

# **M3.4.1 - 4D heart image simulation procedure & D3.4.2 : 4D multi-modality simulated images**

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## **Summary**

This documents describes 4D heart image simulations (M3.4.1), and presents the results available in the VIP database of simulated cardiac images (D3.4.2). It demonstrates that the simulation of multi-modality cardiac images through VIP is feasible. In the four modalities (MRI, CT, PET and US) available in VIP, a set of simulated data is generated to provide a specific database targeting cardiac applications.

## Table of Contents

Introduction.....	2
MRI simulation.....	2
PET simulation.....	3
CT simulation.....	4
Simulated images database.....	4
Conclusion .....	5

## Introduction

This deliverable concerns the simulation of 4D cardiac images. The 4D can be considered as 3D + time or  $n \times 3D$  (multi-patients). To perform these simulations, the simulators available on VIP have been used: **SimuBloch** for MRI, **Sorteo** for PET and **Sindbad** for CT. It complements the ultrasound and MRI simulations performed in **D.3.4.1** with **FIELD-II** and **SIMRI**. The simulations were performed from the virtual beating heart and breathing thorax model called ADAM (Anthropomorphic DynAmic Model of the beating heart and breathing thorax). For MRI, the simulations has been done through 15 instants based on the same ADAM model. For PET, the images have been simulated for a healthy and for a pathological version of the ADAM model. For CT, a single simulation has been done. All simulations have been designed to target cardiac features of selected models.

## MRI simulation

The data has been obtained with the MRI simulator: **SimuBloch**. The full description of the simulator has been done in milestone **M3.3.2**, section 4. SimuBloch allows to generate a full simulated image from different MRI parameters maps (T1, T2, Proton Density mainly).

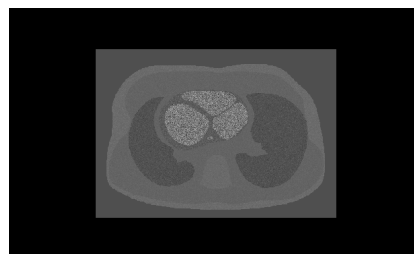
Fifteen volumes from the healthy ADAM model have been simulated with [SimuBloch](#) over the whole cardiac cycle. It allows to have a full sequence of the beating heart.

The different maps T1, T2, Proton Density and T2star have been computed from the values extracted from (C. Tobon-Gomez and al. “[Realistic simulation of cardiac magnetic resonance studies modeling anatomical variability, trabeculae, and papillary muscles](#),” Magnetic Resonance in Medicine, vol. 65, no. 1, pp. 280–288, 2011).

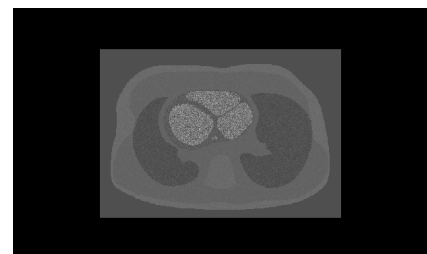
The simulated sequence was a gradient Echo with the following scan parameters: TR (Repetition Time) = 2.9 ms, TE (Echo Time) = 1.2 ms and FA (Flip Angle) = 45°.



