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Augmented reality and image overlay navigation with OsiriX in laparoscopic and robotic surgery: not only a matter of fashion

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Abstract
Background New technologies can considerably improve preoperative planning, enhance the surgeon's skill and simplify the approach to complex procedures. Augmented reality techniques, robot assisted operations and computer assisted navigation tools will become increasingly important in surgery and in residents' education.
Methods We obtained 3D reconstructions from simple spiral computed tomography (CT) slides using OsiriX, an open source processing software package dedicated to DICOM images. These images were then projected on the patient's body with a beamer fixed to the operating table to enhance spatial perception during surgical intervention (augmented reality).
Results Changing a window's deepness level allowed the surgeon to navigate through the patient's anatomy, highlighting regions of interest and marked pathologies. We used image overlay navigation for laparoscopic operations such cholecystectomy, abdominal exploration, distal pancreas resection and robotic liver resection.
Conclusions Augmented reality techniques will transform the behaviour of surgeons, making surgical interventions easier, faster and probably safer. These new techniques will also renew methods of surgical teaching, facilitating transmission of knowledge and skill to young surgeons.

Keywords Augmented reality · Image overlay navigation surgery · Osirix · Laparoscopic surgery · Robotic surgery

Introduction

Laparoscopic surgical procedures brought enormous benefits in the treatment of everyday surgical pathology. But the undeniable advantage given by the sense of touch that guides the surgeon during an operation has been considerably curtailed by these techniques. Indeed, the surgeon appreciates anatomical structures only through what he see in the monitor in front of him while grasping long laparoscopic instruments. His ability is therefore reduced by a fundamental sense that normally guides surgical behaviour. New technologies [1] rapidly developing in recent years aim to restore this lack of sensation by replacing it with artificial enhancement. Robotic surgery helps the surgeon by returning a stereoscopic image and refining his gestures by downscaling movements. In the augmented reality environment, we project 3D reconstructed images directly on the patient body surface. This image overlay [2] gives the surgeon the ability to see the exact position of the anatomical structures through which he will operate. He can precisely locate a particularly body part or a previously enhanced image. This enhanced visualisation tool helps to compensate for the surgeon's missing sense, augmenting his reality.

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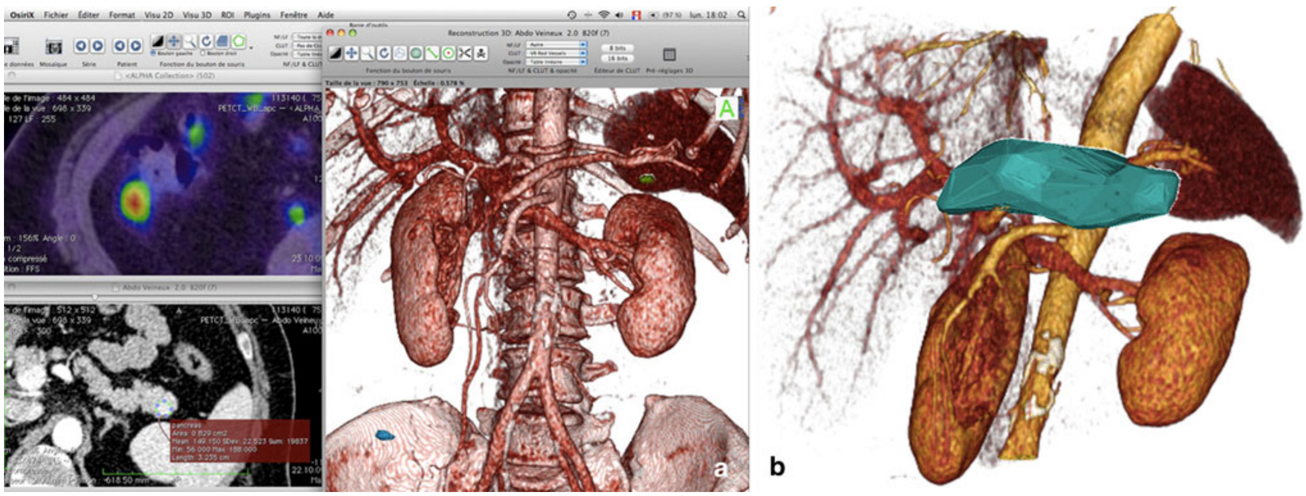

