45ème congrès de la Société de Biomécanique

METZ - 26-28 octobre 2020

IMAGERIE ET BIOMECANIQUE

Session spéciale co-organisée par la Société Française du Génie Biologique et Médical et la Société de Biomécanique

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Sources des images: CNRS le journal

Programme de la session
Lundi 26 octobre - 14h45 - 16h45

Modératrice : Françoise Peyrin

Présentateurs invités:

14h45 - 15h15 : **Stefan Catheline**, *What is next in passive elastography?*
15h15-15h30 : **Damien Garcia**, *Keeping a new echocardiographic eye on the intracardiac flow*
15h30 - 15h45 : **Monica Sigovan,** *L'imagerie dynamique en IRM pour l'évaluation des propriétés biomécaniques de la paroi artérielle pathologique*
15h45 - 16h00 : **Jean-Louis Dillenseger**, *Localisation de nodules pulmonaires en vidéo-thoracoscopie. Intégration d'un modèle biomécanique du poumon dans la chaîne de traitements d'images*
16h00 - 16h15 : **Françoise Peyrin**, *3D X-Ray microscopy for the investigation of bone tissue properties up to the nanoscale*

Présentation orale retenue parmi les soumissions:

16h15 - 16h30 : **Philippe Pouletaut, Fabrice Charleux, Bernard Devauchelle, Jean-Marc Constans, Redouane Ternifi, Salem Boussida, Anthony Hamaoui, Claude Krzisch, Sabine Bensamoun.** *Development of MR Elastography method to characterize the elastic property of the sterno-cleido-mastoid (SCM) muscle*

La session s'achèvera par une discussion autour du lien entre biomécanique et imagerie, des verrous scientifiques et des enjeux actuels et futurs.

Présentateur invité :

Stefan CATHELINE

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What is next in passive elastography?

Stefan Catheline
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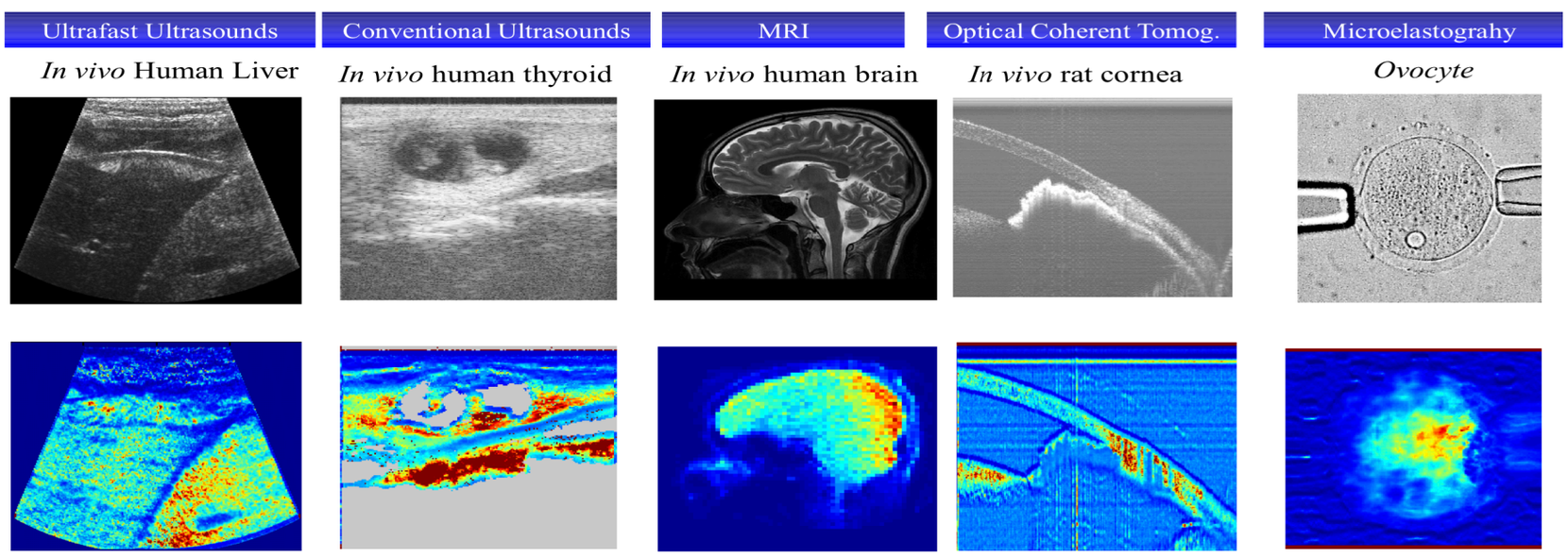
Elastography, sometimes referred as seismology of the human body, is an imaging modality now implemented on medical ultrasound systems. It allows to measure shear wave speeds within soft tissues and gives a tomography reconstruction of the shear elasticity. Elastography is thus a palpation tomography. A new idea inspired by seismology, is to take advantage of shear waves naturally present in the human body due to muscles activities to construct shear elasticity map of soft tissues. It is thus a passive elastography approach since no shear wave sources are used. A general overview of this field starting from the very beginning with the early work of Dickinson [1] in ultrasound, and Campillo [2] in seismology is given in the first part of the presentation. The last part, is devoted to the potential applications of passive elastography in seismology, MRI, optics and ultrasounds to detect shear waves and reconstruct a speed tomography in San Andrea fault (CA), a human liver, thyroid, brain, in a rat eye and a single cell. Perspective of fast biomechanics imaging at a cellular level for monitoring is finally discussed.

