Quantification of viscoelastic properties of Achille's Tendon: a first step to explore muscle-tendon structures exposed to substantial incidence

S. Beuve[1], A. Flandin[2], A. Nordez[3], L. Lacourpaille[3], F. Hug[3], R. Le Galèze[3], G. Guilhem[2], J.-L. Gennisson[1]

[1]BioMaps, Université Paris-Saclay, CEA, CNRS, INSERM, Orsay, France

[2]INSEP, Laboratoire Sport Expertise et Performance, Paris, France

[3]MIP, Université de Nantes, Nantes, France

WHY TENDON CARACTERIZATION IS NEEDED ?

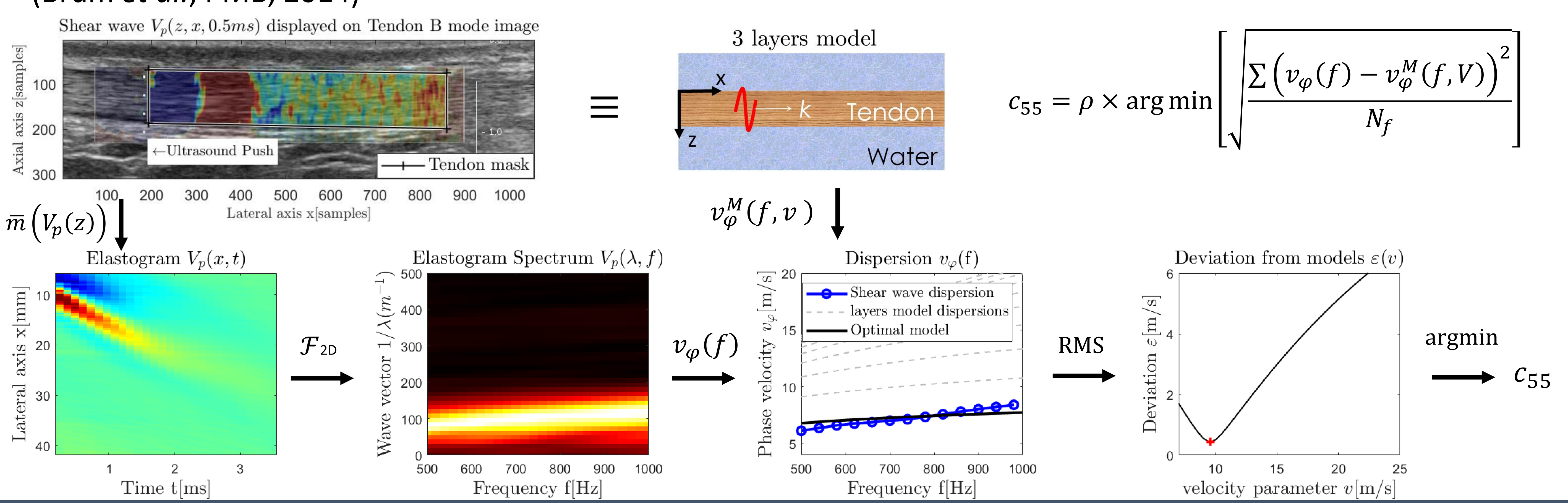
During movements**, muscles and tendons** mechanical properties change to **produce the appropriate force for a given task** or to adapt the body to external outcomes. When these mechanical constraints exceed the strength of muscle-tendon tissues, **specific regions of units units are subjected to frequent strain injuries**. The mechanical properties of these anatomical regions are therefore crucial in their capacity to withstand a given strain or inversely sustain an injury when exposed to such mechanical load. **A guided wave model** was developed to **estimate shear elasticity of tendons c_{55}**. This work is a continuation of the investigations on the Achilles tendon and proposes two new aspects:

1- To quantify new biomarkers such as **shear attenuation α_0**

2- To define the **best configuration** (ankle angle and US sequence) to reduce acquisition errors

