

TLEMsafe D4.1 deliverable report

Prototype of surgeon-model VR system

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1. Introduction

WP4 is dedicated to generate an interactive link between the musculoskeletal (M-S) model and the surgeon. Using Virtual Reality (VR) algorithms the operator is going to modify the M-S model of the patient. The interface may be utilized in two main fields. Experienced surgeons will use it to simulate their operative plans and prepare input data for a surgical navigation system. The interface may also be used by student or novice surgeons who can use it for training.

This deliverable report covers the structure and functionality of the prototype of surgeon-model VR surgery planning system. The main goal of the system is to enable the surgeon to efficiently prepare the optimal surgery scenario and to export it to surgical navigation system. In order to achieve this goal the surgery planning system takes advantage of novel HCI (human-computer interface) devices and communicates with both AnyBody Modeling System™ (AMS) musculoskeletal modeling software and Brainlab Navigation™ surgical navigation system.

The object of Deliverable D4.1 (a prototype of surgeon-model VR system) is a result of the following tasks in Work Package 4 (WP4):

- T4.1 Requirements for surgeon-model VR interaction
- T4.2 UML model of surgeon-model VR system
- T4.3 Prototype of surgeon-model VR system

2. Design considerations

Design specificity

The main application of the developed surgeon-model interface is surgical planning of lower limbs interventions. However, the software modules that the interface directly connects to (Fig. 1), i.e. the M-S modeling module (AnyBody Modeling System™ (AMS)) and the surgical navigation module (Brainlab Navigation™), are universal tools that may be used to analyze/operate on any part of the body. Therefore, the interface had been decided to consist of a general core common for all surgery cases and additional optional modules specific for various intervention types.

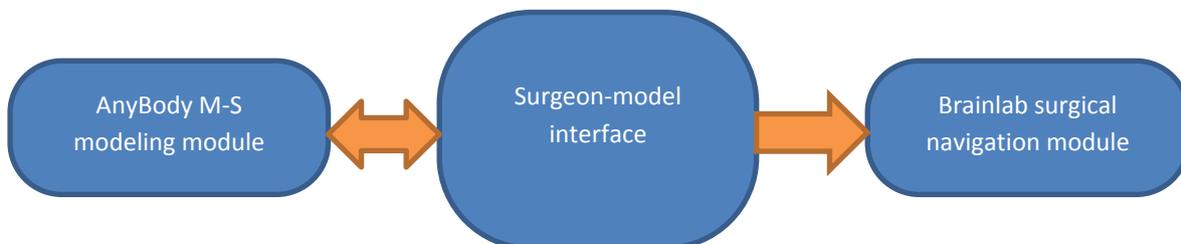


Figure 1. Directions of data flow between the surgeon-model interface and other modules of the system.

Planning software availability

It has been proved that 3-D visualization and virtual manipulation improve the surgeon's understanding and analysis of patient's anatomy. Virtual reality (VR) solutions offer multi-sensorial experience often, however, at a high price that limits the number of users. Also there are studies showing that complete immersion is not required for the surgeons to properly perceive 3-D structures. Lowering the cost of required hardware (HW) as well as avoiding the necessity of the user (possibly a student) to buy expensive software (SW) licenses could add to the total number of users of the developed surgeon-model interface. These were the premises to design the application ready to operate in various hardware configurations (offering different immersion levels) and to limit the number of third-party payable SW components.

Data exchange with other modules

The patient-specific information is acquired from the customized M-S model. For the purpose of surgery planning it is not necessary to parse all data of the complex model. However, it is crucial to interpret the required parameters correctly and from the point of view of the user the loading time should be as short as possible. In order to meet these requirements the AnyBody Modeling System™ application programming interface (API) has been incorporated in the developed surgeon-model interface. Time-consuming simulations of the functional outcome have been decided to be calculated off-line in the AMS application. Modifications introduced to the model by the surgeon as well as parameters of the cutting planes to be used by the navigation software are saved to files on the workstation and may be transferred to other machines if needed.

