Institut Langevin
ONDES ET IMAGES

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

Necker
ENFANTS MALADES
HÔPITAL UNIVERSITAIRE

Institut Langevin
ONDES ET IMAGES

Apport et intérêt de l'élast~~r~~ographie dans l'étude des cardiopathies congénitales
Interest of elastography in CHD

Olivier Villemain
Necker-Enfants Malades, Paris, France

Congrès FCPC, Lille, 2018

Necker
ENFANTS MALADES
HÔPITAL UNIVERSITAIRE

élastographie

🤔

Apport et intérêt de l'élast~~r~~ographie dans l'étude des cardiopathies congénitales
Interest of elastography in CHD

Olivier Villemain

Necker-Enfants Malades, Paris, France

Congrès FCPC, Lille, 2018

Institut Langevin
ONDES ET IMAGES

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

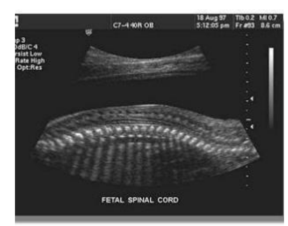
1971: 1st microprocessor

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


1980


1990


1995



2010

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

1971: 1st microprocessor

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

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

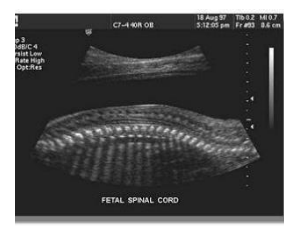
1999: 1st GPU accessible to the public (Nvidia GeForce FX)