GUIDED WAVE DISPERSION ANALYSIS

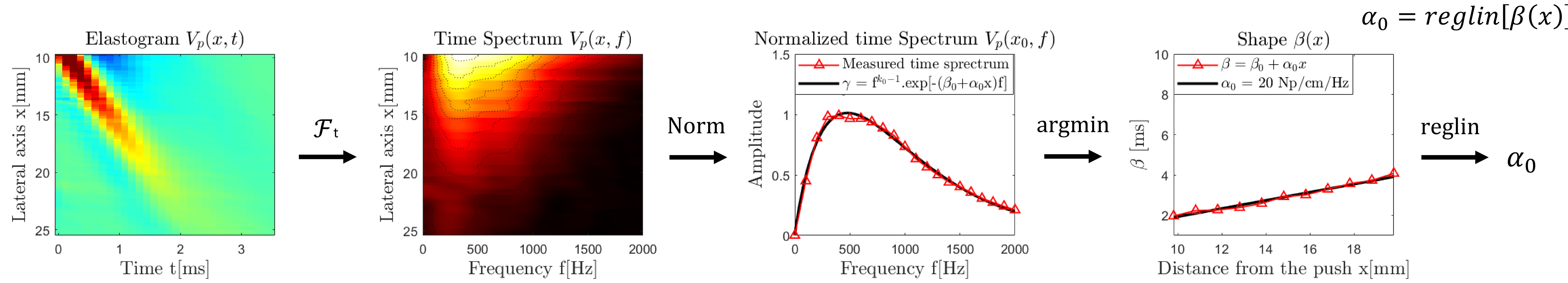
- The **shear wave propagation** movie in the tendon was manually **extracted from B mode image**.
- V_p **Data were averaged** in the depth (*z*) and displayed in the **lateral-time plan** (*x,t*)
- **2D Fourier transform** was computed and the **dispersion was estimated** through the maximum detection
- The **dispersion was compared to a mathematical model** of a layer of tendon surrounded by two layers of water (Brum *et al.*, PMB, 2014)



SHEAR ATTENUATION QUANTIFICATION USING FREQUENCY SHIFT METHOD

- **Time Fourier transform** was computed and the amplitude was normalized in the **lateral-time plan** (*x,f*)
- The normalized amplitude was **fitted with a gamma function** $\gamma = f^{k_0}\exp\left(-\beta(x)\right)$
- The **attenuation α_0** was **the slope of the γ argument**: the shape $\beta(x)$ (Bernard *et al.*, IEEE UFFC, 2016)

