

# Patient-Specific Anatomical Modelling

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**Abstract-** This paper aims at presenting the development of patient-specific anatomical models with a focus on the pelvis region supporting the femoral nerve block. Magnetic resonance imaging (MRI) and virtual physiological human (VPH) model are used for image registration, and a library of segmentation and registration algorithms was compiled for scaling, registration, and segmentation that supports the user in generating patient-specific models. Results are presented in the form of image registration with respect to the skin of the models.

**Keywords:** image registration, VPH models, simulator, assistant, anatomical modelling.

## I. INTRODUCTION

Patient-specific modelling develops computational models of human (patho-) physiology that are individualized to patient-specific data, as opposed to generic anatomical modelling, which cannot express the variability that exists among individuals and may lead to different diagnosis and treatment [1][2].

Through an integration of image processing, physiological models, subject-specific data, and virtual reality, the Regional Anaesthesia Simulator and Assistant (RASimAs) project aims at developing a training simulator and assistant prototype for regional anaesthesia (RA) procedures which will increase the application, the effectiveness, and the success rates of RA by combining a simulator and an assistant supporting ultrasound-guided and electrical nerve-stimulated (conventional) RA [3].

Patient-specific anatomical modelling has been subject for some works. From four dimensional cardiac computer tomography (CT), Mihalef et al. [4] proposed a patient-specific model of the whole human heart to support comprehensive disease assessment, intervention planning, and prediction of therapeutic outcomes. Zadpoor et al. in [5] focused on emerging tools, trends, and approaches that could revolutionize patient-specific modeling of bones.

Considering some works on patient-specific modelling of the pelvis and femur, Bailey et al. [6] generated patient-specific computer models of the femur for the development of a system for setting the femoral component stem shaft angle during hip resurfacing surgery. And Zheng et al. [7] validated a statistical shape model based technique for 3D reconstruction of patient-specific surface model from calibrated x-ray radiographs.

These works mostly presented monomodal image registration (images from same modality) computed on a voxel by voxel basis. Also, a small number of cadavers is used for validation model. One challenge is to consider

individual patient anatomy and use general models to generate patient-specific computer models for application in RA procedures, applying image registration techniques for a mesh and voxel basis. With the aim of focusing on the pelvis region supporting the femoral nerve block, the general idea of this paper is to substitute lacks in subject-specific information by that adopted from general models in order to build virtual physiological humans (VPH). The patient-specific VPH models include anatomical and mechanical properties of the tissues, as well as computational models compatible with real-time simulation.

## II. MATERIAL AND METHODS

### 1. Model Data

The VPH initiative targets the whole human body as the system of interest. It aims at understanding human physiology quantitatively, as a dynamic system and at all relevant levels between genes and the organism [8]. Generic commercial VPH models provide accurate models with high resolution and details to use as reference as well as for prototyping.

Two commercial datasets, Zygote<sup>1</sup> and Anatomium<sup>2</sup>, were used as general models. They yield the human anatomy in 3D and provide polygonal meshes, partly enhanced with texture. Therefore, they are very useful as references as well as for prototyping; however, such datasets do not consider anatomical variations (Fig. 1).

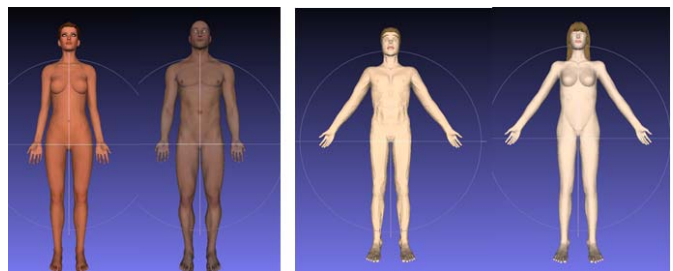


Fig. 1. On the left, female and male bodies from Zygote. On the right, male and female bodies from Anatomium.

### 2. Subject Data

All necessary image data for the anatomical models include MRI. Thirty four sets of MRI of sane male and female have been recorded at Uniklinik RWTH Aachen – Germany,

<sup>1</sup> <http://www.zygote.com>

<sup>2</sup> <http://www.anatomium.com>

Research Centre Jülich – Germany, and Trondheim Hospital, Norway. The images are archived into the web-based RASimAs Information Storage System (ISS), which includes: (i) Picture Archiving and Communication System (PACS) server for medical image storage and retrieval; and (ii) data server for 3D generic and registered models storage and retrieval.

