# A novel Real-Time Web3D Surgical Teaching Tool based on WebGL

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**Abstract.** The purpose of this paper is the demonstration of a real-time Web3D surgical learning application. In contrast to existing medical e-learning portals, we provide interactive web-based 3D models derived from patient-specific image data. The 3D visualizations are accessible in real-time with our newly developed 3D viewer based on X3D and WebGL. Thus, no platform-specific browser plugin is required. Additional information, such as annotated 2D DICOM data, high-quality surgical movies and a quiz can be used by the learner to train his/her knowledge about human anatomy and surgical procedures. Our conclusion is that our presented Web3D e-learning application may support traditional educational methods like lectures and schoolbooks.

## 1 Introduction

E-learning systems increasingly support conventional medical education and training. They are applied to convey anatomical basics or to train therapy decision making and treatment. They allow an autonomous, time- and location-independent as well as active acquisition of knowledge. Graphics, movies, animations and 3D models illustrate complex anatomical relations much better than textbooks. The drawback of local software systems is their limited dissemination and content actuality. In contrast, web-based e-learning platforms can be accessed and updated easily.

There exist several offline and online e-learning systems for teaching anatomical basics by employing 3D models for interactive visualizations (e.g. VoxelMan Inner Organs [1], PrimalPictures 3D Human Anatomy [2] or VIRTUAL Liver [3]). The majority of web-based systems require special plugins, e.g. VRML [4], Flash [5] or QuicktimeVR [6] that have to be installed afore. Most of these systems are not based on individual patient data and offer no verification of the achieved knowledge gain for the learner.

Pape-Köhler et al. [7] have analyzed the five most important online and offline surgical e-learning portals in their study. It turned out that none of the reviewed systems fulfilled all criteria in terms of curricular integrity, currency of scientific content and validity. Therefore, our goal is the development of a surgical learning and communication platform which provides multimedia content and interactive web-based 3D visualizations.

In this paper we present an interactive Web3D tool for liver anatomy teaching based on WebGL [8]. In contrast to previously existing medical e-learning tools, we abandon the usage of 3D modeling software to get high-detailed 3D graphics. Instead, our tool employs real patient-specific 2D and 3D data to show the variety of liver anatomy and to train its interpretation. An integrated quiz shall convey interaction with the 3D model and provide feedback concerning the learning success.

## 2    Materials and Methods

We employed 13 abdominal DICOM CT datasets as basis for our interactive web application. Anatomical and pathological structures were segmented by several medical experts. In order to represent a typical clinical case, further information about radiological findings, preliminary investigation, diagnosis and surgical reports are provided. The generation of web-based medical 2D images and 3D models as well as the combination with a didactical concept is explained in the following sections.

### 2.1    Web-based 2D Viewer

Typically, DICOM volume data are too large for fast online access. Furthermore, clinical DICOM data are often not anonymized adequately for online publishing. Thus, we chose the JPG image format to achieve a fast online access on anonymized patient data. The usage of compressed JPG images instead of high-detailed DICOM data is reasonable, since no exact diagnostics have to be accomplished on the web platform. Nevertheless, we loose the opportunity of interactive level-windowing when using JPG images. To overcome this issue, several image datasets with predefined window levels are provided and can be switched interactively by the user.

MeVisLab [9] is used to export the DICOM CT slices to JPG images. For educational purposes, the 2D slices are overlayed with colored segmented masks, e.g. vessels, tumors or organs serving as context information (Fig. 1). Images and overlays are scrollable by the user similar to a common radiological workstation. The segmented structures are exported as SVG (Scalable Vector Graphics) objects and mapped on the JPG images with the Raphaël JavaScript framework [10]. This procedure allows flexible scaling, coloring and usage of the overlays in our educational web application. Mouseover events on the SVG objects are used to dynamically display textual annotation labels. In addition, SVG enables the flexible integration of symbols, e.g. circles or arrows indicating important medical structures.

