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Sensitivity analysis of a computer model of neonatal oxygen transport

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Introduction

Computer models of neonatal oxygenation could serve as a tool for a comprehensive comparison of closed-loop automated oxygen control systems. The behaviour of such models depends, besides the input data of the inspired fraction of oxygen and the premature infant's breath pattern, on internal parameters of the model. The aim of this study was to perform a sensitivity analysis of the computer model of neonatal oxygen transport to clarify the influence of its internal physiological parameters on the output signal of peripheral oxygen saturation (SpO_2).

Methods

We performed a multi-parameter sensitivity analysis using Monte Carlo simulations for randomly generated values of eight internal parameters. The influence on the output signal was evaluated using five characteristics of the model output SpO_2 signal. The relations between the parameters and the output characteristics were displayed using scatter plots and analysed by linear correlation, standardized regression, and partial correlation.

Results

The main result of the study is that in our model the oxygen consumption in the tissue and the cardiac output have the greatest influence on the SpO_2 drop and minimal SpO_2 value during simulated desaturation. The rate of development of desaturation and its duration are most affected by the diffusion resistance of the alveolar-capillary membrane.

Conclusion

The results of the sensitivity analysis will help to optimize the performance of the computer model of neonatal oxygen transport.

A rule-based expert system for real-time feedback-control in deep brain stimulation

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Introduction

Programming in deep brain stimulation (DBS) to treat movement disorders such as essential tremor (ET) is often a labour-intensive process. Although automatic closed-loop stimulation has recently been receiving considerable attention, it is still far from clinical settings. Testing in-loop stimulation in a clinical setting is extremely challenging due to manual programming and the lack of synchronisation between stimulation and monitoring devices.

Methods

In this work, we present a simple rule-based expert system to test feedback-controlled DBS in a clinical setting. The new application operates in closed-loop with the physician as acting person and real-time feedback from an accelerometer. Patients with movement disorders such as in ET announce an individually acceptable level of tremor as a boundary condition for control. As a proof-of-concept, the expert system provides continuous recommendations of stimulation parameters and guides the physician to increase or decrease DBS amplitude by capturing tremor acceleration power on the patients' forearms. The work discusses technical and practical aspects in clinical settings.

Results

We demonstrate the clinical applicability of the rule-based control system for future research focusing on tremor dynamics and in-loop stimulation. Patients with linear tremor behaviour are preferred to test the introduced rule-based controller. Moreover, data obtained from test subjects give insight into tremor dynamics. However, strong tremor dynamics such as in Parkinson's disease patients may limits the number of examinations and needs further investigation.

Conclusion

This work presents a simple rule-based expert system for testing closed-loop DBS in ET patients. The novel clinical application provides a platform for future research work focused on tremor dynamics and closed loop DBS. Finally, a telemetry streaming system could provide the interface for the application of automatic tremor control without the physician as acting person.

3D-Printed Cardiovascular Phantoms – Planning of Surgical and Interventional Therapies

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Introduction

Patient-specific models can help for an adequate prosthesis selection as well as to improve planning of surgical and interventional procedures. The aim of this study was to develop a process for manufacturing and assessment of cardiovascular 3D-printed models for therapy planning.

Methods

First, different flexible 3D-printing materials were tested in terms of mechanical properties and compared to biological tissues. Furthermore, clinical CT-datasets were collected retrospectively. Datasets covered a wide range of pathologies from cardiac and vascular surgery as well as pediatric cardiology. Based on the datasets, volumetric models were created and phantoms were 3D-printed. Phantoms were evaluated by x-ray, CT, MRI and sonography. For simulation of the intraluminal blood flow, models were connected to a pulsatile mock circulation. Different cardiovascular protheses (e.g. EVAR, TAVI/surgical heart valve prostheses) were implanted. Implant performance was evaluated using sonography and 4D-MRI.

Results

It was possible to produce multiple flexible and hollow 3D-printed models, mimicking various cardiovascular pathologies. Mechanical properties were comparative to native bio-mechanics. Printed models showed a high surface quality and high accordance to underlying CT-scans. X-ray as well as ultrasound imaging was possible and comparable to human tissue. Doppler sonography displayed flow profiles matching native data. 4D-MRI flow measurements of aortic models visualized and quantified fundamental flow characteristics (i.e. low flow areas, turbulences, pressure asymmetry and wall shear stress). EVAR prostheses were implanted under fluoroscopic guidance. Furthermore, surgical and interventional heart valve implantation was possible. Cardiovascular prostheses performance and in-vitro imaging were matching clinical in-vivo results.