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

1980

1990

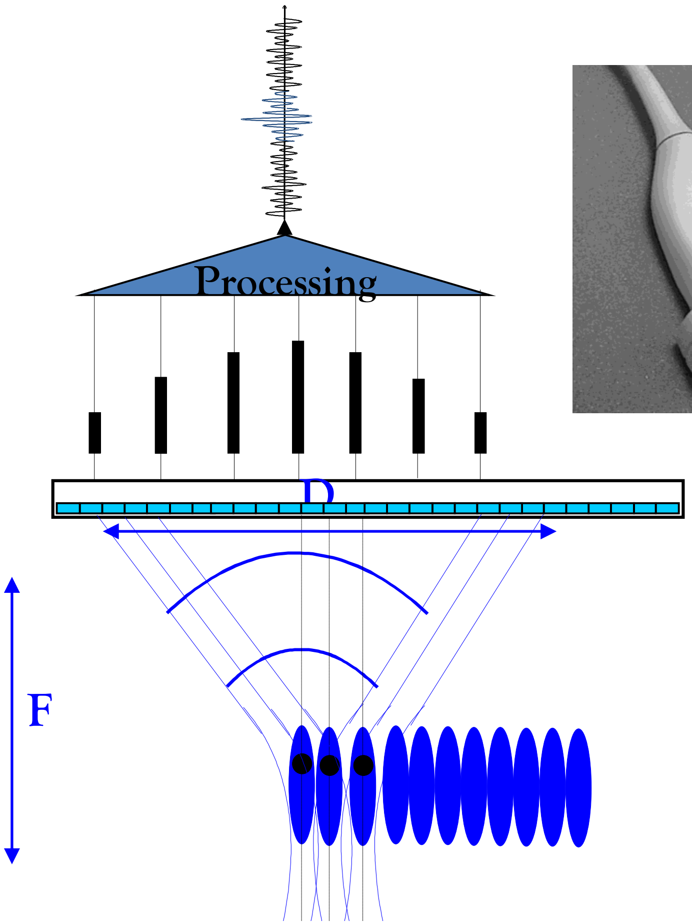
1995



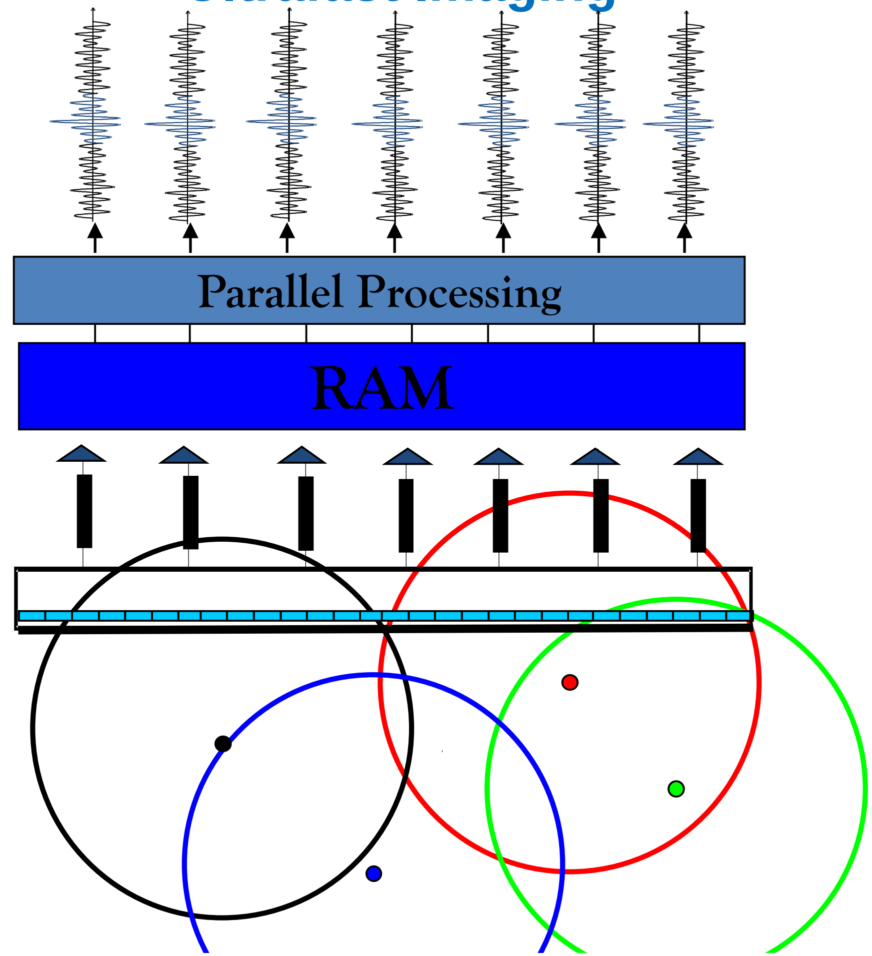
2010

Ultrafast Imaging

Conventional Imaging



Ultrafast Imaging



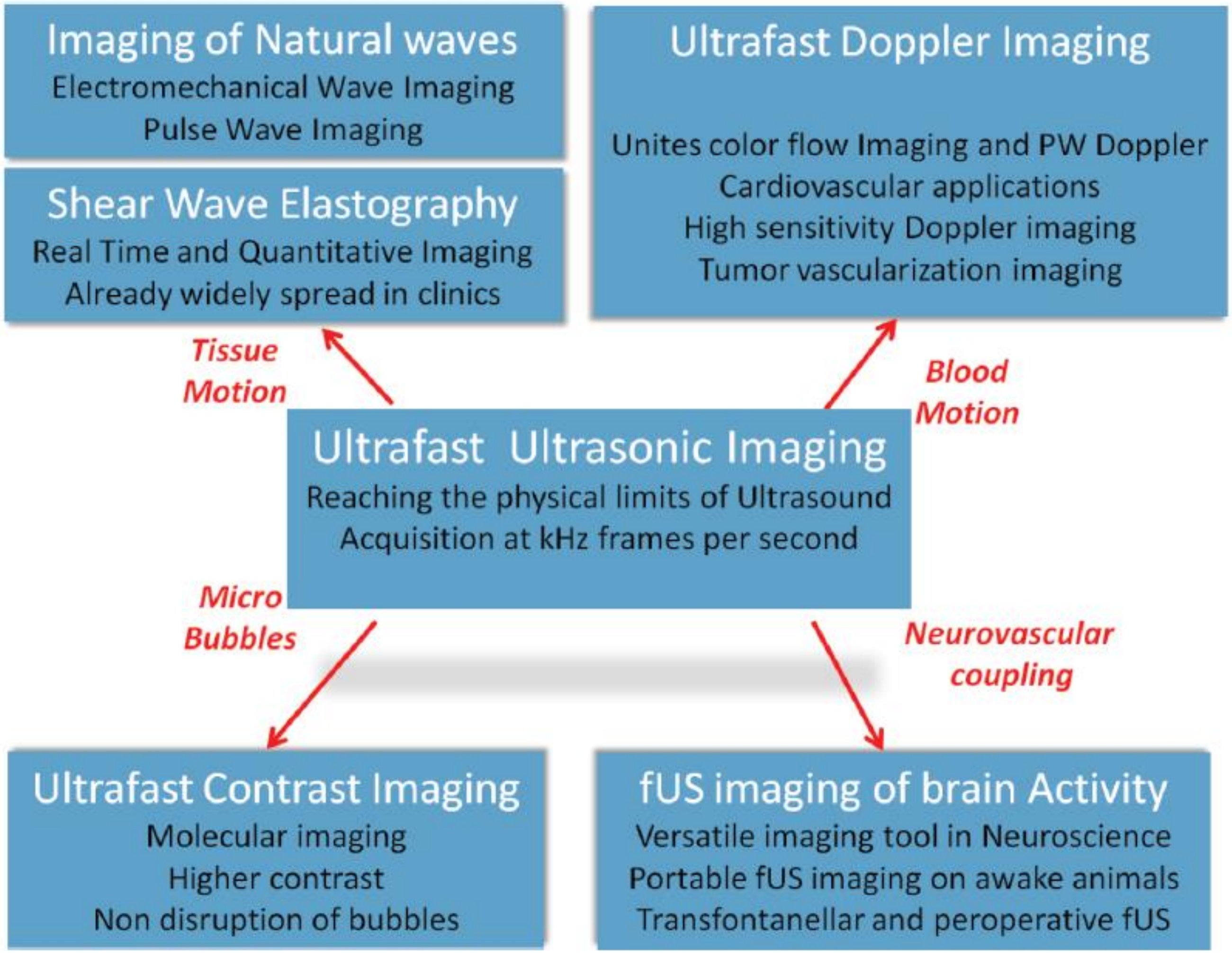
128 to 512 transmits for a full image

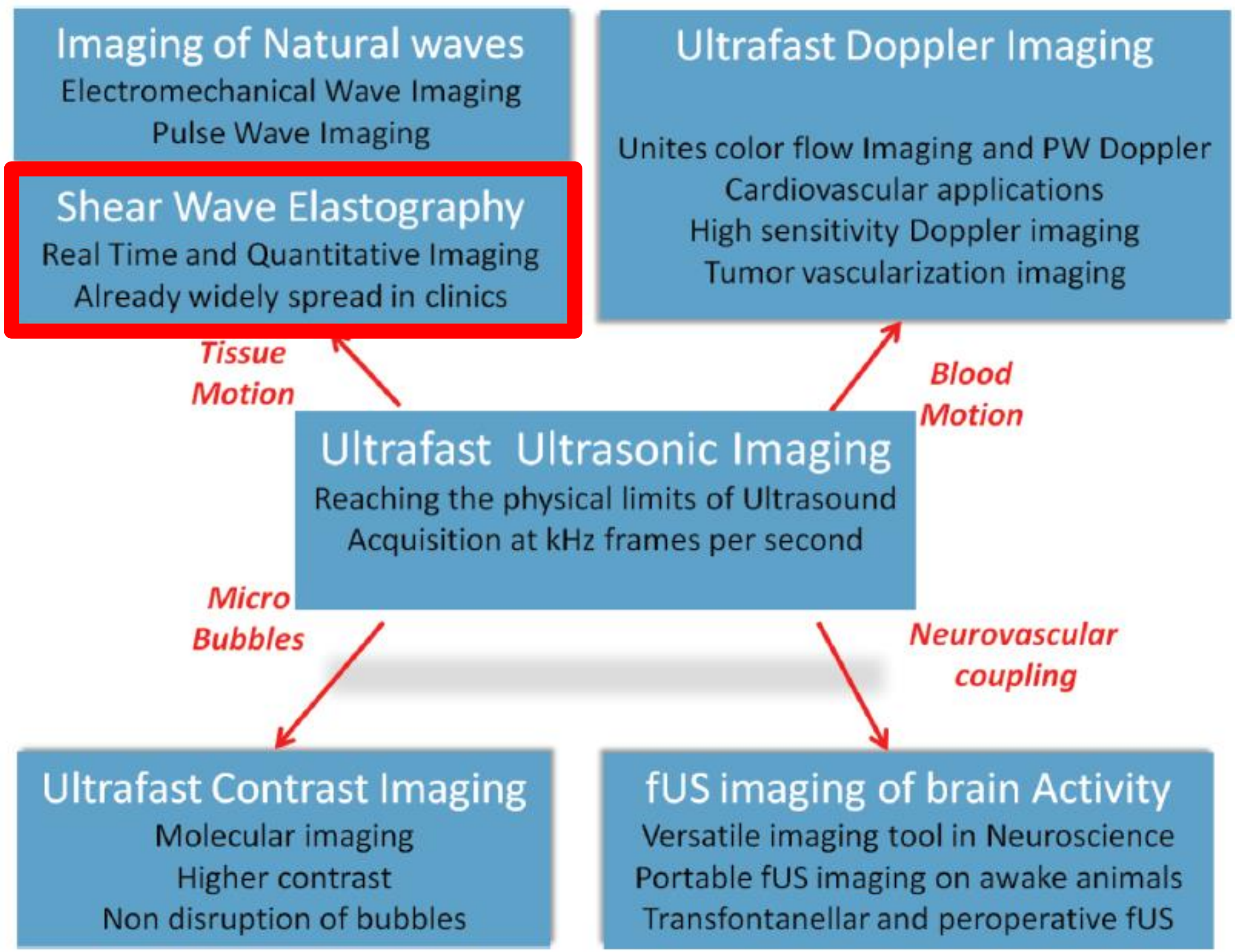
(typically 10 to 50 ms)

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

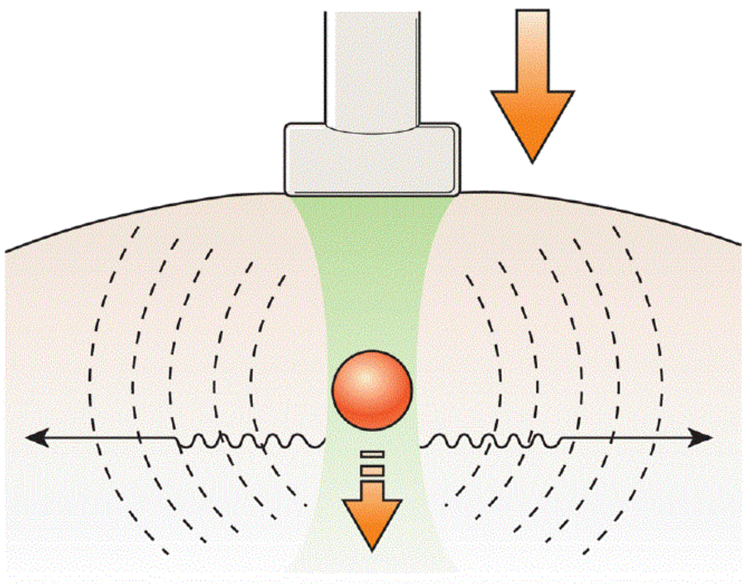

Imaging of Natural waves
Electromechanical Wave Imaging
Pulse Wave Imaging
Shear Wave Elastography
Real Time and Quantitative Imaging
Already widely spread in clinics
Ultrafast Doppler Imaging
Unites color flow Imaging and PW Doppler
Cardiovascular applications
High sensitivity Doppler imaging
Tumor vascularization imaging
Tissue Motion
Blood Motion
Ultrafast Ultrasonic Imaging
Reaching the physical limits of Ultrasound
Acquisition at kHz frames per second
Micro Bubbles
Neurovascular coupling
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

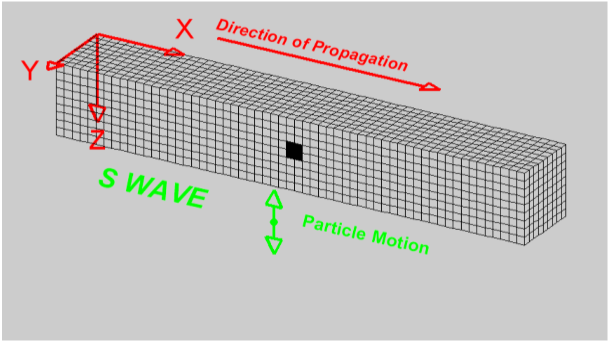

Imaging of Natural waves
Electromechanical Wave Imaging
Pulse Wave Imaging
Shear Wave Elastography
Real Time and Quantitative Imaging
Already widely spread in clinics
Ultrafast Doppler Imaging
Unites color flow Imaging and PW Doppler
Cardiovascular applications
High sensitivity Doppler imaging
Tumor vascularization imaging
Tissue Motion
Blood Motion
Ultrafast Ultrasonic Imaging
Reaching the physical limits of Ultrasound
Acquisition at kHz frames per second
Micro Bubbles
Neurovascular coupling
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


40 TIMES SLOWER

Elastography

Elastography: medical imaging technique (ultrasound or MRI) to measure the elasticity of biological tissue in an organ