3. Software aspects of the developed Surgeon-model interface 3-D graphics and interaction programming environment

The surgeon-model interface has been developed in 3DVIA Virtools™ environment (Dassault Systemes, Vélizy-Villacoublay, France). It allows creation of 3-D compositions and programming human-model interactions. Being a rapid development environment Virtools™ allows quick implementation of behavior modifications (Fig. 2).

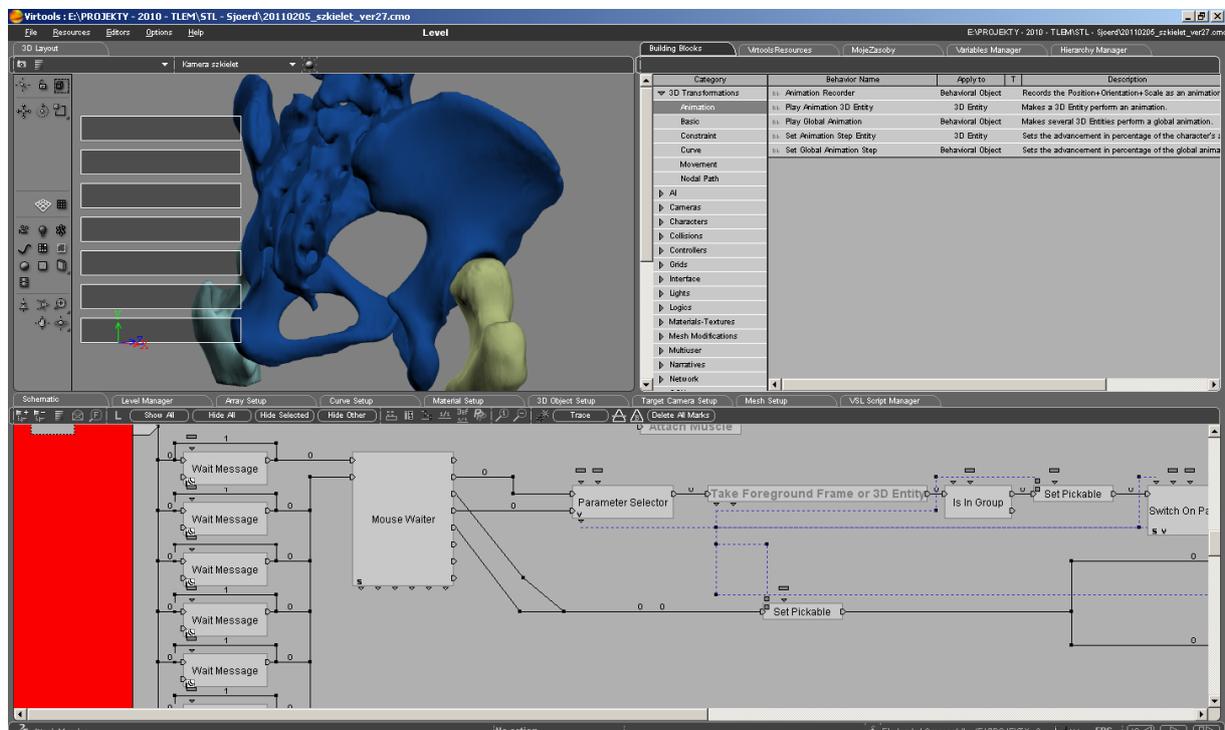


Figure 2. A screenshot of Virtools™ graphical user interface.

Interactions in Virtools™ environment were programmed either graphically with behavior graphs (Fig. 3a) or in a text form with use of Virtools Scripting Language (VSL) (Fig. 3b). More complicated computationally-intensive

building blocks (e.g. for haptic device support) were programmed within the Microsoft® Visual Studio™ application development environment and imported into Virtools as so-called building blocks.

