Evaluation and Validation of Ureteric Jet Index by Glomerular Filtration Rate

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RATIONALE AND OBJECTIVES. Ureteric jet index (UJI), a newly developed technique derived from color Doppler ultrasonography, may hold promise in evaluating renal function because of its ability to evaluate individual renal function and the use of nonionizing radiation. To assess the usefulness of UJI, the authors in this study analyzed the relation between UJI and the glomerular filtration rate (GFR).

METHODS. Fifteen adult patients with a wide range of renal function were included in this study. Subjects were well hydrated before color Doppler ultrasonography examinations. The UJI formula was: $V_{\text{mean}}$ (average jet velocity) x $D_{\text{Uet}}$ (duraiton) x $F_{\text{Uet}}$ (jet frequency). GFR was calculated by the radionuclide method. Correlations between UJI, serum creatinine, and GFR were analyzed.

RESULTS. Ureteric jet index had only a fair correlation with GFR. The coefficient of correlation value was 0.61, and the standard error of estimate of GFR was 17.9 ml/min.

CONCLUSIONS. With the measurement of UJI, color Doppler ultrasound can provide both structural images and individual renal function information. It could substitute for a renal scan in determining individual renal function when a radionuclide examination is unavailable. Even if a renal scan were available, UJI can play a valuable role in the ultrasound examination of patients with suspected impaired renal function, providing further assessment of individual renal function.

KEY WORDS. Color Doppler ultrasound; ureteric jet index; urodynamics; renoureteral function.

THE VALUE OF quantitative renal function information is well recognized. Currently, radionuclide renal scanning is the most commonly used method for evaluating individual renal function because of its accuracy, simplicity, and noninvasive nature. However, the facilities for radionuclide examinations are expensive and not very popular. In addition, there are concerns about radiation exposure.

The ureteric jet phenomenon has been long observed by intravenous urography, and as early as 1981 was reported by real-time ultrasound. With the use of color Doppler ultrasound, ureteric jets can be reliably detected. Because the manifestations of ureteric jets are related to renal function and urodynamics, there have been some reports in which color Doppler ultrasound was used to record ureteric jets and assess clinical applications.

In this study, subjects with differing renal function underwent both color Doppler ultrasonography and a Tc-99m diethylenetriamine penta-acetic acid (DTPA) renal scan. The Tc-99m DTPA renal scan provided an accurate determination of the glomerular filtration rate (GFR) of the individual kidneys. Using color Doppler ultrasonography, a urodynamic parameter, the ureteric jet index (UJI), was derived from Doppler waveforms of ureteric jets. We evaluated the usefulness of UJI in assessing renal function by comparing UJI with GFR.

Materials and Methods

To explore the value of UJI as a substitute for the radionuclide renal scan in determining individual renal function in clinical practice, we conducted this prospective study by enrolling 15 adult patients (7 men, 8 women; age range, 25-80 years; mean age 52.4 years) with a wide range of renal dysfunction. The 15 patients had the following diseases: renal stone (5), renal neoplasm (4), acute pyelonephritis (2), chronic renal failure (1), bladder neoplasm (1), hypertension (1), and no evidence of renal abnormality (1). None of the patients had edema or ascites, because we wanted to eliminate this source of an inaccurate GFR determination by radionuclide renal scan. Also, to avoid any influence on urodynamics, none of the patients had a history of urinary tract obstruction.

For each patient, color Doppler ultrasonography and a Tc-99m DTPA renal scan were performed on the same day. Both examinations were analyzed separately without awareness of the findings of the other examination. Serum creatinine was also measured in all the patients within 2 days. Informed consent for the procedures was obtained.
from each patient.

Before color Doppler ultrasonography, each patient was asked to empty the urinary bladder and then to drink 1050 ml of sugarless Chinese tea (Oolong Tea, President Inc., Tainan, Taiwan) in three 350-ml doses at 10-minute intervals. About 10 minutes after the intake of the 1050 ml of Chinese tea, color Doppler ultrasonography was carried out if the urinary bladder was distended. We used a 128XP color Doppler ultrasound scanner (Acuson, Mountain View, CA) with a 3.5-MHz sector probe. The color scale was adjusted as needed. Color gain was set just below the level where noise was seen. With the patient in a supine position, the probe was placed transversely over the patient’s pelvis to view the distended bladder. The ureteric jets were visualized at the level of the trigone of the urinary bladder. A wide sample gate was applied to cover the ureteric jet and to allow a certain range of abdominal wall motion. A low wall filter and low pulse repetition frequency were used to optimize the waveform obtained. The baseline was set to the bottom and the sweep speed at its lowest to cover the whole jet waveform for analysis.