The medical images are stored using the Digital Imaging and Communications in Medicine (DICOM) standards, which provide methods to ensure data privacy and security in the clinical environments of PACS.

### 3. Image Processing Library

Different technological platforms, interfaces, and algorithms are used for the development of tools. In order to compose the image processing library, existing tools were considered: toolkits that provide task specific support with extensive adaptability; development environments, which are comprehensive applications; and software packages that can be extended by customizes code provided by the user.

Several libraries and software have been identified and reused to process medical images in the RASimAs project:

- Simulation Open Framework Architecture (SOFA)<sup>3</sup> for non-rigid registration of musculoskeletal system.
- MatLab<sup>4</sup> for preparation of 3D data, image processing (filtering, segmentation, denoising), and computer graphics (3D mesh deformation, 3D mesh processing).
- Meshlab<sup>5</sup> for 3D mesh processing (smoothing, slicing, splitting, re meshing).

### 4. Workflow for Anatomical Modelling

The libraries presented in the previous subsection were used in order to provide anatomical models with a focus on patient-specific models of the pelvis for a femoral nerve block. 3D meshes in X3D (XML-based file format representing 3D computer graphics) format are created, which represent skin, muscles and bones of a real patient MRI data.

The process of aligning two or more images with the goal to find the optimal transformation that best aligns the structures of interest in the input images is called image registration [9].

A method for semi-automatic registration of general model data towards partial MRI image of a real patient has been developed (Fig. 2).

This modelling is used on both the simulator and the assistant. In both cases, the user enters a set of DICOM images or characteristics of the patient and the anatomical model will provide the most appropriate virtual patient. Five steps (Fig. 3) are performed to achieve the anatomical

modelling, data selection, gross registration, data conversion, fine registration, and data export.

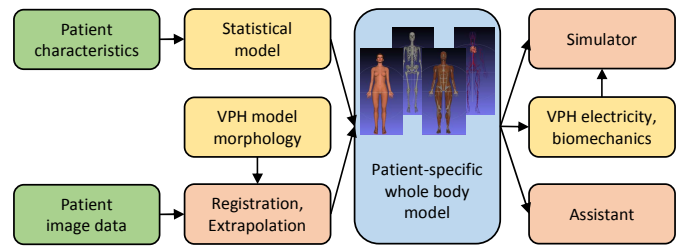


Fig. 2. Data flow for patient-specific modelling.

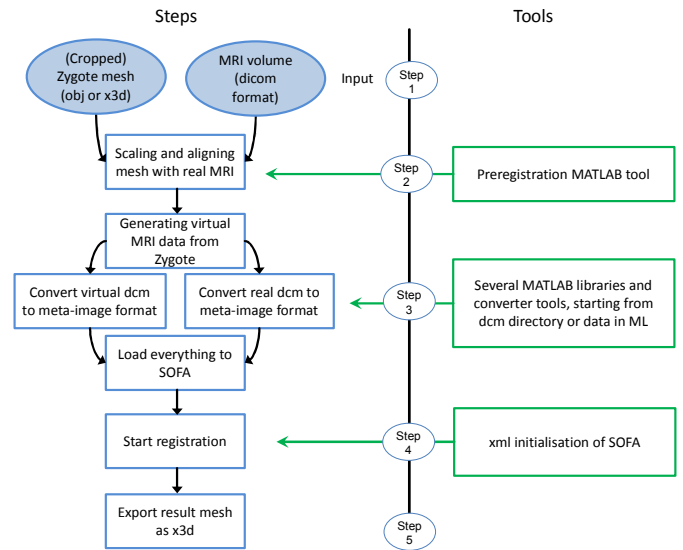


Fig. 3. Workflow for a mesh to voxel basis image registration.

1. *Data selection:* The Zygote model and the MRI patient data are selected from the ISS repository. The mesh is lavishly cut to the region of interest to avoid interference with the neighbored structures like arms, which may cause problems during the automatic registration process.
2. *Gross registration:* The Zygote meshes and the MRI volume are placed in one and the same coordinate system. A gross adjustment of the virtual model to the DICOM data of the patient is performed: digitally reconstructed radiograph (DRR) are computed for both the VPH model and for the DICOM images [10]. For the scaling and rigid alignment between mesh and MRI, a simple user interface has been created using MatLab (Fig. 4). The tool creates frontal and lateral X-rays images of the mesh and the MRI data and distinguishes among skin, muscles, and bones. The user can select the tissue to be displayed.

