instruments, Co., Tokyo). In the spectrum analysis, noises, such as foot steps, closing doors, etc., greatly affected the results, so that a soundproof room was used. The gate can be used by manual key tapping and automatic detection of

![Diagram](attachment:diagram.png)

Fig. 1.  

a: Block diagram of sound detection and recording system developed in our department.  
b: Block diagram of data-analyzing system.
environmental noise if any occurred. The gated signals were then put through a pair of low pass filters (cut-off 2.5 pHz) to reduce hissing noises and to prevent the aliasing effect in the A/D conversion process. The signals were then converted to digital data at the sampling frequency of 5 pHz. Spectrum analysis and cross-correlation analysis were carried out by 7T08 program packages #39 and #100A, where averaging was taken over 32 or 64 beats. The resulting data was displayed on a CRT screen and hard copies were plotted on an XY-recorder (Ferguson 1970; Kosugi et al. 1983).

Prior to sound recording the patients were asked to urinate completely. The urethral catheter was inserted through the urethra and the bladder was filled with 200 ml of distilled sterile water. The detector microphone was placed at the perineum to catch the sound of voiding.

The patients stood upright. Recording began one or two min before the patients began to void and was continued one or two min after finishing of urination. Uroflowmetry was simultaneously performed to compare and analyze the urodynamic aspects of the patients (Siroky et al. 1969, 1980). Apparatus for uroflowmetry was made by Nihon Kohden Co., Tokyo. Routine urological examinations were performed on these patients. Schematic presentation of these procedures is shown in Fig. 2.

RESULTS

Background factors and uroflowmetric analysis

Background factors and uroflowmetric analysis of 10 healthy male volunteers and 25 patients of BPH with regard to uroflowmetry are shown in Table 1. It was clearly shown that patients with BPH exhibited the objective features of difficulty on voiding.

Urophonographic analysis

Urophonographic records (urophonograms) were classified into four types according to shape and characteristics.

Type 1 urophonogram represented smooth diamond-shaped figure during micturition. This type of urophonogram is characterized by gradual increase and decrease in sound. Fig. 3 is a typical pattern of a Type 1 urophonogram, which was found in a patient with BPH aged 71. The two high spikes of sounds, which were found 7–10 sec after beginning micturition, denote the noise as analyzed by the spectrum. Frequencies of the sounds generated during micturition were
found to be 560-610 Hz, while those of the noises were demonstrated in the other region of frequencies.

Uroflowmetric analysis also revealed the obstructive pattern characterized by the retardation of micturition. In comparison with the urophonogram it was demonstrated that the strength of the sounds increased as the urinary flow rate increased, and vice versa. Parallelism was noted in these two parameters.

Type 2 urophonogram showed the random occurrence of the sounds during micturition. There were no definite rules for determining the shapes. Fig. 4 demonstrates the Type 2 urophonogram. The spectrum analysis also indicated that the sounds produced by prostatic tumors had two frequencies, 300 Hz and 540-590 Hz. It was assumed that the low frequency sound might be noise. Uroflowmetric records demonstrated the occurrence of an irregular micturition pattern showing severe dysuria.

Type 3 urophonogram was characterized with the mixture of Type 1 and Type 2. In a definite time there occurred Type 1, diamond-shaped configuration first, and thereafter a random occurrence of Type 2 sound spikes. As shown in Fig. 5 there were two types of sound spikes. The sound spectrum analysis revealed the predominance of frequencies of 610 Hz. Uroflowmetric records of smooth shape corresponded to the diamond-shaped configuration, while unsmooth

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**Table 1. Characteristics of patients with benign prostatic hyperplasia (BPH) and normal healthy male volunteers**

<table>
<thead>
<tr>
<th></th>
<th>Number of patients</th>
<th>Average age</th>
<th>Tmax (sec)</th>
<th>MFR (ml/sec)</th>
<th>AFR (ml/sec)</th>
<th>Mt (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPH</td>
<td>25</td>
<td>67.8±6.6</td>
<td>8.73±3.31</td>
<td>14.34±3.28</td>
<td>7.15±2.07</td>
<td>35.76±8.39</td>
</tr>
<tr>
<td>Volunteers</td>
<td>10</td>
<td>66.3±4.4</td>
<td>5.59±0.97</td>
<td>22.86±2.02</td>
<td>15.21±1.57</td>
<td>19.49±1.43</td>
</tr>
</tbody>
</table>

Values are means±s.d.

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![Fig. 3. Urophonogram Type 1. Diamond shape of the sound configuration is clearly seen.](image)

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Fig. 4. Urophonogram Type 2. There are random occurrences of sound spikes.

Fig. 5. Typical Type 3 urophonogram seen in a patient with BPH. The mixture of Type 1 and Type 2 is demonstrated.

