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ORIGINAL ARTICLE

Augmented reality to the rescue of the minimally invasive surgeon. The usefulness of the interposition of stereoscopic images in the Da Vinci™ robotic console

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Abstract

Background Computerized management of medical information and 3D imaging has become the norm in everyday medical practice. Surgeons exploit these emerging technologies and bring information previously confined to the radiology rooms into the operating theatre. The paper reports the authors' experience with integrated stereoscopic 3D-rendered images in the da Vinci surgeon console.

Methods Volume-rendered images were obtained from a standard computed tomography dataset using the OsiriX DICOM workstation. A custom OsiriX plugin was created that permitted the 3D-rendered images to be displayed in the da Vinci surgeon console and to appear stereoscopic.
These rendered images were displayed in the robotic console using the TilePro multi-input display. The upper part of the screen shows the real endoscopic surgical field and the bottom shows the stereoscopic 3D-rendered images. These are controlled by a 3D joystick installed on the console, and are updated in real time.

Results Five patients underwent a robotic augmented reality-enhanced procedure.
The surgeon was able to switch between the classical endoscopic view and a combined virtual view during the procedure. Subjectively, the addition of the rendered images was considered to be an undeniable help during the dissection phase.

Conclusion With the rapid evolution of robotics, computer-aided surgery is receiving increasing interest. This paper details the authors' experience with 3D-rendered images projected inside the surgical console. The use of this intra-operative mixed reality technology is considered very useful by the surgeon. It has been shown that the usefulness of this technique is a step toward computer-aided surgery that will progress very quickly over the next few years. Copyright © 2012 John Wiley & Sons, Ltd.

Keywords mixed reality; augmented reality; osiriX; robotic surgery

Introduction

Since the early 2000s, robotic technology has been successfully introduced in almost all surgical fields. The evolution of this new technology has enabled the performance of more advanced, minimally-invasive procedures, such as hepatic and pancreatic resections, lung resection, and difficult oncological procedures (1–4).

In addition, the introduction of robotics has brought new technological possibilities thanks to the computerized interface between the patient and the surgeon, integrated in the robotic system. At the same time, we live in a world in which our interaction with elements is often augmented by computer-generated information, mostly simplifying our daily tasks. The advantages brought by such a virtual-enhanced environment are evident to everyone, but remain poorly used in surgery. In the robotic era, augmented reality is a really interesting tool that could be used in surgical consoles. However, the development of a virtual environment coupled with endoscopic and robotic technologies has received very little attention to date (5–7). Nonetheless, the possibility of coupling radiological images directly inside the surgical field is of great interest.

The starting point of our project was to use and display a stereoscopic 3D projection of previously acquired computed tomography data in the surgical robotic console. We reported our preliminary experience and proved that this system was easily applicable in an operating room setting (8).

Our objective was to create more than just a proof of concept; we wanted to create a tool that would be immediately useful. We built a plugin for software already used in our and several others' institutions, a DICOM viewer already widely distributed in the medical community and easily accessible on the internet for free, OsiriX.

The OsiriX software (9) is indeed widely adopted by non-specialized audiences such as surgeons, and it is used to analyse radiological information and to plan complex operations.

We describe herein the development of the software plugin and our experience in the clinical application of the integration of 3D-rendered images with depth perception in the operative workflow of the surgeon.

Materials and Methods

We wanted to implement a tool that could be used to display volume-rendered images derived from CT scans in the da Vinci console. In addition to showing a volume-rendered CT, the interface had to allow the surgeons to easily import patient data, modify rendering parameters, and add annotations to delimit regions of interest (ROIs). These annotations had to be precisely placed by the surgeon when preparing for surgery. In order to ensure the highest accuracy in the placement of these annotations, the surgeons needed intuitive tools with which they are experienced and felt comfortable. OsiriX (9) implements all the features necessary to create, annotate and display volume renderings of CT studies, and thus is an ideal candidate to use as a foundation for our new application.