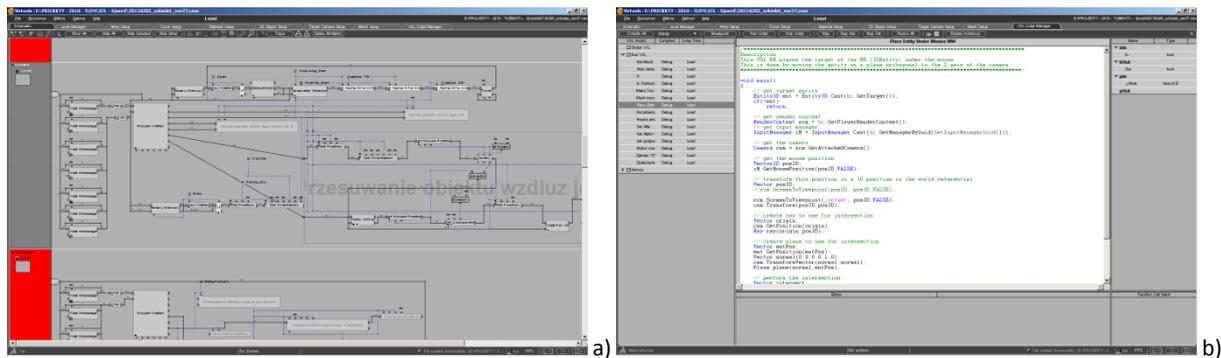


Figure 3. a) A screenshot of Virtools™ interaction modeling with use of a behavior graph. b) A screenshot of Virtools™ interaction programming with VSL.

It is worth mentioning that the 3-D surgery planning application may be launched on virtually any PC using a free 3DVIEW player for Internet Explorer or Mozilla Firefox web browsers. The application may be run in the browser window or full-screen.

AnyBody Modeling System™ API

The customized musculoskeletal model of a patient is imported with use of the AnyBody Modeling System™ API. It has been incorporated into the software part of the planning system and allows:

- importing original (pre-op) M-S model,
- applying changes introduced to the model by the surgeon in the planning application,
- importing/exporting changes committed to the model in AnyBody's *.anyscript file format for off-line analysis in the AMS application.

The imported parameters of the patient's model include:

- bone geometry,
- muscle paths and attachment points,
- joint parameters.

Yet the parameters listed above are a small subset of data contained in the patient-specific model they are sufficient to analyze it and prepare a surgery scenario. After completion of the intervention plan the parameters that have been changed are saved to a file for off-line simulation of functional outcome.

Software – data exchange with Brainlab™ Navigation software

The XML file format was selected for exporting the cutting planes parameters for the surgical navigation system. Each exported cutting plane is described by its name, the position and orientation of its coordinate system as well as the thickness of the tool. The internal data structure was agreed with Brainlab in order to make the output files acceptable for the navigation software.

4. Hardware configurations of the interface

In order to make surgeon's work efficient the planning system takes advantage of novel VR instrumentation, such as 3-D displays and haptic devices. However, to ensure better accessibility, the system may be operated with use of standard input devices, like keyboard and mouse.

The simplest set-up utilizes a standard computer keyboard and mouse as the input devices while the image is presented on a 2-D display. This system does not use any VR technology except from presenting virtual 3-D models on a 2-D screen. The operator is not stimulated with force feedback nor can use a 3-D manipulator. However, this version is possible to be installed on practically every computer workstation and does not require any additional hardware purchases what makes it very cost effective. The use of a web browser with a

freeware 3DVIA player limit the additional software cost to the license of the AnyBody Modeling System™ (demo and academic licenses are available). However, even on a station without AMS license installed the surgeon-model interface may be used with limited functionality. The STL bone model may be imported, inspected, modified (cut and displaced) and the results may be exported to navigation software. In such case no muscle data is processed and there is no possibility to simulate the functional outcome.

