Validating a Numerical Simulation of Human Heart Motion Using Clinical Data

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Numerical simulations are increasingly often involved in developing new and improving existing medical therapies. While the models involved in those simulations are designed to resemble a specific phenomenon realistically, their interplay with other models in a more complex simulation is often not sufficiently validated. We created a plugin for a cardiac simulation framework to validate the simulation results using clinical MRI data. The MRI data were used to create a static whole-heart mesh as well as slices from the left ventricular short axis, providing the motion over time. The static heart was a starting point for a simulation of the heart's motion. From the simulation result, we created slices and compared them to the clinical MRI slices using two different metrics: the area of the slices and the point distances. The comparison showed global similarities in the deformation of simulated and clinical data, but also indicated points for potential improvements. Performing this comparison with more clinical data could lead to personalized modeling of elastomechanics of the heart.

Loss of Resistance modelling for an Epidural Anaesthesia Simulator

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Introduction

The success rate of epidural anaesthesia is highly dependent by the experience of the clinician. Therefore, training is essential, especially for newcomers. At present, this competence is mainly acquired directly on the patient. Alternatively, a simulation device represents a safer, more ethical, but also more economical training option. Such a novel hybrid simulator for epidural anesthesia must mimic the haptic sensation of the procedure as closely as possible, since no imaging modality is normally used. The haptics are split into two components; the force required to insert a needle into the epidural space; and the counter pressure perceived while applying pressure on a plunger of a syringe, mounted on the needle. A loss of resistance (LOR) is sensed in the counter pressure, when the needle tip penetrates the ligamentum flavum and enters the epidural space. This LOR is the most important feedback an anaesthesiologist experiences when performing an epidural anaesthesia.

Methods

To imitate the LOR, a silicon tube (outer diameter = 20mm, wall thickness = 3mm, shore hardness 60A) covered with a silicone adhesive was encapsulated in silicon rubber (shore hardness 0035) mixed with 33% silicon oil. The assembled block (65x30x100mm) was penetrated in a test bench using a saline filled LOR syringe with an 18 gauge Tuohy needle attached. The required force on the plunger at a feed rate of 0.1mm/s was recorded. With the inner diameter of the syringe (15.5mm), the fluidic pressure can be calculated.

Results

The measured drop of the insertion force, and the calculated LOR pressure were 4.58±0.06N and 24.25±0.32kPa respectively (n = 9).

Conclusion

Compared to studies on porcine or human subjects these values are within the same range. Further variation of the materials could also improve the overall LOR of the tested artificial materials.

Simulation system for intraoperative neuromonitoring

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Introduction

This paper presents a simulation system ("patient model") for intraoperative neuromonitoring (IONM) applied to mastoidectomy. IONM is an electrophysiological method for monitoring the integrity and localization of nerve tracts, which helps the surgeon to avoid injuries and damage to neural risk structures (e.g. facial nerve) during surgery. To use the IONM successfully, the surgeon needs appropriate training and experience. The presented simulation system provides training possibilities in a realistic, cost-efficient and reproducible way.

Methods

The simulation system essentially consists of an anatomy model equipped with the sensor electronics for position measurement and a microcontroller-based processing unit used for position calculation and generation of the EMG signal and equipped with an interface to the neuromonitor and to a mobile device as HMI.

The position of the stimulation probe during training is determined by a magnetic tracking method. The location of the nerve tracts is stored in the system software and is not necessarily linked to a physical realization. Depending on position and distance, the EMG signal can therefore be generated in such a way that the output of the neuromonitor largely corresponds to that in the real application. To increase the degree of reality the EMG signal can be corrupted by an additive white noise signal.

The anatomy model allows a direct representation of the intraoperative situation with a high level of detail. It consists of a plastic skull anatomy based on real CT data. The surgical area manipulated by the surgeon (e.g. by milling) is designed as an interchangeable module. With these modules, various special anatomies can be simulated.

Results

The tracking system is able to determine the position of the sample with an accuracy of 0.2 mm. Therefore the EMG action potential can be generated in such a way that the relationship between distance and threshold value can be adapted to the operative training situation. The resulting EMG signal and thus the output of the neuromonitor comes very close to reality. In addition, various complications during an operation can be simulated, such as a faulty connection, wire break, defect in the device.

The trainee learns to interpret the output of the neuromonitor in different operative situations. The trainer can choose different training scenarios, such as localization of the nerve, drilling or coalescing, using a web application.

Conclusion

The presented simulation system is a tool for a realistic training for the use of intraoperative neuromonitoring in mastoidectomy. It allows the presentation of different operative scenarios, various situations and additional complications. This allows the surgeon to gain valuable experience, which reduces the risk of an application error.

