Apport et intérêt de l’élastrographie dans l’étude des cardiopathies congénitales

*Interest of elastography in CHD*

Olivier Villemain
Necker-Enfants Malades, Paris, France

Congrès FCPC, Lille, 2018
Apport et intérêt de l’élastrographie dans l’étude des cardiopathies congénitales

Interest of elastography in CHD

Olivier Villemain
Necker-Enfants Malades, Paris, France

Congrès FCPC, Lille, 2018
élastographie

Apport et intérêt de l’élastographie dans l’étude des cardiopathies congénitales

Interest of elastography in CHD

Olivier Villemain
Necker-Enfants Malades, Paris, France

Congrès FCPC, Lille, 2018
Use of ultrasound in medicine

1938: First ultrasound medical exploration (Dr Dussik, psychiatrist)

1952: Using the Doppler effect (Howry, Wild et Reid; USA)

1967: First medical images performed by an ultrasound system

1970-80: Mechanical sweeping with motorized movement of a ultrasound probe → first imagery of a moving tissue

1980-90: Improved digital memory → real-time multilocalization

1990-2000: Hardware optimization, miniaturization, appearance of matrix array probes...

2000-2010: Technological opportunity (GPU) to process more information in a short time. Appearance of the very high frame rate in real time
Use of ultrasound in medicine

1938: First ultrasound medical exploration (Dr Dussik, psychiatrist)

1952: Using the Doppler effect (Howry, Wild et Reid; USA)

1967: First medical images performed by an ultrasound system

1970-80: Mechanical sweeping with motorized movement of a ultrasound probe → first imagery of a moving tissue

1980-90: Improved digital memory → real-time multilocalization

1990-2000: Hardware optimization, miniaturization, appearance of matrix array probes…

2000-2010: Technological opportunity (GPU) to process more information in a short time. Appearance of the very high frame rate in real time

1971: 1st microprocessor

1999: 1st GPU accessible to the public (Nvidia GeForce FX)
Conventional Imaging

- 128 to 512 transmits for a full image (typically 10 to 50 ms)

Ultrafast Imaging

- 1 single transmit for a full image (typically 100 to 500 µs)

Sandrin, et al. Ultrasonic Imaging. 1999
Tanter et al. IEEE Transactions on Ultrasonics. 2002
Ultrasound Imaging

- Imaging of Natural waves
  - Electromechanical Wave Imaging
  - Pulse Wave Imaging

- Shear Wave Elastography
  - Real Time and Quantitative Imaging
  - Already widely spread in clinics

- Ultrafast Doppler Imaging
  - Unites color flow Imaging and PW Doppler
  - Cardiovascular applications
  - High sensitivity Doppler imaging
  - Tumor vascularization imaging

- Ultrafast Ultrasonic Imaging
  - Reaching the physical limits of Ultrasound Acquisition at kHz frames per second

- Ultrafast Contrast Imaging
  - Molecular imaging
  - Higher contrast
  - Non disruption of bubbles

- fUS imaging of brain Activity
  - Versatile imaging tool in Neuroscience
  - Portable fUS imaging on awake animals
  - Transfontanellar and peroperative fUS
Institut Langevin
ONDES ET IMAGES

Imaging of Natural waves
- Electromechanical Wave Imaging
- Pulse Wave Imaging

Shear Wave Elastography
- Real Time and Quantitative Imaging
- Already widely spread in clinics

Ultrafast Doppler Imaging
- Unites color flow Imaging and PW Doppler
- Cardiovascular applications
- High sensitivity Doppler imaging
- Tumor vascularization imaging

Ultrafast Ultrasonic Imaging
- Reaching the physical limits of Ultrasound
- Acquisition at kHz frames per second

Ultrafast Contrast Imaging
- Molecular imaging
- Higher contrast
- Non disruption of bubbles

fUS imaging of brain Activity
- Versatile imaging tool in Neuroscience
- Portable fUS imaging on awake animals
- Transfontanellar and peroperative fUS

Tissue Motion
Blood Motion
Micro Bubbles
Neurovascular coupling
Elastography: medical imaging technique (ultrasound or MRI) to measure the elasticity of biological tissue in an organ

\[ E = 3 \mu \]

Shear Modulus

\[ \mu = \rho (Vc)^2 \]
Shear wave imaging

- Operator free
- Real time
- Freehand
- Quantitative

Some µm displacements

Time of flight

kPa

35 mm

50 mm
Elastography Applications

Breast

Liver

Prostate

- Evans et Al., Radiology, 2012
- Wong et al, Hepatology, 2009
- Correas et al., Diagnostic and Interventional Imaging, 2013
Is there a link between liver stiffness & right heart preload (= central venous pressure) ?

→ only few, recent (but very interesting) papers…

Millonig et al.¹

Taniguchi et al.²

Jalal et al.³
OBJECTIVE: Evaluation of the variation impact of central venous pressure (CVP) on liver stiffness (LS) in real time by shear wave elastography (SWE) in a cohort of children with heart disease.
Liver stiffness & CVP Results

**Figure 1** Results

Correlation between liver stiffness and central venous pressure (CVP), pre- and post-volume loading, with an example of evaluation of liver stiffness by shear wave elastography (kPa).
Liver stiffness & CVP
Results

Liver Stiffness > classical clinical parameters

Villemain et al. JACC Imaging. 2017
Liver stiffness & CVP
Next?

