Evaluation of Doppler Ultrasound Velocity Measurements

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Aims

• To evaluate the accuracy of Doppler velocity measurements typically used as a diagnostic tool for arterial diseases

• To investigate the effects of Doppler machine parameter settings on velocity measurements

• To investigate how different transducer and ultrasound machine models influence velocity measurements
The Doppler Effect

- Doppler effect utilised in ultrasound to determine velocity of blood flow within a vessel

\[ f_D = \frac{2 \cdot ft \cdot V \cdot \cos \theta}{c} \]

- \( f_D \) - doppler shift
- \( c \) - speed of sound in tissue
- \( ft \) - transmitted beam
- \( V \) - velocity of the blood
- \( \theta \) - angle of incidence between the ultrasound beam and the direction of the flow

Higher Doppler frequency obtained if:
- velocity is increased
- beam is more aligned to flow direction
- higher frequency is used

flow velocity = V
Carotid Disease

- Patient’s referred for a Doppler carotid scan with suspected Transient Ischemic Attack (TIA) symptoms

- Higher risk of a patient having a stroke with increased narrowing of the arteries (stenosis) supplying the brain
## Quantification of Carotid Artery Disease

<table>
<thead>
<tr>
<th>Degree of Stenosis (%)</th>
<th>Peak Systolic Velocity (PSV) (cm/s)</th>
<th>End Diastolic Velocity (EDV) (cm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>&lt;125</td>
<td>&lt;40</td>
</tr>
<tr>
<td>&lt;50</td>
<td>&lt;125</td>
<td>&lt;40</td>
</tr>
<tr>
<td>50-69</td>
<td>125-230</td>
<td>40-100</td>
</tr>
<tr>
<td>≥ 70</td>
<td>&gt;230</td>
<td>&gt;100</td>
</tr>
<tr>
<td>Near Occlusion</td>
<td>High, low, or undetectable</td>
<td>Variable</td>
</tr>
<tr>
<td>Total Occlusion</td>
<td>Undetectable</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>

Grant et al. Radiol, Carotid Artery Stenosis: Gray-Scale and Doppler US Diagnosis—Society of Radiologists in Ultrasound Consensus Conference, 2003; 229 (2); pp. 340-46
Carotid Disease

• Surgical intervention is available but possesses its own risks
• 70% stenosis is the NASCET recommended threshold above which natural risk outweighs the risk associated with surgical intervention
• 2363 carotid scans in Cardiff and Vale Trust during 2011
• 162 patients received a carotid endarterectomy or stent surgery
Factors investigated that might affect Doppler velocity accuracy

- Beam-vessel angle
- Doppler machine parameters
- Transducer
- Ultrasound system
Method

• Doppler string and flow phantoms used to assess the various factors that might affect the accuracy of velocity measurements
• Callipers and velocity measuring tools used to determine peak string and flow velocities
• The % error between true and measured velocity values calculated
Doppler String Phantom

- Designed and manufactured within the department under Matthew Talboys’ MSc project by the mechanical workshop
- Motor driven pulley system designed to drive a piece of rubber o-ring through a range of velocities
- Variable voltage supply
Beam Vessel Angle

- Doppler angle varied by steering ultrasound beam
- Waterproof adhesive holding rubber material identified within Doppler spectrum and used to accurately determine the string velocity
- Velocity = Distance / Time
Beam-Vessel Angle

- Measurements made over a range of Doppler angles

\[ y = 0.0235x^2 - 1.4869x + 38.399 \]

\[ R^2 = 0.9986 \]

- Up to 70% error in velocity measurements
- Results measured are consistent with current evidence
- Essential for operators to maintain a 40-60° Doppler angle for routine clinical measurements
Doppler Machine Parameters

- Due to the relative size of blood scattering molecules in relation to the ultrasound wavelength, only a small fraction of the transmitted ultrasound is reflected back towards the transducer.
- Doppler gain settings can be used by the operator to amplify the received signal.
- Doppler signals can be selected from a pre-defined region of interest can be displayed using Duplex.
• Flow phantom programmed to deliver a steady constant flow of 100cm/s

• Doppler gain chosen by operator can vary measured velocity by up to 40%
- Minimal variation in measured velocity when altering Doppler gate width

- Minimal variation in measured velocity when varying Doppler Pulse Repetition Frequency (PRF)
Method

- Doppler flow phantom assessed over a range of velocities using 9 transducers
- Linear and curvilinear transducers primarily used for velocity measurements
- Average % error calculated for each transducer
Doppler Flow Phantom

- Transducers assessed using a portable Gammex RMI flow phantom
- Preset flow programs allow for reproducible comparative testing
Transducer Variation

- All 9 transducers over-estimate the blood velocity by varying degrees of error
- With certain patients receiving multiple carotid examinations over time, important for operators to appreciate errors associated with PSV measurements when reporting scan findings
Transducer Variation

- 30% error obtained from an old 5MHz linear transducer with a Toshiba Nemio ultrasound system
- Transducer and ultrasound system primarily used for training purposes
- The large % error caused by crystal dropout within the transducer, reducing the intensity of Doppler signals received by the transducer
- Important for operators to identify and report any crystal dropout immediately
Ultrasound System Influence

- Measurements performed using same transducer on 4 ultrasound systems
- Minimal variation found in the measured velocities when varying ultrasound system
Conclusions

• 40-60° Doppler angle essential for minimising velocity uncertainty
• Optimum Doppler parameters for specified clinical investigations should be programmed onto ultrasound systems to minimise operator variation
• Users should be aware of errors associated with velocity measurements, and considered when deciding patient outcome
• B-mode greyscale carotid appearance should be included when reporting scan findings
References

• http://0.tqn.com/f/p/440/graphics/images/en/18006.jpg
• Grant et al. Radiol, Carotid Artery Stenosis: Gray-Scale and Doppler US Diagnosis—Society of Radiologists in Ultrasound Consensus Conference, 2003; 229 (2); pp. 340-46
Questions?