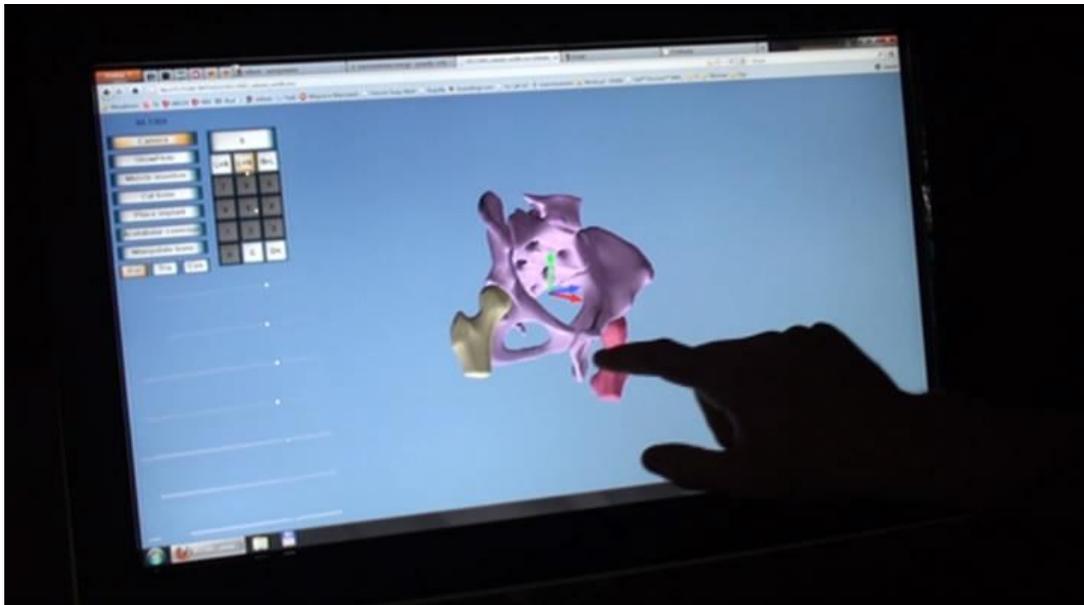
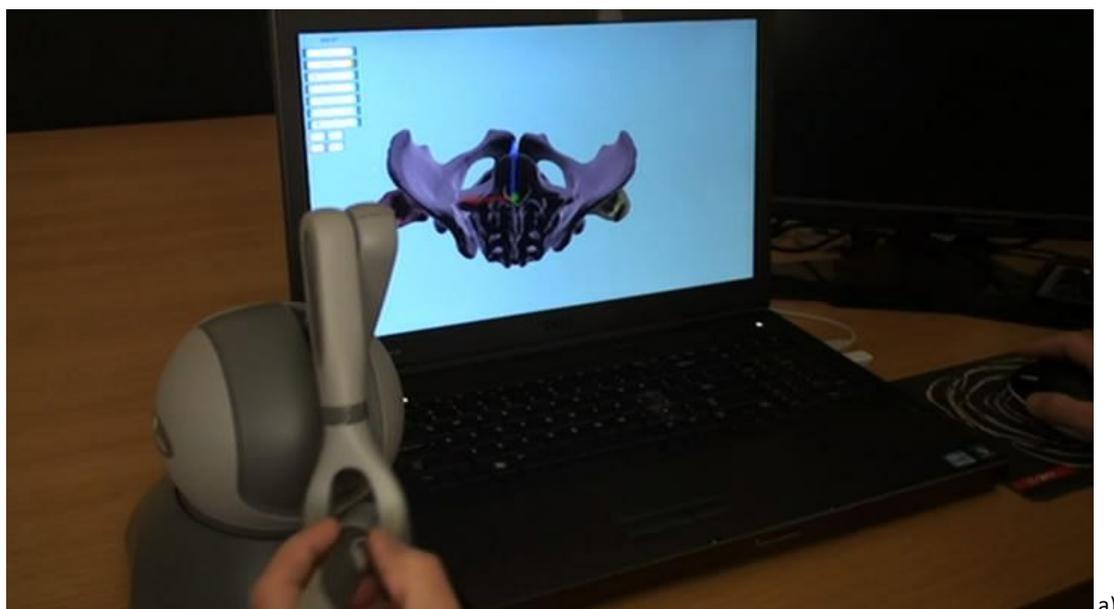


Figure 4. Inspection of a 3-D pelvis model with a touchscreen (application launched in a Mozilla Firefox browser window).