The open-source nature of OsiriX made it possible for us to build a plugin that went far beyond what most plugin architectures would allow. We were able to build a plugin that preserves all the features present in the original software, makes no modifications to the user interface, and allows any volume-rendered scene to be viewed in 3D in the da Vinci surgeon console. This approach satisfied all our requirements and led to a tool that could be used 'out of the box' with no learning curve.

To connect to the da Vinci surgeon console we used the TilePro multi input display, which includes two DVI ports. When connected to the video output of a standard video card, these inputs appear as ordinary 1080p computer monitors. These two virtual monitors communicate their names as DA_VINCI_LEFT and DA_VINCI_RIGHT, respectively, using standard DVI protocols to identify which virtual monitor will appear before which eye in the surgeon's console. The surgeon's console uses two separate displays that are presented to each eye when the surgeon peers into the console. Usually these displays will be filled with the video generated by the laparoscopic camera. When the TilePro software is activated, the laparoscopic video is reduced to half its usual size and is placed at the top of the display, and the left and right video inputs appear just below. Since both the left and right displays show video from the corresponding video inputs, it is possible to generate a stereoscopic pair of volume renderings, assigning to each monitor the required features for parallax, distance between the eyes and depth of field. In this way the scene appears to the surgeon as a single 3D image. A 3D joystick (3DConnexion Inc.) was installed on the console bar and permitted the surgeon to manipulate the images in every direction, and to zoom in and out, turn and pan in a very intuitive way. At each change in position of the scene the images are re-rendered with the appropriate information on the two virtual monitors of the da Vinci surgeon console.

Results

We performed five interventions by integrating the stereoscopic-rendered images into the robotic console. The first two patients presented symptomatic gallstone disease. CT studies with intravenous and biliary contrast media were conducted during the diagnostic process. This allowed the surgeon to proceed with the reconstruction of 3D images of optimal quality using the OsiriX software (Figure 1). The surgeon displayed the stereoscopic-rendered images several times during the procedure for a few seconds. The spatial location of the biliary tree and its relationship with the surrounding structures were clearly established. The surgeon could virtually turn around structures that were not directly in his field of vision such as the inner face of the Calot triangle or any aberrant biliary duct going directly through the gallbladder (Figure 2). Thanks to the 3D joystick the surgeon could control the virtual rendering, endeavouring to faithfully reproduce the spatial arrangement of the endoscopic view. At times he focused on a specific anatomical area. This added about 5 minutes to the intervention time.

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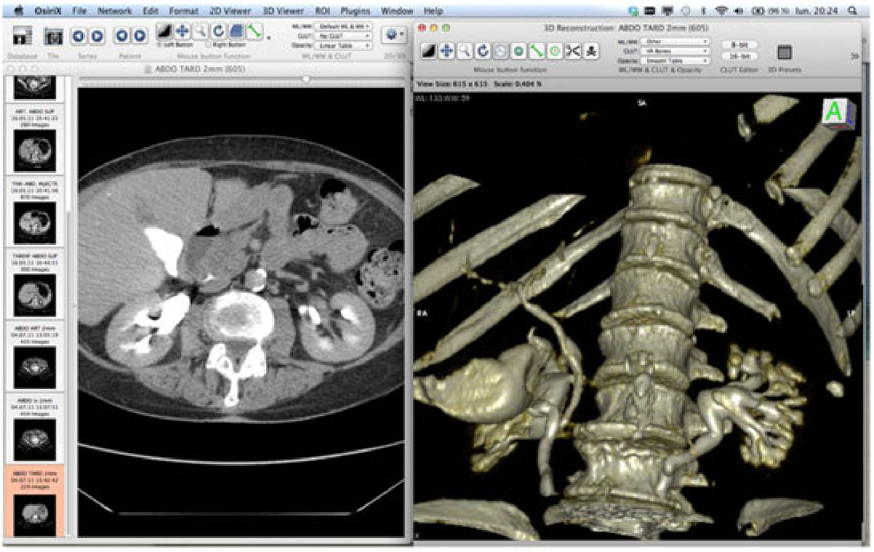

Figure 1. OsiriX DICOM viewer and 3D image volume rendering

Our next case was a totally robotic right colectomy. The surgeon was able to appreciate the location of the tumour in space, displaying a virtual 3D colonoscopy of his patient (Figure 3). Vessels nourishing the tumour were clearly identified, and variations in vascular anatomy were quickly and accurately established.

