Regional Anaesthesia Simulator and Assistant (RASimAs): Medical Image Processing Supporting Anaesthesiologists in Training and Performance of Local Blocks

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***Abstract*—In worldwide health systems, regional anaesthesia (RA) is not applied as frequent as it should be and benefits to patient's cure and cost savings are wasted. The Regional Anaesthesia Simulator and Assistant (RASimAs) project combines image processing, physiological models, and virtual reality to support ultrasound-guided and electrical nerve stimulation-guided RA. The simulator component maps patient-specific data to general models and composes virtual reality environments using a haptic device coupled with the needle. The assistant component provides enhanced feedback mapping online-acquired ultrasound data. Regarding image processing, RASimAs aims at acquiring subject data for model development and composing a library of segmentation and registration algorithms to provide localized, patient-specific, material properties within anatomical context. Subject posing and extrapolation of body regions without patient-specific data are central challenges.**

***Keywords*-regional anaesthesia; regional anaesthesia simulator; regional anaesthesia assistant; anatomical model**

I. Introduction

Regional anaesthesia (RA) performs by blocking the peripheral nerves through local injection of anaesthesia, being a technique which demands training and assistance. RA has perceived advantages in comparison with general anaesthesia (GA):

- For the patient: no loss of consciousness, no risk of aspiration, less risk of postoperative nausea and vomiting and minimized probability for adverse drug reactions or allergy, less cardiovascular stress, and superior pain control after the surgery [1].
- For the society: shorter hospital stay and costs savings of €100.000 per year per operation theater without compromising care [2].

However, the safe performance of RA requires good theoretical, practical, and non-cognitive skills to allow trainees to achieve confidence in its performance and also in keeping complications to a minimum. Current training methods for RA include cadavers, video teaching, ultrasound guidance, and sample virtual patient modeling, which are approaches that do not consider patient-specific anatomy [3]. It requires also the need for supervision that is expensive and may reduce the time for practising.

Because of the aforementioned difficulties to learn RA, GA is often performed instead. This observation may be attributed to the lack of physician training, which turns on a key challenge for RA adoption (Fig. 1).

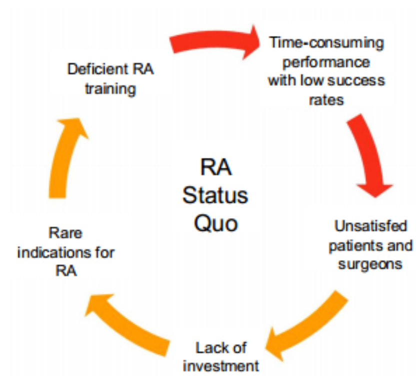

Figure 1. Status quo of RA procedures.

Regarding peripheral RA, there are only two simulators available or under development. The first one is a VR-based RA simulator which was developed by Energid Technologies in the context of a research contract for the United States Army [4] but did not result in a commercial product. The second system is a commercial simulator named SAILOR [5], which is distributed as a supplement to a multimedia atlas for nerve blocks.

Therefore, the Regional Anaesthesia Simulator and Assistant (RASimAs) project has the goal of increasing 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 through an integration of image processing, physiological models and subject-specific data, and virtual reality (VR).

II. METHODS

A. RASimAs Components

Extending a previous prototype [6], the RA simulator component recreates RA procedures in a virtual environment, which allows the trainee to practice on various anatomies avoiding on-patient training. The medical simulator is applicable to all body regions of relevance and supports RA training using electrical nerve stimulation, ultrasound (US) guidance, or a combination of both. Also, an advanced haptic framework allows a complete immersion in a virtual environment combining stereoscopic rendering and US probe interaction.

The RA assistant component is supporting anaesthesiologists during the practice of RA by providing enhanced feedback on image interpretation and patient-specific anatomy. The patient-specific models generated by the simulator for training are used to develop the assistant which underlying framework consists of a number of patients datasets retrieved from magnetic resonance imaging (MRI), magnetic resonance angiography (MRA) and computed tomography (CT) scans. Next to real-time ultrasound imaging, the prerecorded datasets are displayed to guide the trainee while performing RA and also the combination of pre-calculated needle adjustments based on the datasets allow the trainee to guide the needle within a restricted area to find the right position for the RA.