Elasticity

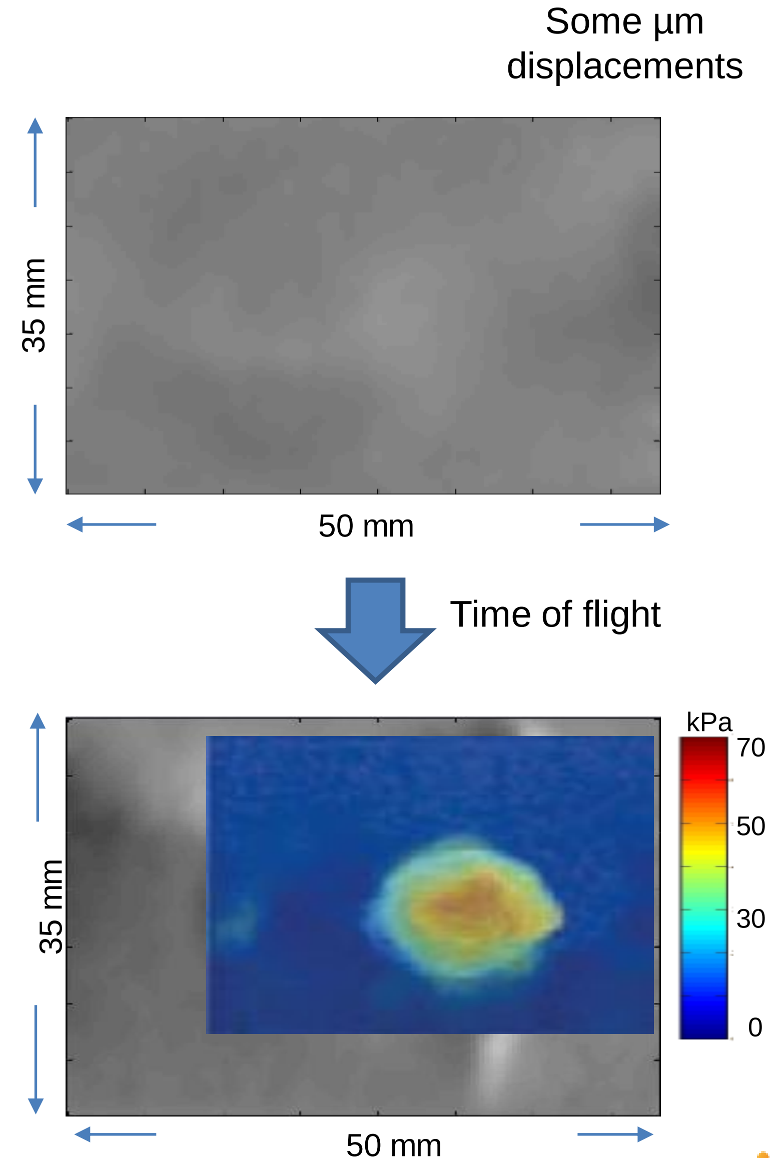
$$E = 3\,\mu$$

Shear Modulus

$$\boxed{\mu = \rho\,(Vc)^2}$$

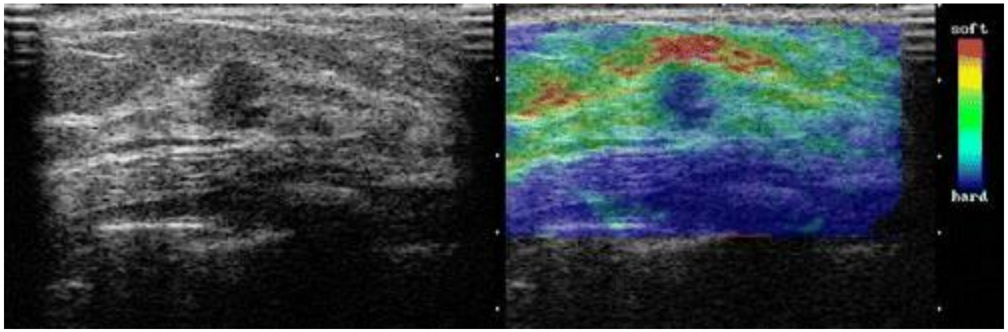
« Shear wave imaging »

- Operator free
- Real time
- Freehand
- Quantitative

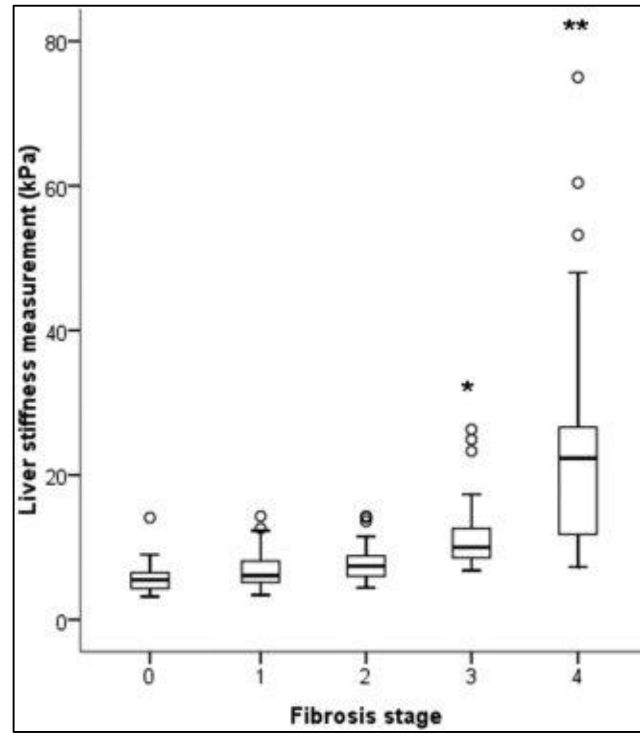


Elastography Applications

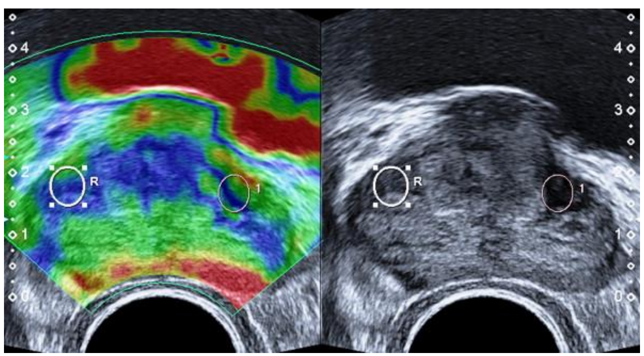
Breast



Liver

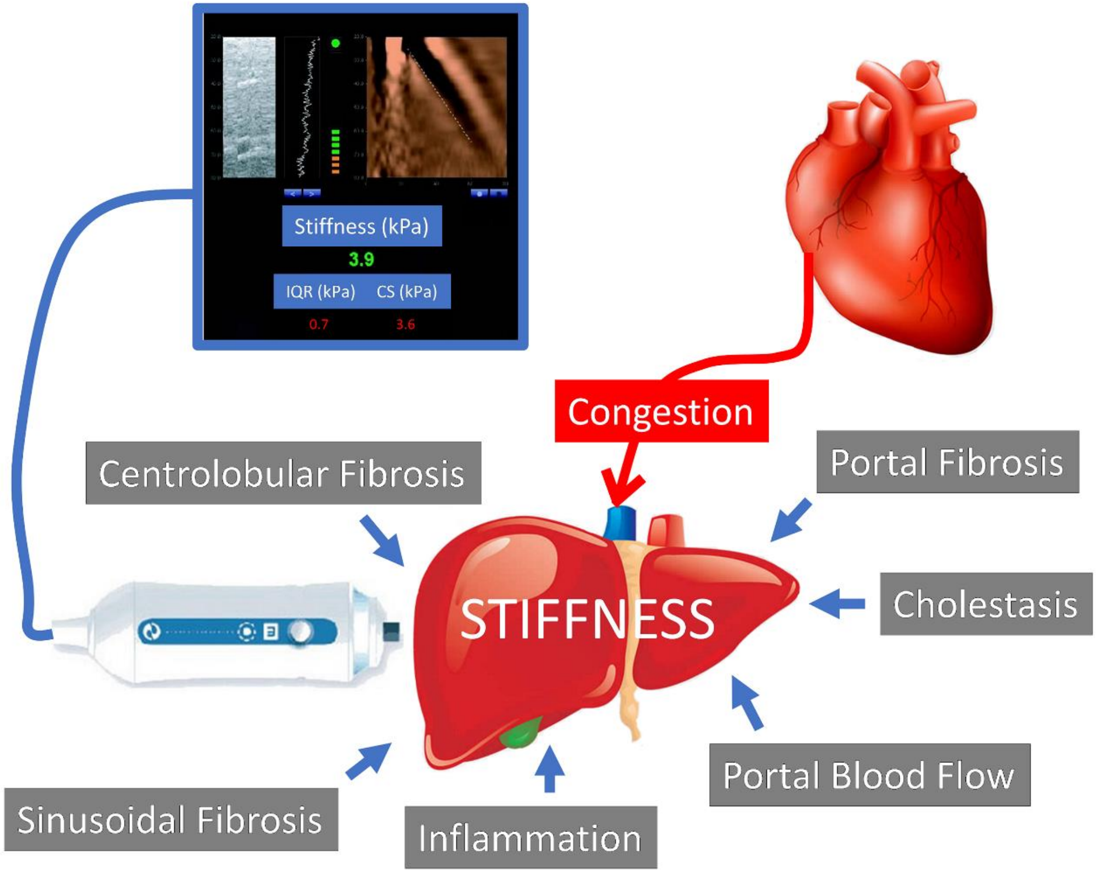


Prostate



- Evans et Al., *Radiology*, 2012
- Wong et al, *Hepatology*, 2009
- Correas et al., *Diagnostic and Interventional Imaging*, 2013

Elastography & Cardiology



Pernot and Villemain. *JACC Imaging.* 2017

Elastography & Cardiology

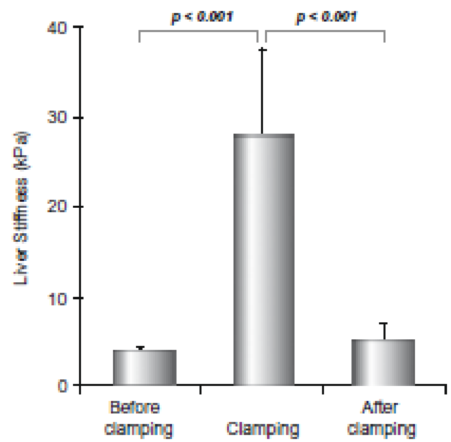
Is there a link between liver stiffness & right heart preload (= central venous pressure) ?

