The future of heart scanning

Drs Hervé Liebgott, Olivier Bernard, Adrian Basarab and **Loic Boussel** discuss their pioneering research into the development of an ultrasound tagging method that could revolutionise the diagnosis of cardiac pathologies


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To begin, could you outline the key aims and objectives of your investigation? How did you come to study echocardiography and new ultrasound (US) methods?

HL: The context of our investigation is cardiac imaging. Our objective is to develop automatic diagnostic tools based on the processing of US image sequences. We are developing specific kinds of US images to make this processing more precise. Our lab has a long history of cardiac imaging due to our close collaboration with the Cardiologic Hospital in Lyon.

What are the current methods used by clinicians to monitor the pathological state of the heart?

LB: Monitoring the pathological state of the heart, in terms of wall motion, relies mainly on US and magnetic resonance imaging (MRI) examinations. A major feature in MRI, in comparison with US, is the potential to use a tagging method to accurately quantify the complex 3D motion of the heart wall. However, the duration of an MRI examination (between 30 minutes and an hour), the limited number of MRI scanners and the price of one exam limit the diffusion of this method.

HL: In tagged MRI, specific sequences are used to create magnetisation perturbations within the tissue. These perturbations produce dark marks on the image of the tissue. Tagging aims to produce marks that look like a grid. The deformation estimation of such a grid, and as a result of the heart tissues, is then relatively easy to track using dedicated image processing techniques.

Could you outline the concept of US-Tagging?

HL: In US-Tagging we modify image formation to facilitate heart motion estimation. Similar techniques have been used in US since the late 1990s for blood flow in the vessels or elasticity imaging of other organs, but never on the heart.

LB: The possibility of having a tagging technique with US – a rapid and widely available examination modality – will allow better assessment of cardiac wall motion in a large population of patients.

What challenges are associated with US imaging and how are you working to address these?

OB: Most researchers from the image processing community believe US image formation cannot be modified. If the information is hidden it will be very difficult for any technique to recover it. It is much easier to estimate the motion in the direction perpendicular to the US beam axis

using conventional equipment than it is along this axis. One of the main reasons for this is that the transverse image patterns feature fewer details than the axial ones. We have thus proposed to modify the transverse image patterns and make them look like the axial ones as far as possible.

AB: The ultimate goal is to have images at a very high frame rate, with good spatial resolution, and to have patterns that can be followed easily. The US-Tagging project is focused more on the last point. We need to modify the way the raw signals received by all the piezoelectric elements (that constitute the US probe) are combined to form one column of the final image. We mainly modify the weights (also called apodization) applied to each of these signals. The difficulty is in choosing these weights to obtain the best tagging. This is one of the main tasks in the US-Tagging project.

What are the benefits of applying a dual imaging mode, ie. a tagging mode that works in parallel with the conventional imaging approach?

OB: Ideally, only one mode should be used. However, even if the US-Tagging images are adapted to motion estimation, the patterns of the underlying images are modified and it is not clear for the moment if clinicians will accept these new images. We are not sure that anatomical examination will be as easy with US-Tagging images as it is with conventional images. As a result, we imagine a dual mode where conventional images are computed for anatomical inspection, and US-Tagging images for functional imaging. This approach is not optimal and we would like to be able to provide images that are adapted for both purposes.

Could you elaborate on the *in vivo* feasibility study? How will you test your prototype US-Tagging scanner?

LB: The first step is to finalise the prototype and to be sure that the true vector field is estimated in simple situations like rigid translations or rotations of test media. Then, for *in vivo* feasibility we will concentrate on the comparison with other imaging modalities, mainly MRI with tagging imaging. This will allow us to validate this new method.

Multidisciplinary movements

The US-Tagging group brings together experts from various fields who are contributing across the image formation pipeline. **Olivier Bernard** reports

Medical imaging is intrinsically multidisciplinary. In our project, we need to understand what important information ought to be visualised from a medical point of view. It is then necessary to imagine the best scenario and conditions for the image processing technique to enable us to extract the pertinent information from the image sequence. Physics and image formation expertise is necessary in order to develop the adapted image formation. In the past, geniuses conducted research on mathematics, physics, biology and philosophy. Nowadays, at least in applied sciences, each domain is so specific that only a multidisciplinary group can handle this kind of problem.