Table 1. Types of Heart Disease That May Be Associated With Liver Disease

<table>
<thead>
<tr>
<th>Heart Disease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right-sided heart disease</td>
</tr>
<tr>
<td>Fontan physiology</td>
</tr>
<tr>
<td>TOF with residual pulmonary regurgitation</td>
</tr>
<tr>
<td>Complete transposition of the great arteries after atrial switch surgery</td>
</tr>
<tr>
<td>Pulmonary valve disease</td>
</tr>
<tr>
<td>Ebstein anomaly and other tricuspid valve disease</td>
</tr>
<tr>
<td>Eisenmenger syndrome</td>
</tr>
<tr>
<td>Pulmonary hypertension</td>
</tr>
<tr>
<td>Pericardial disease</td>
</tr>
<tr>
<td>Left-sided heart disease</td>
</tr>
<tr>
<td>Left ventricular outflow obstruction</td>
</tr>
<tr>
<td>Mitral valve disease</td>
</tr>
<tr>
<td>Ischemic and nonischemic cardiomyopathy</td>
</tr>
<tr>
<td>Cor triatriatum</td>
</tr>
</tbody>
</table>

TOF indicates transposition of Fallot.
Liver stiffness & CVP
Next?

Table 1. Types of Heart Disease That May Be Associated With Liver Disease

<table>
<thead>
<tr>
<th>Type of Disease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right-sided heart disease</td>
</tr>
<tr>
<td>- Fontan physiology</td>
</tr>
<tr>
<td>- TOF with residual pulmonary regurgitation</td>
</tr>
<tr>
<td>- Complete transposition of the great arteries after atrial switch surgery</td>
</tr>
<tr>
<td>- Pulmonary valve disease</td>
</tr>
<tr>
<td>- Ebstein anomaly and other tricuspid valve disease</td>
</tr>
<tr>
<td>- Eisenmenger syndrome</td>
</tr>
<tr>
<td>- Pulmonary hypertension</td>
</tr>
<tr>
<td>- Percardial disease</td>
</tr>
<tr>
<td>Left-sided heart disease</td>
</tr>
<tr>
<td>- Left ventricular outflow obstruction</td>
</tr>
<tr>
<td>- Mitral valve disease</td>
</tr>
<tr>
<td>- Ischemic and nonischemic cardiomyopathy</td>
</tr>
<tr>
<td>- Cor triatriatum</td>
</tr>
</tbody>
</table>

TOF indicates tetralogy of Fallot.

Figure 1. Noncardiac complications in adults with congenital heart disease (CHD).
Myocardial Elastography

Step 1: Shear wave remote generation

Step 2: Ultrafast imaging (10,000 images/s)

Pernot et al. JACC, 2011
Song et al. J Ultrasound Med. 2015
Pernot et al. JACC Imaging, 2016
The goal of our human studies was to investigate the potential of Myocardial Elastography, to quantify noninvasively the passive diastolic myocardial stiffness in healthy populations (children and adults) and its variation vs. hypertrophic cardiomyopathy with heart failure with preserved ejection fraction (HCM-HFpEF) population.

*What is normal?*

*Could we make a difference between a normal and a pathologic case?*
ClinicalTrial.gov: NCT02619825 (Non-Invasive Evaluation of Myocardial Stiffness by Elastography in Pediatric Cardiology)
1) Shear wave generation

- Acoustic Radiation force
- ~ 300 µs

2) Ultrafast imaging

- Shear wave propagation
- ~ 0.2 ms

ECG Trigger

Villemain et al. JACC Imaging. 2017
(Top) B-mode and shear wave elastography imaging examples from an HCM patient. Shear wave propagation in short- and long-axis views (tissue axial velocity images). (A) Elastography results. (B) Fractional anisotropy results. HCM = Hypertrophic cardiomyopathy; HV = healthy volunteer.
Characteristics of patients with MS > CI95% (>10.5 kPa)

7/28 HCM patients had MS >10.5 kPa.

Among the seven HCM patients who had MS > CI95% (>10.5 kPa), six had an echocardiographic **restrictive profile** assessed by LAVI >48 ml/m², E/A >2, E-wave DT <150 ms, and e’ medial <6 cm/s.
Interpretation of Left Ventricular Diastolic Dysfunction in Children With Cardiomyopathy by Echocardiography: Problems and Limitations
Andreea Dragulescu, Luc Mertens and Mark K. Friedberg

_Circ Cardiovasc Imaging_. 2013;6:254-261; originally published online January 23, 2013;

**Conclusions**—Assessment of DD in childhood CM seems inadequate using current guidelines. The large range of normal pediatric reference values allows diagnosis of DD in only a small proportion of patients. Key echo parameters to assess DF are not sufficiently discriminatory in this population, and discrepancies between criteria within individuals prevent further classification and result in poor interobserver agreement. (Circ Cardiovasc Imaging, 2013;6:254-261.)
Conclusions—Assessment of DD in childhood CM seems inadequate using current guidelines. The large range of normal pediatric reference values allows diagnosis of DD in only a small proportion of patients. Key echo parameters to assess and discrepancies between criteria within individuals prevent further classification and result in poor interobserver agreement. (Circ Cardiovasc Imaging. 2013;6:254-261.)
ClinicalTrial.gov Identifier: NCT02537041 (Non-Invasive Evaluation of Myocardial Stiffness by Elastography)
Results

Aging, with linear increase of myocardial stiffness depending on the age

Significant difference between each age group

For the HCM-HFpEF group (mean MS=12.68±2.91 kPa), the MS was significantly higher than in the healthy volunteer (p<10^-4), with a cut-off identified at 8 kPa (AUC=0.993, Se=95%, Sp=100%).
Valve & Elastography

(A) Example of bioprosthesis elastography in vitro by shear wave elastography. (B) Elastography results (in vitro and in vivo).
Elastography in CHD

Liver

Myocardium

Valve

Conclusion
Thank you for your attention