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

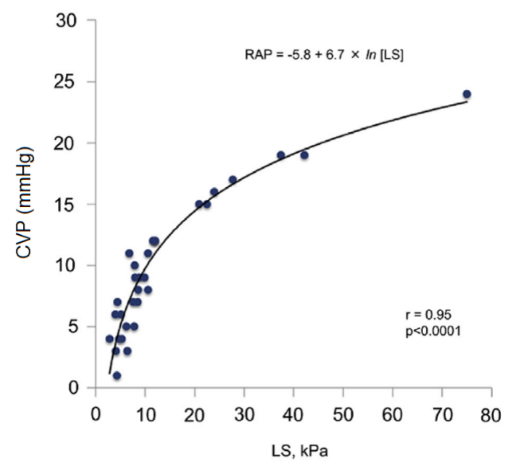
Millonig et al.[1]

Taniguchi et al.[2]

Jalal et al.[3]



Millonig et al



Taniguchi et al

[1] *Journ of Hepatology. 2010*
[2] *Am Journ Cardiology. 2014*
[3] *Heart. 2015*

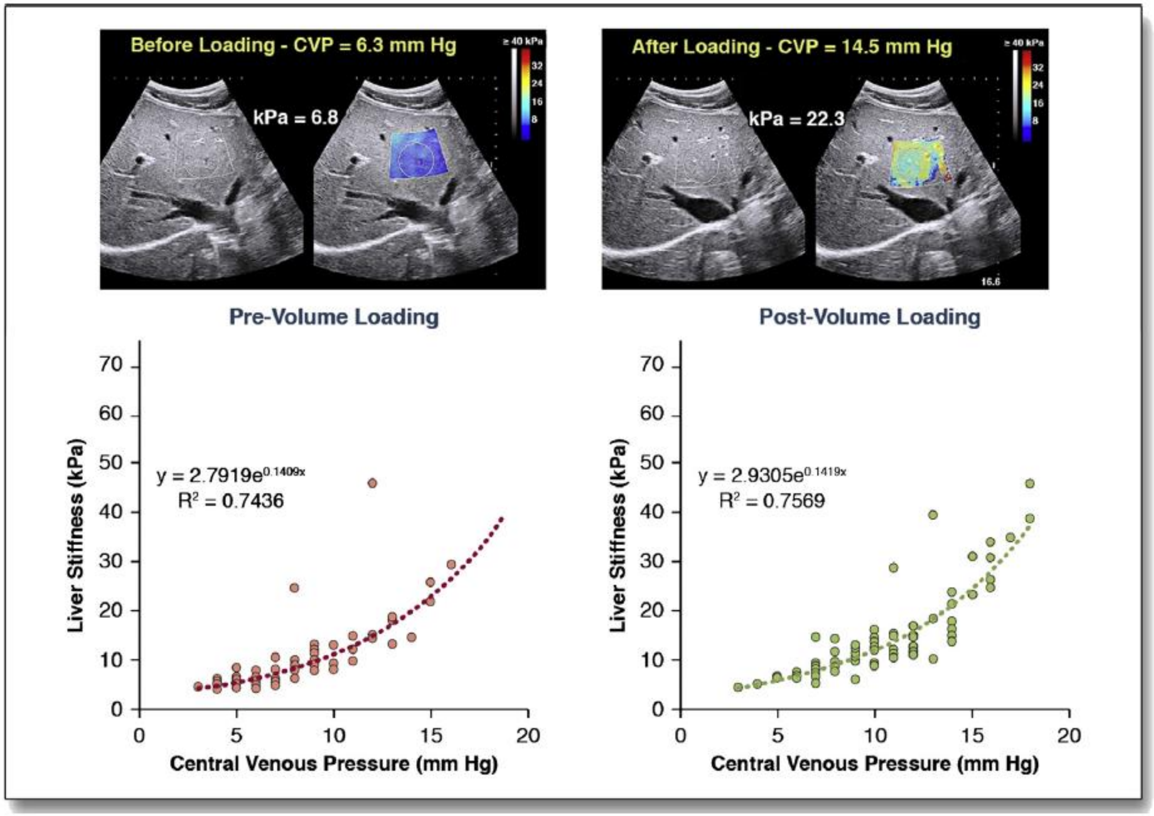
Clinical study – Liver stiffness

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.

Villemain et al. *JACC Imaging.* 2017

Liver stiffness & CVP
Results

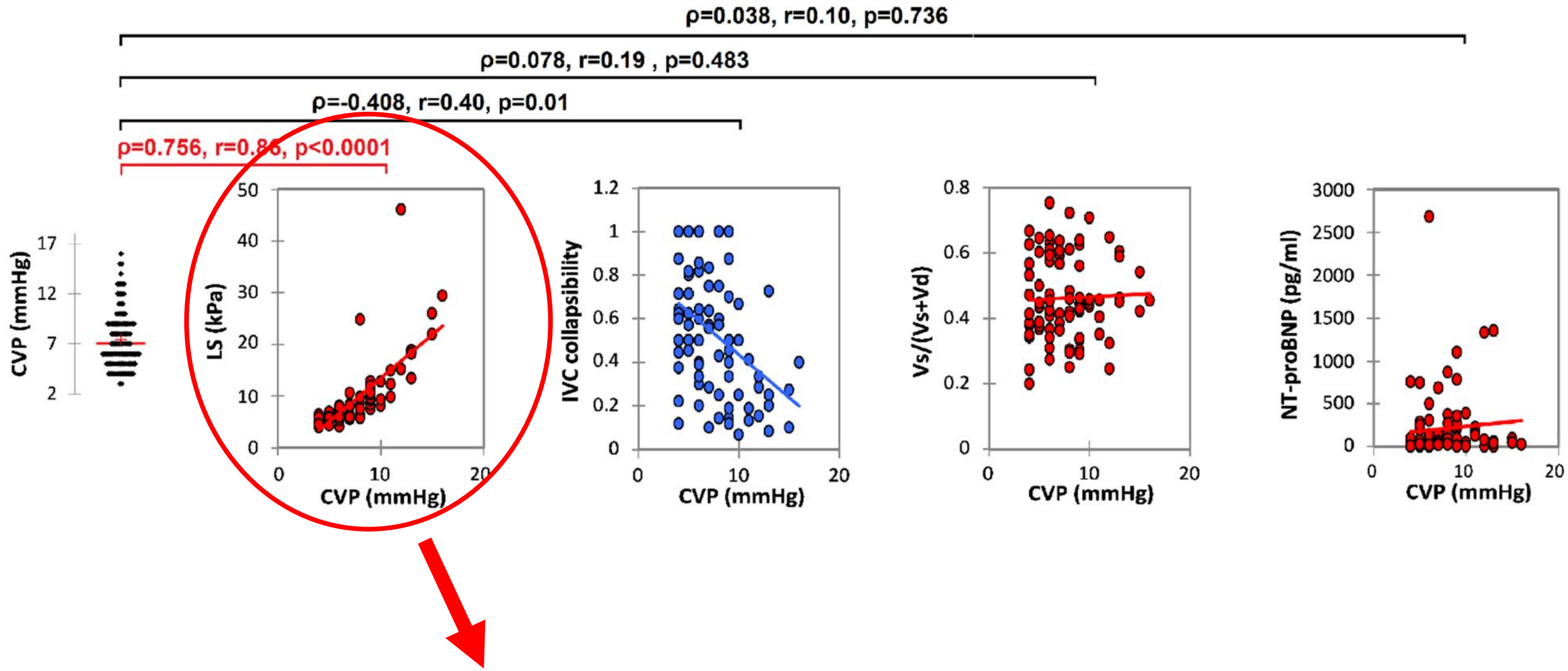
FIGURE 1 Results



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).

Villemain et al. *JACC Imaging.* 2017

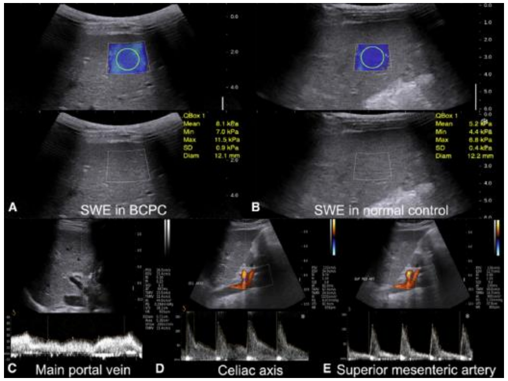
Liver stiffness & CVP
Results

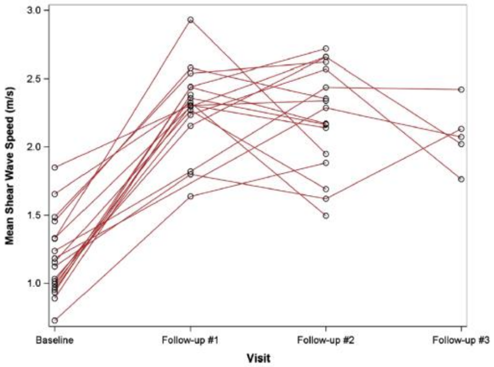


Liver Stiffness > classical clinical parameters

Villemain et al. *JACC Imaging.* 2017

Liver stiffness & CVP
Next?