Fig. 1 **a** OsiriX software allows a rapid 3D volume reconstruction from simple plain series. **b** ROIs enhanced pancreas with 3D volume reconstruction

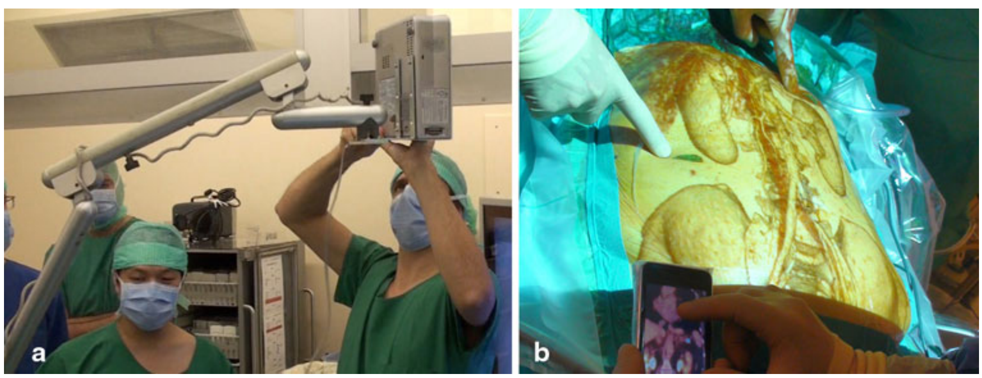

Fig. 2 **a** Beamer fixation directly over the operating table. **b** Image projection on the patient's body surface

Method

We used this kind of visualisation enhancement for interventions such as cholecystectomy, laparoscopy for suspected carcinomatosis, caudal pancreatic resection and robotic liver resection. All the patients had pre-operative CT scan investigations (2 mm slice thickness, contiguous). For better visualisation of the structures, intravenous contrast enhancement was required. These images were then manipulated with OsiriX [3] (Pixmeo, Geneva, Switzerland), an image processing software package dedicated to DICOM images. This software is specially designed for the navigation and the visualisation of multimodality and multidimensional images. It is indeed possible to navigate through 2D, 3D and 4D (3D series with temporal dimension) images. The software also permits display of 5D images, which consists of a 3D series with temporal and functional dimensions, like cardiac Pet CT.

The OsiriX 3D viewer offers a variety of rendering modes. The 3D volume rendering is the simplest and fastest way to obtain reconstructions to use for augmented reality. The program builds a 3D model from a 2D image series obtained from the patient CT scan. This model can than be manipulated depending on the structures the surgeon wants to highlight. Changing the window level and wideness allows the user to navigate through the patient's body, from the skin to the deepest bone layer. A wide range of presets in the colour look up table gives the opportunity to highlight, in the normal colour range, information that would otherwise be invisible. The important thing is that the surgeon himself can perform all these manipulations. There is therefore no need for a radiological specialistic consultation. A ready-to-project reconstructed model takes no longer then 10 min to be realized (Fig. 1).