B. RASimAs Team

With a duration of three years, the RASimAs project was lounched in November 2013. The project gathers experts in a consortium of academic (scientists specialized in medical imaging, computer science or virtual reality), industrial (specialized in medical devices) and clinical partners (specialized in anaesthesia):

- Uniklinik RWTH Aachen, Germany
- RWTH Aachen University, Germany
- Bangor University (PBU), United Kingdom
- University College Cork (UCC), Ireland
- Universidad Rey Juan Carlos (URJC), Spain
- Foundation for Research and Technology Hellas (FORTH), Greece
- Nord Europe Research Center (INRIA), France
- University of Zilina (UNIZA), Slovakia
- Catholic University of Leuven (KUL), Belgium
- Stiftelsen SINTEF, Norway
- SenseGraphics AB, Sweden

C. RASimAs Strategy

A work plan was structured in order to ensure the proper development of the project, divided into eight work packages (WP) that are composed of three parts: the simulator system, the assistant system, and a comprehensive evaluation by means of controlled clinical trials:

- WP1 ensures the financial and management administration of the project.
- WP2 provides the general technological environment necessary to build the simulator and assistant prototypes.
- WP3 develops the virtual models that will be used by the simulator and assistant.
- WP4 aims at developing the various components that will be assembled to build the simulator and the assistant.
- WP5 has the goal of building the simulator and assistant prototypes.
- WP6 intends to evaluate both simulator and assistant.
- WP7 has the objective to ensure compliance with all legal requirements in research involving humans and focuses on the maximum patient's safety during the evaluation of the project.
- WP8 encompasses the dissemination and exploitation activities of the project.

D. Image Processing

The RASimAs project will make use of several open source frameworks, and therefore contribute to these communities:

- Simulation Open Framework Architecture (SOFA) for soft tissue simulation;
- Medical Imaging Interaction Toolkit (MITK) for image processing/segmentation;
  - Open source C++ library Visualization Toolkit VTK for visualization;
  - The Insight Segmentation and Registration Toolkit (ITK);
- H3D API for visio-haptic systems;
  - Bullet Physics Library for collision detection;
  - CHAI 3D for haptic device support and haptic rendering.

The general idea is to substitute lacks in subject-specific information by that adopted from general models in order to build VPH models (Figure 2). RASimAs will create specific ontologies enabling conceptual mapping between imaging modalities and model parameters so that it will be possible to fully streamline the process of model building and its personalization.

E. Model and Patient Data

Model data is necessary and two commercial 3D anatomical models are used for patient-specific data modeling. The first one is Zygote[1] which provides 3D polygonal models with textures, and the second one is Anatomium[2] which yields the human body anatomy sets in 3D view. Figure 3 presents an example of both models. These models have

[1] http://www.zygote.com/
[2] http://www.anatomium.com/

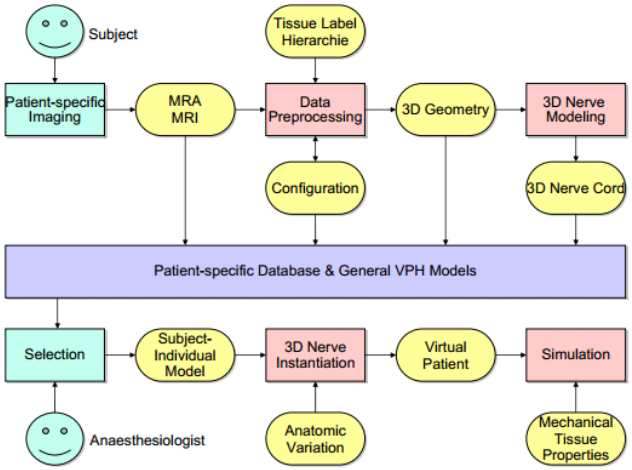

Figure 2. The data flow describes all the steps from a real subject to the RA training and guidance. The patient-specific subject database with the VPH models forms the core component of RASimAs.

been extended with respect to structures (e.g., the fascias), and mechanical tissue properties.