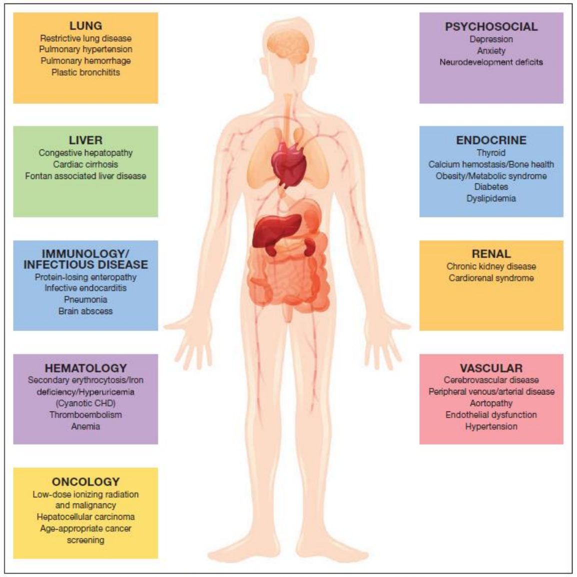


Figure 1. Noncardiac complications in adults with congenital heart disease (CHD).

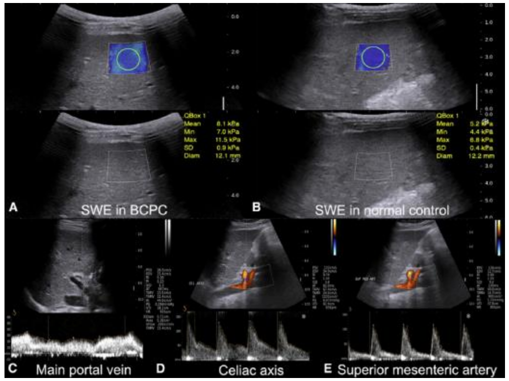
Table 1. Types of Heart Disease That May Be Associated With Liver Disease

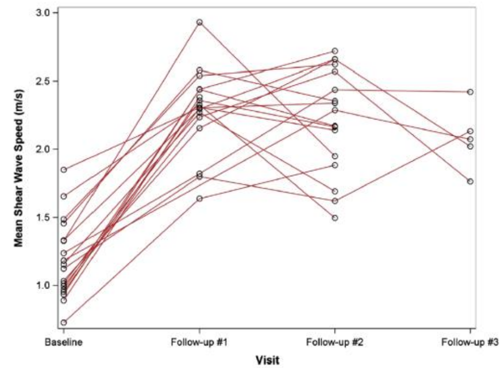
Right-sided heart disease
Fontan physiology
TOF with residual pulmonary regurgitation
Complete transposition of the great arteries after atrial switch surgery
Pulmonary valve disease
Ebstein anomaly and other tricuspid valve disease
Eisenmenger syndrome
Pulmonary hypertension
Pericardial disease
Left-sided heart disease
Left ventricular outflow obstruction
Mitral valve disease
Ischemic and nonischemic cardiomyopathy
Cor triatriatum

TOF indicates tetralogy of Fallot.

Di Paola et al. *Eur Radiol.* 2017
Kutty et al. *JTCVS.* 2016
Burchill et al. *Circ Res*. 2017
Lui et al. *Circulation.* 2017
Mebus et al. *Int J Cardiol*. 2017

Liver stiffness & CVP
Next?





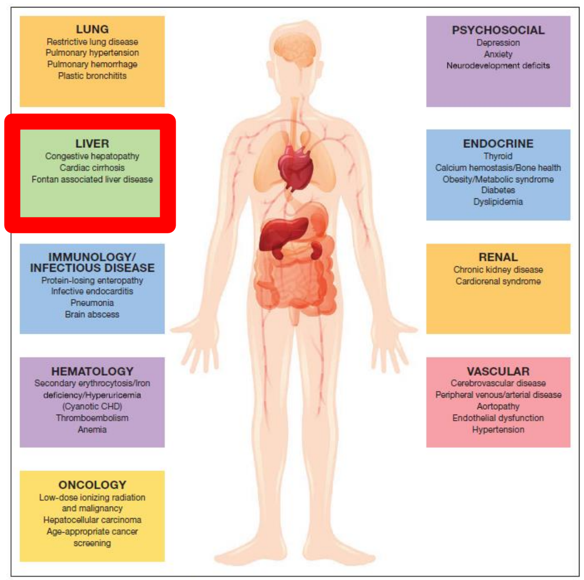


Figure 1. Noncardiac complications in adults with congenital heart disease (CHD).

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

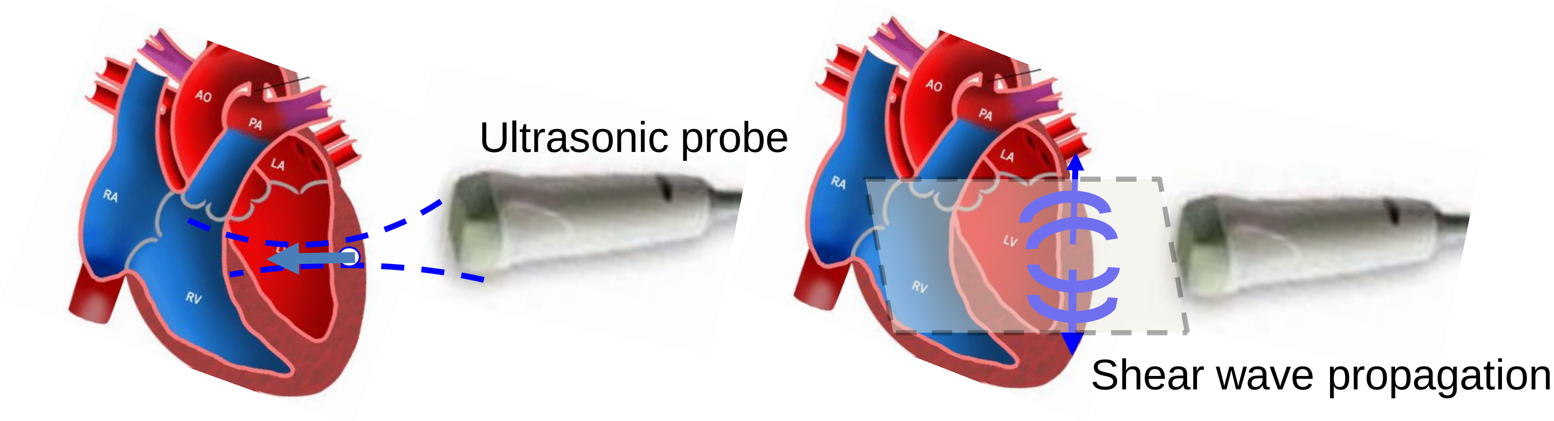
Right-sided heart disease
Fontan physiology
TOF with residual pulmonary regurgitation
Complete transposition of the great arteries after atrial switch surgery
Pulmonary valve disease
Ebstein anomaly and other tricuspid valve disease
Eisenmenger syndrome
Pulmonary hypertension
Pericardial disease
Left-sided heart disease
Left ventricular outflow obstruction
Mitral valve disease
Ischemic and nonischemic cardiomyopathy
Cor triatriatum

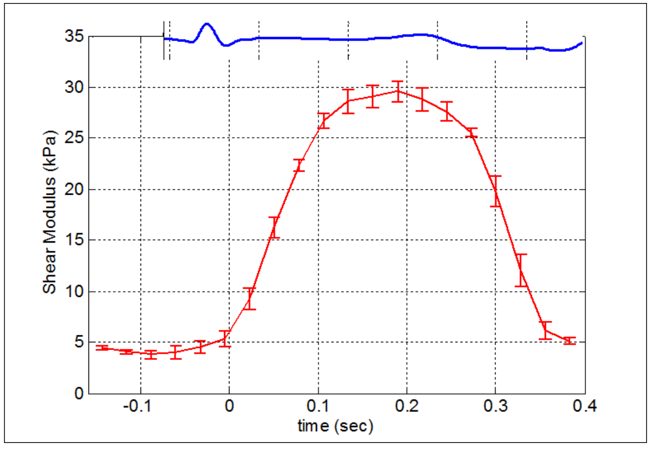
TOF indicates tetralogy of Fallot.