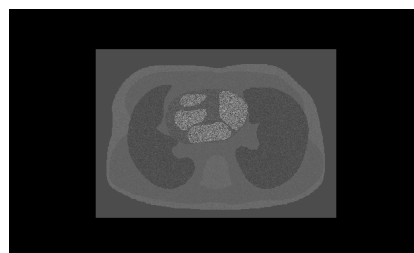
Instant 1

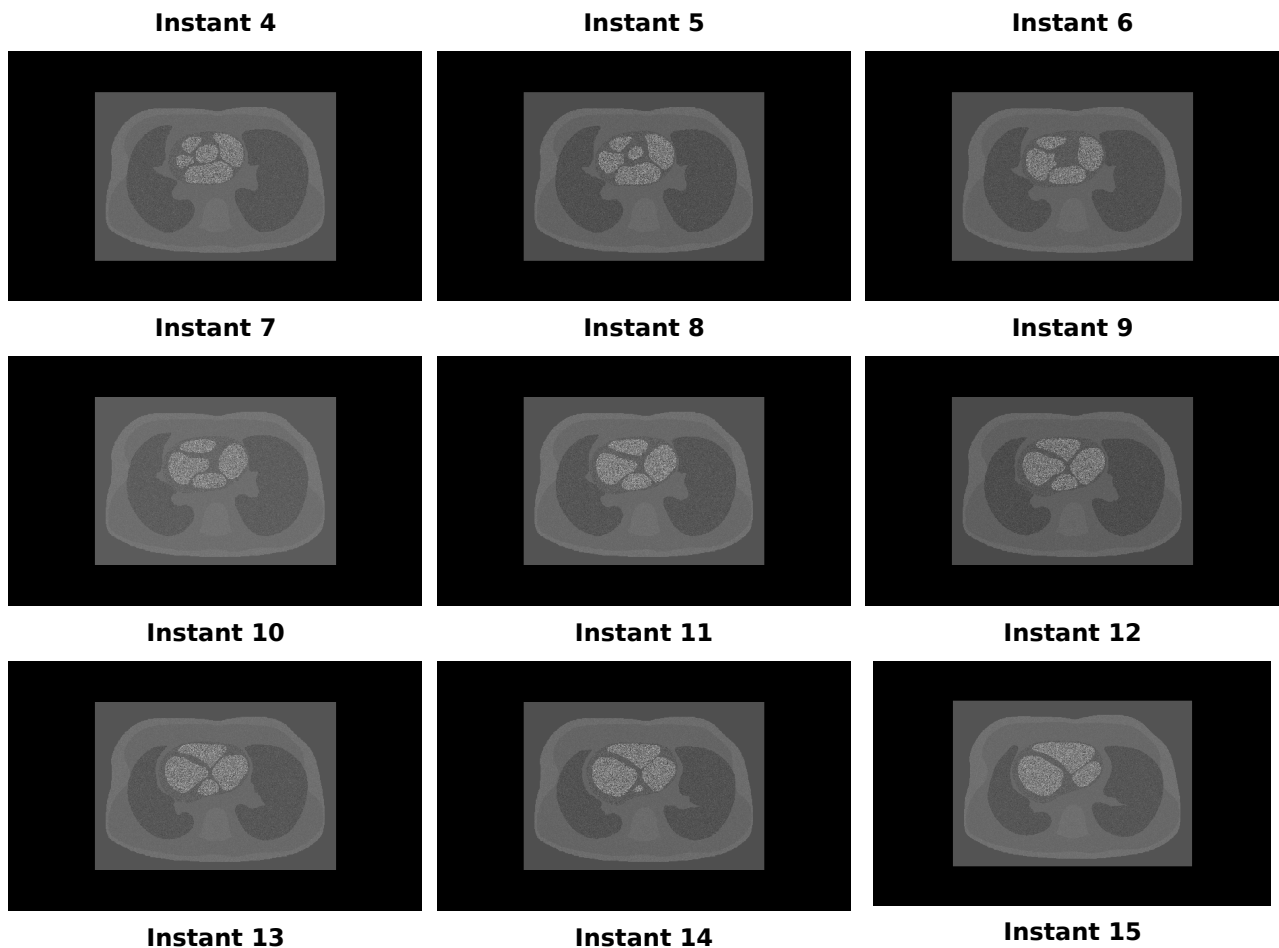


Instant 2



Instant 3



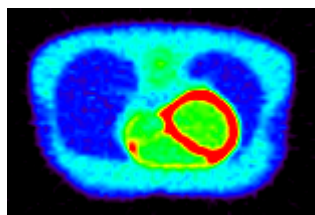


**Fig. 1:** cine-MRI simulated sequence of beating heart

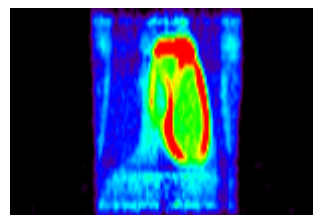
A transverse slice extracted from the series of 15 simulated volumes is shown in Figure 1. In spite of the limited number of anatomical structures compared to real bSSFP MR images, contrasts in the images are realistic in all the anatomical structures and in particular in the cardiac ones. Short and long axes slices can easily be extracted from the 3D images for further analysis.