Examples of standard imaging (top raw) and passive elastography reconstruction (bottom raw)



[1] R.J.Dickinson, C.R.Hill, "measurement of soft tissues motion using correlation between A-Scans", Ultr.MedBio. 8(3), pp.263 (1981).
[2] A.Paul, M.Campillo "Long range correlations in the diffuse seismic coda", Science 299 (5606), pp.547 (2003)

Présentateur invité :

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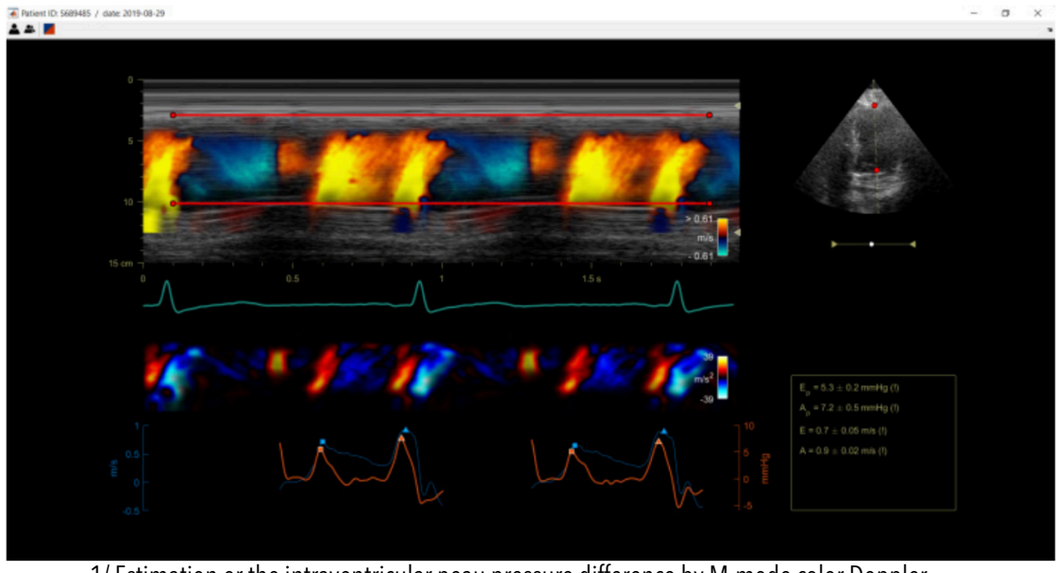
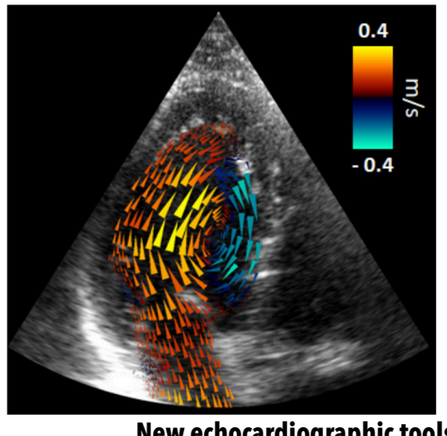


1/ Estimation or the intraventricular peau pressure difference by M-mode color Doppler



2/ Deciphering the.intraventricular flow vortex by color Doppler echocardiography

New echocardiographic tools for new insights in left ventricular filling

Keeping a new echocardiographic eye on the intracardiac flow

Damien Garcia

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Keywords: Doppler echocardiography; left ventricular filling; vector flow imaging; vortex; relative pressure

Clinical context – Heart failure alters the ability of the heart pump to meet the oxygen demand. It affects more than one million people in France. It is characterized by the reduced ability of the heart to empty (systolic dysfunction) or fill with blood (diastolic dysfunction). Diagnosing diastolic dysfunction is often imprecise because the recommended clinical indices may show discrepancies. A thorough analysis of the intraventricular flow could change this situation.

