# NON-INVASIVE ASSESSMENT OF HUMAN MULTIFIDUS MUSCLE STIFFNESS USING ULTRASOUND SHEAR WAVE ELASTOGRAPHY: A FEASIBILITY STUDY

Baptiste MOREAU[a*], Claudio VERGARI[a], Hisham GAD[a,b], Baptiste SANDOZ[a], Wafa SKALLI[a], Sébastien LAPORTE[a]

## Abstract

INTRODUCTION: There is a lack of numeric data for the mechanical characterization of spine muscles, especially in vivo data. The multifidus muscle is a major muscle for the stabilization of the spine and may be involved in the pathogenesis of chronic low back pain (LBP). Supersonic shear wave elastography (SWE) has not yet been used on back muscles. The purpose of this prospective study is to assess the feasibility of ultrasound SWE to measure the elastic modulus of lumbar multifidus muscle in a passive stretching posture and at rest with a repeatable and reproducible method.

METHOD: A total of 10 asymptotic subjects (aged 25.5±2.2 years) participated, 4 females and 6 males. Three operators performed 6 measurements for each of the 2 postures on the right multifidus muscle at vertebral levels L2-L3 and L4-L5. Repeatability and reproducibility have been assessed according to ISO 5725 standard.

RESULTS: Intra-class correlation coefficients (ICC) for intra- and inter-observer reliability were rated as both excellent [ICC=0.99 and ICC=0.95, respectively]. Reproducibility was 11% at L2-L3 level and 19% at L4-L5. In the passive stretching posture, shear modulus was significantly higher than at rest (u<0.05).

DISCUSSION: This preliminary work enabled to validate the feasibility of measuring the shear modulus of the multifidus muscle with SWE. This kind of measurement could be easily introduces into clinical routine like for the medical follow-up of chronic LBP or scoliosis treatments.

**Keywords**: Elastography; Multifidus; Muscle; Lumbar spine; Shear modulus; Biomechanics.

[a] Arts et Metiers ParisTech, Institut de Biomecanique Humaine Georges Charpak, LBM, 151 bd de l'hopital, 75013 Paris, France

[b] Service de Chirurgie Orthopédique et Traumatologique, Centre Hospitalier de Bayeux, France

* Corresponding author: bpt.moreau@hotmail.fr

## Introduction

Information on muscle mechanical properties is essential in clinical practice as well as in biomechanical research on muscle disorders. The multifidus muscle – medial part of the erector spinae – is a stabilizer muscle of the spine. Therefore, it may give useful information in numerical modelling of the spine and in the clinical review of chronic low back pain (LBP) [1-5] or spine deformities[6-10].

Few imaging techniques already exist to assess *in vivo* stiffness of muscles, as magnetic resonance elastography[11-13], transient elastography[14-16] and tissue ultrasound palpation system [17]. Shear wave elastography (SWE) enables quantitative real-time measurement of local tissue elasticity without constraining the patient position. Eby *et al.* demonstrated on brachialis muscle that there is a linear correlation between Young's modulus measured with mechanical testing and shear modulus measured with SWE[18]. SWE has been recently used to describe limbs muscles characterization[19-21], but has never been used on the multifidus muscle. It is therefore essential to ensure the reliability of measurements before starting large quantitative measurement studies using ultrasound SWE, to provide relevant clinical information.

The purpose of this study is to evaluate an acquisition protocol and to determine the reliability of SWE for measuring *in vivo* shear modulus of the lumbar multifidus at rest and stretch.

## Materials and Methods

### *Subjects*

A total of 10 non-pathologic subjects (mean ±SD: age 25.5 ± 2.2 years; height 174.4 ± 7.6 cm; weight 68.5 ± 12.4 kg) volunteered for this study. The subjects had no history of significant orthopaedic problems related to the trunk or the posture, no history of spinal surgery or spinal abnormalities, and no back pain.

The purpose and the procedure of this study were explained, and written informed consent was obtained from all subjects. This study was approved by the ethical committee of our institution and conformed to the principles established in the Declaration of Helsinki.