Electrode Model and Simulation of His Bundle Pacing for Cardiac Resynchronization Therapy

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Background: A disturbed synchronization of the ventricular contraction can cause a highly developed systolic heart failure in affected patients, which can often be explained by a diseased left bundle branch block (LBBB). If medication remains unresponsive, the concerned patients will be treated with a cardiac resynchronization therapy (CRT) system. The aim of this study was to integrate His bundle pacing into the Offenburg heart rhythm model in order to visualize the electrical pacing field generated by His bundle pacing.
Methods: Modelling and electrical field simulation activities were performed with the software CST (Computer Simulation Technology) from Dessault Systèms. CRT with biventricular pacing is to be achieved by an apical right ventricular electrode and an additional left ventricular electrode, which is floated into the coronary vein sinus. This conventional type of biventricular pacing leads to a reduction of the left ventricular ejection fraction. Furthermore, the non-responder rate of the CRT therapy is about one third of the CRT patients.
Results: His bundle pacing represents a physiological alternative to conventional cardiac pacing and cardiac resynchronization. An electrode implanted in the His bundle emits a stronger electrical pacing field than the electrical pacing field of conventional cardiac pacemakers. The pacing of the His bundle was performed by the Medtronic Select Secure 3830 electrode with pacing voltage amplitudes of 3 V, 2 V and 1.5 V in combination with a pacing pulse duration of 1 ms.
Conclusions: Compared to conventional cardiac pacemaker pacing, His bundle pacing is capable of bridging LBBB conduction disorders in the left ventricle. The His bundle pacing electrical field is able to spread via the physiological pathway in the right and left ventricles for CRT with a narrow QRS-complex in the surface ECG.

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Characterization of the Fluid Dynamic Pressure Field in the Human Heart as a Basis for Coupled Fluid-Structure Simulations

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Introduction

Personalized models of the whole human heart can be used to investigate underlying disease phenomena and to support physicians in medical treatment. Time efficient but still highly accurate models are of great importance.
To investigate this tradeoff, we studied the influence of fluid dynamic pressure fields on the mechanical movement.

Methods

A healthy patient specific finite element whole heart geometry created from MRI scans was used. As the mechanical motion and the fluid dynamics are computed in two seperate solvers, a coupling scheme was set up:
First, a mechanical simulation was performed to obtain the defomation over one heart cycle. The movement of the four endocardial surfaces was extracted to serve as a boundary condition for the fluid simulation. The inlet and outlet pressures were provided by the closed-loop circulatory model. Using these boundary conditions, the fluid dynamics were computed.
To evaluate the effects that a fluid pressure field has on the mechanical motion, a spatially resolved relative pressure factor was introduced. The pressure in each face i was calculated using the mean, maximum and minimum value of the chamber pressure: $factor = (p_{i,t} - p_{mean,t})/(p_{max,t} - p_{min,t}) + 1$ for each time step t.

Results

Except from two specific phases, we observed that the calculated pressure factor remains in the medium range between 0.5 and 1.5 throughout the cycle. During atrial systole a pressure value higher then 1.5 can be observed in the lower part of both ventricles. Also a local increase of the pressure factor can be observed in the area around the pulmonary valve during ventricular systole.

Conclusion

These results suggest an impact of fluid dynamic pressure fields on the mechanical deformation. In future studies, additional mechanical simulations have to be executed, to investiagte the quantitative changes in the displacement of the endocardial surfaces caused by the locally increased pressure factor.

How to Make Patients Embrace their Brace: The Influence of Aspects of a Brace on Patients´ Compliance during Scoliosis Therapy

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Introduction

Idiopathic adolescent scoliosis (IAS) is the most common spinal disease in children and teenagers causing three-dimensional spinal curvature during growth. Depending on the degree of curvature, brace treatment is administered. Brace treatment involves wearing the brace 16-23 hours/day for several years. Amongst other factors, the therapy success depends on the compliance of patients. In this study, we approach the question which aspects of bracing influence the compliance from patients' perspective. The determined aspects may inform future brace designs with the potential to enhance compliance and lays the groundwork for future steps of the project.

Methods

We approached research question through mixed methods research employing user interviews and a questionnaire. All participants were IAS-patients with experience wearing a brace. Interviews (n=5) were conducted to understand patients' interaction with and their perception of the brace. Analysing the questionnaire (n=30) descriptively validates influences on compliance known from literature and previous, exploratory interviews and collects feedback on possible solutions.

Results

In the patients' perception, wearing comfort and appearance influence compliance the most. Wearing comfort is reduced by pain, mobility, and heat development. Unnecessary pain is caused by inconvenient design of the brace but also by the brace loosing fit during everyday activities. The limited mobility hinders daily activities, breathing, eating, and digesting. Heat development keeps patients from wearing the brace during summer. Major challenges regarding appearance are interactions with clothing and well-being. Especially, the unflattering, unnatural shape of the brace influences wellbeing and thereby compliance.