Imaging context – Its ability to provide non-invasive real-time information makes echocardiography the prerequisite technique for evaluating cardiac function. To date, only local blood velocities are measured for clinical diagnostics. Although it is feasible to obtain 2-D flow information by ultrasound imaging, no Doppler method has proven routine clinical benefit at the patient's bedside.

Biomechanical context – Since the intracardiac flow is sensitive to dynamical changes of the myocardium, we hypothesized that analysis of the intraventricular flow, by Doppler echocardiography, could improve the assessment of cardiac function. We are seeking this information during left ventricular filling in 1) the vortex, 2) the intracavitary pressure difference.

Methods – We have developed and validated innovative and 100%-clinically compatible ultrasound-based tools (see Fig.) to 1) quantify the flow vortex [1], and 2) measure the peak pressure difference [2], that both appear during left ventricular filling.

Results and clinical perspective – Preliminary clinical results demonstrate that quantitative analysis of the left intraventricular blood flow is feasible in a clinical context by Doppler echocardiography. Additional mechanical blood- flow measures, such as pressure difference and vortex size, could lead to a better assessment of diastolic function.

[1] K. C. Assi et al., "Intraventricular vector flow mapping-a Doppler-based regularized problem with automatic model selection," Phys Med Biol, vol. 62, no. 17, pp. 7131–7147, 2017, doi: 10.1088/1361-6560/aa7fe7.

[2] A. Hodzic et al., "Echocardiographic evidence of left ventricular untwisting-filling interplay," Cardiovascular Ultrasound, vol. 18, no. 1, p. 8, 2020, doi: 10.1186/s12947-020-00190-6.

Présentatrice invitée :

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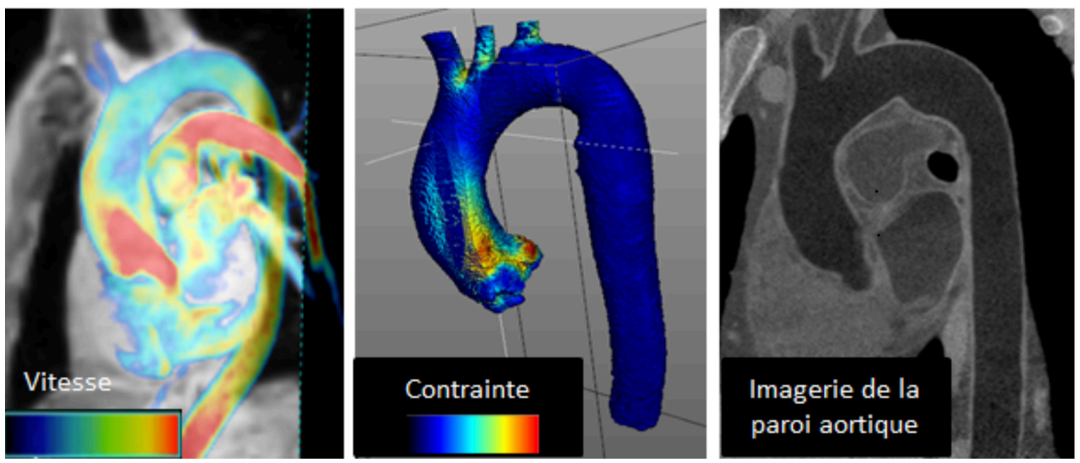
L'imagerie dynamique en IRM pour l'évaluation des propriétés biomécaniques de la paroi artérielle pathologique

Monica Sigovan, *Ruifen Zhang, Eduardo Davila, Philippe Douek, Patrick Clarysse, Loic Boussel*

L'écoulement sanguin joue un rôle très important dans les maladies vasculaires ; particulièrement l'interaction entre le sang et la paroi elle-même est reconnue comme une cause potentielle de déclanchement et des pathologies vasculaires (athérosclérose et anévrysmes). Par conséquent, il est essentiel d'étudier directement *in vivo* l'écoulement sanguin en relation avec les modifications morphologiques de la paroi vasculaire.