<sup>3</sup> <http://www.sofa-framework.org>

<sup>4</sup> <http://www.mathworks.com/products/matlab>

<sup>5</sup> <http://meshlab.sourceforge.net>

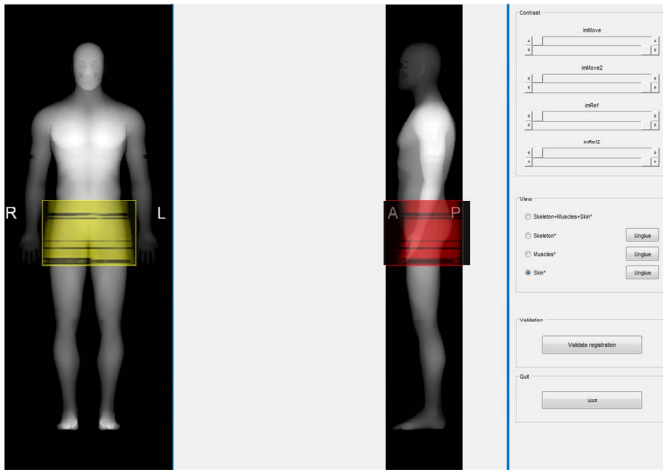


Fig. 4. MatLab tool for rigid alignment and scaling. The user has to drag the MRI images (yellow and red insets) to the correct position corresponding to the mesh. In this case, only the X-rays of the skin are made visible.

From this rigid image registration process a quaternion transformation matrix results, which is then applied to the cropped meshes.

3. *Data conversion*: The final step is performed by means of SOFA [11], which algorithm plugin is based on Gilles et al. [12] [13]. Gilles' non-rigid registration approach offers the possibility to register a three-dimensional (3D) mesh-model/voxel-data combination on a target voxel space. The technique from Gilles focus on the application of shape matching and elastic deformation in musculoskeletal MRI images for inter-patient registration. The source input combination, can for example consist of a MRI from which a mesh was generated by manual segmentation. In the case of this work, a virtual MRI is generated based on the Zygote mesh. To set up intensity profiles, a step size  $s$  and the number of steps  $n$  that shall be taken in each direction is needed. For each vertex, there are  $n$  inwards and  $n$  outwards steps taken in each direction of the normal vector belonging to the vertex. In Fig. 5, each line of the images relates to a vertex. The left half of the images belongs to the inner intensity profile. That is why this part is colored white or gray, as it basically goes through the fat tissue of the virtual MRI. In the right part of the images, the pixels represent the part outside the body of the mesh and also the body in the MRI, which is the reason why they are black. From left to right it is possible to see (left) reference intensity profile of Zygote skin mesh respective to the virtual MRI in the initial setup, (middle) intensity profile of skin mesh respective to target MRI (before registration), and (right) intensity profile of skin mesh respective to target MRI (after registration).

Based on the normalized cross correlation between the reference and the target profiles, the algorithm calculates external forces for each vertex, i.e., it searches in a certain distance  $d$ , points which have the highest similarity value. Additionally, internal forces

are computed with a computer animation technique [14] to reduce the effect of outliers in the external forces. To improve the performance regarding the processing time, the vertices of the source mesh are sorted in location dependent subsets (clusters) on which a combination of the two different forces is applied.

4. *Fine registration*: For the initialization of the algorithm of Gilles, a reference volume of the mesh is needed, which is used to set up initial intensity profiles. Therefore, a virtual MRI of the Zygote mesh with generic intensity values for the four most important tissues of the MRI, i.e., fat, muscle, bone, air is created. Although there is a certain lack of reality in this rough approach for virtual MRI generation, it turns out as sufficient for initialization purposes.