Another version of the interface is aimed at using a touch screen as a single device for both input and output information from and to the user (Fig. 4). It is meant to be used especially in environments where the use of other interface devices may be not recommended, such as operating rooms. The use of a planning station in the operating room may be caused by unforeseen circumstances that occur during the operation.

Regardless of the hardware configuration used, the functionality of the application and methods of interaction with the model remain coherent. As a result the operator can easily switch between differently accessorized workstations e.g. in the planning room, at home and in the operating room. Eliminating the need for changing the path of reasoning and interaction principles while swapping from one workstation to another saves the surgeon's time and lets him focus on the intervention.



a)



Figure 5. a) 3-D model manipulation with use of a Sensable Phantom Omni haptic device. b) 3-D image presented by the nVidia 3D Vision stereoscopic display set.

Offering the highest level of immersion version of the user interface takes the most advantage of modern VR devices (Fig. 5). Equipped with a 3-D display it allows the operator to immerse in the virtual world of surgery planning environment. An intuitive way of 3-D objects manipulation with use of a haptic device is provided as well. It has been observed that a 3-D haptic device is well-suited for operations of manipulating viewport or a bony fragment. However, precise pointing of a spot (e.g. muscle insertion area) of 3-D object's surface is easier completed with a standard mouse. For this reason, a 2-D mouse has been included in this hardware configuration.

5. The functionality of the surgery planning system

The functionality of the planning system was aimed at meeting the requirements of surgery types that had been selected as the most important for the TLEMsafe project, i.e.:

- tumor surgery (requires such functionalities as osteotomies, removal of muscles, tendons and bony structures),
- bony corrections (requires such functionalities as multiple osteotomies and repositioning of muscle insertion sites).

The surgeon-model interface developed provides the operator with required functionalities accessible in ways that are intuitive to the user or the ways that he is used to (Fig.6). The developed interface enables full functionality regardless of the human-computer interface devices used.

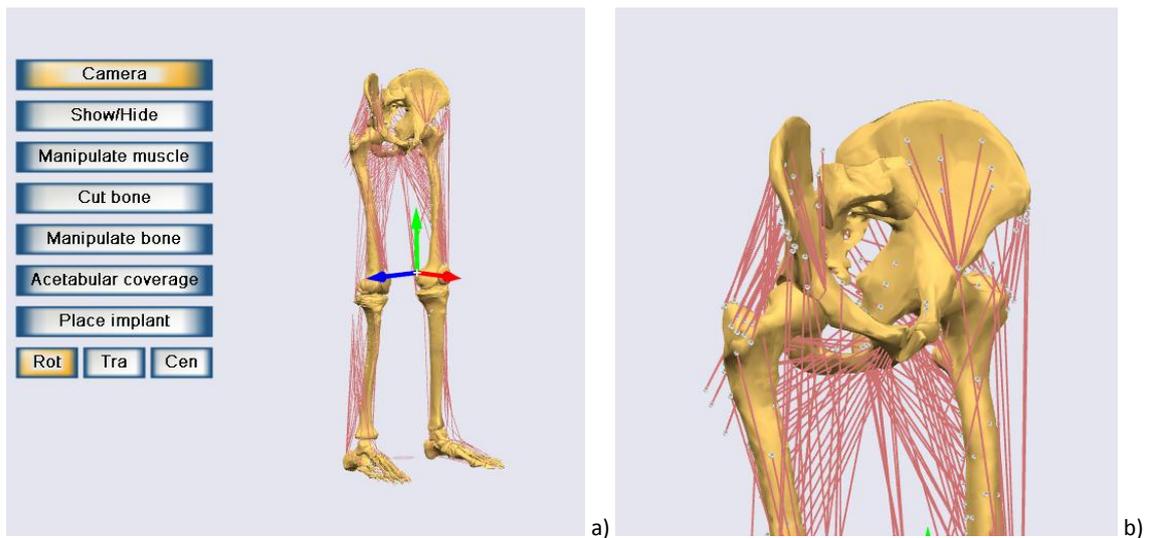


Figure 6. Screenshots of the surgeon-model interface. A M-S model of lower extremities is visible. a) Overall view. b) A close-up of the pelvis.

