Evaluation of Doppler ultrasound for renal transplant evaluation

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Disclosure of commercial interest

Neither I nor my immediate family members have a financial relationship with a commercial organization that may have a direct or indirect interest in the content.
## Diagnoses

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Number of patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Normal, with creatinine $\leq 1.5$</td>
<td>7</td>
</tr>
<tr>
<td>2. Delayed graft function post-operatively</td>
<td>6</td>
</tr>
<tr>
<td>3. Acute rejection</td>
<td>8</td>
</tr>
<tr>
<td>4. Chronic rejection, transplant glomerulopathy, or drug toxicity, creatinine $&gt; 1.5$</td>
<td>5</td>
</tr>
<tr>
<td>5. Hydronephrosis</td>
<td>5</td>
</tr>
<tr>
<td>6. Renal vein thrombosis</td>
<td>2</td>
</tr>
<tr>
<td>7. Other</td>
<td>14</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>47</strong></td>
</tr>
</tbody>
</table>
Resistive index = \frac{V_{max} - V_{min}}{V_{max}}
Resistive index

Sensitivity 38% for acute rejection
Specificity 63%

<table>
<thead>
<tr>
<th>Resistive index</th>
<th>Normal (0.71 ± 0.11)</th>
<th>Acute rejection (0.77 ± 0.11)</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.7</td>
<td>20%</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>0.70 – 0.79</td>
<td>35%</td>
<td>35%</td>
<td>5%</td>
</tr>
<tr>
<td>0.80 – 0.89</td>
<td>25%</td>
<td>10%</td>
<td>5%</td>
</tr>
<tr>
<td>0.90 – 0.99</td>
<td>10%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥1</td>
<td>10%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Acute rejection
Delayed graft function
Renal vein thrombosis
Mid renal artery velocity waveform
Velocity waveforms

Renal artery flow (ml/s)

Fraction of cardiac cycle

Normal
Acute rejection
Velocity waveforms

Renal artery flow (ml/s)

Fraction of cardiac cycle

- Normal
- Acute rejection
- Delayed graft function
- Chronic rejection
- Hydronephrosis
- Renal vein thrombosis
- Other
Velocity waveforms (average)

Normal

Acute rejection

Renal vein thrombosis

Main renal artery flow (ml/s)

Fraction of cardiac cycle
Velocity waveforms (Average ± stdev)

Thick lines: average
Thin lines: one standard deviation

Main renal artery flow (ml/s)

Fraction of cardiac cycle

Normal
Acute rejection
Renal vein thrombosis
Windkessel model

Systole

Pulsatile pump

Continuous capillary flow

Image credits: Piotr Michał Jaworski (kidney) and User ZooFari on Wikipedia (heart). Creative Commons Attribution-Share Alike 3.0 Unported license.
Windkessel model

Systole

Pulsatile pump

Continuous capillary flow

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Windkessel model

Diastole

Pulsatile pump

Continuous capillary flow

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Windkessel model

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3-element Windkessel model

\[ R_1 \quad \text{Pre-glomerular resistance (renal artery)} \]
\[ C \quad \text{Vascular compliance} \]
\[ R_2 \quad \text{Post-glomerular resistance (renal vein)} \]
3-element Windkessel model

![Diagram of a 3-element Windkessel model with a distensible tube and resistances $R_1$, $C$, and $R_2$.](image)

- Arterial pressure over time
- Flow velocity over time
Normal
High $R_1$
Normal

Diagram showing a distensible tube connected to two resistances, $R_1$ and $R_2$, and a compliance, $C$. Graphs below show arterial pressure and flow velocity over time.
High $R_2$
Normal

Distensible tube

$R_1$, $C$, $R_2$

Arterial pressure

Flow velocity

Time

Time
Low $C$

![Diagram of a distensible tube with resistance points $R_1$, $C$, and $R_2$. The arterial pressure and flow velocity are shown over time.]
3-element Windkessel model
3-element Windkessel model

Renal vein thrombosis

- Normal
- Acute rejection
- Delayed graft function
- Chronic rejection
- Hydronephrosis
- Renal vein thrombosis
- Other
Doppler ultrasound

Acute rejection can’t be diagnosed using:

• resistive index (intra-renal)
• pre-glomerular resistance
• post-glomerular resistance
• vascular compliance
• the shape of the velocity waveform (mid renal artery)
Conclusions

• Doppler ultrasound of kidney transplants has limited value in diagnosing acute rejection.

• Resistive index > 0.9 is seen in acute rejection, delayed graft function, and renal vein thrombosis.

• The 3-element Windkessel model can be used to determine vascular resistance and compliance.
Additional slides
3-element Windkessel model

Resistive index is increased with:

• Increased $R_2$ (post-glomerular resistance)
• Decreased $R_1$ (pre-glomerular resistance)
• Increased $C$ (vascular compliance)
• Increased pulse pressure
• Increased heart rate
Principal component analysis

**Average waveform**

**Principal components**

![Graph showing average waveform and principal components](image_url)
Principal component analysis

- Biphasic pulsatility vs. Flow
- Triphasic pulsatility vs. Flow

Symbols:
- ● Normal
- ■ Acute rejection
- ▲ Delayed graft function
- ▲ Chronic rejection
- ○ Hydronephrosis
- ▲ Renal vein thrombosis
- □ Other

Chronic rejection:
- ▲ Delayed graft function
- ○ Hydronephrosis
- ▲ Renal vein thrombosis
- □ Other