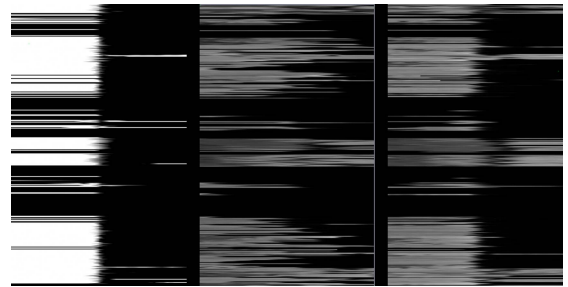


Fig. 5. Reference intensity profile of skin meshes for Zygote (left) and target MRIs (middle and right).

5. *Data export*: The registered and deformed mesh of the Zygote model is exported back into ISS for further use in the simulator as well as the assistant component.

### III. RESULTS AND DISCUSSION

The final results are stored at RASimAs ISS. Fig. 6 and Fig. 7 show examples of registration (white area in the figures) with different orientations for two different subjects, a male and a female, respectively, regarding the skin of the models. Here, the subject-specific data is co-aligned with the model data allowing to adopt the meta-information that is stored with the model to the patient data ending up in patient-specific models.

VPH models are rarely used for the task of patient-specific anatomical image registration in comparison with the use of cadavers, especially with a focus on the pelvis area. This work has adopted commercial general models, however some shortcomings were discovered which had to be corrected and altered in order to make them suitable for use. In both models, Zygote and Anatomium, some biologically separated structures (e.g., muscles and bones) overlap, making harder the process of image registration of patient-specific images. Also, the Zygote model was extended to fit the needs of the project by (i) replacing the femoral nerve towards a more common position in regards to blood system and the muscles and (ii) adding fascia, i.e., flats bands of tissue below the skin

that cover underlying tissue, separate different layers of tissue, or enclose muscles [15].

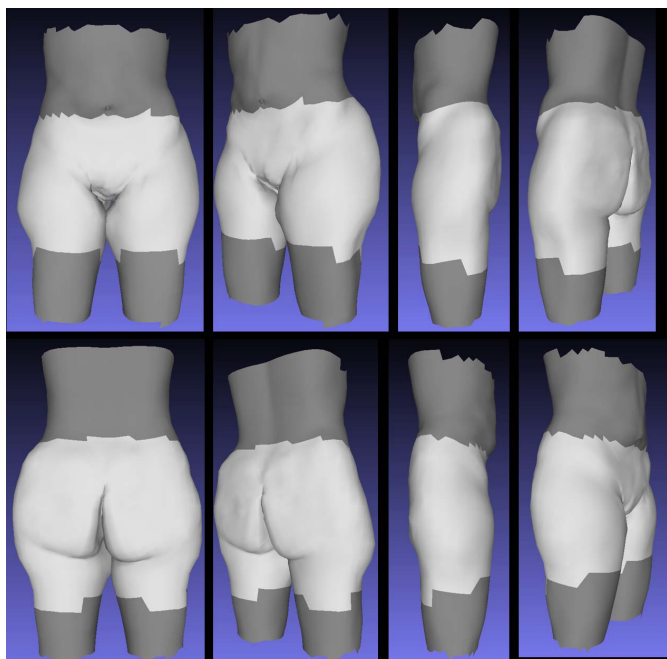


Fig. 6. Final registration regarding the skin for a female subject-specific model.

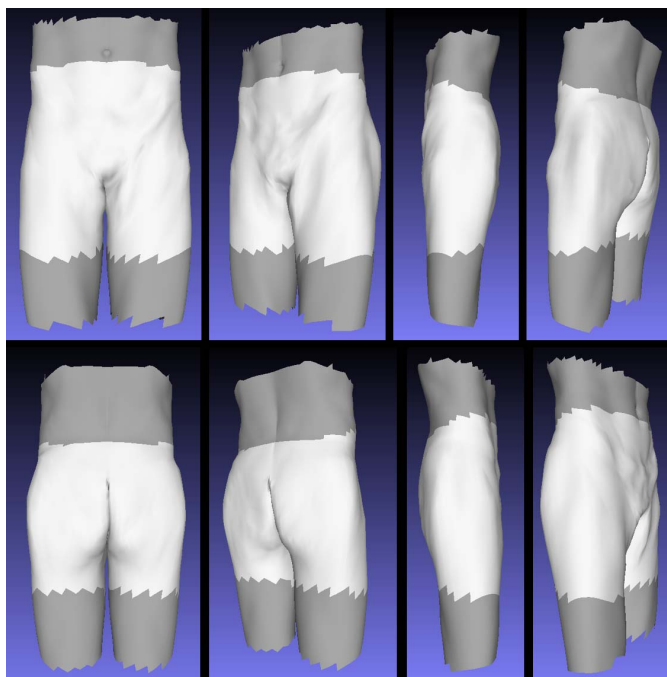


Fig. 7. Final registration regarding the skin for a male subject-specific model.