After loading the required musculoskeletal model, the interface enables the user to inspect the it from any direction (viewport manipulation). The user may select each structure to be visible as opaque, semitransparent or hidden. The semitransparent visualization was introduced after surgeons' requests (semi-transparent bones look similar to what they are familiar with from x-ray imaging). The bones may be cut with a virtual cutting blade. The user sets the desirable position and orientation of the blade and performs the cut (osteotomy). A single bone may be cut multiple times. A cut fragment of the bone may be removed and replaced by an implant or manipulated in order to better function in the musculoskeletal system.

A simulation of a surgery aimed at increasing the acetabular coverage is shown in Figure 7. First the surgeon inspects the 3-D model (Fig. 7a). Then he plans three cuts (triple osteotomy) (Fig. 7b). Next he manipulates the bony fragment in order to get a better bony coverage of the acetabulum over the femoral head (Fig. 7cd). The current coverage may be evaluated any time (Figure 8). All changes committed to the model (the surgery scenario) may be stored in an *.anysset file for biomechanical analysis in AnyBody application. The parameters of osteotomies performed in the scenario are exported to an XML file and may be used by the Brainlab surgical navigation module.

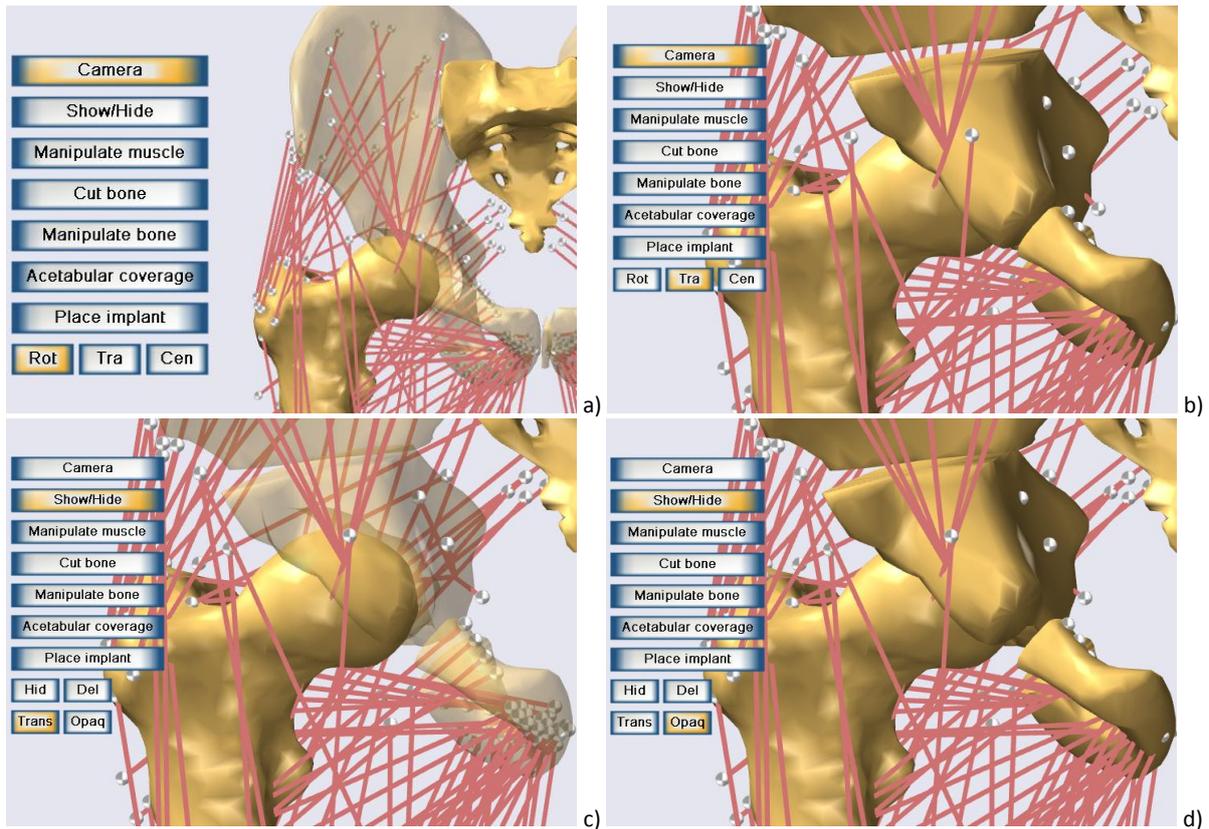