Par sa polyvalence, l'IRM permet de réaliser des mesures directes de l'écoulement sanguin dans l'arbre vasculaire humain en 4 dimensions (3D + t). Ces techniques ont mis en évidence des écoulements non-physiologiques en lien avec la progression pathologique de la paroi vasculaire, par exemple un écoulement lent et oscillatoire dans la bifurcation carotidienne et dans les sacs anévrysmaux. Par ailleurs, l'information dynamique permet d'évaluer le changement du calibre vasculaire sous la contrainte de la pression artérielle. En complément aux mesures d'écoulement sanguin, la haute résolution en contraste de l'IRM, permet d'obtenir une image spécifique de la paroi artérielle, afin d'estimer son épaisseur et sa composition tissulaire.

Ses mesures permettent d'obtenir des paramètres mécaniques simples décrivant l'état physiologique de la paroi *in vivo*. Cependant, l'imagerie peut être combinée a la modélisation afin d'étudier plus en détails les paramètres mécaniques patient spécifiques.



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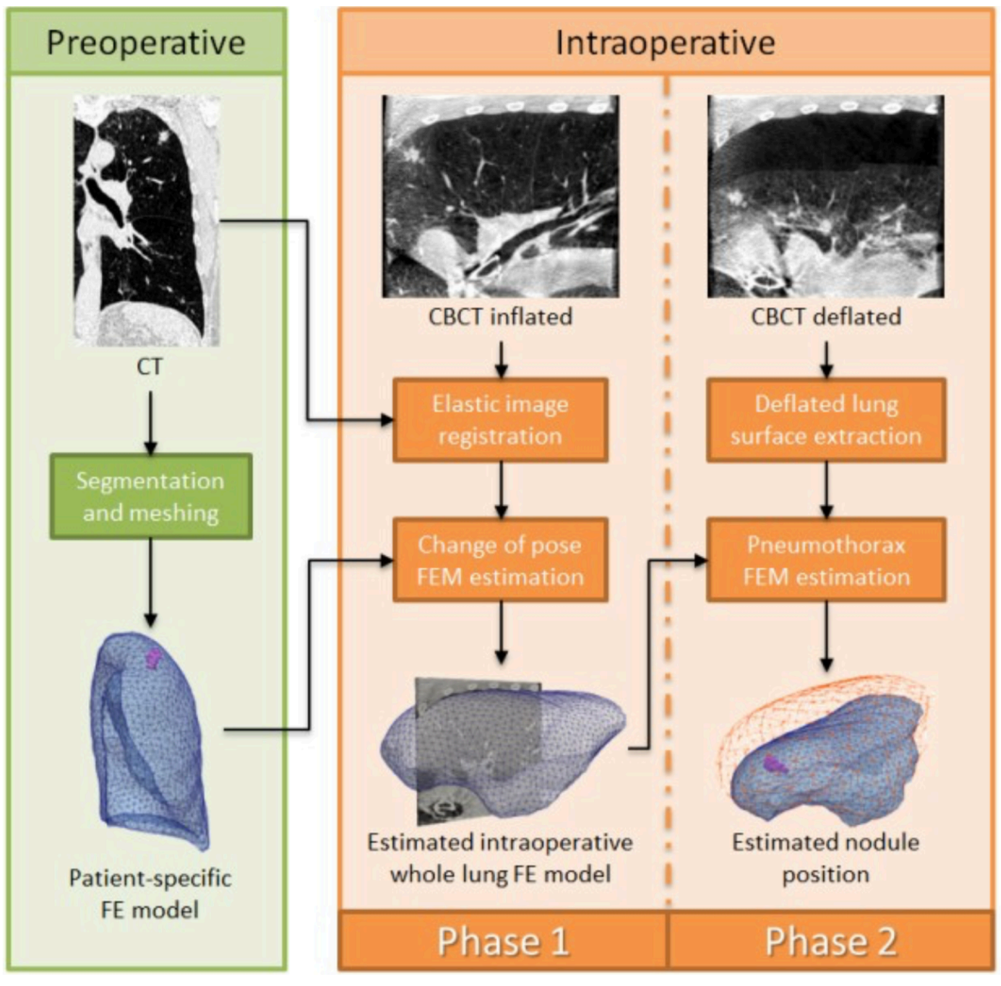

