APPLIED SESSION: ELASTOGRAPHY FOR MUSCLE BIOMECHANICS

Antoine Nordez[1], Jean-Luc Gennisson[2], Gaël Guilhem[3], François Hug[1,4]

"Movement, Interactions, Performance" (EA4334), University of Nantes, France[1]
Institut Langevin - Ondes et images, CNRS UMR7587, INSERM U979, ESPCI ParisTech, Université Paris VII, Paris, France [2]
French National Institute of Sport (INSEP), Research Department, Laboratory "Sport, Expertise and Performance" (EA 7370), Paris, France [3]
NHMRC Centre of Clinical Research Excellence in Spinal Pain, Injury and Health, School of Health and Rehabilitation Sciences, the University of Queensland, Brisbane, Australia [4]

The purpose of this applied session is to demonstrate the potential of shear wave elastography for the study of muscle biomechanics using both real-time demo and recent results, with a special focus on sport applications (stretching, fatigue, pain, damage).

KEY WORDS: ultrasound, shear wave, muscle force estimation, stretching, coordination, fatigue, muscle damage

INTRODUCTION

In vivo muscle-tendon biomechanical (i.e., contractile and viscoelastic) properties have been classically inferred from inverse dynamics or measurements of joint torque performed using ergometers. However, these measures provide information about the combined behaviour of several structures (e.g., muscles, tendons, nerves, skin) acting around a given joint; and cannot isolate the behaviour of an individual muscle. Since the introduction of elastography in the 90's, many techniques have been developed with the aim to non-invasively assess localized muscle stiffness. The aim of this session is to present elastography techniques (1-) and the use of the supersonic shear imaging technique for muscle studies (2-, 3- and 4-) with application to sports (Hug, Tucker, Gennisson, Tanter & Nordez, in press).

1- PRESENTATION OF ELASTOGRAPHY METHODS AND SUPERSONIC SHEAR IMAGING (Jean-Luc Gennisson, 25 min)

Shear wave ultrasound elastography is an emerging technique that allows to estimate tissue mechanical properties. In the case of muscles, this technique must be adapted in order to estimate multiple parameters such as stiffness, viscosity or anisotropy, in a large field of view and moreover in real time to follow muscle contraction. In this presentation an overview on elastography methods will be presented (Gennisson, Deffieux, Fink & Tanter, 2013). The supersonic shear imaging technique (SSI, Bercoff, Tanter & Fink, 2004) will be specifically described in details to explain how it provides a measure of localized muscle shear modulus.

2- PASSIVE MUSCLE ELASTOGRAPHY: TOWARD A BETTER UNDERSTANDING OF THE EFFECTS OF STRETCHING (Antoine Nordez, 20 min)

Recent work from our team demonstrated that the shear modulus measured using SSI can be used to estimate changes in individual muscle force during passive stretching (Maïsetti, Hug, Bouillard & Nordez, 2012). Therefore, this technique can be very relevant to compare the stiffness of several muscles within a group, in order to provide a better understanding of factors that limit the maximal range of motion at a joint (Andrade, Lacourpaille, Freitas, McNair & Nordez A, in press). In addition, it provides a unique opportunity to measure muscle-tendon slack length (Hug, Lacourpaille, Maïsetti & Nordez, 2013) and to analyse

interactions between muscles in vivo. Furthermore, a series of experiment aimed to measure localized effects of stretching using elastography in order to provide a better understanding of stretching effects (Freitas, Andrade, Lacourpaille, Mil-Homens & Nordez, in press).

3- MUSCLE ELASTOGRAPHY DURING CONTRACTION: NEW INSIGHTS INTO ADAPTATION OF MUSCLE COORDINATION TO FATIGUE, PAIN (François Hug, 25 min)

Recent experiments demonstrated that measurement of muscle stiffness using elastography can be used to estimate changes in muscle force during isometric contractions (Bouillard, Nordez & Hug, 2011). This presentation will overview a series of experiments that took advantage of this method to provide a deeper understanding of motor adaptations during experimental pain (Tucker, Hodges, Van den Hoorn, Nordez & Hug, 2014) and neuromuscular fatigue (Bouillard, Hug, Guével & Nordez, 2012; Bouillard, Jubeau, Nordez & Hug, 2014).

