Conceptual Design and Prototypic Implementation of a Case-based Training System for Spine Surgery

J. Cordes [1] , K. Hintz [1], J. Franke [2], C. Bochwitz [2], B. Preim [1]

[1] Institute of Simulation and Graphics, Otto-von-Guericke University, Universitaetsplatz 2, 39106 Magdeburg, Germany

[2] Orthopaedic University Hospital of Magdeburg, Leipziger Str. 44, 39120 Magdeburg, Germany

{cordes, preim}@isg.cs.uni-magdeburg,de

Abstract: We are describing the conceptual design and prototypic implementation of a training system for spine surgery. Based on real case data the SPINESURGERYTRAINER shall impart cognitive strategies for decisions on effective therapy and possible therapy variations as well as anatomical knowledge and interaction techniques for the computer-based planning of therapies for spinal diseases. To understand the requirements of future users and to establish a common basis for communication between surgeons and developers we used the informal specification method of scenarios for the whole design process of our system.

1 Introduction

Similar to other surgical disciplines, education and further education in orthopaedic spine surgery depends on available experts and the existing case spectrum. Besides the training of surgical techniques, the choice of an ideal treatment strategy and the procurement of anatomical characteristics are essential. For the treatment of diseases different strategies exist. To select the appropriate therapy the radiological diagnostic finding, neurological disturbed functions, discomforts and the social surrounding of the patient have to be taken into account. For a realization of access paths to the spine without complications the spatial relationship between nerval and spinal structures and the location of the spine in reference to surrounding muscles, vessels und other structures have to be considered. To impart the variability of treatment alternatives and their indication in an effective way, preferably many cases containing different criterions and demanding different therapy approaches have to be trained.

The SPINESURGERYTRAINER shall impart knowledge about the necessary criteria for decisions and anatomical knowledge for different diseases (e.g., herniated disks, stenosis of the spinal canal) and possible therapy variations for minimal invasive interventions or open surgery procedures to prospective spine surgeons on the basis of real case data. Main aims of the system are the training of therapy decisions and the interactive planning of therapies. Learners can train the planning of access paths to the operating field and the virtual processing of the chosen therapy. Doctors in training, especially orthopaedic surgeons and neurosurgeons, are able to practice the necessary competences for the treatment of spinal diseases using an appropriate set of cases. The system is not aimed at the training of surgical interventions with haptic feedback or feedback by tissue deformation or bleeding like surgery simulators.

2 Related Work

In medical education students are first taught the theoretical basics. CASUS [AH06], for example, makes cases for selected medical specializations available to train the therapy finding and medicinal therapy at different learning levels. Therefore, the learner gets a multimedia-based presentation of the cases and has to answer questions in free or multiple choice ways. In most of the multimedia-based learning systems there is no interaction with medical data or image data. For the training of manual skills surgical simulators are developed. They contain deformable models of the different tissue types as well as the simulation of bleeding and handling of surgical instruments (KISMET [KC00], TEMPOSURG [ZR07]). However, most of them cannot impart patient individual anatomical variations, since they are not based on real patient data.

For the orthopaedic domain Sourina & Sourin [SS00] developed a system for the training of fracture treatment. The system imparts techniques, necessary instruments and implants for the fixing of fractures. Therapy decisions and the interactive course of action during the placement of implants can be trained. The TELTRA GMBH [SC00 generates visualizations of operations for traumatology and surgery. High fidelity courses (movies and interactive 3d animations) of different operation techniques (e.g., stabilization of the spine with bone grafts) are provided to the users. Both systems are not based on real case data as well. Training systems, which enable a case-based training of the workflow from the diagnosis to the therapy planning for the domain of spine surgery, are not known.

3 Conceptual Design

To develop a training system which provides a successful training of the treatment decision and therapy planning in spine surgery, we included the future users of the system into the process of conceptual design by using the informal specification method of scenarios. To impart the knowledge and the skills in an effective and adequate way, the conceptual design of the training system is furthermore orientated on an instructional design model.

3.1 Scenario-based Design

The scenario-based design [RC02] offers the possibility of an informal specification of software systems and thus a constructive communication with all participants and their close integration into the design process. Benyon et al. [BT05] distinguish between four types of scenarios, which are used in different states of the design process. *User Stories* are used at the beginning of the development process to understand the tasks, needs, expectations and preferences of the future users. They contain detailed descriptions of the user activities and their context. In a process of abstraction and aggregation these user stories were turned to *Conceptual Scenarios*. They are used to define the requirements of the system and to specify general design proposals. For the implementation of the design ideas, the prototyping, and the evaluation of the system several *Concrete Scenarios* are generated out of one Conceptual Scenario to describe a particular situation and a particular function respectively in detail. Several Concrete Scenarios were summarized to *Use Cases*, which contain interactions between the users and the system (as well as slight variations of circumstances). The amount of generated Use Cases should cover the complete functionality of the system as well as the necessary interactions.