Figure. Étapes de la localisation des nodules. Phase préopératoire : segmentation du poumon et nodule sur le scanner préopératoire et élaboration du modèle biomécanique du poumon. Phases per- opératoires : 1) estimation des déformations du poumon dues au placement latéral du patient par le couplage d'une méthode de recalage élastique basée image et le modèle biomécanique et 2) simulation de la déflation du poumon ajustée sur le CBCT per-opératoire

Localisation de nodules pulmonaires en vidéo-thoracoscopie. Intégration d'un modèle biomécanique du poumon dans la chaîne de traitements d'images

Alvarez P. [1], Rouzé S. [1], Chabanas M. [2], Payan Y. [2], **Dillenseger J.-L.** [1]

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La problématique médicale concerne la localisation per-opératoire de nodules pulmonaires en vidéo- thoracoscopie. La procédure originale de guidage et d'ablation des nodules élaborée au CHU de Rennes est basée sur les étapes suivantes : 1) Une phase de planning avec la localisation préopératoire du nodule sur un scanner X de diagnostic. 2) La mise en place de la vidéo thoracoscopie par l'incision de 3 voies d'entrée dans le thorax et l'introduction d'une caméra et des outils d'intervention. Ces incisions provoquent un affaissement du poumon connu sous le nom de pneumothorax. 3) une acquisition du volume pulmonaire thoracique à l'aide d'un Cone Beam CT (CBCT) afin de localiser le nodule et 4) le guidage vers le nodule par Réalité Augmentée. L'affaissement du poumon provoque par contre une modification des densités des tissus pulmonaires ne permettant pas toujours la localisation peropératoire du nodule (généralement pour les formes les plus agressives de nodules)

L'idée générale de notre approche est de prédire la position du nodule par la simulation des déformations subies par le poumon lors de l'intervention : a) la mise en position latérale du patient et b) le pneumothorax. Cette simulation est menée grâce à un modèle biomécanique poro-élastique du poumon intégré et couplé à la chaîne de traitements d'images nécessaire au guidage. Plus précisément, une méthode de recalage élastique basée image associé au modèle biomécanique permet d'estimer la déformation des tissus lors de la mise en position latérale du patient. La position du nodule après pneumothorax est ensuite estimée par la simulation de la déflation du poumon à l'aide du modèle biomécanique guidé par la position finale du poumon extraite du CBCT.

Modératrice de session

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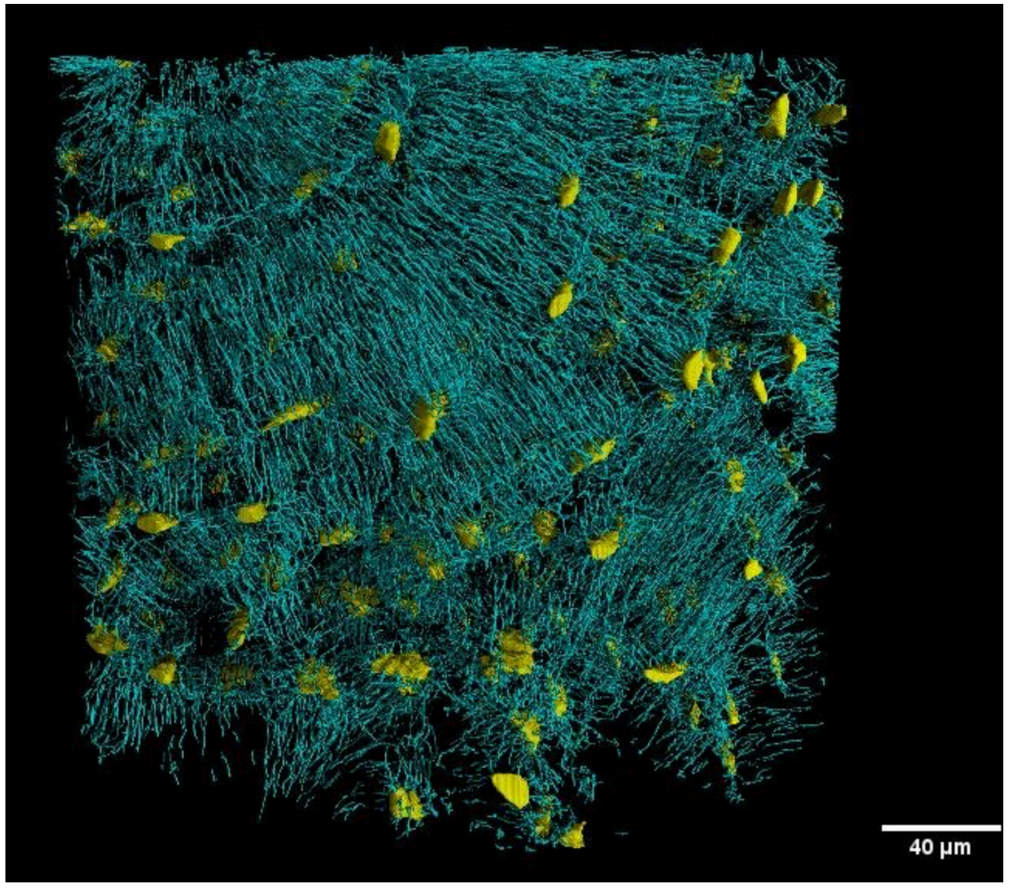