Figure 7. Screenshots of the surgeon-model interface. a) Initial inspection of the pelvic area. b) Planning triple osteotomy. c) Manipulating acetabular bony fragment with respect to the articular surface. d) Final result of the planned intervention.

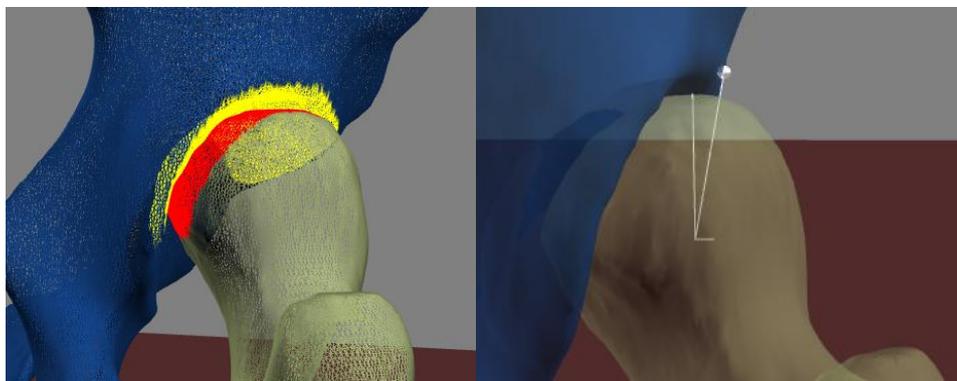


Figure 8. A screenshot of surgeon-model interface. Automatic evaluation of acetabular coverage angle.

The surgeon-model interface may also be used to plan a removal of any bony fragment and putting an implant (a geometry from an STL file) instead. In such surgeries muscle insertion areas often need to be repositioned from the removed bone fragment to the remaining ones. The application offers the functionality required. Having repositioned the muscle, the surgeon can check the intervention's functional outcome with use of AnyBody Modeling System™.

A simulation of a surgery aimed at removing tumorous fragment of the femoral bone is shown in Figure 9. First the surgeon inspects the 3-D model and conducts the double osteotomy (Fig. 9a). Then he places the virtual implant (Fig. 9b). Lastly he manipulates the muscle insertion areas from the removed fragment to be placed on the remaining bone fragments. Some of the muscles may also be removed. All changes committed to the model (the surgery scenario) may be stored in an *.anyset file for biomechanical analysis in AnyBody application. The parameters of osteotomies performed in the scenario are exported to an XML file and may be used by the Brainlab surgical navigation module.