Scenarios for the SPINESURGERYTRAINER were developed in different states of the development process in cooperation with medical specialists. Scenarios serve as the basis for discussions, for the determination of the amount and the content of representative training cases as well as for the workflow, the layout and the functionality of the system.

Based on general discussions with orthopedists concerning the content and medical background of the learning targets of the system, we developed some User Stories, which describe the basic structure of the SPINESURGERYTRAINER. These scenarios were discussed and adapted with the medical partners. By abstraction and aggregation of the User Stories Conceptual Scenarios were generated. They contain descriptions of the general requirements, the training steps and the design of the system as well as first options for the training. With this basis an effective communication with the surgeons concerning the training process was possible. All training steps (for example how the user can define the position of an injection in the original medical image data) were described in a detailed way in Concrete Scenarios. Important contextual and interactive aspects or the feedback for the users (for example to show a danger warning if relevant structures like blood vessels were penetrated) could be discussed based on these scenarios. Finally, *Use Cases* were produced, which provide a basis for the implementation and future evaluations of the SPINESURGERYTRAINER. They give a complete description of the structure and processes of the system and give hints for the implementation (for example which controls are available and have to be used in which order to define the injection path). All possible interactions between the users and the program were summarized and explained.

Below there are some scenarios presented as examples, which were developed during the conceptual design of the SPINESURGERYTRAINER. They exemplify the design process of the training system.

User Story: *"The doctor in training has to place an injection in the area of the cervical spine for the first time. He is not sure and wants to train this procedure before, to test his skills and to do the real injection with self-confidence. He thinks about a training of the injection on a cadaver. Furthermore, an expert shall attend his training to show him possible mistakes and the right treatment. But there are no expert and no cadaver available at the moment. Since he is pressed for time and wants to start the training directly, he decides to train the injection virtually. He sits down in front of his pc and starts the SPINESURGERYTRAINER. He chooses the training object (medical training case) according to his needs. He selects a case with a herniated disk. At first he is presented the data and the anamnesis of the patient. The examination results are provided as well. On the basis of this information he decides for the therapy - an injection to alleviate the patients´ pain. By means of the provided 2d and 3d data of the patient anatomy he is able to perform the virtual injection and to comprehend the penetration point as well as the path of the needle through the tissue. That way his 3d imagination and the mental scheme of the injection process are trained. By the presentation and comparison of his result with that of an expert, he is able to identify and correct the mistakes during his procedure. To improve his knowledge about therapies and the necessary background similar cases to the current training case are provided. "*

Conceptual Scenario: "*The doctor in training has to place an injection in the area of the cervical spine for the first time. He is not sure and wants to train this procedure. He chooses the SPINESURGERYTRAINER to train the injection process virtually. He starts the program and selects a training case where a herniated disk has to be treated. He starts with the survey of the patient data and anamnesis. After that he decides for an injection as therapy and starts the training of the virtual placement of the needle [Concrete Scenario 1] on the basis of the MRI data and the 3d model of the patient anatomy. As a self control he can compare his planning result with that of an expert. This type of training can be repeated as often as desired and with different training cases. "*

Concrete Scenario 1 (Details of injection planning): "*During the planning of the injection the attending doctor has to pay attention to follow the right injection path to avoid lesions of important structures and to place the needle to the target point [Comment 1]. To get explanations how to place the injection, he clicks the help button in the menu and carefully reads the help texts for this step. After that he chooses the therapy by clicking the button "Injection" and starts the planning. With the mouse (left mouse click) he defines one marker for the penetration point and one for the target point of the needle in the 2d data. Therefore he has to navigate through the slices by using a slider next to the viewer or the mouse wheel. The needle takes up its position. In an animation (started by pressing the button "Show animation") the user can view the process of the injection of the needle to his defined position. Nevertheless, he can manually move the needle forwards and backwards, using a slider, to get a better impression of the injection path and the penetrated structures (see Figure 3)." [Comment 1: A warning should be presented, if a collision with important structures occurs.]*

3.2 Instructional Design Model

The conceptual design of the training system is oriented on the four-component-instructional-design model [MC02]. This model supports the transfer of procedural knowledge and is therefore suited for the conceptual design of surgical training systems. It supports the training of subtasks, which may be safety critical within the whole task. This model supports the arrangement of training cases into simple and more complex classes and provides a decreasing support within one task class. Supportive and just-in-time information is presented to the learner at different time points of the learning process.

