Hyper-Frequency Viscoelastic Spectroscopy of Fresh Calf Brain Using RheoSpectris™

What is the mechanical impact of shocks on brain?

A high frequency characterization tool

To understand and prevent traumatic brain injury

characterization of brain tissues, shock prevention, brain elastography

SUMMARY

Mechanical properties of brain tissues and the knowledge of their dynamic behaviour are relevant to many applications. For example, understanding of the relation between applied external forces (e.g. motor vehicle accidents, ballistic impacts, sports-related impacts) and traumatic brain injury is crucial for the development of brain injury prevention systems. In addition, modeling and simulation tools (finite element models) require realistic mechanical parameters to allow for the design of reliable and efficient solutions that will help preventing brain damage. The brain injury is a result of sudden vibration (broadband stress frequencies from a few Hz to several kHz) from the impact, leading to tissue shearing. Furthermore, the mechanical properties of certain regions of the brain are also of great interest. An example of such region is brain stem, which forms a junction with spinal cord and transmits neural signals to the rest of the body.

Currently, mechanical instruments, such as rheometers, dynamic mechanical analysers (DMA) or indentation systems, are limited to measuring viscoelasticity in a frequency range typically below 200 Hz and with long acquisition time (around 30 min), during which the tissue may change significantly due to contamination. Moreover, since brain tissue is soft and difficult to handle, it is likely to cause measurement errors with current instruments.

In this original study, the new RheoSpectris™ instrument is introduced to measure the hyper-frequency viscoelasticity of brain samples (cerebrum cortex and brain stem).

RheoSpectris™ C500+

RheoSpectris™ C500 is dedicated to the Hyper-Frequency Viscoelastic Spectroscopy (HFVS) of materials for research and development (R&D) and quality control (QC) applications. It measures the viscoelastic properties of materials using an innovative technology (patent pending) based on vibrational shearing or bending. The main specifications of the RheoSpectris™ C500 are as follows:

- Viscoelastic spectroscopy between 10 and 1500 Hz
- Ultrafast measurement (less than 1 second for broadband characterization)
- Thermal control between RT and 400°C
- Viscoelasticity measurements between 100 Pa and 500 GPa
- Non-destructive and contactless measurements
- Adaptable geometries (fibres, thin films, beams, slices, adapted moulds) and low sample volumes
- Automated measurements and control

Rheolution instruments

EXPERIMENTAL PROTOCOL

From a fresh calf brain, small rectangular cuboid samples (thickness = 7 mm; width = 40 mm; length = 40 mm) were cut parallel to the transverse plane of the cerebrum cortex and brain stem (Figure 1). The fresh cerebrum and brain stem samples were tested using the 'slice' geometry of the RheoSpectris™ C500. All measurements were performed at room temperature (23 °C).

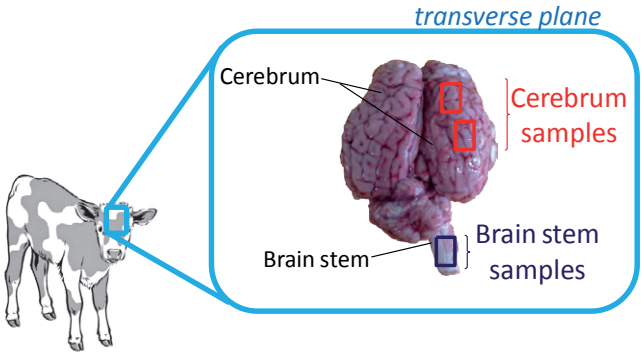


FIGURE 1
Calf brain and localization of the samples characterized using the RheoSpectris™ C500.

RESULTS

The shear storage modulus of the cerebrum cortex and brain stem were measured for a minimal pre-load and over frequencies up to 1000 Hz (Figure 2). Tissue elasticity at low frequencies (< 100 Hz) provides limited information regarding its dynamic behaviour over a wide frequency spectrum. RheoSpectris™ makes it possible to observe significant differences between the two plots in an extended frequency range, since the brain stem tissue is stiffer than cerebrum cortex throughout the explored frequency range (74% higher at 10 Hz and 48% higher at 1000 Hz). In addition, the viscoelastic behavior of both samples is strongly frequency-dependent. Indeed, the elasticity of tissues is five to seven times greater at 1000 Hz than it is at 10 Hz. These results are essential to precisely predict and study the effect of such tissue stiffening (dispersion) during tissue shearing at higher frequencies.

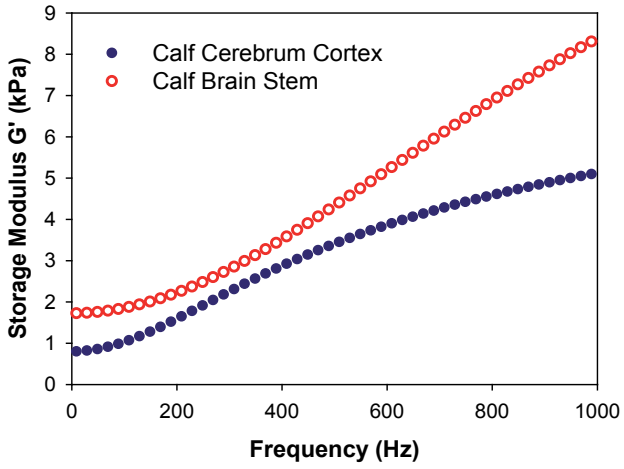


FIGURE 2
Frequency dependence of the shear storage modulus of fresh cerebrum and brain stem samples.