If the structure the surgeon is looking for is of almost the same density as the surrounding tissues, automatic recognition and emphasizing by the program can give unsatisfactory results. This could happen, for example, with small pancreatic nodules or hepatic tumours. Furthermore, these central organs may have a density that is in the same range

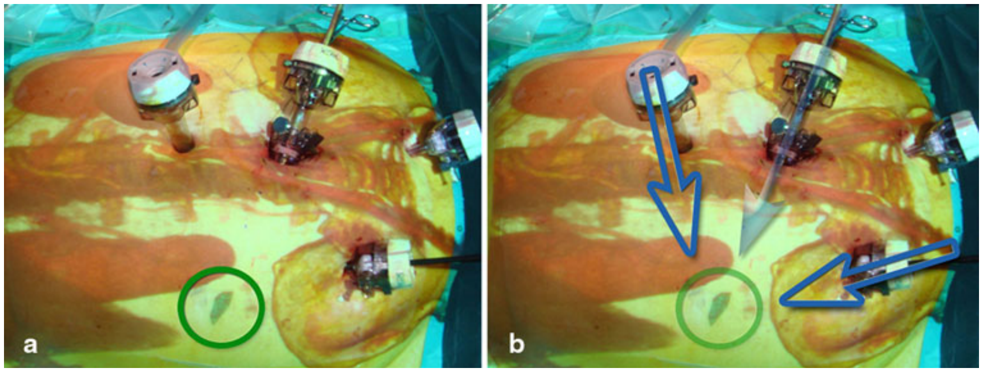

Fig. 3 **a** Image overlays allow exact identification of the nodule position and **b** visual triangulation with laparoscopic instruments

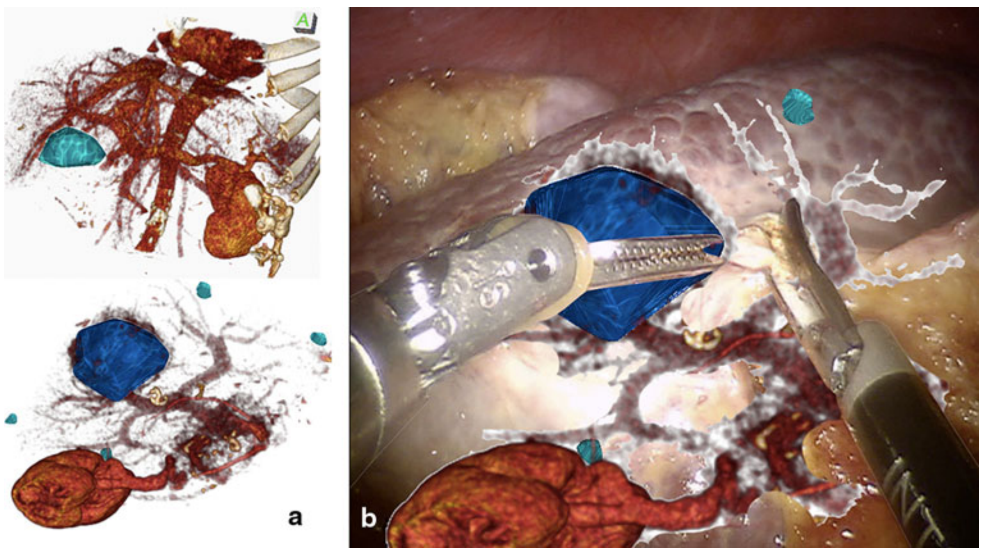

Fig. 4 **a** 3D volume rendering of a hepatic tumour. **b** Fusion of 3D reconstructed images and stereoscopic vision for robotic liver surgery

as the surrounding tissues. In these cases OsiriX allows the user to draw some lines around the structure the surgeon is looking for. These are called regions of interest (ROI). The program then computes all the missing ROIs and constructs a solid volume in the place of a nodule or tumour. In this way, the surgeon can turn on and off different reconstructed volumes during the operation, depending on the structure he is looking for at a specific time.

The next step in the augmented reality procedure is to link these 3D reconstructed images and the real patient lying on the table. To accomplish this task, we fixed a beamer directly on the operating table by the mean of a mechanical arm. The beamer is connected with a Macintosh running OsiriX software. The images are then directly projected on the patient's skin (Fig. 2).