Training Cases. The cases of the SPINESURGERYTRAINER are classified according to their complexity. After a detailed analysis of the patient´s anamnesis and complaints, simple cases for example obviously require a conventional therapy with physiotherapy units or a simply executable surgery intervention like the resection of a prolaps in an easily accessible position. The help of experts decreases within one class, the learner gets less information of what to do in critical situations, which functions are available and how to use them.

Subtasks. For users without experience in interacting with 3d visualizations, a special training with artificial 3d models shall be provided. Users shall be enabled to familiarize with the exploration techniques (like rotation, translation, zooming, picking, etc.). Another subtask is the training of defining resection surfaces in the slice data or the 3d model. The user shall draw the resection lines into artificial models to generate mental models of how to place the lines to get the required surface.

Supportive and just-in-time information. The learner gets supportive and just-in-time information in the theoretical modules of the training system (see Section 4.4 and 4.3). The learner gets (optional) support by help texts, which give hints for the use of the systems functionality and expert comments concerning medical and surgical aspects.

3.3 Data

The diagnosis-relevant data contain age, gender, weight, anamnesis, family anamnesis and the assessment of the professional environment. Based on this data the effects of the symptoms on everyday life, job and psyche of the patient can be assessed. For the generation of 3d models the slice data (in the majority of the cases MRI) ideally need to exhibit a standard resolution of minimally 1 mm and a slice thickness of maximally 3 mm. Important anatomical structures for the SPINESURGERYTRAINER in the area of cervical spine are the vertebral bodies, the spinal disks, the dura and the nerve roots. Furthermore, some surrounding structures may be relevant: thyroid gland, trachea, gullet, muscles and vessels. To impart information about the real case, real therapy or operative and post-operative process the system provides reports, videos, photographs and expert descriptions for the user.

3.4 Workflow

The training structure of the SPINESURGERYTRAINER is based on the clinical workflow. After selecting the training case, the process of the diagnosis based on the provided patient data and examination results follows. Through the original slice data and an interactive 3d model of the patient anatomy the diagnosis shall be defined and a therapy decision shall be made. Afterwards the therapy planning has to be carried out. After completing the therapy planning the treatment plan is compared to several expert recommendations in the analysis step of the system. In the final step the user can read up on the processing of the real surgery and the postoperative process and can optionally train another variation of this case (see Figure 1).

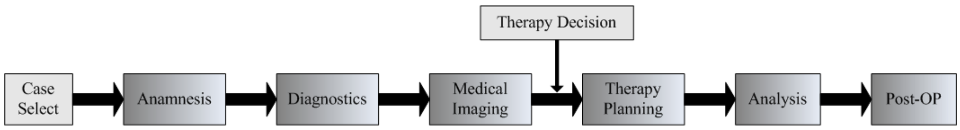

Figure 1: Workflow of the training with the SPINESURGERYTRAINER

4 Prototypic Implementation

Initially, the first prototype of the SPINESURGERYTRAINER contains some cases of cervical and lumbar spine. With these cases the planning process for a conventional therapy (for example physical therapy), the planning of a peridural injection as well as the planning of the access to the operating field during an open surgery, can be trained. After the patient data, anamnesis, physical examinations (see Figure 2) and the medical imaging data has been presented, the user has to decide on the therapy. In the following sections some special aspects and features of the system are presented.

4.1 Interactive virtual therapy

If the peridural injection has been chosen as method of treatment, the learner can train the access to the target region of the injection. Based on the original slice data the position of the needle has to be defined. Therefore, the user has to place two markers into the 2d data, one to define the penetration point and the second to define the target point of the virtual needle. The learner has the possibility to check his planning result on the basis of a 3d model of the patient's anatomy (see Figure 3) and to adjust the needle position, if necessary. An animation imparts the learner insertion process of the needle along his defined path into the defined position.

To plan an access path to an operating field during an open surgery the learner has to define this path by directly drawing lines into the 2d slice data. Afterwards the anatomical structures are moved apart by virtual spread tools on the basis of this path. The structures were not deformed during this action.

The training of the planning of surgery strategies (e.g., the insertion of an artificial spinal disk, and the acampsia on the basis of implants or the resection of a spinal disk) will be available in the next version of the training system.