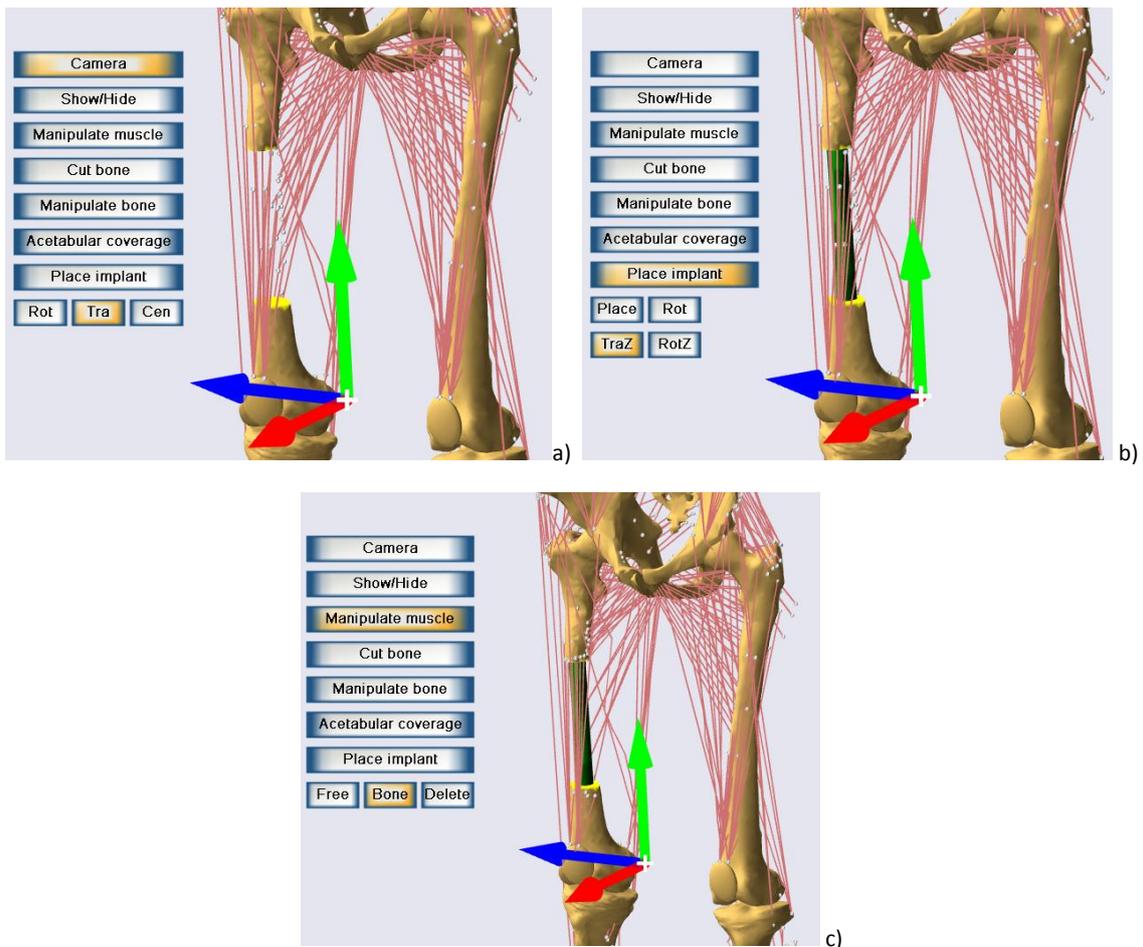


Figure 9. Screenshots of the surgeon-model interface. a) Removal of tumorous bone fragment. b) Placing an implant. c) Repositioning muscle insertion areas to the remaining bone fragments.

6. Summary

The VR surgeon-model interface developed in task T4.3 was designed in accordance with the directives set in tasks T4.1 and T4.2 of work package WP4. The implemented functionality allows planning of tumor surgeries and bony corrections but the modular design allows broadening the range of applications in future. The developed surgery scenarios can be directly used by a) modeling software to simulate the functional outcome of the surgery and b) surgical navigation system if the simulated outcome is satisfactory. The interface takes advantage of semi-immersion when used with 3-D display (shutter glasses) and a haptic device. However, complete planning functionality is available even for simple configurations with a 2-D display and a standard mouse. The surgery planning system is ready to be tested and verified by the test users (doctors engaged in the TLEMsafe project).