Our last two patients underwent a robotic sigmoidectomy. The surgeon was helped by the illustration of the vascular anatomy as described above. In addition, the possibility of locating in space the left ureter, highlighted before the operation, was clearly a great benefit. Indeed, thanks to the depth perception allowed by the plugin, the relationship between the ureter and the vessels and mesocolon and its position in the pelvis were easily evaluated (Figure 4). The duration of display of the dual image did not exceed 5 minutes for each situation described above. There was no conversion or intra-operative complications.

The surgeon no longer needs to turn his head outside the operating field, and this was subjectively considered as a gain as his attention could be focused on the task. Sight diversion was no longer necessary. Depth perception was definitively perceived as being useful by the surgeon.

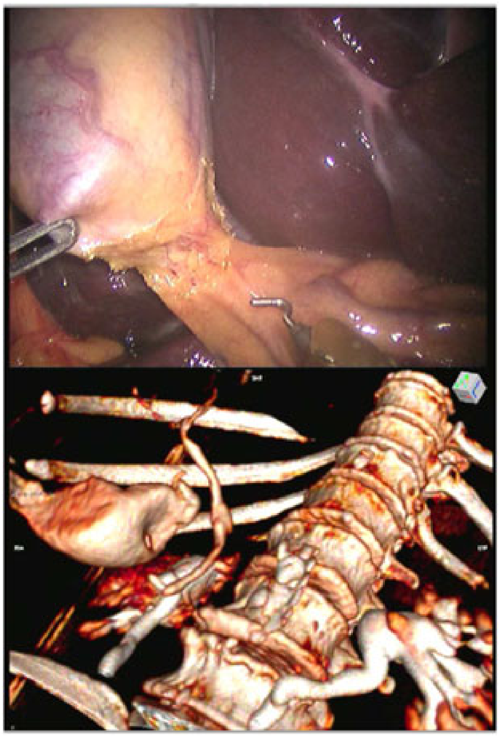

Figure 2. Surgeon's console display with the endoscopic surgical view in the upper part and the stereoscopic virtual reconstruction of the gallbladder and the biliary tree in the lower part

Figure 3. Localization of the tumour is facilitated by the stereoscopic rendering displayed in the lower part of the surgeon's console

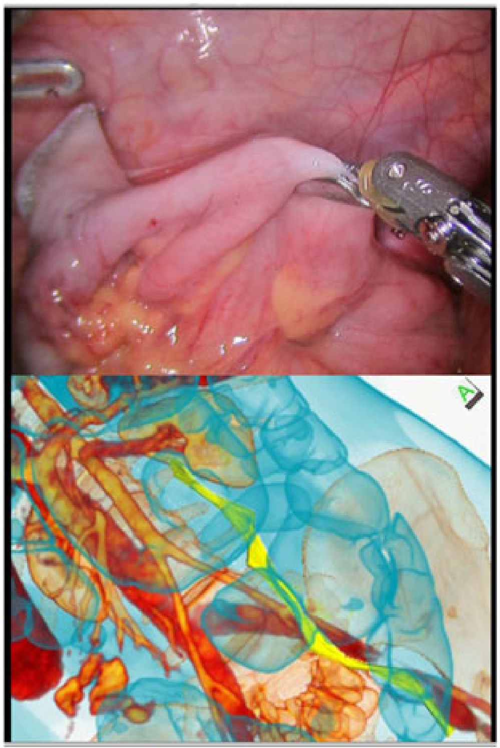

Figure 4. Endoscopic view of the surgical procedure in the upper part and stereoscopic virtual reconstruction with ureter highlighted in yellow in the lower part

Discussion

These patients benefited, during the surgical operation, from the addition of 3D renderings to the usual endoscopic images. The surgeon has also benefited due to the direct and immediate availability of additional information about the procedure being executed. This was achieved using a homemade plugin, allowing stereoscopic virtual images to be displayed directly in the surgical console, just below the endoscopic view.