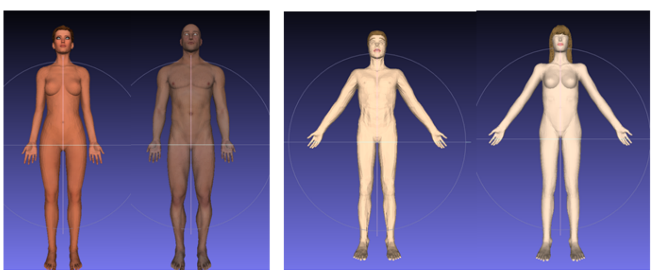

Figure 3. On the left, female and male bodies from Zygote. On the right, male and female bodies from Anatomium.

The patient-specific VPH models include anatomical and mechanical properties of the tissues, as well as computational models compatible with real-time simulation. They are based on magnetic resonance imaging (MRI), magnetic resonance angiography (MRA), and computed tomography (CT).

For management, data is archived in RASimAs repository which in the clinical environment of picture archiving and communication systems (PACS), the Digital Imaging and Communications in Medicine (DICOM) standards provide methods to ensure data privacy and security.

III. Results

In order to provide an anatomical model where the user obtains a complete virtual patient from a limited number of information known on the real patient (pre-operational medical images on another region of interest, age, sex, height), a method for semi-automatic registration of the data model (Zygote and Anatomium) towards partial MRI or CT images of a real patient has been developed. Its integration into the RASimAs workflow is depicted in Figure 4.

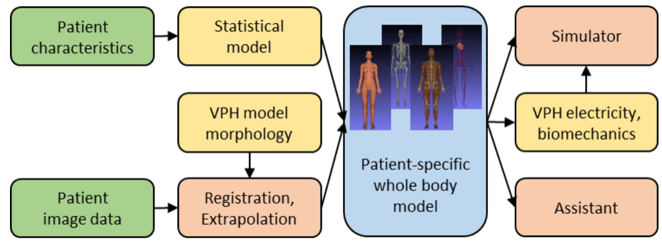

Figure 4. Integration in RASimAs.

This modeling is used both on the simulator and the assistant. The user enters a set of DICOM images or characteristics of the patient and the anatomical model provides the most appropriate virtual patient. In case of the assistant, the generated virtual patient will be registered additionally in the region of the RA to the US data, the new virtual patient will be fed back into the database, and the statistics will be updated.

Several processing steps are performed:

1) Gross adjustment of the virtual model to the DICOM data of the patient: digitally reconstructed radiograph (DRR) are computed both for the virtual patient and for the DICOM images [7]. The DRRs allow the user to superimpose the data sets (Figure 5), and the whole body reference patient is rigidly registered.
2) Finer automatic elastic registration of the already grossly adjusted whole body reference patient to the DICOM images (for example based on image gradient) is performed. Here, the SOFA-integrated software package of Gilles is applied [8], [9].
3) Generation of a database of whole body virtual patient according to this method, with known patient characteristics of the patients such as age, weight, etc.
4) Statistical analysis to be able to generate a whole body virtual patient according to patient characteristics.

IV. Discussion

Instead of relying on generic models and by fitting automatically relevant patient data into virtual physiological humans (VPH) template models [10], the RASimAs project will enhance the state of the art. Some of the RASimAs innovations are:

- use of an advanced VR engine to provide training (before the procedure) and an advanced augmented reality (AR) engine for guidance (during the procedure), leveraging shared data sets and supplementing each other appropriately.
- the VR's engine will use stereoscopic rendering (for 3D perception) to enhance immersion. In addition, the simulator will provide an intuitive six degrees of

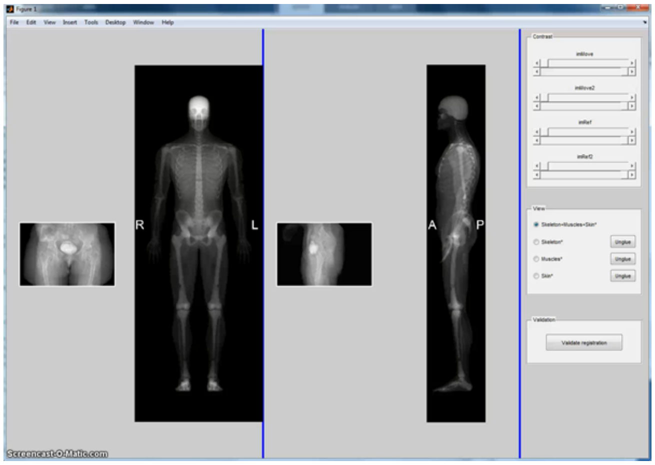

Figure 5. Tool for semi-automatic image registration based on DRR [7].