Di Paola et al. *Eur Radiol.* 2017
Kutty et al. *JTCVS.* 2016
Burchill et al. *Circ Res*. 2017
Lui et al. *Circulation.* 2017
Mebus et al. *Int J Cardiol*. 2017

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*

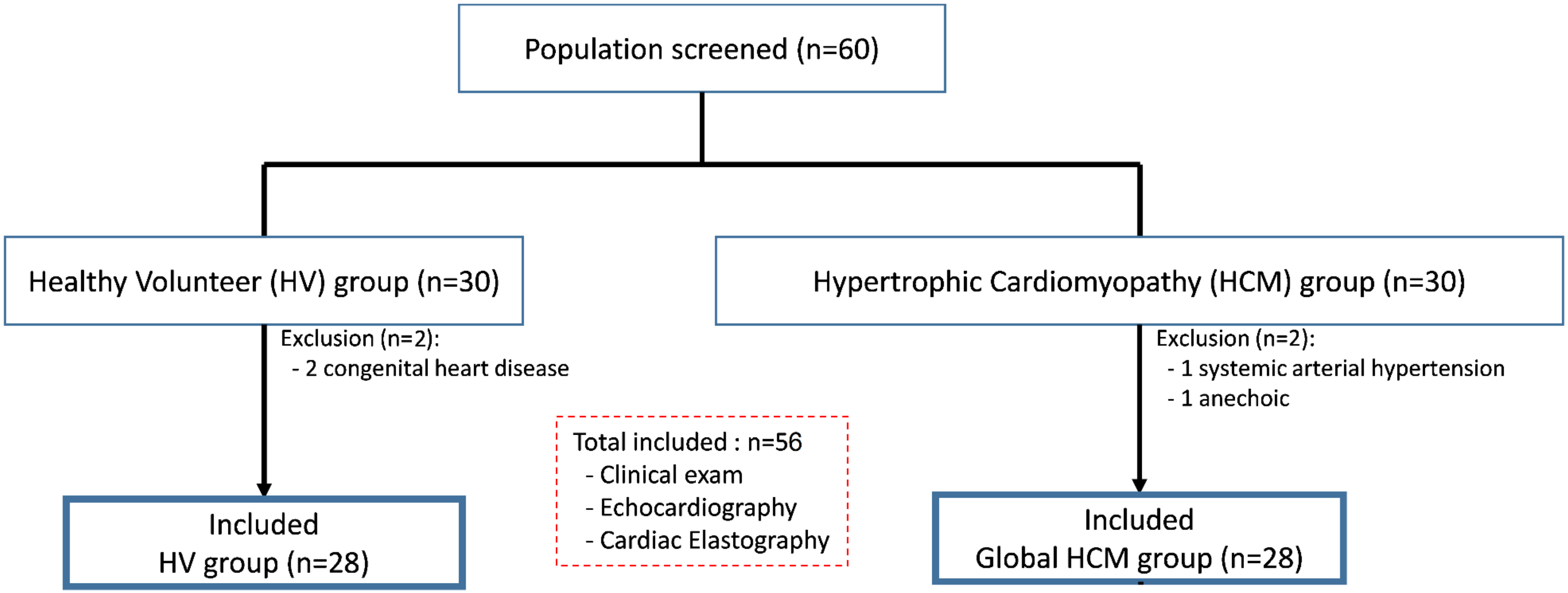
Human studies objective

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?

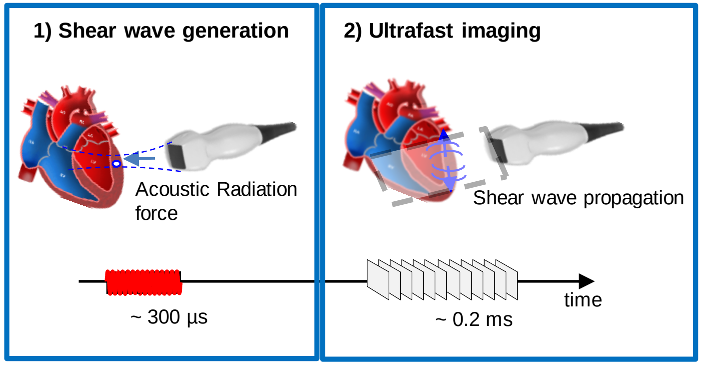
Could we make a difference between a normal and a pathologic case?

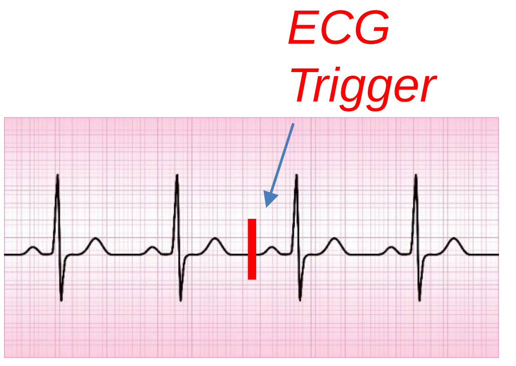
Pediatric Study

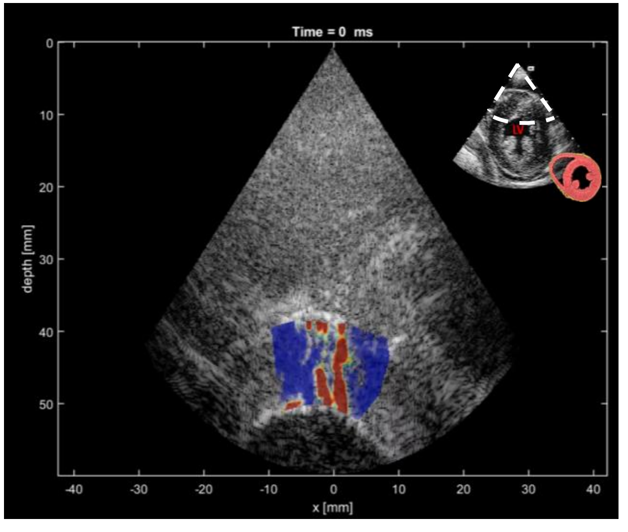


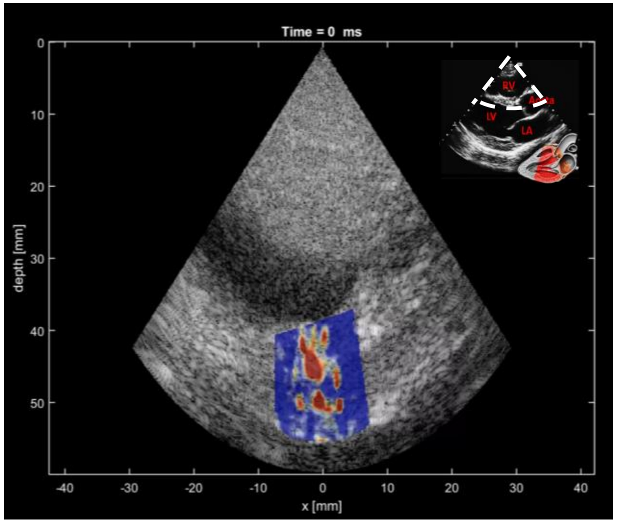
ClinicalTrial.gov: NCT02619825 (Non-Invasive Evaluation of Myocardial Stiffness by Elastography in Pediatric Cardiology)