### *Principle of measurements*

SWE[22] is based on the propagation of shear waves in the tissue. These waves are generated by ultrasound pulses successively focused at different depths. Shear wave speed *($V_S$)* is measured by an ultrafast imaging mode, and it is directly related to the tissue shear modulus *(μ)* by the following equation:

$$\mu = \rho . V_S^2 \qquad \text{[Equation 1]}$$

where $\rho$ is the mass density of the medium (1000 kg/m$^3$). This is done automatically by the commercial device (Aixplorer with a linear ultrasonic probe of 8 MHz central frequency, SuperSonic Image, France) that was used in this study. Operators were free to adjust the imaging parameters (depth, brilliance, etc.) in order to optimize the acquisition for each patient.

*Protocol*

Before studying and observing the muscle *in vivo*, it is essential to know properly the morphology and the biomechanics of the multifidus [23, 24].

Measurements were performed in 2 postures (Figure 1):

- First, the subject was sitting on an ergonomic forward leaning massage chair that gave access to the subject's back. The multifidus muscle was passively stretched in this standardized posture. Therefore, this posture was called "in passive stretching". Subjects were asked to stand up and walk for a few minutes between each measurement session in order to avoid muscle fatigue and limit muscle stiffness variations in time.
- Then, the subject was lying prone on a table, with a pillow placed below the abdomen to eliminate the lumbar lordosis and minimize movements of the lumbar spine. The multifidus muscle was relaxed in this standardized posture. Therefore, this posture was called "at rest".

Elastographic images of the lumbar multifidus muscle were taken at 2 vertebral levels: between L2-L3 and between L4-L5 vertebral levels.

In order to identify the vertebral levels, the spinous process of L4 was localized by palpation of iliac crest. This stage was executed on the massage chair because the palpation was easier in this posture.

With a B-mode imaging, palpations were confirmed by a sagittal ultrasound scan. The probe was placed between the spinous processes of L2 and L3 (Figure 2

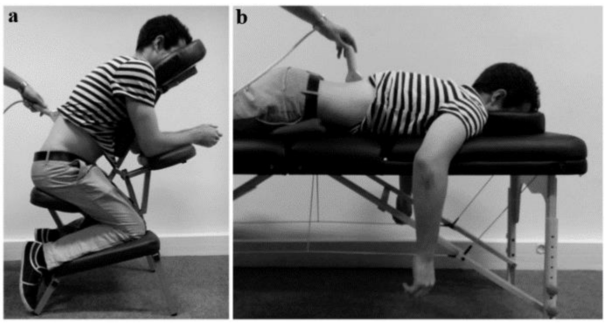


Figure 1 - The two postures assumed by the subjects during measurements: muscle in a passive stretching posture on a massage chair (a) and at rest prone on a table (b).

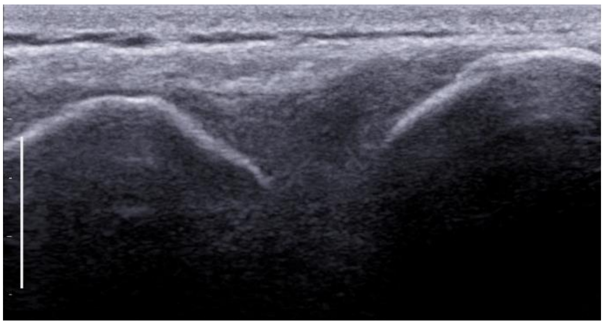

Figure 1 – A longitudinal B-mode image of the spinous processes of L3 (a) and L2 (b) used to confirm the good position of the probe before the measurements at the vertebral level L2-L3.

shows the image which confirms the correct position of the probe) and between L4 and L5. The position of these processes was then marked on the skin.

Once the probe was in the sagittal plan between the spinous processes L2-L3 or L4-L5, it was slightly moved laterally towards the multifidus. Then, the probe was slightly rotated to be parallel to muscle fibres and the position of the rectangular area of measurement was adapted to the subject morphology (usually between 1 and 3 cm in depth, Figure 1).

Each acquisition was a 10 seconds video (about 10 frames); previously validated custom post-processing software[25] was used to define a region of interest (ROI) in the first video frame and automatically tracked in the following frames. The average shear modulus was calculated in each frame ROI, and then averaged to obtain one value per acquisition. This allowed always measuring the same ROI and avoiding zones where the signal was unreliable.

*Reliability assessment*

Three operators acquired 6 measurements at L2-L3 and L4-L5 vertebral levels in sitting position, while measurements were only performed at L4-L5 level in lying position.