Conclusion

It was possible to produce patient specific cardiovascular phantoms with mechanical properties mimicking human tissues. Multimodal assessment, using common clinical imaging techniques as well as 4D-MRI was possible and were matching clinical results. This new process is an ideal supplementary tool for patient specific therapy planning.

Reduced order modeling for finite difference cardiac bidomain

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Bidomain model is considered the most detailed model for studying cardiac propagation. Thus, it is important to develop efficient numerical techniques to solve the complex bidomain equations. Due to its simple grid generation and low computational overhead, the finite difference method has become one of the major numerical approaches for bidomain modeling. The large grid size and small time step, as well as the nonlinear ionic current, make the numerical solution computationally demanding. Here, the computational complexity of the finite difference bidomain solution is reduced with the proper orthogonal decomposition (POD) method. POD, in combination with the Galerkin projection, reduces the computational costs but still offers acceptable accuracy.

The unknown action potential, V_m, and interstitial potential, φ_o, are represented as truncated Taylor series in deriving the finite difference approximation. The Luo-Rudy phase 1 model is employed to evaluate the ionic current as a complex nonlinear function of V_m. The snapshot matrix is constructed from a simulation of the full model, which represents its characteristic dynamics. The reduced order POD basis functions are obtained from the eigen-decomposition of the covariance matrix of the snapshots. Next, the bidomain model is projected onto this POD subspace to construct the reduced order surrogate model. The system equation involving much fewer unknowns is then solved, and finally, the solution is projected back to the original bidomain model.

The reduced order technique using POD has been applied to a three-dimensional rectangular bidomain model consisting of 72^3 nodes. The low-dimensional POD modes are obtained from the largest 18,562 eigenvalues of the covariance matrix of the snapshots. The efficiency and stability of the proposed algorithm are confirmed by showing the reduction of the order of the system and, subsequently, the solution time, as well as the RMS error between the original and reduced order solution.

Developments in Modelling Bone Screwing

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Introduction

A torque-rotation model of the bone-screwing process has been proposed. Identification of model parameters using recorded data could potentially be used to determine the material properties of bone. These properties can then be used to recommend tightening torques to avoid over or under-tightening of bone screws. This paper improves an existing model to formulate it in terms of material properties and remove some assumptions.

Methods

The modelling methodology considers a critical torque, which is required to overcome friction and advance the screw into the bone. Below this torque the screw may rotate with elastic deformation of the bone tissue, and above this the screw moves relative to the bone, and the speed is governed by a speed-torque model of the operator's hand. The model is formulated in terms of elastic modulus, ultimite tensile strength, and frictional coefficient of the bone and the geometry of the screw and hole.

Results

The model output shows the speed decreasing and torque increasing as the screw advances into the bone, due to increasing resistance. The general shape of the torque and speed follow the input effort. Compared with the existing model, this model removes the assumption of viscous friction, models the increase in friction as the screw advances into the bone, and is directly in terms of the bone material properties.

Conclusion

The model presented makes significant improvements on the existing model. However it is intended for use in parameter identification, which was not evaluated here. Further simulation and experimental validation is required to establish the accuracy and fitness of this model for identifying bone material properties.

Analysis and visualisation of tremor dynamics in deep brain stimulation patients

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Introduction

Deep brain stimulation (DBS) is an established therapy for movement disorders such as in Parkinson's disease (PD). Adjusting the stimulation parameters, however, is a manual and labour-intensive process. Physicians prefer objective tools to improve (or maintain) the performance in DBS. Wearable motion sensors (WMS) are able to detect some manifestations of pathological signs, such as tremor in PD. However, methods to visualise tremor data of patients undergoing DBS in a clinical setting are lacking.

Methods

This work aims to visualise the dynamics of tremor responses to DBS parameter changes with WMS while patients performing clinical hand movements. We describe the methodology of the new approaches and results are illustrated by a collection of examples. Parkinsonian and essential tremor were effectively quantified by acceleration amplitude and frequency. Tremor dynamics were analysed and visualised based on setpoints, movement transitions and stability aspects. These methods have not yet been employed and examples demonstrate how tremor dynamics can be visualised with simple analysis techniques.

Results

The analysed data give an insight into tremor dynamics of DBS patients and are consistent with results in the literature. We visualise these results, which demonstrates that PD and ET patients with DBS therapy often balance between tremor and tremor suppression during the execution of movements, especially when non-optimal DBS parameters are set. Note that the results of the two case studies were generated based on a time-intensive work to process, label, analyse and visualise the data; especially due to the manual programming and synchronisation between the stimulation device and WMS.

Conclusion

The novel visualisation methods provide a base for future research work on visualisation tools in order to assist clinicians who frequently encounter patients for DBS therapy. This could lead to benefits in terms of enhanced evaluation of treatment efficacy in the future.