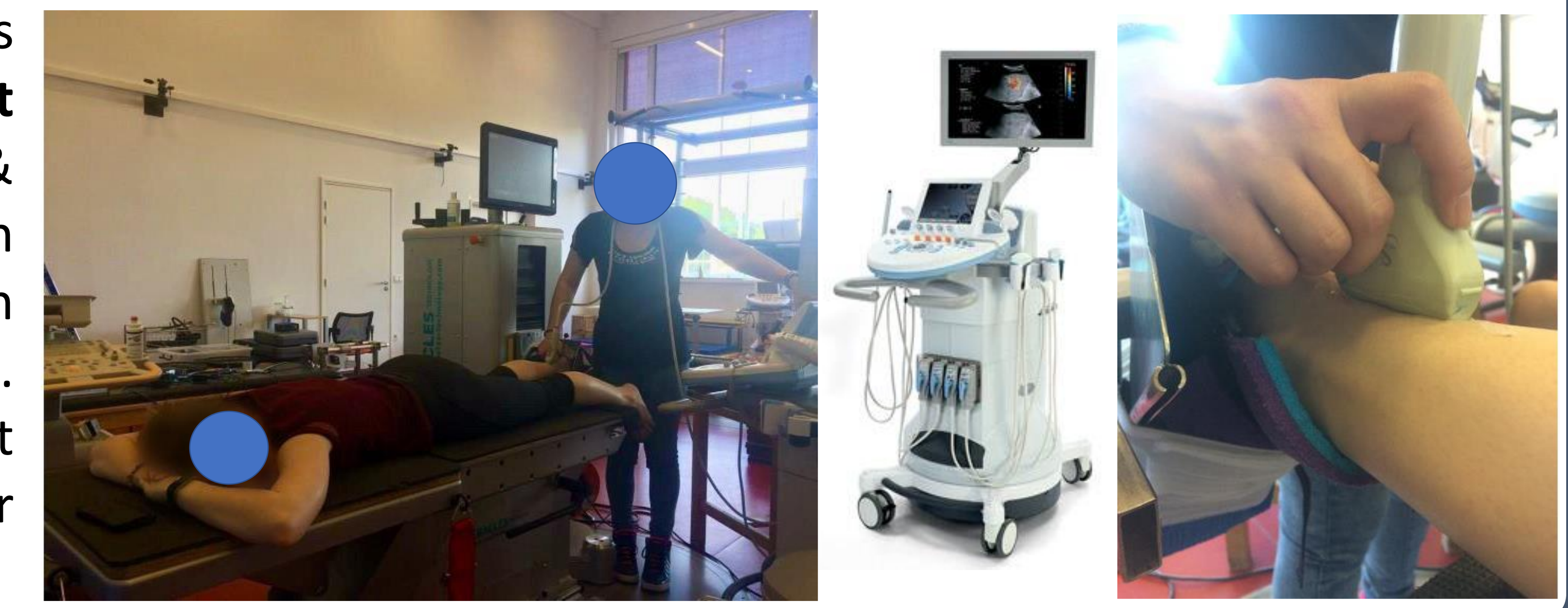
$$\alpha_0 = reglin[\beta(x)]$$



EXPERIMENTAL SETUP

Two groups (#1 N = 14; #2 N = 9) of non professional athletes volunteered to be subjects of this study. Both were scanned in two different laboratories by using an **ultrafast ultrasound device** (Aixplorer, Supersonic Imagine, Aix-en-Provence, France) driving a **SL15-4 probe**. A **custom Shear Wave Elastography sequence** was designed to generate and track waves in the tendon at **8000 Frames/sec**.

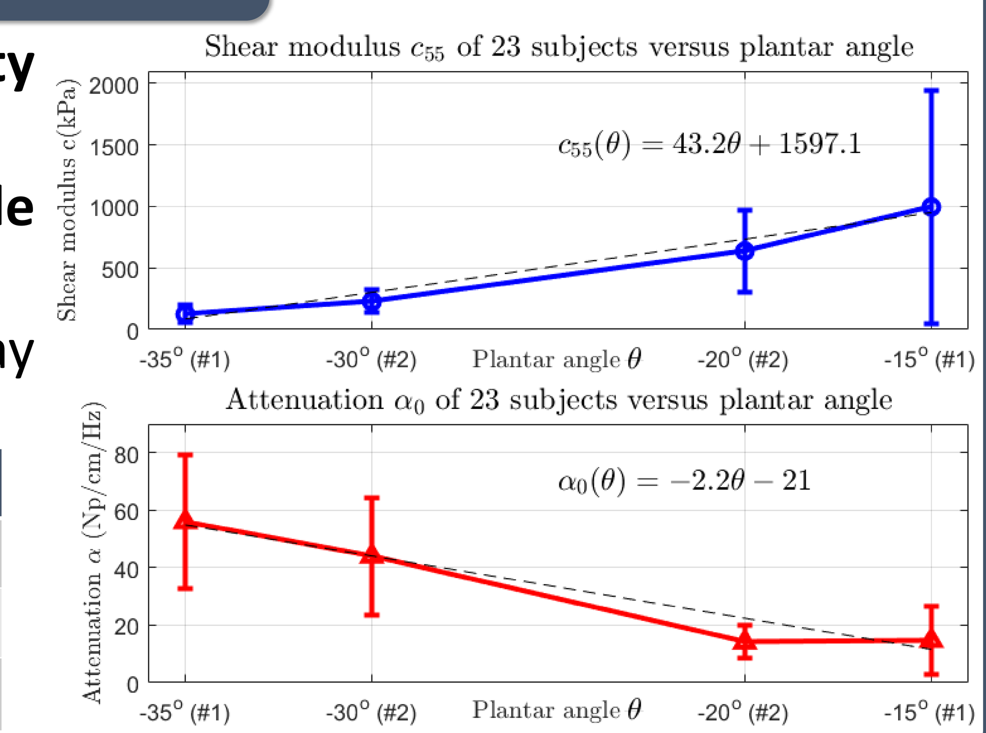
5 wave propagation movies were acquired for **different ankle angles** (#1 (-35°,-15°) & #2 (-30°,-20°)) for each Achille's tendon of each volunteer **twice 48h apart**. (0° corresponds to the foot perpendicular to the lower leg)