Figure : 3D display of the complex LCN from SR phase nano-CT (voxel size: 100nm) showing the dense network formed by osteocyte lacunae (yellow) and canaliculi (green)

3D X-Ray microscopy for the investigation of bone tissue properties up to the nanoscale

Françoise Peyrin

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The understanding of the biomechanical properties of bone is fundamental for a better prediction of the fracture risk in bone-related diseases such as osteoporosis. In this context, imaging methods provide instrumental information to input bone tissue properties into biomechanical models.

X-Ray micro CT (µCT) has become a standard technique for the investigation of the three-dimensional (3D) trabecular bone micro-architecture. However, bone features up to the nanoscale scale have also an impact on bone strength. Bone micro-damage occurring due to stress and strain imposed on the tissue are hypothesized to trigger bone repair. The osteocyte network deeply embedded in bone tissue is also playing a major role in bone remodeling. It is included in the complex lacunar-canalicular network (LCN) contributing to the nano-porosity of bone. Due to their size and location, such features are challenging to assess.

In this work, we coupled 3D X-Ray µCT to 3D image analysis to assess bone ultrastructure. We focus on Synchrotron Radiation (SR) CT, which can be used in absorption and phase modes.

The 3D observation of linear bone micro-cracks in human trabecular bone was first demonstrated using SR-µCT at a voxel size of 1.4 µm. SR phase µCT was then used to image damage after applying different types of biomechanical constraints. We show characterizations of the LCN from SRµCT at the micrometer scale and phase nano-CT at voxel sizes up to 30nm. As a perspective, this technique is expected to provide new information about the 3D organization of collagen fibrils which are constitutive of bone extra cellular matrix.

Development of MR Elastography method to characterize the elastic property of the sterno-cleido-mastoid (SCM) muscle

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Keywords: Head and neck cancers; sterno-cleido-mastoid muscle; muscle elasticity; Magnetic Resonance Elastography.

1. Introduction

Radiotherapy applied to head and neck cancers causes fibrosis that is a very frequent side effect of this treatment. Fibrosis provides an increase of muscle stiffness, responsible for an impairment in the quality of life of patients (Langendijk et al. 2008), and can obstruct a possible catch-up surgery or a possible re-irradiation (Moloney et al. 2015). The appreciation of radiation-induced cervical fibrosis within the sterno-cleido-mastoid (SCM) muscle is subjective and radiotherapists have attempted to define standardized clinical measurement scales, which bring several objective criteria such as the level of indurations of cutaneous tissues and the quality of life. The correlation between these different classifications is often poor (Davis et al. 2003). Thus, the purpose of this study is to develop MR Elastography (MRE) protocol for healthy neck muscle to latterly used for patient having neck muscle fibrosis.

2. Methods

2.1 Participants

Five volunteers, without muscle abnormality and no history of muscle disease underwent a MRI neck acquisition. This study was approved by the Institutional Review Board (CPP IDF6).

2.2 Localization of the sterno-cleido-mastoid muscle

The subject lays supine inside the 3T MRI Philips machine (GIE Faire-Faces) and a head coil was used inducing a stable position of the neck without tension. The sterno-cleido-mastoid (SCM) muscle is a neck muscle with two points of insertion in the upper (bony point behind the ear, occipital bone at the posterior and lower part of the skull) and lower (sternum, collarbone) sides of the neck.
Accurate anatomical localization of the SCM has been performed with a coronal 3D T1 sequence (coronal plane, figure 1A; sagittal plane figure 1B). The slice thickness was 2 mm and the pixel size 0.65 x 0.65 mm².