Fig. 6. Type 4 urophonogram showing no remarkable sound spikes. This type of urophonogram was usually found in healthy male volunteers.
micturition curves corresponded with the random type.

Type 4 urophonogram is shown in Fig. 6. There were no remarkable sound spikes generated by the turbulent flow at the bladder neck. Uroflowmetric analysis also exhibited the normal pattern.

Frequencies of these four types of urophonograms in the healthy male volunteers and the patients with BPH are shown in Table 2. It was clearly demonstrated that the urophonograms of normal healthy male volunteers belonged to Type 4. No exceptions were noted. Urophonograms of BPH distributed equally on Types 1, 2 and 3. BPH had no Type 4 urophonograms.

**DISCUSSION**

Recently urodynamic investigations have been utilized in determining the diagnosis and prognosis. However, there have been no methods using sounds occurring in the affected areas in urology.

At first it should be checked whether sound occurs when urine passes through the urethra. Then, Reynolds' number was taken into account for the investigation (Nanzando 1981). It is given in the following formula, if we consider urine as water.

\[
R = \frac{U \cdot \rho \cdot r}{\eta}
\]

where \( R \) is a Reynolds' number, and \( \eta \) is the temperature-dependent figure viscosity (at 37°C it is given as 0.007 g/cm, sec). \( U \) is converted into \( Q/S \) (\( Q \) is Maximum urine flow rate, 30 cmm/sec and \( S = \pi r^2 \) : the square of the urethra). \( r \) is the urethral radius (0.45 cm). \( \rho \) is the density expressed as 1 g/cmm.

Therefore, the formula (1) is changed to the following:

\[
R = \frac{Q \cdot \rho \cdot r}{\eta \times \pi r^2} = \frac{30}{0.07 \times \pi \times 0.45} \div 3000
\]

In the normal healthy male volunteers \( r \) is around 1.3 cm, so that the Reynolds' number is below 1000. A Reynolds' number over 1000 would be an evidence of a turbulent flow.
From these theoretical points of view it was postulated that the turbulent flow really existed in the human posterior urethra of the patients with BPH during micturition. If this was true, there would be some possibility of making sounds or noise during voiding.

It is important to develop the device to detect the sounds generated by the urinary flow. The system was composed of three parts: the detector, amplifier, and recorder of the sounds. The detector was settled at the perineum to catch and follow-up the sounds from the urethra. However, there would be some possibility that the sound signal would be mixed up and masked by handling and body movements. To avoid this contamination, the records were taken at one or two min before micturition to know whether there would be other noises. Differentiation of the urethral sounds during voiding with the other noises would be made by analyzing the sound spectrum. By these two procedures it was easy to cut off the noises which occurred in other parts of the body and elsewhere. The amplifier and recorder were equipped to detect and record the sounds with frequencies from 0.4 to 1.5 kHz.

In order to adjust the condition of the patients the bladder was emptied and 200 ml of distilled sterile water was inserted through the catheter.

The healthy male volunteers, their ages matched to the patients with prostatic diseases, were examined to take the sounds from the posterior urethra during micturition. However, no apparent sounds were taken.

Patients with BPH were also examined upon urophonography. On the contrary, to the healthy male volunteers, patients exhibited the occurrence of urethral sounds. The mechanism of the sound utterance might be attributed to mechanical factors, such as narrowing of the bladder neck, rough surface of the prostatic tumors into the urethral lumen. By these mechanisms it might be considered that the sounds were generated in patients with BPH (Richardson and Kofman 1951).

The procedure for the detecting and recording of these urethral sounds was postulated to be called “urophonography”. The records would be named “urophonogram”.

Classification of urophonograms was undertaken. Four types were identified. Type 1 was characterized by a diamond-shaped urophonogram, which might be produced by the urinary flow passing through the narrow channel of the bladder neck. The shape of the sound recording was smooth with gradual increases and decrease. Type 2 urophonograms showed random spike sounds throughout the micturition, which would be generated by an irregular narrowing and widening of the posterior urethra. Type 3 urophonogram was a mixture of Types 1 and 2. Type 4 was characterized by normal and there were no significant or prominent spikes.

Type 1 urophonograms were seen in 32% of the patients with BPH characterized with the urethra of a smooth surface and a narrowing of the bladder neck.
Types 2 and 3 urophonograms were also seen in BPH. Type 4 urophonograms were postulated as normal. This type was seen in healthy volunteers and never noted in the patients with BPH.

The urophonography is characterized with analysis of urine flow dynamics by the detection and recording of the urethral sounds. This procedure is simple, not complicated as those urodynamic procedures ever used. Analyzing the urophonographic parameters would contribute to the diagnosis of obstruction in the lower urinary tract. Moreover this procedure could be used for mass screening and assessing the results of treatments of this urinary tract.

References