4- ELASTOGRAPHY TO STUDY THE EFFECTS OF MUSCLE DAMAGE (Gaël Guilhem, 15 min)

Changes in muscle stiffness after exercise-induced muscle damage have been classically inferred from passive torque measured at the joint level. This presentation will address the changes in the localized muscle shear elastic modulus and the dissipative properties induced by eccentric exercise in the damaged muscle (Lacourpaille, Nordez, Hug, Couturier, Dibie & Guilhem, 2014). In addition, another study was designed to determine the ability of elastography to estimate the amount of damage of an individual muscle. In that way, preliminary results showed a high correlation between the increase in shear modulus immediately after eccentric exercise and the amount of muscle strength decrease two days after exercise. If confirmed, these results would indicate that elastography can be a unique early indicator of functional impairments that occurs in the days after eccentric exercise.

CONCLUSION

After an overview of elastography methods, this applied session will present results obtained in the last five years using elastography for muscle biomechanics, with a special focus on sports applications (muscle damage, fatigue, coordination and stretching). For each talk, demo will be performed in real time (~35 min) to illustrate the experiments performed in the presented studies. In addition, a large time will be dedicated to questions from the audience.

REFERENCES:

Andrade, R.J., Lacourpaille, L., Freitas, S.R., McNair, P.J. & Nordez A. (in press). Effects of hip and head position on ankle range of motion, ankle passive torque, and passive gastrocnemius tension. *Scandinavian Journal of Medicine and Science in Sports.*

Bercoff, J., Tanter, M. & Fink M. (2004) Supersonic shear imaging: a new technique for soft tissue elasticity mapping. *IEEE transactions on ultrasonics, ferroelectrics, and frequency contro,* 51(4), 396-409.

Bouillard, K., Nordez, A. & Hug F. (2011). Estimation of individual muscle force using elastography. *PLoS One,* 6(12), e29261.

Bouillard, K., Hug, F., Guevel, A. & Nordez A. (2012). Shear elastic modulus can be used to estimate an index of individual muscle force during a submaximal isometric fatiguing contraction. *J Appl Physiol,* 113(9), 1353-61.

Bouillard, K., Jubeau, M., Nordez, A. & Hug F. (2014). Effect of vastus lateralis fatigue on load sharing between quadriceps femoris muscles during isometric knee extensions. *J Neurophysiol,* 111(4), 768-76.

Freitas, S.R., Andrade, R.J., Lacourpaille, L., Mil-Homens, P. & Nordez, A. (in press). Muscle and joint responses during and after static stretching performed at different intensities. *European Journal of Applied Physiology.*

Gennisson, J.L., Deffieux, T., Fink, M. & Tanter M. (2013). Ultrasound elastography: principles and techniques. *Diagnostic and interventional imaging,* 94(5), 487-95.

Hug, F., Lacourpaille, L., Maïsetti, O. & Nordez, A. (2013). Slack length of gastrocnemius medialis and Achilles tendon occurs at different angles. *Journal of Biomechanics,* 46(14), 2534-8.

Hug, F., Tucker, K., Gennisson, J.L., Tanter, M. & Nordez, A. (in press). Elastography for muscle biomechanics: toward the estimation of individual muscle force. *Exercise and Sport Sciences Reviews.*

Lacourpaille, L., Nordez, A., Hug, F., Couturier, A., Dibie, C. & Guilhem G. (2014). Time-course effect of exercise-induced muscle damage on localized muscle mechanical properties assessed using elastography. *Acta physiologica,* 211(1), 135-46.

Maisetti, O., Hug, F., Bouillard, K. & Nordez A. (2012). Characterization of passive elastic properties of the human medial gastrocnemius muscle belly using supersonic shear imaging. *Journal of Biomechanics,* 45(6), 978-84.

Tucker, K., Hodges, P.W., Van den Hoorn, W., Nordez, A. & Hug F. (2014). Does stress within a muscle change in response to an acute noxious stimulus? *PLoS One,* 9(3), e91899.

Acknowledgements

The authors would like thank the Supersonic Imagine Company that sponsored this applied session.