Three-hundred and sixty measurements were performed in passive stretching (3 operators x 6 measurements x 10 subjects x 2 vertebral levels) while 240 were performed at rest (3 operators x 6 measurements x 10 subjects x 1 vertebral level L4-L5 + 1 operator x 6 measurements x 10 subjects x 1 vertebral level L2-L3).

The probe was repositioned from the beginning of the measurement process by each operator. ISO 5725 standard (Appendix) was used to calculate intra-operator repeatability and inter-operator reproducibility in terms of standard deviations (in kPa units) and coefficient of variation (percentage). Intra-class correlation coefficient (ICC) was also calculated

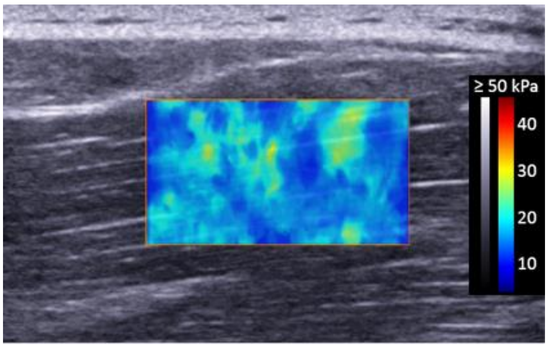


Figure 2 - The probe was parallel to muscle fibres and so measurements of the Shear modulus could be done in the rectangular colour map. The scale gives shear modulus values in kPa.

to evaluate intra-observer agreement. Differences were analysed with Mann-Whitney rank sum test; significance was set at 0.05.

## Results

The shear modulus of the multifidus at level L2-L3 (L4-L5) was 13.8 ± 2.9 kPa (22.7 ± 3.8 kPa) with the muscle in passive stretching and 8.5 ± 1.9 kPa (6.8 ± 1.2 kPa) with the muscle at rest. Data for L2-L3 level is summarized in Table 1 while reliability results are reported in Table 2.

At vertebral level L2-L3, the inter-operator reproducibility of measurements in passive stretching with 3 different operators was 1.5 kPa (corresponding to 11% coefficient of variation of the overall average) and ICC was 0.95. Repeatability of measurements was assessed both on the massage chair and on the massage table with 6 repeated measurements on each subject: 1.2 kPa (9% of the overall average) and 1.2 kPa (14% of the overall average), respectively. ICC was 0.94.

At vertebral level L4-L5, reproducibility of measurements was 4.3 kPa (19% of the global average) and ICC was 0.72.

These results showed that measurements at level L2-L3 were more reliable than measurements at level L4-L5, although no operator effect was observed in the latter. Shear modulus was significantly higher when muscle was stretched at both vertebral levels ($u < 0.05$).

**Table 1 - Patient- and operator-specific data for shear modulus at L2-L3 vertebral level.**

| | | | Shear modulus [kPa] | | | |
|---|---|---|---|---|---|---|
| **Subject N.** | Age | Sex | Operator 1 | | Operator 2 | Operator 3 |
| | | | Rest | Passive stretching | Passive stretching | Passive stretching |
| **1** | 23 | M | 5.5 | 13.1 | 13.6 | 14.1 |
| **2** | 23 | M | 6.9 | 11.1 | 11.0 | 11.0 |
| **3** | 23 | M | 11.2 | 14.8 | 15.6 | 13.1 |
| **4** | 24 | M | 7.0 | 10.3 | 11.6 | 8.5 |
| **5** | 24 | M | 10.4 | 15.2 | 13.8 | 15.3 |
| **6** | 26 | F | 8.1 | 11.7 | 11.1 | 11.1 |
| **7** | 26 | F | 10.4 | 16.2 | 18.1 | 17.9 |
| **8** | 28 | F | 8.4 | 18.1 | 19.9 | 17.5 |
| **9** | 28 | F | 8.4 | 11.4 | 11.2 | 10.0 |
| **10** | 29 | M | 8.5 | 16.4 | 13.8 | 16.6 |

## Discussion

The present study has shown the reliability of ultrasound SWE in the assessment of the shear modulus of the lumbar multifidus muscle at level L2-L3 in two postures: passive stretching and at rest. Ten healthy subjects participated to this study; reproducibility was assessed with 3 operators and repeatability with 6 consecutive measurements on each subject. An excellent agreement was observed among operators: ICCs were 0.95 and 0.94 in both postures (Table 2), as well as a repeatability below 14%.