Developing a picture of health

Cardiovascular disease is one of the major causes of mortality amongst Western European adults. Research at the **University of Lyon**, France is currently underway to discover a fast, affordable and effective method of identifying the early risk factors

IT HAS LONG been recognised that changes to the motion of the heart are indicative of many cardiovascular pathologies. However, detecting these changes has always presented a challenge, with ultrasound (US) scanning being reliant on an individual clinician's interpretation of the image produced and thus providing qualitative rather than quantitative results. Whilst magnetic resonance imaging (MRI) scanning does produce quantitative results, the practicalities of performing an MRI scan pose huge limitations in terms of accessibility to a large patient population.

Drs Hervé Liebgott, Olivier Bernard, Adrian Basarab and Loic Boussel of the University of Lyon believed there had to be a better way. With their combined expertise covering a huge range of disciplines, including US imaging, motion estimation, inverse problems, electrical engineering and medical image processing, the team began researching how the established techniques of US scanning might be utilised to produce similar quantifiable results to those produced by an MRI scan.

With such a huge undertaking ahead of them, Liebgott explains how the team broke the task down into more manageable areas of study: "The project is firstly split into a methodological and experimental axis. The first concerns all the theoretical developments of the proposed algorithms and methods". It is here that they worked on the specific image formation technique and the image analysis methods for automatic identification of the limits of the heart muscle and its motion estimation. In an intermediate task, all these steps have been validated using numerical simulations. "Currently, we are finalising the implementation on our research scanner; this task will need some additional time, after which we will be ready to validate experimentally the whole imaging mode."

SECTORIAL GEOMETRY

The ultimate aim of the project is to develop an imaging technique that will enable clinicians to estimate the 2D motion and deformation of the heart. The team will use established techniques that have been developed to estimate motion in blood flow and elastography. However, the limitation of these existing techniques is that they were initially developed in linear geometry. In order to produce an image that can be used for accurate estimation of the heart's motion and deformation, the group would need to revise these existing techniques and redevelop them using sectorial geometry. "Transverse oscillations have initially been developed by the research group of Professor J A Jensen from the Technical University of Denmark," Basarab elaborates. These were initially focused on the estimation of blood flow velocity; this kind of imaging is performed with what is called a linear array, which lead to a rectangular image showing parallel beams. The same kind of linear probe has also been used for thyroid elasticity characterisation. In echocardiography, as the heart is situated behind the ribs and the acquisition window is very limited, the acquisition is done with so-called phased arrays. This kind of probe performs an acquisition by steering the US beam and leads to a typical image having a fan shape. For this reason, the team has to adapt all work previously done in the linear geometry to the sectorial one.

THE STRAIN RATE MAP

Once an image of the heart has been developed using the team's pioneering imaging processing techniques, motion and deformation can then be estimated using a strain rate map. This is a well-established method of obtaining important quantitative information regarding local stress and deformation of the myocardial segments, which in turn gives a good indication of overall myocardial function. The strain rate map has the additional advantage of being a non-invasive assessment technique. Use of a colour scale to determine stress and deformation of the heart wall also circumvents the need for assessment based purely on the clinician's visual analysis of the image – as was the case with images of the heart developed through US previously – which allows for a more standardised assessment.

HEALTH AND ECONOMIC IMPLICATIONS

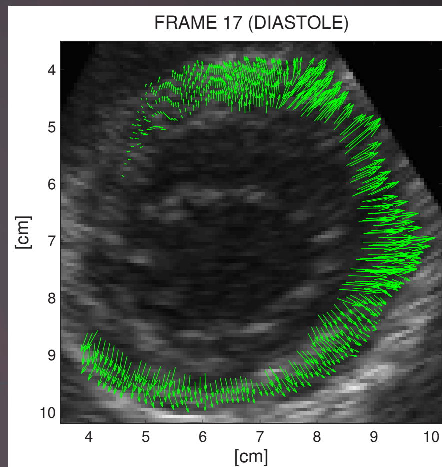
The collaborators are now two years into this three-year project. To date, they have developed the image formation technique for cardiac assessment, and have successfully implemented this technique on an US scanner. Moreover, the developed technique has proven extremely accurate, producing 30 images per second in real-time when being used for both conventional and US-tagging imaging simultaneously, and up to 60 images per second when being used solely for the production of US-Tagging images. To facilitate swift and accurate analysis, the team has also ensured that the motion estimation and segmentation algorithms are available offline. For the remainder of the project, the group will collaborate closely with clinicians in order to perform an *in vivo* feasibility study on a healthy volunteer, whilst simultaneously developing a fully functional prototype of their technique in operation on an US scanner.