Villemain et al. *JACC Imaging*. 2017



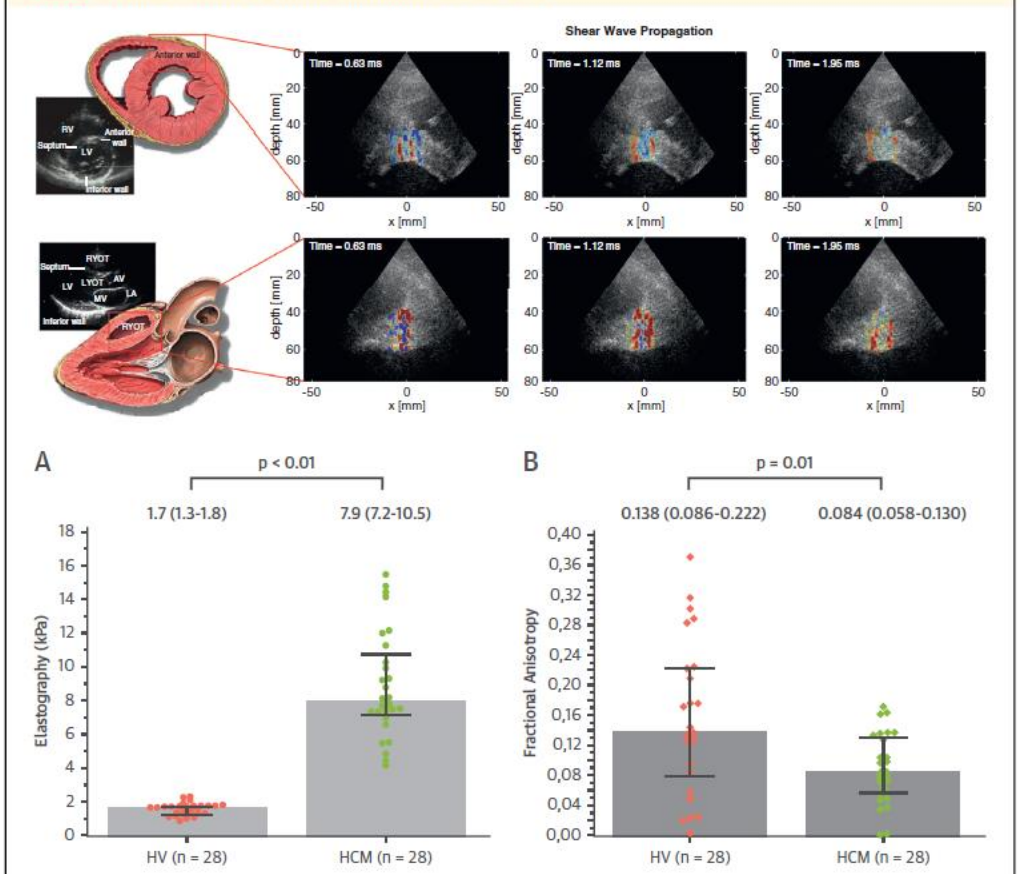






Villemain et al. *JACC Imaging*. 2017

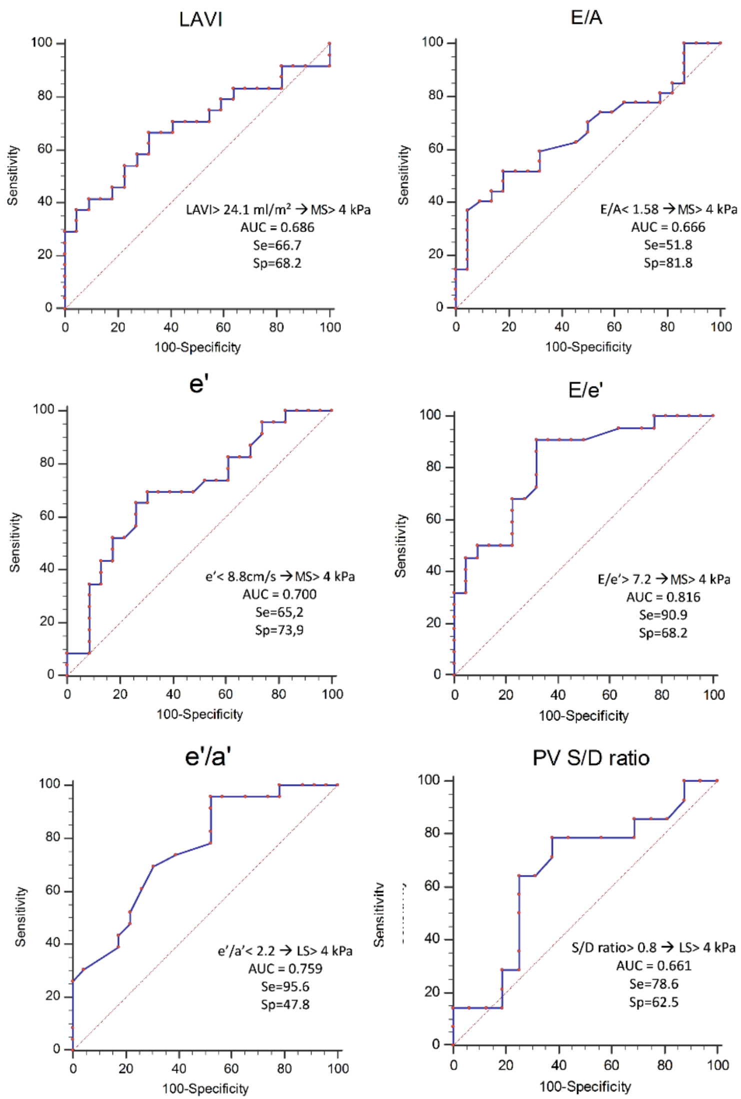
Results



(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.

Villemain et al. *JACC Imaging*. 2017

SWI & Echocardiography



No unique echocardiographic parameter used to estimate the diastolic function of the left ventricle could predict MS up to 4 kPa with high specificity and sensitivity.

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.

Villemain et al. *JACC Imaging*. 2017

Institut **Langevin**
ONDES ET IMAGES

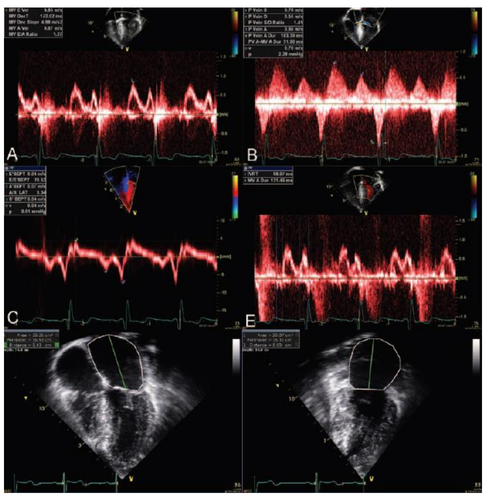
Circulation
Cardiovascular Imaging

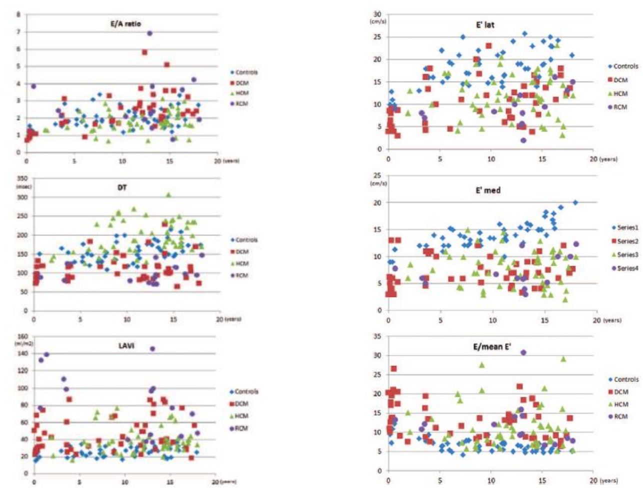
American Heart Association

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.**)

ESPCI ParisTech

Institut Langevin
ONDES ET IMAGES

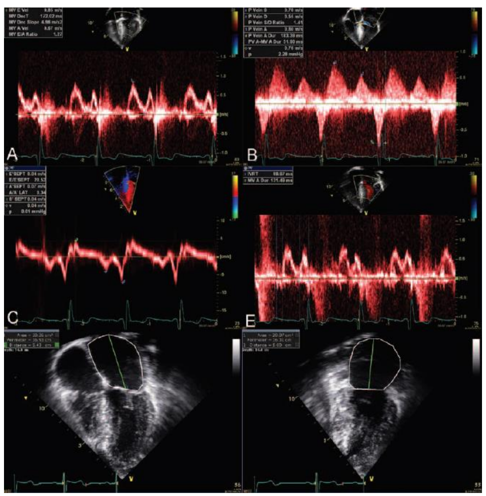
Circulation
Cardiovascular Imaging

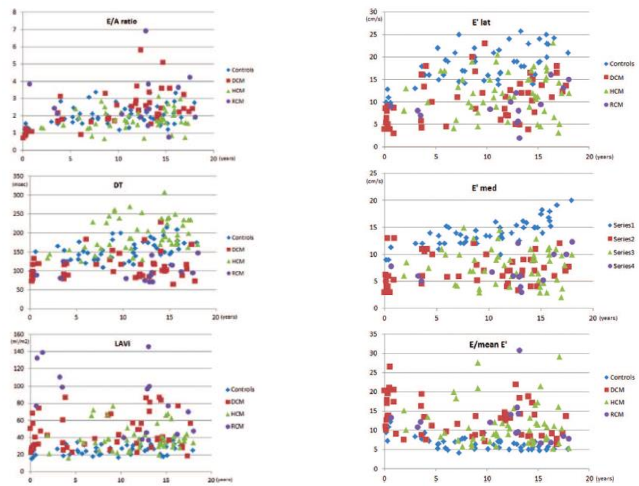
American Heart Association

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;

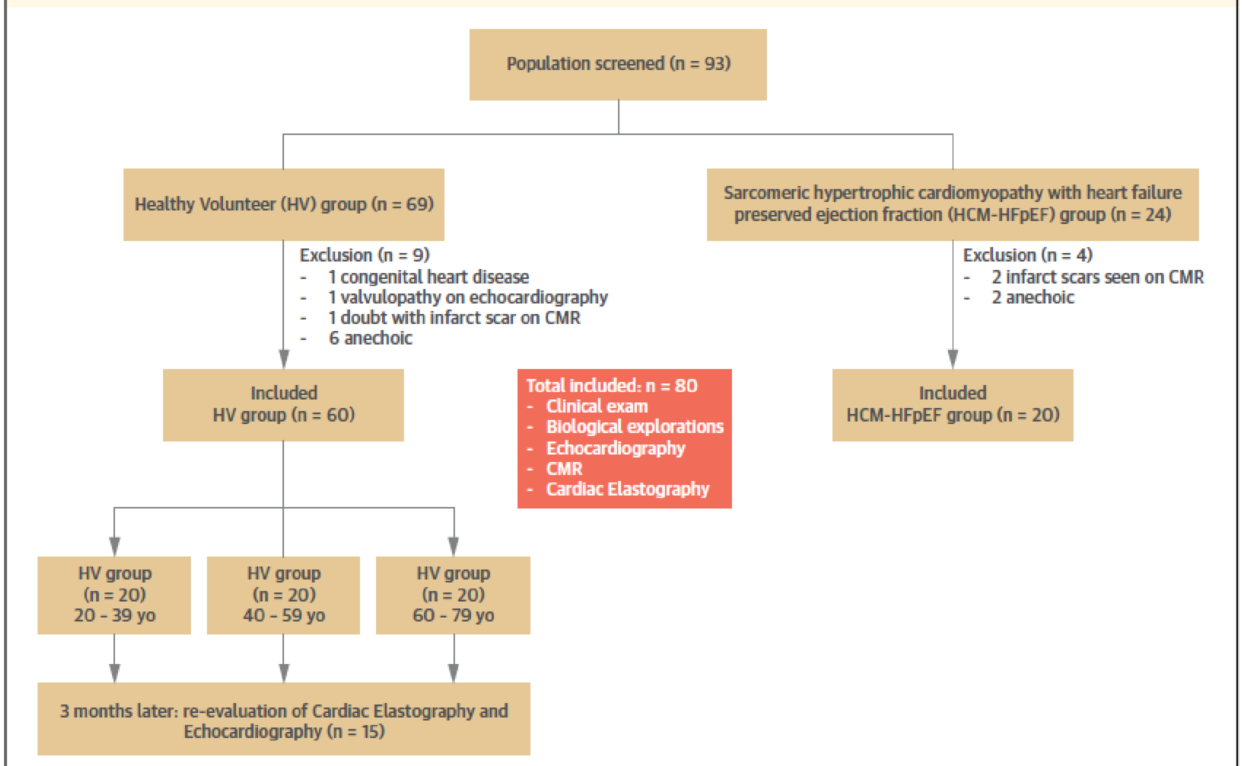




Conclusions*—**Assessment of DD in childhood CM seems inadequate using current guidelines. The large range of normal pediatric reference values allows diagnosis of DD in only a small proportion of patients. Key echo parameters to assess DF are not sufficiently discriminatory in this population, and discrepancies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