The main limitation if this study is the small number of subjects; however, this validation step is strictly necessary to support and justify further studies on larger cohorts including patients.

Previous work[26, 27] showed reliability of muscular SWS (between 4.6% and 24 %) similar to this study (between 16% and 19 %) .

At vertebral level L4-L5, results were less reliable with a reproducibility of 19% and an ICC of 0.72 (Table 2). Apart from the lower reliability, the images themselves appeared noisier; a lower frequency probe could improve ultrasound penetration, although muscle depth did not seems to be the main problem. The posterior layer of the thoracolumbar fascia could explain the less repeatable results and slightly worse image quality at this level: it is a superficial tendinous layer which is attached to the gluteus maximus and medius, the external oblique and the latissimus dorsi. This entanglement of fibres is thicker and denser in its caudal part than in its cranial part because of its attachments[28, 29]. These thickening of the interface between muscle and fascia could strongly attenuate the ultrasound pulses that generate the shear waves, thus lowering the signal stability and reliability.

No operator effect was observed at L4-L5 vertebral level, as shown by the small difference between repeatability and reproducibility, corroborating this hypothesis. Since an operator effect was not observed at this level, which given the lower intra-operator reliability can be

Table 2 - Synthesis of measurement results of multifidus shear modulus at vertebral levels L4-L5 and L2-L3. The mean value for all operators and the standard deviation (SD) among subjects are in kPa, as well for repeatability and reproducibility; the percentage in brackets is in proportion to the mean value.

| | Shear modulus (kPa) in passive stretching | | | | | Shear modulus (kPa) at rest | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Repeatability | Reproducibility | ICC | Mean | SD | Repeatability | Reproducibility | ICC |
| **L4-L5** | 22.7 | 3.8 | 3.6 (16%) | 4.3 (19%) | 0.72 | 6.8 | 1.2 | 1.2 (17%) | 1.3 (19%) | 0.92 |
| **L2-L3** | 13.8 | 2.9 | 1.2 (9%) | 1.5 (11%) | 0.95 | 8.5 | 1.9 | 1.2 (14%) | / | 0.94 |

considered a worst-case scenario, inter-operator reproducibility was not assessed at L2-L3 level. This allowed shortening the full protocol, which still lasted about one hour for each subject (3 operators x 6 repeated measurements x 2 postures x about one minute per measurement plus resting time for the sitting posture). Measurements in clinical routine, however, might realistically last about 10 minutes, for both passive stretching and rest. Differences between the two states could inform on the nonlinear behaviour of this muscle, which could change with pathology.

Ward *et al.* [30] previously made *in vitro* tests on single fibre and fibre bundle of multifidus and found a Young's modulus of 33.71 ± 1.89 kPa and 91.34 ± 6.87 kPa, respectively. Chan *et al.* [17] studied multifidus with ultrasound palpation system which is a quasi-static method to assess Young's modulus and they found 37.4 ± 3.7 kPa. Comparing our results with these other studies which assessed Young's modulus of the multifidus muscle with different methods, SWE gave values in the same range of magnitude: a Young's modulus between 20.4 kPa and 42.5 kPa at rest which was evaluated, for the sake of comparison, assuming a Young modulus/ shear modulus ratio between 3 and 5, according to the literature[18].

This study proposed a measurement protocol which is compatible with the clinical routine, and it determined, for the first time, the limits and the reliability of elastographic measurements in multifidus muscle, thus opening the way to the non-invasive characterization of the muscles of the back. Perspective of this study is to compare pathological patient back muscles with a non-pathological population, as well as broadening the subject cohort with children or elderly people.

**Acknowledgments**

The authors are grateful to the ParisTech BiomecAM chair program on subject-specific musculoskeletal modelling for funding (with the support of ParisTech and Yves Cotrel Foundations, *Société Générale*, Proteor and Covea).

## Appendix

Repeatability ($\boldsymbol{s_r}$) and reproducibility ($\boldsymbol{s_R}$) were calculated according to the norm ISO 5725-2:1994 about trueness and precision of measurements – chapter 7.4.5.