## PET simulation

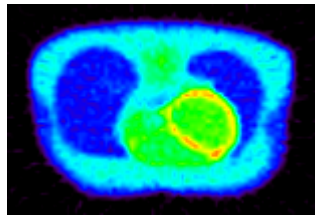
Two FDG-PET acquisitions (one healthy and one pathological) were also simulated with the ADAM model and SORTEO simulator. The scanner geometry of the ECAT EXACT HR+ (CTI/Siemens Knoxville) was used, and  $^{18}\text{F}$ -FDG was the radiotracer to study the glucosis metabolism during one cardiac cycle. The simulated activities were 45.1 MBq (1.22 mCi) for healthy and 43.8 MBq (1.18 mCi) for pathological (as used in R. Haddad, “[Un modele numerique anthropomorphique et dynamiquedu thorax respirant et du coeur battant](#),” Ph.D. dissertation, INSA Lyon 2007). The raw data was corrected from attenuation and reconstructed using a standard 3D filtered backprojection algorithm resulting in a 128x128x63 3D image with a voxel size of 5.15 x 5.15 x 2.42 mm.



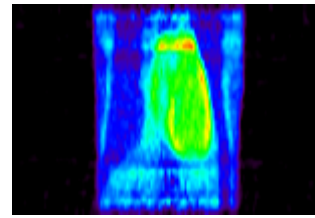
**transverse view of healthy model**



**coronal view of healthy model**



**transverse view of pathological model**



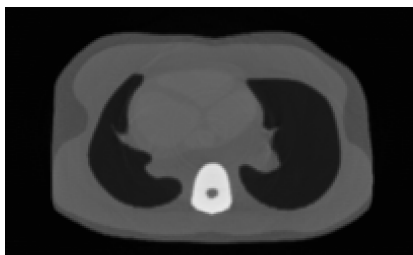
**coronal view of pathological model**

**Fig. 2:** Transverse and coronal views from the 3D FDG-PET simulations from healthy and pathological ADAM model.

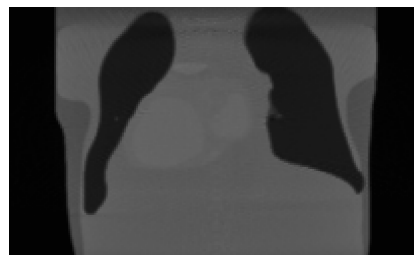
Figure 2 shows transverse and coronal views extracted from the obtained 3D FDG-PET simulated volumes from the healthy and pathological (imposed global reduction of the cardiac activity) versions of ADAM. The simulation of the complete cardiac cycle represented 91 CPU hours and was obtained in 39 hours on VIP. The appearance is close to a real cardiac FDG-PET image with high homogeneous FDG captation in the healthy myocardium and lower fixations for the pathological myocardium.

## CT simulation

The CT simulation was exclusively analytical although SINDBAD also has a Monte-Carlo mode. The scanner model was a simplified version of the Philips Scanner (PHILIPS MX8000) which is the CT component of the PET/CT Gemini scanner. We assumed a point source located at 0.7m from the center of the thorax (also considered as the rotation axis of the CT system) and at 1.0m from the plane detector. We used a cone-beam geometry and a standard X-ray energy spectrum with a tube voltage of 110kVp and an aluminium filter of 2.5mm. The typical values for intensities and scanner rotation length corresponded to a very low-dose acquisition (resp. 1mA and 0.5s). The detector was a planar matrix of 512x512 pixels of ideal absorber with an isotropic pixel size of 2mm. The accuracy of the CT voxel model was chosen coherently with the detector resolution (500x500x689 volume with a isotropic voxel size of 1 mm). A set of 480 projections were reconstructed with a Feldkamp cone-beam reconstruction algorithm resulting in a 512x512x512 matrix with an isotropic pixel size of 2mm. Figure 3 shows 3 orthogonal views from the generated 3D CT image of the ADAM model at end diastole.



**coronal view**



**sagittal view**



**transverse view**

**Fig. 3:** 3 orthogonal views extracted from the simulated 3D CT volume of ADAM at end diastole.

## Simulated images database

All simulated data are available in a database publicly accessible for users with a “Cardiac simulated images” account in VIP. The database, shown on a screen capture of the corresponding web page of the VIP portal (Figure 4), has the following functionalities:

- Simulated images are described and associated with a set of files, one or several modalities, and VIP simulations.
- Users can download file associated to simulated images.
- Users can access the simulation parameters (user, date, input parameters, execution times,

- etc) when the simulation was obtained using VIP.
- Administrators can add/delete simulated images.