freedom (DOF) input with haptic feedback for needle and US probe navigation.
- the ability to fuse patient-specific data (from MRI, MRA or US imaging) into the VPH model used by the simulator and assistant system, using advanced image processing libraries and algorithms.
- leverage of improvements in commercial hardware platforms (GPU, parallel processing) to implement non-linear FE methods to simulate soft tissue deformation related to needle insertion and provide true haptic feedback.

RASimAs is expected to bring significant clinical, economic and scientific impacts:

- Clinical impact: strengthened evidence of the clinical benefits in using computer-based models. RASimAs will demonstrate the clinical benefits of the technology by conducting controlled clinical trials with patient-specific models.
- Scientific impact: acceleration of the deployment of VPH technologies in clinical environments and increased acceptance and use of predictive models by healthcare professionals. RASimAs will enrich the VPH models with subject-specific data, in order to improve clinician performance even in RA procedures where significant inter-subject differences exist.
- Economic impact: significant reduction of costs through the use of VPH technologies. RASimAs will increase the replacement of GA by RA and improve the success rate of RA procedures, thus decreasing costs by an estimated 100,000 Euros by year and operating theater.

The project results shall also call the attention of patients as well as health professionals for novel patient management concerning application of peripheral nerve blocks. Beyond that the project results shall initiate a vital discussion and initiate further research within the European scientific community.

However, the patient-specific anatomical modeling is an ongoing task and further evaluation is needed regarding the assistant and simulator. The resulting RASimAs tools are expected to benefit both patients and society, with safer and lighter medical load at reduced costs.

Future works include a refined automatic elastic registration of skin, muscle, and skeleton on MRI, building a database of 3D virtual patients and provide statistics on this database for use in RASimAs without patient-specific data.

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References

[1] Gonano C, Kettner SC, Ernstbrunner M, et al. Comparison of economical aspects of interscalene brachial plexus blockade and general anaesthesia for arthroscopic shoulder surgery. Br J Anaesth. 2009;103(3):428–33.

[2] Marhofer P, Harrop-Griffiths W, Kettner SC, et al. Fifteen years of ultrasound guidance in regional anaesthesia: part 1. Br J Anaesth. 2010;104(5):538–46.

[3] Smith HM, Kopp SL, Jacob AK, et al. Simulation-based military regional anesthesia training system. Br J Anaesth. 2009;34:88–94.

[4] Lim YJ, Le T, Valdivia P, et al. Simulation-based military regional anesthesia training system. US Army Telemedicine and Advanced Technology Research Center (TATRC), Medical Research and Materiel Command (MRMC), Fort Detrick, MD Contract W81XWH-06-C-0052. 2008;.

[5] Bibin L, Lecuyer A, Burkhardt JM, et al. SAILOR: a 3-D medical simulator of loco-regional anaesthesia based on desktop virtual reality and pseudo-haptic feedback. ACM Symposium on Virtual reality software and technology. 2008; p. 97–100.

[6] Grottke O, Ntouba A, Ullrich S, et al. Virtual reality-based simulator for training in regional anaesthesia. Br J Anaesth. 2009;103(4):594–600.

[7] Serrurier A, Bnsch A, Lau R, et al. MRI visualisation by digitally reconstructed radiographs. Proc SPIE. 2015; p. in press.

[8] Gilles B, Pai DK. Fast musculoskeletal registration based on shape matching. Br J Anaesth. 2009;34:88–94.

[9] Gilles B, Magnenat-Thalmann N. Musculoskeletal MRI segmentation using multi-resolution simplex meshes with medial representations. Med Image Anal. 2010;14(3):291–302.

[10] Kohl P, Noble D. Systems biology and the virtual physiological human. Mol Sys Biol. 2009;5(292):1–6.