In a previous study, we observed that after being well hydrated, the ureteric jets presented in three phases: the initial phase of pulsed oozing or flattened type (or a combination of both), the steady phase of uniform Doppler waveforms at regular intervals, and a final phase of uneven waveforms at irregular intervals (Fig. 1). The Doppler waveforms of the ureteric jets during the steady phase were recorded for analysis in this study. We measured the averaged phase velocity (Vmean, cm/sec), the jet duration (D, sec), and the jet frequency (F, once per x sec) of the ureteric jets on each side. About 5 to 10 waveforms were adopted for assessment. The UJI was calculated according to the following formula: Vmean (cm/sec) x D (sec) x F (sec⁻¹).

For the Tc-99m DTPA renal scan, each subject was injected intravenously with 185 MBq (5 mCi) Tc-99m DTPA (Pentetate II; Amersham International, London, UK). Differential GFR was determined from the net counts accumulated by each kidney during the first 2 to 3 minutes of the study after correction for background activity. Blood samples were taken at 1 hour and 3 hours postinjection. We used Russell’s double blood sample methods with correction for body surface area to calculate GFR. This method has been proved highly reliable and is recommended for investigational use.

We analyzed the correlation between the UJI, serum creatinine level, and GFR by least-squares analysis. The standard error of the estimate of GFR and the coefficient of correlation were calculated.

**Results**

From the total of 30 ureteric orifices (15 patients), 24 ureteric jets were satisfactorily recorded by color Doppler ultrasound. In 6 patients, no ureteric jets could be observed on one side of the ureteric orifice despite well-visualized ureteric jets on the opposite side. The mean UJI was 10.8 (range, 0–28.2; standard deviation 8.2).

Based on the data from the Tc-99m DTPA renal scan and the double blood sample method, the body surface area-normalized GFR of the individual kidneys of our patients ranged from 0 to 79.7 mL/min/1.73 m² (mean 36.6; standard deviation 22.1). Table 1 shows the UJI and GFR of our patients.

The mean, standard deviation, and range of serum creatinine were 1.62 mg/dL, 0.46 mg/dL, and 0.8 to 8 mg/dL, respectively. UJI had a fair correlation with GFR (Fig. 2). The coefficient of correlation between UJI and GFR was 0.61, and the standard error of the estimate of GFR was 17.9 mL/min. The coefficient of correlation between serum creatinine and GFR was 0.46, and the standard error of the estimate of GFR was 25.5 mL/min. The coefficient of correlation between serum creatinine and UJI was 0.39. Table 2 summarizes the correlation between UJI, serum creatinine level, and GFR.

Figure 1. (A) Initial phase of ureteric jets: pulsed oozing of urine discharge. (B) Steady phase of uniform Doppler waveforms at regular intervals.

**Figure 2. Correlation between UJI and GFR. R: coefficient of correlation; SEE: standard error of estimate.**

**TABLE 1. Summary of the Results of Color Doppler Ultrasound and Tc-99m DTPA Renal Scan**

<table>
<thead>
<tr>
<th>Sex</th>
<th>Age</th>
<th>UJI</th>
<th>GFR</th>
<th>UJI</th>
<th>GFR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>78</td>
<td>0</td>
<td>9.0</td>
<td>11.3</td>
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<tr>
<td>Male</td>
<td>49</td>
<td>26.6</td>
<td>37.6</td>
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<td>Female</td>
<td>45</td>
<td>0</td>
<td>6.9</td>
<td>67.5</td>
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<tr>
<td>Male</td>
<td>64</td>
<td>15.7</td>
<td>31.6</td>
<td>22.9</td>
<td>30.3</td>
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<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
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<td>Male</td>
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<tr>
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<td>------</td>
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</tr>
<tr>
<td>Age</td>
<td>27</td>
<td>40</td>
<td>76</td>
<td>43</td>
<td>80</td>
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<tr>
<td>UJI</td>
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<td>23.8</td>
<td>6.7</td>
<td>9.8</td>
<td>3.8</td>
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<td></td>
<td>53.1</td>
<td>53.8</td>
<td>23.5</td>
<td>57.0</td>
<td>23.0</td>
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<td></td>
<td>7.2</td>
<td>21.5</td>
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<tr>
<td></td>
<td>43.4</td>
<td>49.6</td>
<td>15.7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>GFR</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

UJI: ureteric jet index; GFR: glomerular filtration rate.

TABLE 2. Correlations Between UJI, Serum Creatinine, and GFR

<table>
<thead>
<tr>
<th>Method</th>
<th>Coefficients of regression</th>
<th>Standard error estimate of GFR (ml/min)</th>
<th>Correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ureteric jet index</td>
<td>18.74, 1.65</td>
<td>17.9</td>
<td>0.61</td>
</tr>
<tr>
<td>Serum creatinine</td>
<td>85.08, -7.3</td>
<td>25.5</td>
<td>0.46</td>
</tr>
</tbody>
</table>

UJI: ureteric jet index; GFR: glomerular filtration rate.