RESULTS OF SHEAR WAVE PROPAGATION ANALYSIS

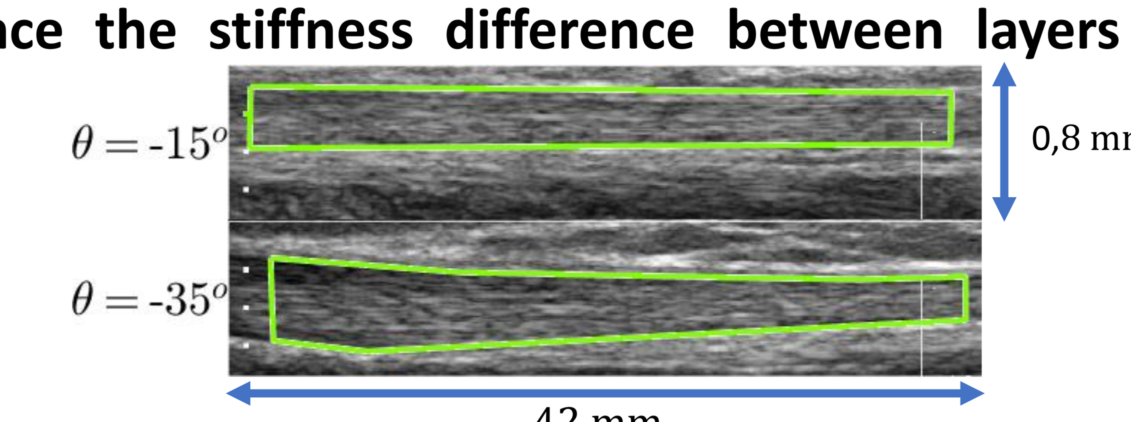
- Confirmation of the **dependence of the shear elasticity c_{55} on the ankle angle** (Helfenstein *et al.*, PMB, 2016)
- **Shear wave attenuation** α_0 also **decreases with ankle angle** towards plantar flexion
- The **coefficient of variation** quantify the inter-day **reproducibility**

Coefficient of Variation inter day (%)				
	-35°	**-30°**	**-20°**	**-15°**
c_{55}	18.0	21.35	25.9	61
α_0	10,7	12,5	22,2	18,8



OBJECTIVE OLYMPIC 2024

- **Attenuation coefficient** of Achille's tendon can be measured using a **frequency shift method.**
- The **optimal ankle angle** to get reproducible results is **between -30° and -20°.** It allows to maintain a small variation intra and inter subject for c_{55} and α_0 measurements. A **small ankle angle** (-15°) implies that **shear wave speed is too high** to be measured with only one ultrafast ultrasound sequence adapted for all positions. A **high ankle angle** (-35°) soften the tendon, **making the model less relevant since the stiffness difference between layers becomes negligible and the thickness varies**.
- As a perspective such an approach will be use to monitor a **cohort of athletes preparing for the 2024 Olympic Games** in athletics in Paris. We expect to bring this new biomarkers as a tool to prevent from injuries.



This study was supported by "ANR Sport de très haute performance, PRR investir l'avenir, #19-STHP-0003" under the project name FULGUR.