Studying the mechanical response of tissues, particularly brain tissue, to frequencies corresponding to actual blast or crash impact is important in evaluating and designing new restraint technologies and countermeasures, for example in automobile safety, military restraints, and sports biomechanics. In this perspective, the RheoSpectris™ is a dedicated instrument for fast hyper-frequency viscoelastic spectroscopy measurements of tissue samples, vital in impact and injury biomechanical studies. Here, its utility has been demonstrated for brain tissue samples. The regional viscoelastic differences (cerebrum cortex vs. brain stem) and the elasticity dispersion over a broad frequency range (10-1000 Hz) measured using RheoSpectris™ C500 are important parameters in developing realistic models of brain tissue.

The viscoelastic information provided by RheoSpectris™ C500 can also promote new understanding of the differences between healthy and abnormal brain tissues (caused by injuries or pathologies) to support elastographic imaging and to develop suitable therapies.This instrument is a suitable tool for performing large-scale studies for better understanding of the clinical implications of the mechanical behaviour of the brain and other tissues.

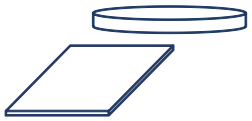
RheoSpectris™ C500+ Technology

SAMPLES

Slice

Cylinder

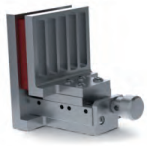
Disks and plates



Beams, fibers, o-rings

SAMPLE HOLDERS

Slice geometry

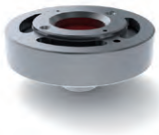


For very soft materials

Cylindrical geometry

For pourable gels

Disk geometry



For elastomers

Beam geometry

For medium to hard materials

MEASUREMENT

High-frequency dynamical excitation + Contactless optical measurement + Material dynamical resonances analysis

MECHANICS

Shearing slice (G', G'')

Shearing cylinder (G', G'')

Bending plate (E', E'')

Bending beam (E', E'')

INSTRUMENT

RheoSpectris™ C500+

- Hyper-Frequency Viscoelastic Spectroscopy (patent pending)
- Ultra-fast, non-destructive & contactless measurements
- Easy-to-use
- Wide variety of sample geometries and stiffnesses

SOFTWARE

RheoView™ C500

- An intuitive software to control RheoSpectris™ C500
- HFVS™, 3D-HFVS™, HFVS-Mapping™ modalities
- Data processing & reporting
- Sequences for statistic

THERMAL CONTROL

RheoHeater™ C500

- Flexible heating solutions
- Fast, precise & homogeneous heating
- Programmable temperature history
- Dynamic mechanical thermal analysis

TECHNICAL SPECIFICATIONS

	RheoSpectris™ C500+
Elastic Modulus	
Min	100 Pa
Max	500 GPa
Frequency	
Min	10 Hz (62.8 rad/s)
Max	1500 Hz (9424.8 rad/s)*
Acquisition Time	
Max (full frequency range)	< 10 seconds
Temperature	
Min	Room temparature
Max**	400°C
Measurement Geometries	
Cylinder	Diameter 10 mm Length 45 mm
Slice	Thickness < 12 mm Width < 40 mm Length < 40 mm
Beam - double cantilever	Height (or diameter) < 4 mm Width (or diameter) < 4 mm Length 10 mm - 65 mm
Beam - single cantilever	Thikness (or diameter) < 2 mm Width (or diameter) < 2 mm Length < 40 mm
Disk	Conformed diameter 15 mm or 20 mm Thickness < 1.5 mm
Acquisition Modalities	
HFVS™	yes
3D-HFVS™	yes**
Thermo-viscoelasticity	yes
Samples	
Min (# of samples)	1
Max (# of samples)	4**
Strain control	yes
Measurements	Fully automatic
General	
RheoHeater™	yes**
RheoView™	yes
Instrument dimensions	170 cm x 70 cm x 76 cm
Instrument weight	175 kg

(*) The upper frequency limit is given as an indication. Higher frequencies (2 000 Hz) can be reached depending on applications and customer specifications.
(**) Optional.

	RheoHeater™ C500
Temperature range	
Min temperature	Room temperature
Max temperature	400°C
Heating speed and stability	
Maximum heating speed	70°C/minute
Temperature stability	< 1%
Temperature homogeneity	< 3%
Heating chambers	
Universal thermal chamber	Cylindrical, beam, slide and disk geometris
Control	
Full automatic control	RheoView™ functionalities Programmable time profiles

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