### 2.2    Web-based 3D Viewer

We use X3D [11], an ISO Web3D standard, since it allows to export and represent 3D objects in a hierarchical scene graph via XML-based textual encoding. Furthermore, X3D content can be easily integrated and rendered in real-time with

**Fig. 1.** An interactive purely HTML-based 2D viewer for slicing through a medical image stack. Colored overlays and textual annotations indicate segmented anatomical and pathological structures.

our interactive web application using the X3DOM [12] framework. The advantage of X3D is the simple integration into the HTML DOM since no additional transformation of 3D nodes is necessary to display 3D content on a website. WebGL is a JavaScript API and provides a platform-independent, plugin-free, scalable and GPU-supported access on dynamic 3D models. WebGL closely matches OpenGL ES 2.0 and uses GLSL as language for shader programs. By now, WebGL is supported by the most used web browsers in the latest releases (e.g. Mozilla Firefox or Google Chrome).

The segmented 2D structures are automatically transformed into 3D models (Fig. 2(a)) and exported as X3D files using MeVisLab. In addition, mesh simplification algorithms are used to decimate the number of polygons and thus reduce rendering time in the web-based 3D viewer. The X3D content is not embedded directly in HTML to assure fast access to the web application. Instead, the 3D elements are dynamically downloaded from the server and integrated on the client side into the website using AJAX (Asynchronous JavaScript and XML).

The medical 3D scenes rendered with WebGL can be rotated, tanslated and zoomed freely without the need of installing any additional browser plugin. However, free exploration of 3D scenes like rotating the scene, zooming in/out and enabling/disabling different structures can be a complex and tedious task for unfamiliar users. Therefore, we provide easy-to-learn interaction modes to ease the exploration of the 3D models and to reduce the learning effort. The rotation can be restricted to fixed axes to avoid unwanted viewpoints. Furthermore, we enable different levels of zooming by providing an interactive zoom slider.

Surgeons often want to manipulate only a few parameters of a 3D visualization. Therefore, we provide several visualization presets that can be used to adjust the visualization result depending on user's requirements. For example, a complex 3D liver model displaying the tumor, several vessels and territories can be simplified by one click to show just the tumor in its correlation to the portal vein. Thus, the 3D scene is less complex and gives the learner the possibility to concentrate on certain details. In particular, this is a beneficial feature if the learner wants to gain knowledge about surgical procedures. Therefore, we provide several 3D resection proposals made by medical experts, depending on
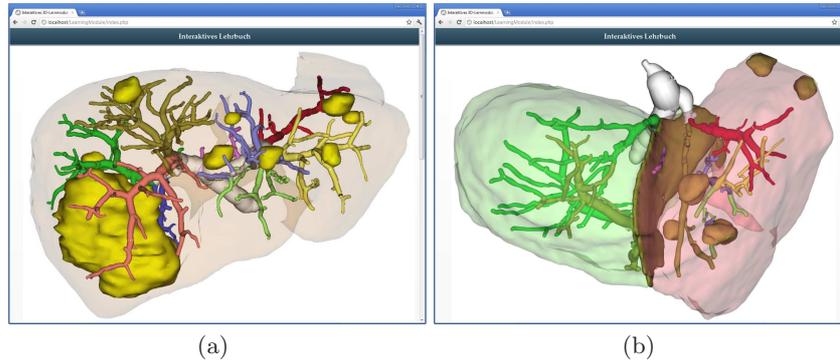
(a)                                   (b)

**Fig. 2.** a) High-quality X3D liver model with several colored tumors and vessels derived from individual patient anatomy. b) 3D resection proposal of a hemihepatectomy (green: remnant, red: resection volume, orange: resection plane) displayed in our WebGL-based 3D viewer in Google Chrome 16.

the individual patient case. A 3D resection proposal consists of a resection and remnant volume visually separated by a resection plane. The tumor(s), vessel territories and the surrounding liver are also integrated into the 3D scene (Fig. 2(b)). The learner can interactively explore the 3D resection proposal and has to decide whether this surgical procedure (e.g. a left hemihepatectomy) is indicated or not. To support the learner's decision, the resulting resection and remnant volume measurements can be enabled. After choosing one of the proposed resection methods, the user receives an immediate feedback on his/her answer.