The technique from Gilles et al. had to be adapted in order to work with a mesh to voxel image registration providing a new possibility for it, although only one surface per time can be registered. The results presented are regarding the skin, but

the non-rigid registration for muscles and bones are still being implemented.

#### IV. CONCLUSION

This project uses existing commercial VPH models and enhance them by incorporating patient data collected by MRI and utilizing existing libraries and algorithms for image processing to support image segmentation, registration and 3D mesh processing. The focus is the deployment of a VPH model enriched with patient-specific data into clinical environments. A mesh-voxel registration was applied to create subject-specific VPH models.

The resulting tools are expected to benefit both patients and society, with safer and lighter medical load at reduced costs.

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#### REFERENCES

- [1] Neal ML, Kerckhoffs R. Current progress in patient-specific modelling. *Brief Bioinform.* 2010;11(1):111-26.
- [2] Zuffi S, Black MJ. The stitched puppet: a graphical model of 3D human shape and pose. In: *Proceedings of IEEE Conf on Comput Vis Pattern Recognit (CVPR)*; 2015 Jun 7-12; Boston, United States; 2015.
- [3] Deserno TM, Oliveira JEE, Grottko O. Regional Anaesthesia Simulator and Assistant (RASimAs): medical image processing supporting anaesthesiologists in training and performance of local blocks. In: *Proceedings of the 28<sup>th</sup> IEEE International Symposium on Computer-Based Medical Systems*; 2015 Jun 22-25; Sao Carlos – Ribeirao Preto,
- [4] Mihalef V, Ionasec RI, Sharma P, et al. Patient-specific modelling of the whole heart anatomy, dynamics and haemodynamics from four-dimensional cardiac CT images. *Interface Focus.* 2011;1(3):286-96.
- [5] Zadpoor AA, Weinans H. Patient-specific bone modelling analysis: the role of integration and automation in clinical adoption. *J Biomech.* 2015;48(5):750-60.
- [6] Bailey C, Gul R, Falworth M, et al. Component alignment in hip resurfacing using computer navigation. *Clin Orthop Relat Res.* 2009;467(4):917-22.
- [7] Zheng G, Schumann S. 3D reconstruction of a patient-specific surface model of the proximal femur from calibrated x-ray radiographs: a validation study. *Med. Phys.* 2009;36(4):1155-66.
- [8] Kohl P, Noble D. Systems biology and the virtual physiological human. *Mol Sys Biol.* 2009;5(292):1-6.
- [9] Oliveira FPM, Tavares JMRS. Medical image registration: a review. *Comput Methods Biomech Biomed Eng.* 2014;17(2):73-93.
- [10] Serrurier A, Bönsch A, Lau R, Deserno TM. MRI visualisation by digitally reconstructed radiographs. In: *Proceedings of SPIE 9418, Medical Imaging 2015: PACS and Imaging Informatics: Next Generation and Innovations*; 2015 Feb 21-26; Orlando, United States; 2015. p. 94180I-94180I-7.
- [11] Allard J, Cotin S, Faure F, et al. SOFA – an open source framework for medical simulation. *Stud Health Technol Inform.* 2007;125:13-8.
- [12] Gilles B, Pai DK. Fast musculoskeletal registration based on shape matching. *Med Image Comput Comput Assist Interv.* 2008;11(Pt2):822-9.
- [13] Gilles B, Magnenat-Thalmann N. Musculoskeletal MRI segmentation using multi-resolution simplex meshes with medial representations. *Med Image Anal.* 2010;14(3):291-302.
- [14] Muller M, Heidelberger B, Teschner M, et al. Meshless deformations based on shape matching. *ACM Trans Graph.* 2005;24(3):471-78.
- [15] Serrurier A, Herrler A, Deserno TM. Towards realistic patient-specific human models for virtual reality regional anaesthesia simulator. In: *Proceedings of 34<sup>th</sup> ESRA Congress*, 2015 Sep 02-05.