Conclusion

To improve compliance through the design of the brace, the brace should provide feedback to patients on correct fit, be designed to maintain fit, and avoid shapes which restrict physiological functions. Further, the brace should limit mobility as little as possible, while having a natural shape and being made of pleasant material regarding looks and heat development.

Analysis of airflow resistance of the nasal cavity based on CT data

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Introduction

Airflow resistance is an important parameter that affects the quality of breathing. The resistance of the nasal cavity flow can be influenced by various factors (cross-section of the nose valve, microflora) as well as different pathological processes (septum curvature, nasal polyps). Understanding of their effect on the airflow resistance is highly important to select an efficient treatment strategy. Thus, the aim of this work was to conduct structural and functional studies and to analyse airflow resistance of the nasal cavity.

Methods

The main source for structural studies was a series of CT data (600 × 600 pixel × pixel CT slices, pixel spacing 0.2 mm) of a nasal cavity. Rhinomomanometry was used as a functional method for determination of pressure inside the nasal cavity. A mathematical model was developed based on the geometry of the nasal cavity in order to describe aerodynamic resistance.

Results

A three-dimensional reconstruction of the nasal cavity of patients with different characteristics of air resistance was performed. This included normal and pathologic states (with a curvature of the nasal septum and sinusitis). The results indicate that due to small length of the nasal cavity in comparison with the area of local resistance of the mutual impulse, only sole application of a local resistance resulted in successful determination of the total aerodynamic nasal resistance.

Conclusion

The obtained results show the need to consider the features of the anatomical structure of the nasal cavity for quantitative assessment of human breathing in normal and pathological states. Of particular importance is the evaluation of functional surgery planning. Further work will be conducted to perform full-scale modelling of the nasal cavity according to application of 3D printing.

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Transverse dose profile simulation of extruded lines for a 3D printed models for superficial skin cancer therapy

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Introduction

The short-range and sharp dose fall-off of beta particles in tissue make them an interesting option for use in the radiation therapy of superficial skin tumors. This can be used to protect bony or other sensitive structures located right beneath the tumor.

Methods

In a previous study, we studied the feasibility of using 3D printing technology to create 2D radioactive models for the treatment of skin tumors. In the current study, the Monte Carlo method was used to simulate the transverse dose profile form 3D printed extruded line containing yttrium-90 (Y-90) particles. The time and activity required for treating a superficial skin tumor using these extruded lines were also calculated.

Results

Transverse dose profiles extend to greater off-axis distances by increasing the number of extruded lines laid side by side. As shown in the figure the dose of one extruded line drops to 80% of the maximum dose at the lateral distance of < 1 mm. For the 15 extruded lines, positioned side by side, the maximum dose drops to 80% at the lateral distance of about 5 mm. It is also clear from this figure that the transverse dose profiles of all setups have desirable lateral dose uniformity at the first 0.5-mm layer of the skin phantom.

Conclusion

This study confirmed the symmetry pattern of the dose distribution around the central axis of the extruded lines. This observation, together with the extended dose profiles as a result of increasing the number of extruded lines, shows the possibility of treating superficial skin tumors with different 2D extensions.

Cole and Hanai models based postmastectomy lymphedema diagnostics

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Breast cancer today is the most common type of cancer among women. Modern cancer treatment techniques combine surgery, chemo- and radiotherapy for the effective tumour removal and the minimization of the negative side effects. However, radical surgical removal of the tumour can still lead to the postmastectomy lymphedema.
Lymphedema is characterized by the accumulation of the protein-rich fluid in the interstitial space of the upper limb. It is caused by the blockage of the lymph outflow from the limb due to the removal of the lymphatic nodes and vessels during mastectomy. Clinicians have to plan the lymphedema treatment specifically for each patient, based on their individual symptoms and particular features of surgical and other treatments of their cancer.
Bioimpedance spectroscopy method combined with equivalent electrical Cole model of biological objects and Hanai emulsion model of apparent resistivity of materials can be used to determine the changes in fluid compartments of upper limb. Two main conductive fluid compartments in body segment is extracellular fluid, which is divided into the plasma volume and interstitial fluid volume, and intracellular fluid, enclosed in small cells behind the cellular membranes. Cole model allows to estimate from the impedance spectroscopy data the conductive properties of extracellular fluid and combined properties of extra- and intracellular fluids. Hanai emulsion model is used to estimate the volume proportion of extra- and intracellular compartments. It is then used as an index of the lymphedema stage, because lymphedema causes the increase in extracellular fluid volume without change in cellular fluid volume. Our studies show that lymphedema index is able to discriminate between affected and unaffected limbs of patients with one-sided lymphedema. Future studies are required to determine the volume proportion distribution in larger population.
It was proposed to enhance this method by accounting for the conductivity change due to the ion balance change, by using electrolyte conductivity models, e.g. Debye–Hückel–Onsager model. In the end this method is simple for the widespread use and has a promise of a robust lymphedema stage determination.