### 2.3   Anatomy Quiz and Additional Multimedia Content

X3D allows an easy combination of 3D content with simple HTML, CSS and JavaScript elements. In our case, we combine our educational application by providing a quiz beside the 3D viewer. Multiple choice questions can be used by the learner to reflect and test his/her anatomy knowledge. On the one hand, questions can be answered by simply choosing an option in the quiz (e.g. "What is the correct medical term for the blue vessel displayed in the 3D scene?"). On the other hand, interactive selections of certain 3D elements are also supported (e.g. "Please identify and click on the portal vein!"). This can be achieved by simple JavaScript *onClick* event handlers. If all questions were answered successfully, a new patient case with higher difficulty is selected and can be investigated by the learner.

Additional hyperlinks to relevant websites are provided to support the learning process of the user. Furthermore, each patient case is enhanced by a high-detailed surgical movie composed and annotated by a surgeon. Thus, the learner is able to gain insight typical workflows of surgical interventions, e.g. surgery preparation, resection techniques and potential complications.

## 3   Results

We have presented a real-time Web3D surgical learning application which has many advantages for medical students. Web-based learning contents are accessible anywhere and anytime on demand. Compared to existing e-learning portals, we provide interactive medical 3D models that can be explored in common web browsers, without the need to install any plugin. The high-quality Web3D graphics derived from patient-specific anatomy allow for more realistic and detailed representations of anatomical and pathological structures. Since we use WebGL, every major web browser which implemented the forthcoming HTML 5 standard (e.g. Mozilla Firefox 8 or Google Chrome 16) can be employed. X3D as free file format enables easy exchange, reuse and integration of Web3D content in existing and future e-learning applications. A typical X3D scene is approximately 5 MB in size and is therefore accessible in a few seconds with high bandwidth. Our interactive web-based learning tool can be easily deployed in the classroom due to its simplicity. In order to improve the teaching and training process, the e-learning tool is supplemented by a web-based 2D DICOM image viewer and high-quality surgical movies.

Until now, we have carried out an informal evaluation with one radiologist. It turned out that the medical expert had no major problems to explore the web-based 2D data and 3D models. The physician favored the free exploration of high-detailed 3D graphics derived from individual patient data. However, the radiologist suggested that annotation labels might be essential for medical students to indicate anatomical structures. Furthermore, the radiologist claimed that interactive annotations of important structures is not possible, yet. A promising feature would be to highlight certain pathologies in order to collaborate with other learners about annotated findings and appropriate therapy strategies. Further evaluations with prospective users, which will investigate usability, knowledge gain and user acceptance of our application, are currently prepared.

## 4   Discussion

Our Web3D learning application can be beneficial to traditional educational methods like lectures and schoolbooks since it provides highly interactive web-based 3D visualizations of patient anatomy. However, further developments will be considered in order to enhance surgical education and training. Amongst others, annotations seem to be essential in 3D anatomy teaching applications. These textual annotations can help learners to identify anatomical structures. Mühler et al. [13] describe promising annotation techniques that shall be integrated in our e-learning application. Furthermore, WebGL is a promising technology for providing highly interactive surgical training tools online. It would be desirable to train surgical procedures [14] online without installing special browser plugins or applications. We will also concentrate on the development of an online authoring system for web-based 3D data. This authoring tool might give tutors the chance to update existing 3D models online, upload new cases and build questionnaires based on the uploaded content.

Further developments will also concentrate on medical visualization using mobile devices that are highly welcome by medical doctors. WebGL is basically a JavaScript binding of OpenGL ES 2.0 [15] and enables 3D renderings on portable devices like smartphones or tablets. Therefore, several hardware limitations and optimized shaders have to be considered carefully to assure high-quality performance on such devices.

### Acknowledgment

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