**a) Intra-operator repeatability**

Repeatability variance ($\boldsymbol{s_{rj}^2}$) for six repeated measurements on the jth subject was calculated as follows:

$$s_{rj}^2 = \frac{\sum_{i=1}^{p} s_{ij}^2}{p}$$

where $\boldsymbol{s_{ij}}$ is the standard deviation of the 6 repeated measurements by the ith operator on the jth subject, p = 3 is the number of operators. To obtain the overall repeatability variance $\boldsymbol{s_r^2}$, the mean of $\boldsymbol{s_{rj}^2}$ was calculated across all subjects.

**b) Inter-operator reproducibility**

Reproducibility variance ($\boldsymbol{s_{Rj}^2}$) was calculated as follows:

$$s_{Rj}^2 = s_{rj}^2 + s_{Lj}^2$$

where $\boldsymbol{s_{Lj}^2}$ is the inter-operator variance:

$$s_{Lj}^2 = \frac{s_{dj}^2 - s_{rj}^2}{n}$$

$\boldsymbol{s_{dj}^2}$ was defined as follows:

$$s_{dj}^2 = \frac{1}{p-1} * \sum_{i=1}^{p} n * \left(\overline{y_{ij}} - \overline{\overline{y}}_j\right)^2$$

where n = 6 is the number of measurement repetitions, $\overline{\mathbf{y_{ij}}}$ and $\overline{\overline{\mathbf{y}}}_\mathbf{j}$ are the average shear modulus of the jth patient measured by the ith operator and the average shear modulus of the jth patient across operators, respectively.

Intra- and inter-operator reliability in this paper were reported in terms of standard deviation as $\sqrt{\mathbf{s_r^2}}$ (repeatability) and $\sqrt{\mathbf{s_R^2}}$ (reproducibility), respectively.

**References**


1. Hides JA, Richardson CA, Jull GA. Multifidus Muscle Recovery Is Not Automatic After Resolution of Acute, First-Episode Low Back Pain. *Spine*. 1996; 21: 2763-9.
2. Hides J, Stokes M, Saide M, Jull G, Cooper D. Evidence of lumbar multifidus muscle wasting ipsilateral to symptoms in patients with acute/subacute low back pain. *Spine*. 1994; 19: 165-72.
3. Danneels L, Vanderstraeten G, Cambier D, et al. Effects of three different training modalities on the cross sectional area of the lumbar multifidus muscle in patients with chronic low back pain. *British journal of sports medicine*. 2001; 35: 186-91.
4. Danneels L, Coorevits P, Cools A, et al. Differences in electromyographic activity in the multifidus muscle and the iliocostalis lumborum between healthy subjects and patients with sub-acute and chronic low back pain. *European Spine Journal*. 2002; 11: 13-9.
5. Wallwork TL, Stanton WR, Freke M, Hides JA. The effect of chronic low back pain on size and contraction of the lumbar multifidus muscle. *Manual therapy*. 2009; 14: 496-500.
6. Ward SR, Kim CW, Eng CM, et al. Architectural analysis and intraoperative measurements demonstrate the unique design of the multifidus muscle for lumbar spine stability. *The Journal of Bone & Joint Surgery*. 2009; 91: 176-85.
7. Rantanen J, Hurme M, Falck B, et al. The lumbar multifidus muscle five years after surgery for a lumbar intervertebral disc herniation. *Spine*. 1993; 18: 568-74.
8. Fidler M, Jowett R. Muscle imbalance in the aetiology of scoliosis. *Journal of Bone & Joint Surgery, British Volume*. 1976; 58: 200-1.
9. Meier MP, Klein MP, Krebs D, Grob D, Müntener M. Fiber transformations in multifidus muscle of young patients with idiopathic scoliosis. *Spine*. 1997; 22: 2357-64.
10. Khosla S, Tredwell S, Day B, Shinn S, Ovalle Jr W. An ultrastructural study of multifidus muscle in progressive idiopathic scoliosis: Changes resulting from a sarcolemmal defect at the myotendinous junction. *Journal of the neurological sciences*. 1980; 46: 13-31.
11. Dresner MA, Rose GH, Rossman PJ, Muthupillai R, Manduca A, Ehman RL. Magnetic resonance elastography of skeletal muscle. *Journal of Magnetic Resonance Imaging*. 2001; 13: 269-76.
12. Manduca A, Oliphant TE, Dresner M, et al. Magnetic resonance elastography: non-invasive mapping of tissue elasticity. *Medical image analysis*. 2001; 5: 237-54.
13. Bensamoun SF, Ringleb SI, Littrell L, et al. Determination of thigh muscle stiffness using magnetic resonance elastography. *Journal of Magnetic Resonance Imaging*. 2006; 23: 242-7.
14. Gennisson J-L, Catheline S, Chaffaı S, Fink M. Transient elastography in anisotropic medium: application to the measurement of slow and fast shear wave speeds in muscles. *The Journal of the Acoustical Society of America*. 2003; 114: 536-41.
15. Gennisson JL, Cornu C, Catheline S, Fink M, Portero P. Human muscle hardness assessment during incremental isometric contraction using transient elastography. *Journal of biomechanics*. 2005; 38: 1543-50.
16. Nordez A, Gennisson J, Casari P, Catheline S, Cornu C. Characterization of muscle belly elastic properties during passive stretching using transient elastography. *Journal of biomechanics*. 2008; 41: 2305-11.
17. Chan ST, Fung PK, Ng NY, et al. Dynamic changes of elasticity, cross-sectional area, and fat infiltration of multifidus at different postures in men with chronic low back pain. *The spine journal : official journal of the North American Spine Society*. 2012; 12: 381-8.
18. Eby SF, Song P, Chen S, Chen Q, Greenleaf JF, An K-N. Validation of shear wave elastography in skeletal muscle. *Journal of biomechanics*. 2013; 46: 2381-7.