4.2 Case Variations

Often the attending physician has to decide whether a conventional therapy or an operative intervention is the best. This decision depends, for example, on the success of a previously performed conventional therapy. To support this decision process the integration of comparable cases is helpful. The learner shall be confronted with two cases, which appear similar at first glance, but require different therapy strategies.

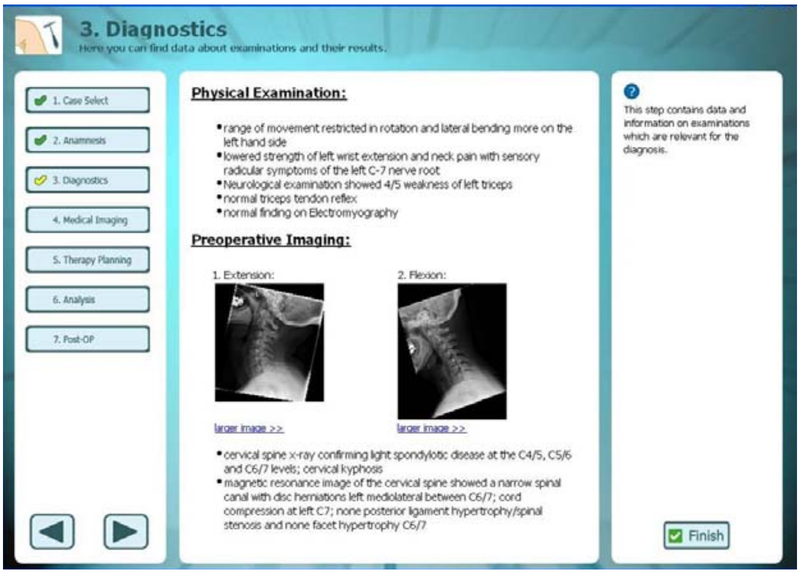

Figure 2: Diagnostics - The user gets information on physical examinations, preoperative imaging.

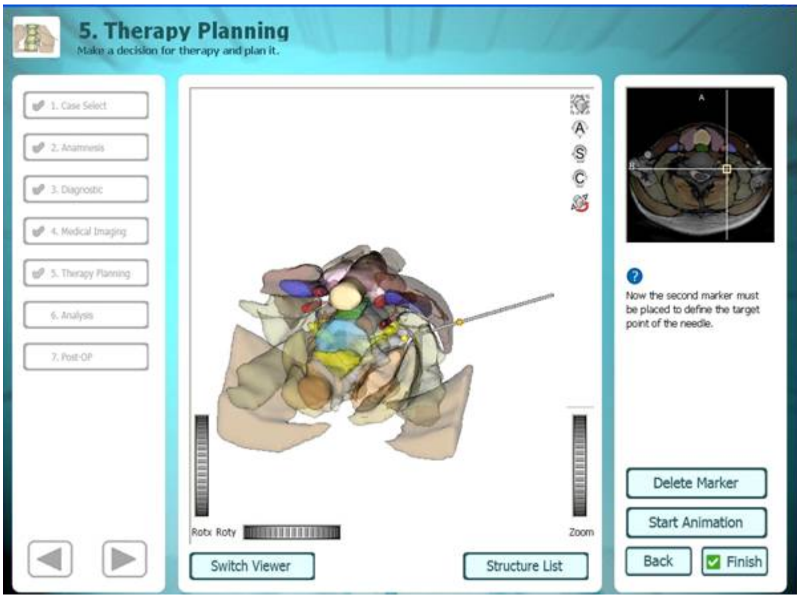

Figure 3: Virtual planning of the placement of an injection in the 3d model (vertebrae, spinal disks, nerve roots and important surrounding structures are shown) of the cervical spine region. The puncture and target point of the needle were previously defined in the slice data. After defining these points the learner can check the position of the needle in the 3d model and view an animation of the needle placement.

For the procurement of decision transitions variants of the original cases were generated. These variants contain minor shifts in anatomy or variations of the symptomatical ailments of the patient and lead to another mode of therapy and another course respectively. The learners shall discover that these minor changes in anatomy or pathology of a case may have a strong influence on the selection of an appropriate therapy. This training of differential therapies is provided in combination with the original case. After processing a training case the learner has the possibility to make up new therapy proposals for variations of this case. He also gets feedback of experts concerning the therapy strategy. Thus, it is not necessary to load a completely new case and the learner does not have to execute all steps until he reaches the situation of therapy decision. Effects of minor variations of the finding are more explicit, if they were not presented in a separate training case.