The widespread interest in augmented and mixed reality is not new (10,11). However, with the introduction of robotics in surgery the development of augmented reality is becoming more interesting and feasible. The concept behind robotic surgery is to integrate an interface between the surgeon and the operative field. This interface allows developments such as augmented reality, simulation and computer-assisted surgery. Surgeons and researchers are aware that the possibilities are endless.

We created a simple plugin and demonstrated that this technique is not only readily applicable in an operating room setting, but also the required investment in terms of human and material resources is very minor (8). The use of mixed reality in our clinical setting showed numerous advantages. When the surgeon needs to consult the rendered images prepared before the operation, like a pilot examining his flight plan, he no longer has to leave the cockpit and remains completely immersed in the intervention that is currently underway. This new technology allows the real-time identification of important anatomical structures. The dissection phase is thus safer and probably quicker. In our cases, the cholecystectomies were facilitated by the ability to check the biliary anatomy throughout the procedure. For colorectal resections, the identification of vascularization was seen as a great help. The ergonomics was also improved. Indeed, the surgeon does not need to quit the operative field when he/she wants to confirm the preoperative findings. These results are of course subjective, but the comfort of the surgeon was considerably increased due to the adjunction of the virtual information. However, this in turn increased the duration of the operation by 6.4 minutes, the mean time period during which the rendered images were displayed in the surgeon's console during our interventions.

Other teams have reported the successful use of different types of mixed reality. In the robotic field, Pietrabissa *et al.* (5) demonstrated the use of augmented reality during the treatment of a splenic artery aneurysm. Previously rendered images were superimposed with transparency on the real scene with a virtual helmet. Another team developed a projector to superimpose semi-synchronised images directly onto the organ (12). In 2009, Su *et al.* (6) used augmented reality during a robot-assisted partial nephrectomy, in which they overlaid reconstructed 3D computer tomography images onto real-time stereo video footage. While very preliminary, these data showed the growing possibility of incorporating these images directly in the surgical field during the operation.

Steady direct projection of the reconstructed volumes has also been reported (7,10,13), but with obvious issues of the precision and synchronization of the superimposed images. The reason for the interest in such technology in the field of minimally invasive surgery for procedures that are technically more demanding is clear.

Again, the importance of a technology such as the one described for teaching young surgeons should not be underestimated. Indeed the virtual world must be used to provide a preliminary experience to a young surgeon before his actions have a measurable effect on the course of the intervention. As of today, some interventions are becoming so complex that it makes sense to allow these physicians to increase their experience with this type of technology. The benefit of a technique in which the real world is enhanced by virtual images is clear, compared with a completely virtual world.

There are of course various other programs available on the market that are capable of 3D virtual rendering, ROIs creation and organ segmentation. However, OsiriX is a free and open-source program already widely used in the medical community and readily available for download on the Internet (14). We think this could facilitate the widespread acceptance of such a technique.

An obvious issue with this technique is the real-time synchronization of the virtual images, with changes in the position and shape of intra-abdominal organs. This is a problem that is being solved and that will soon make a step forward in augmented reality techniques. Indeed, the power of computers increases exponentially. The definition of images produced by today's HD cameras gives unexpected

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opportunities in detecting organ shape modifications and texture detection. For this reason, plastic deformation of virtual structures and real-time synchronization will become easier and faster. Perioperative ultrasonography as a tool to locate fixed and predefined points inside the organ also seems a promising and feasible technique. The computer can indeed re-render the deformed structure of the organ concerned, and ultrasound examination can be repeated frequently and simply during the procedure. This will be valuable during the surgery of solid organs such as hepatic resections (15,16).

Conclusion

Although the majority of our data are subjective, surgeon comfort was considerably increased and the security of the procedure appeared to be improved. Emerging technologies such as augmented reality offer new possibilities to the surgical world, filling the surgeon's toolbox with a new virtual instrument. The introduction of mixed reality in robotics is an important step towards computer-assisted surgery.

Conflict of Interest

The other authors have no conflict of interest or financial ties to disclose.

Disclosure

Monika Hagen is consultant for Intuitive Surgical Inc.

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