19. Gennisson J-L, Deffieux T, Macé E, Montaldo G, Fink M, Tanter M. Viscoelastic and anisotropic mechanical properties of in vivo muscle tissue assessed by supersonic shear imaging. *Ultrasound in medicine & biology*. 2010; 36: 789-801.
20. Nordez A, Hug F. Muscle shear elastic modulus measured using supersonic shear imaging is highly related to muscle activity level. *Journal of Applied Physiology*. 2010; 108: 1389-94.
21. Arda K, Ciledag N, Aktas E, Arıbas BK, Köse K. Quantitative assessment of normal soft-tissue elasticity using shear-wave ultrasound elastography. *American Journal of Roentgenology*. 2011; 197: 532-6.
22. Bercoff J, Tanter M, Fink M. Supersonic shear imaging: a new technique for soft tissue elasticity mapping. *Ultrasonics, Ferroelectrics and Frequency Control, IEEE Transactions on*. 2004; 51: 396-409.
23. Macintosh JE, Bogduk N. The biomechanics of the lumbar multifidus. *Clinical biomechanics*. 1986; 1: 205-13.
24. Macintosh JE, Valencia F, Bogduk N, Munro RR. The morphology of the human lumbar multifidus. *Clinical biomechanics*. 1986; 1: 196-204.
25. Vergari C, Rouch P, Dubois G, et al. Intervertebral disc characterization by shear wave elastography: An in vitro preliminary study. *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine*. 2014; 228: 607-15.
26. Lacourpaille L, Hug F, Bouillard K, Hogrel J-Y, Nordez A. Supersonic shear imaging provides a reliable measurement of resting muscle shear elastic modulus. *Physiological measurement*. 2012; 33: N19.
27. Dubois G, Kheireddine W, Vergari C, et al. Reliable Protocol for Shear Wave Elastography of Lower Limb Muscles at Rest and During Passive Stretching. *Ultrasound in medicine & biology*. 2015; 41: 2284-91.
28. Vleeming A, Pool-Goudzwaard AL, Stoeckart R, van Wingerden J-P, Snijders CJ. The Posterior Layer of the Thoracolumbar Fascia| Its Function in Load Transfer From Spine to Legs. *Spine*. 1995; 20: 753-8.
29. BOGDUK N, MACINTOSH JE. The applied anatomy of the thoracolumbar fascia. *Spine*. 1984; 9: 164-70.
30. Ward SR, Tomiya A, Regev GJ, et al. Passive mechanical properties of the lumbar multifidus muscle support its role as a stabilizer. *Journal of biomechanics*. 2009; 42: 1384-9.