For example, if a herniated disk is located more laterally in the spine, the access to the operating field can be performed from the back. Usually, a frontal access to the cervical spine is necessary. Due to possible instabilities of the spine, the segment with the removed disk must be ankylosed in the case of kyphotic position of the vertebrae which enclose the herniated disk.

4.3 Support and Expert Recommendations

The user is (optionally) directed through the whole training process by offering him information for each step on functionality and interaction possibilities. If he needs help to the medical procedure, for example which access path is the best, he can request assistance from an expert. The expert describes his strategy and explains why this is the best way in his opinion. As support, the important anatomical structures can be shown as colored overlays (optionally with labels) in the 2d slice data. The anatomical knowledge can be improved.

In the analysis step of the system the learner can compare his therapy strategy visually and textually with those of several experts. The simultaneous presentation of the learner’s therapy planning and processing and the recommendations of several experts provide the learner with the possibility to check his results and get an impression of the variety of surgical and therapeutical strategies for a particular case. Currently, there are only a few widely accepted standards for spinal surgery.

4.4 Theoretical Modules

Additional to the training of the planning and processing of interventions there are several modules intended which provide basic knowledge or allow the deepening of existing knowledge on the basis of general examples and interactive models. One of these theoretical modules shall, for example, contain interactive 3d models of the spinal anatomy and spinal nerves. These models shall convey the supplied region of each nerve and which consequences a crushing of a particular nerve root by a herniated disk may have. The learner can interactively decide on the basis of the 3d model which nerve root transfers only limited or no impulses. For this nerve root the user gets feedback which receptors drop out and which symptoms a patient will show.

5 Conclusion and Future Work

The SPINESURGERYTRAINER is a case-bases interactive training system, which provides training for the complete clinical workflow of the domain of spinal surgery. With the current prototype users are able to acquire and improve their anatomical knowledge concerning spinal and surrounding structures, and they can train diagnosis and therapy decisions on the basis of several cases and case variations. Available expert recommendations and explanations as well as the analysis of the planning results help the user to plan the therapy on its own and to understand the planning processes of the experts.

In the future development phase the training of the planning of surgery strategies (e.g., the insertion of an artificial spinal disk, the acampsia on the basis of implants or the resection of a spinal disk) as well as more cases (especially concerning the lumbar spine) will be added. Thus, a representative amount of different planning processes will be formed and the learners get an overview over possible disease patterns and therapies. Furthermore, it is essential to provide several expert recommendations for each case. That way the manifold procedures of the experts were revealed, since there are no clearly defined standards for spine surgery at the moment. The theoretical modules have to be implemented.

To validate the learning success, which can be achieved by the training with the SPINESURGERYTRAINER, an evaluation is essential. It shall be verified if the users are able to acquire the necessary competences to build diagnosis, make therapy decisions and plan a therapy for different spinal diseases.

Acknowledgement

We want to thank MeVis Research for providing MeVisLab and for their support in implementation and integration.

Literature

[AH06] Adler, M., Hege, I., Holzer, M. & Fischer, M. "CASUS - new implementations and challenges". In *Slice of Life Conference*, 2006.

[BT05] Benyon, D., Turner, S. & Turner, P. "*Designing Interactive Systems: People, Activities, Contexts, Technologies*". Addison Wesley, 2005.

[KC00] Kühnapfel, U., Cakmak, H.K. & Maass, H. "Endoscopic Surgery Training using Virtual Reality and deformable Tissue Simulation". In *Computers & Graphics 24 (5)*, pages 671-682, 2000.

[MC02] van Merriënboer, J.J.G., Clark, R.E. & de Croock, M.B.M. "Blueprints for Complex Learning: The 4C/ID-Model". In *Educational Technology Research & Development*, number 50(2), pages 39–64, 2002.

[RC02] Rosson & Carroll "*Usability Engineering - Scenario-based development of human computer interaction* ". Academic Press, 2002.

[SC00] Seiffert, C., Clasbrummel, B., Gemünden, H.G. & Bolz, A. „Strategieentwicklung für ein telemedizinisches Dienstleistungsunternehmen am Beispiel der TELTRA GmbH". In *Biomedizinische Technik*, Vol 45-1, 2000.

[SS00] Sourina & Sourin: "Virtual Orthopedic Surgery Training on personal computer". In *International Journal of Information Technology*, pages 16-29, 2000.

[ZR07] Zirkle, M., Roberson, D.W., Leuwer, R. & Dubrowski, A. "Using a Virtual Reality Temporal Bone Simulator to Assess Otolaryngology Trainees". In *Laryngoscope 117 (2)*, pages 258-263, 2007.