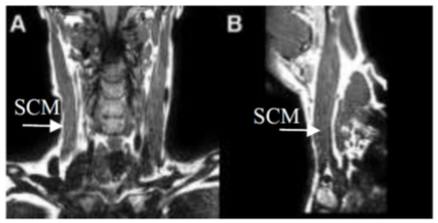

Figure 1. SCM in coronal (A) and sagittal (B) planes.

2.3 Development of pneumatic drivers

In the literature, fibrosis has been quantified in pathological muscle (Bensamoun et al. 2015). This quantification was realized with Magnetic Resonance Elastography (MRE) technique which is combined with specific pneumatic drivers such as a silicone tube driver (Chakouch et al. 2015) wrapped around the thigh. The role of the driver is to generate a non-invasive vibration at the surface of the tissue. In the present study, three pneumatic drivers were developed: a tie shape placed around the neck, a rectangular bar in contact with the lower part of the SCM and a square cushion driver, made of memory form, placed above the collarbone.

2.4 Magnetic Resonance Elastography (MRE)

MRE is an imaging technique based on the propagation of shear waves in soft tissue allowing the quantification of mechanical properties. To follow the displacement of the waves, the motion encoding gradients in the three orthogonal directions have been performed with four time offsets. Subsequently, the waves have been generated with three different frequencies (60 Hz, 90 Hz, 120 Hz) for each pneumatic drivers in order to select the best wave propagation in the SCM. Moreover, different wave amplitudes (from 50 to 100 %) have been tested to make the wave deeply penetrate the muscle.

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Phase images were collected with a gradient-echo sequence (flip angle:20°; field of view: 24 cm; acquisition matrix: 256x256; TR/TE = 50.0/20.3, 55.5/14.1 and 58.3/11.3 ms at 60 Hz, 90 Hz and 120 Hz, respectively). The acquisition times per direction were 59 s, 54 s and 56 s at 60 Hz, 90 Hz and 120 Hz, respectively. Image processing has been performed with a directional filtering (Manduca et al. 2003) to limit the effects of interferences and cartography of elasticity has been obtained with inversion algorithm (Manduca et al. 2001).

3. Results and discussion

Figure 2A showed shear waves in the SCM muscle and the associated cartography of shear modulus (μ) (Figure 2B). This result has been obtained with the square cushion driver, a frequency of 90 Hz, an amplitude of 90 % and a motion encoding applied in the anterior-posterior direction. These parameters associated to the cushion driver allow to consistently visualize the propagation of the waves in the SCM. However, figure 2B shows a heterogeneous cartography with a red spot revealing an irregular propagation of the waves due to experimental problems. The next step will be to obtain a better propagation with consistent wavelength along the SCM. The variation of wavelength induced a high (7.91 kPa) standard deviation. The average shear modulus (7.76 kPa) in the region of interest, represented by white border line, is in agreement with other studies which have performed shear wave elastography on SCM (Ewertsen et al 2018, Liu et al 2015) but must be confirmed with additional MRE tests. These results (phase image, elasticity) show the feasibility of this MRE protocol to quantify the mechanical properties of SCM muscle.

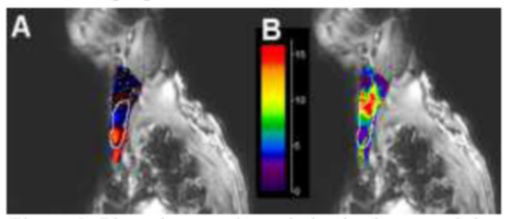

Figure 2. Phase image (A) and elastic shear modulus (μ=E/3) image in kPa (B) in the region of interest of SCM represented by white border line.

This MRE protocol will be further improved by adjusting the placement of the driver in a reproducible way. The next step will be to apply this protocol for patient having neck muscle fibrosis after radiotherapy, and to correlate quantitative measurements (elasticity, viscosity) to the subjective results obtained with functional and clinical scales, in patients with different stages of fibrosis.

4. Conclusions

There is currently a significant lack of studies on the treatment of complications and side effects of radiotherapy. The present protocol could bring a decisive element (benefit / risk ratio) to better guide the patients for surgical treatment and/or reirradiation.

Acknowledgements

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