ESPCI ParisTech

Adult study



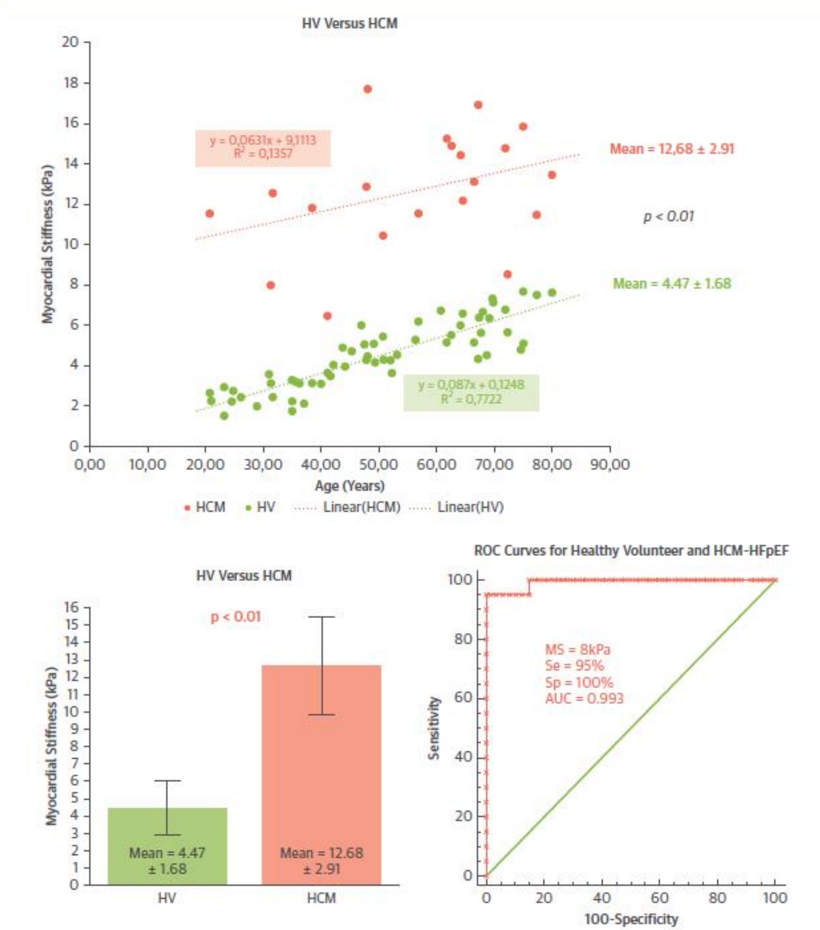
The study was performed on 60 healthy volunteer and 20 HCM patients. CMR = cardiac magnetic resonance; HCM = hypertrophic cardiomyopathy; HFpEF = heart failure with preserved ejection fraction.

ClinicalTrial.gov Identifer: NCT02537041 (Non-Invasive Evaluation of Myocardial Stiffness by Elastography)

Villemain et al. *JACC Imaging*. 2018

Results

FIGURE 4 Myocardial Stiffness in HCM and HV Groups



Comparison of Myocardial Stiffness between healthy volunteer group (HV) and hypertrophic cardiomyopathy with HFpEF group (HCM group). AUC = area under the curve; MS = myocardial stiffness; Se = sensitivity; Sp = specificity; ROC = receiver-operating curve; other abbreviations as in Figures 1 and 2.

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

Significant difference between each age group

For the HCM-HFpEFgroup (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%).

Villemain et al. *JACC Imaging*. 2018

Valve & Elastography

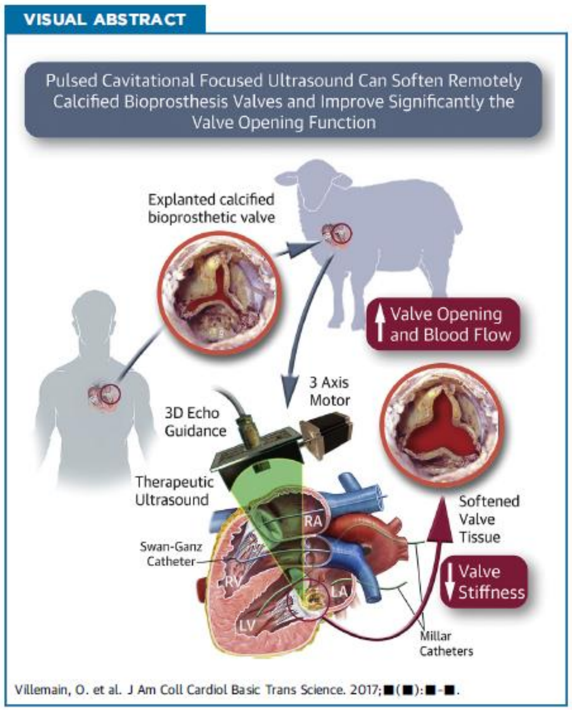
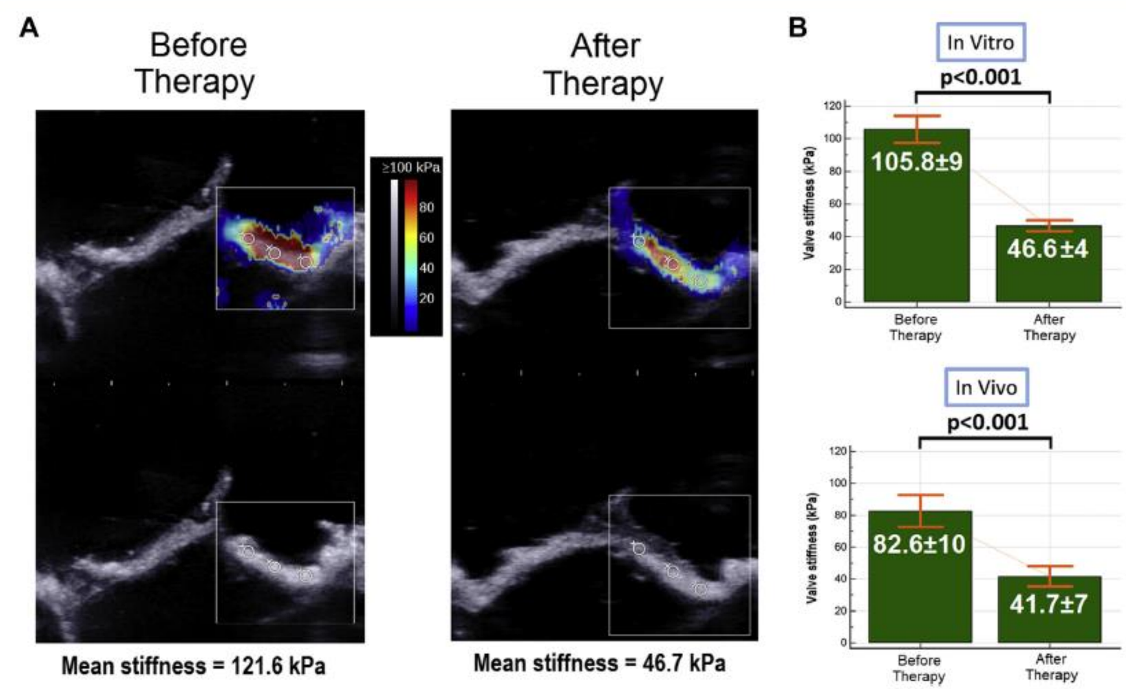


FIGURE 7 Elastography



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

Villemain et al. *JACC Basic Trans Science*. 2018

Conclusion

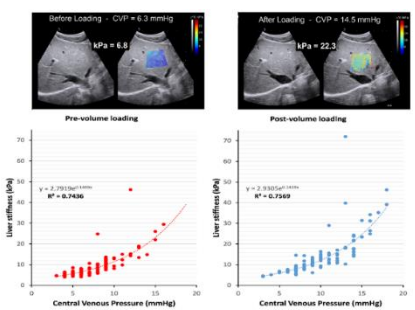
Elastography in CHD

now

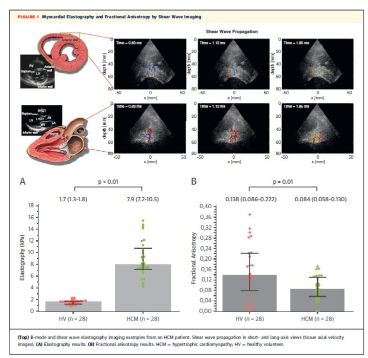
2020 ?

2020 ?

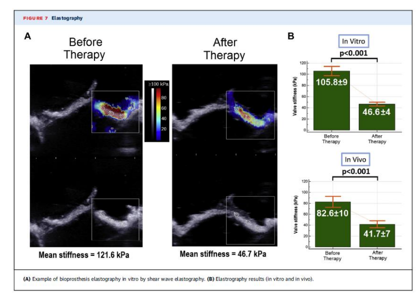
Liver



Myocardium



Valve



Thank you for your attention