Discussion

Our study showed a fair correlation (0.61) between UJI and GFR. The correlation was not very good for, we believe, the following reasons. First, we used UJI, a linear measure, instead of estimating urinary volume. We did not measure urinary volume because it was difficult to determine the diameter of the distal ureteric orifice. Using the current ultrasound instrument, it is impossible to depict the ureteric jet at the pelvoureteral junction. To measure the diameter of the proximal ureteric jet was also not easy, because it was difficult to define the border of the proximal ureteric jet. Second, because we recorded UJI only during the steady phase, not all the produced urine was included. Third, the estimation of urine production by estimating volume alone is itself not a good method of assessing renal function. The problem arises of assessing patients with renal failure in a nonoliguric form. Currently, we do not know at which phase urine is discharged in this type of patient; this issue requires further study. Fourth, although nonvisualization of the ureteric jet was not one of the reasons for the deteriorated correlation between UJI and GFR in this study—our patients with no detectable jets all had markedly impaired renal function on that side—it might be a potential source of error in determining renal function. There is a theory that detection of urinary jets depends on the density differences between ureteric and bladder urine. The jet may not be detectable despite adequate hydration and high rates of diuresis if the well-hydrated patient is allowed to void completely and then refill the bladder before ureteric jet analysis.

Despite only a fair correlation between UJI and GFR, we believe that UJI measurement is valuable clinically. The UJI measurement procedure is simple and can be made part of a routine renal ultrasound examination. Ureteric jets could be easily recorded by color Doppler ultrasound in almost all our patients, except those with very poor renal function. When considering other examinations, although the serum creatinine level is an inexpensive screening test for renal function, our study revealed a poor correlation (0.46) between serum creatinine level and GFR. In addition, serum creatinine can provide only global renal function, whereas UJI can assess individual renal function. Radionuclide renal scanning offers a more accurate determination of individual renal function than UJI. However, depiction of detailed anatomic structures is impossible with a renal scan. The facility for radionuclide examination is expensive. Radiation exposure and the cost of radiotracers are also disadvantages of renal scanning. Because renal ultrasound is a popular clinical examination method, with the use of color Doppler and ureteric jet analysis, renal ultrasound may become more powerful, useful, and cost-effective by providing both anatomic and functional information in a single examination.

The manifestations of ureteric jets are related to renal function, renal pelvic filling, ureteric filling, and ureteric discharge of urine. The production of urine depends on renal function, as the minor calyces pump the urine into the major calyces and renal pelvis by active and rhythmic, but pressure-independent, peristalsis. The renal pelvis then
contracts intermittently at a rate dependent on diuresis to transport urine into the upper ureter. With adequate hydration, the renal pelvic urine flow leads to continuous production of small volumes of urine; this keeps the ureter open and finally induces a ureteric discharge of urine through the summed contractions of the calyces, the renal pelvis, and the ureter itself.

Color Doppler ultrasound is at present the best modality to observe ureteric jets. Velocity, duration, and frequency of ureteric jets can be recorded. Because ureteric jets are related to renal function and urodynamics, the clinical applications of ureteric jets, including examining renal function, have been assessed. For evaluating renal function, Blomley et al. used jet frequency to determine divided renal function, with encouraging results. However, they also mentioned that an index that could account for differences in jet volumes and duration would be more useful. Therefore, in our study we adopted the UJI by combining average velocity, jet duration, and jet frequency to determine renal function.

A standard procedure is necessary for quantitative analysis of ureteric jets. Because the frequency, duration, and amplitude of ureteric jets vary greatly according to fluid intake, all patients should be well hydrated. In view of the diuretic effect of tea, we adopted Chinese tea instead of water in this study. Previously we found that the intake of 1050 mL of Chinese tea had an effect similar to that of 1500 mL of water on the ureteric jet phenomenon. Recording time is also important. We picked up the ureteric jets only at the steady phase. During this steady phase, the waveforms of the ureteric jets are of uniform shape with similar jet velocity, duration, and regular intervals. With this standard procedure, we solved the problem of temporal variation in ureteric jets. Determining an optimal plane and vector of the ureteric jets is crucial for their analysis. It is also of great importance to maintain the cursor precisely in the center of the jets during examination to obtain consistent results. To achieve this, longitudinal, transverse, and oblique scanning of ureteric jets should all be done to obtain the optimal plane for positioning the transducer.

Urinary tract obstruction is a limitation in using ureteric jets to evaluate renal function. No jets, flattened waveform, absence of a late peak, shortening of jet duration, decreased mean velocity, and less jet frequency have been observed in patients with urinary tract obstruction. Thus, the urodynamic changes of urinary tract obstruction may cause underestimation of renal function by ureteric jets. Further investigations are therefore needed to determine the use of ureteric jets in patients with urinary tract obstruction.

In conclusion, measurement of UJI can make renal ultrasound more valuable. It could serve as a substitute for renal scanning to determine individual renal function when radionuclide examination is unavailable.

References