The commercial implications of this study are very significant, as any company developing US scanners could potentially include this imaging technique on future models as standard, thus offering clinicians a swift, reliable and cost-effective method for analysis of cardiac motion and deformation. As such, it is likely that a follow-up to this project will see the researchers collaborating with an industry leader in the production of US scanners, to implement their revolutionary technique onto subsequently developed models.

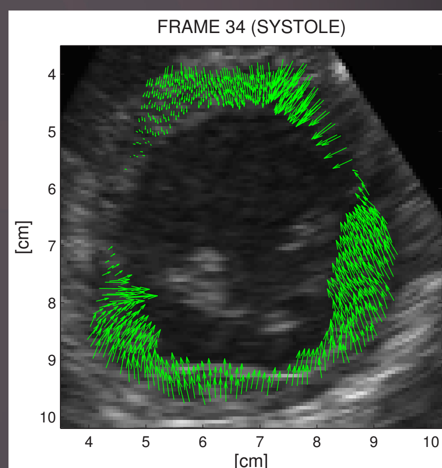
Faster and more accessible cardiac assessment will also be hugely beneficial in terms of detecting early signs of cardiac pathologies in patients, as Liebgott explains: "Even if patients do not systematically die because of these pathologies, they are commonly accompanied with many complications. The main idea behind US-Tagging really follows the proverb, 'prevention is better than cure'". The consortium aims to develop a technique that could be used as a mass prevention tool. Any family doctor could practise this exam routinely as an early stage risk detection technique and many complications could then be avoided for the patient.

The team is optimistic and passionate that their research could truly revolutionise the way in which clinicians approach their assessment of cardiac stress and deformation. "We really hope that our research will lead to the development of an efficient tool for the clinicians," Liebgott says. "Having the US-Tagging button on a commercial scanner like the Doppler mode would just be fantastic for us. The possibility of finding solutions to major public health questions like the detection of cardiac pathologies is extremely exciting work."

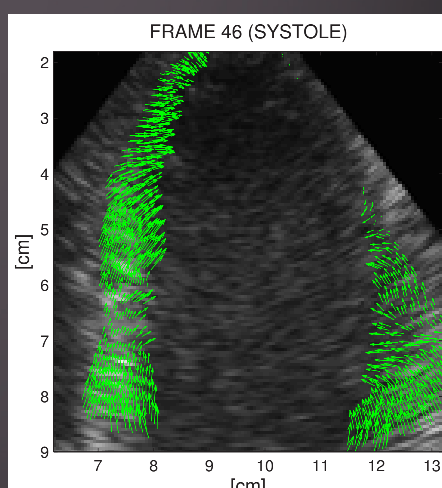
Estimated motion fields (green arrows) in the myocardium overlaying US Tagging images (grayscale background).



Parasternal short axis view during diastole.



Parasternal short axis view during systole.



Apical four chambers view during systole.

INTELLIGENCE

US-TAGGING

ESTIMATION AND MONITORING STRUCTURES IN ECHOCARDIOGRAPHY FROM SPECIFIC IMAGES

OBJECTIVES

This project concerns the detection of cardiovascular pathologies thanks to a new ultrasound (US) imaging method: US Tagging. It is well known among clinicians that the analysis of the motion and deformation of the heart muscle can bring relevant information about the pathological state of the heart and be of great use in diagnosis.

KEY COLLABORATORS

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FUNDING

French ANR in the frame of the 2010 Young Researcher call (€205,000)

Project duration: three years from February 2011

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