## Conclusion

Multi-modality cardiac images can be simulated with VIP and made available to the community in a database. To illustrate this possibility, the following cardiac images were simulated from the ADAM thorax model :

- Ultrasound (FIELD-II simulator): 2D+t sequence and 2D slices
- PET (Sorteo simulator): two 3D volumes of healthy and pathological patients
- MRI (SimuBloch and SIMRI simulators): a 3D+t sequence
- CT (Sindbad simulator): a 3D volume

Such simulated cardiac database could serve as a basis for the evaluation of cardiac image analysis methods (segmentation, motion estimation...) in the sense that it can produce a large variety of images with various quality (by varying simulation parameters) on a potentially infinite set of subjects. The modality simulators currently show quite satisfactory realism. At present, the main limitation with this whole simulation based approach comes from the limited realism of the anatomical and functional models, which still exhibit too few structures with incompletely determined physical parameters.

Home

Cardiac Images

simulation name

simulated images

Download the results

Relaunch the simulation

Add Simulation

Refresh

<div> <div>ADAM apéc</div> <div>adam-ap4c-dynamic.tar.gz</div> <div> <p>A 64-element cardiac phased array of center frequency 3Mhz was simulated with <b>FELDT</b>. The image had 128 lines for a 90° sector angle. The transmit focus was at 67mm depth and dynamic receive focusing was applied. Constant Hanning apodization was used both in transmit and receive. The excitation pulse was a two-cycle sinusoid at 3Mhz. RF data was sampled at 40Mhz. Scatterer positions were generated from a uniform spatial distribution with a density of 10 scatterers per voxel. Scattering coefficients were generated from centered Gaussian distributions with amplitudes 0 (air), 0.5 (fat, muscle and lung), 0.2 (blood), 1 (spine and spinal chord) and 1.5 (myocardium). More details in this <a href="#">paper</a>.</p> <p>If you publish any work with this data please refer to <a href="#">VIP</a>.</p> </div> </div>	<div> <div>ADAM healthy</div> <div>adam_healthy.v</div> <div> <p>A healthy FDG-PET acquisition has been simulated with the ADAM model using <b>SORTEO</b>. The scanner geometry of the ECAT EXACT HR+ (CT/Siemens Knoxville) was used, and 18F-FDG was the radiotracer to study the glucose metabolism during one cardiac cycle. The simulated activity was 45.1 MBq (1.22 mCi) (as used in R. Haddad, "Un modèle numérique anthropomorphe et dynamique du thorax respirant et du cœur battant", Ph.D. dissertation, INSA Lyon 2007). The raw data was corrected from attenuation and reconstructed using a standard 3D filtered backprojection algorithm resulting in a 128x128x63 3D image with a voxel size of 5.15 x 5.15 x 2.42 mm.</p> <p>If you publish any work with this data please refer to <a href="#">VIP</a>.</p> </div> </div>	<div> <div>ADAM pathological</div> <div>adam_pathological.v</div> <div> <p>A pathological FDG-PET acquisition has been simulated with the ADAM model using <b>SORTEO</b>. The scanner geometry of the ECAT EXACT HR+ (CT/Siemens Knoxville) was used, and 18F-FDG was the radiotracer to study the glucose metabolism during one cardiac cycle. The simulated activity was 43.8 MBq (1.18 mCi) (as used in R. Haddad, "Un modèle numérique anthropomorphe et dynamique du thorax respirant et du cœur battant", Ph.D. dissertation, INSA Lyon 2007). The raw data was corrected from attenuation and reconstructed using a standard 3D filtered backprojection algorithm resulting in a 128x128x63 3D image with a voxel size of 5.15 x 5.15 x 2.42 mm.</p> <p>If you publish any work with this data please refer to <a href="#">VIP</a>.</p> </div> </div>	<div> <div>ADAM sindbad</div> <div>ADAM2_De512x512_2mm_360proj_xfdr_512x512x512_360deg_flip1.raw</div> <div> <p>The simulated data is a 512x512x512 volume in float little endian with an isotropic voxel of 2mm.</p> <p>If you publish any work with this data please refer to <a href="#">VIP</a>.</p> </div> </div>
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Add/Edit Cardiac Simulation

Name

Modalities

VIP simulation ID

Description

B

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U

management interface

Fig. 4: simulated cardiac database