Synchronisation of the two worlds, the real one (the patient) and the virtual one, is obtained by direct palpation of fixed points such as the lower costal edge and the iliac crest. The visual landmark of the umbilicus, directly available on the skin, is also very useful. During the projection the surgeon has the possibility to navigate through the patient's body, going from the surface, the skin, to the deepest layer, enhancing regions useful for the operation. He may then turn on the different volumes of the ROIs computed previously and identify them on the patient's body. In this way, the relevant anatomy of the patient is mixed with the structures that have to be resected, facilitating their spatial identification and easily saving surrounding structures.

Results

The first patients operated upon using the augmented reality technique needed cholecystectomies. The anatomy of the biliary tree can be very different from one patient to another and the localisation of the gallbladder under the liver may differ by several centimetres. The liver position under the diaphragm depends on the patient morphology.

The projection of the reconstructed biliary images permitted an adaptation of the port position, especially in obese patients (BMI > 30 kg/m^2). Even if an experienced surgeon could automatically adapt the port positions, the projection of real patient anatomy will facilitate this decision, especially for a young surgeon. This fine-tuning of the port location avoids extreme instrument positions and consequently dangerous behaviours. Critical view of the important structures coming from the hepatic pedicle is therefore guaranteed.

In the same way, laparoscopic identification of a nodule suspected to be of tumoral nature could be very difficult, if the latter is lost in the fat of the paracolic gutters. The 3D reconstruction of the nodule, identified on a PET-CT, is projected on the patient. This allows the surgeon to create a triangulation with his instruments in the direction of the wanted structure (Fig. 3) and a small portion of fat, containing the nodule, can be resected and analyzed. Moreover a nodule in the tail of the pancreas can be hidden by folds of the colon mesentery or by adhesions in the bursa omentalis. The nodule itself could be invisible from the surface of the pancreas. Projecting the pancreas and the nodule on the patient helps the surgeon in the dissection and in locating the nodule. In addition, dorsal veins joining in the splenic one could differ in position and calibre. Augmenting the reality of the situation projecting all this information directly on the patient allows the surgeon to know exactly the position and direction of these vessels and their relationship with the pancreas that has to be dissected, thus possibly avoiding dangerous haemorrhage.

With robot trocars, even more than in laparoscopic surgery, position is critical. Hepatic tumours must be highlighted with 3D volume rendering from ROIs, because their density is quite similar to that of the surrounding liver (Fig. 4a). The superimposition of the liver image with the 3D reconstructed tumour permits a careful positioning of the trocars. Docking the robot in the right position is therefore guaranteed. Naturally, when this is done, the beamer should be removed because the robotic arms prevent the superimposition of the images on the patient body. But the 3D reconstructed images on a monitor just next to the surgeon are still useful, showing him the precise location of the tumour and relationship with intra-hepatic vessels. The next step in the image overlay process is to integrate the 3D reconstructed structure directly in the stereoscopic view of the operating field offered by the robot (Fig. 4b). This superimposition should be constantly synchronised with organ movements to ensure a perfect guidance of the robotic arm and an extremely precise dissection. This is crucial in surgery of solid organs, where the dissection of tumoral tissue should save as much of the normal tissue as possible.

Discussion

Laparoscopic surgery brought enormous benefits in treating current surgical pathology, and laparoscopic surgeons continue to progress to ever more technically demanding procedures. Today, more than ever, operating skills are crucial. Augmenting the reality [4–6] of a surgical procedure should help the surgeon during the operation, reducing risks and therefore operative complications. Young surgeons could greatly benefit from such a technology, which could contribute to a new way of teaching. Indeed, the experienced surgeon can put in his toolbox a new instrument that will facilitate the transmission of knowledge to the training surgeon. The emergence of software such as OsiriX, which makes 3D modelling accessible to the nonspecialist, has led to a sharp progression on the way to new technologies. The image overlay then brings this considerable amount of information directly to the operating table, where the surgeon needs it.

The next logical step is to dynamically merge the virtual and the robotic world. The surgeon will be guided in this way directly by 3D images moving with corresponding solid organs on the same monitor. Synchronisation of plastic deformations of virtual models and solid organs is the crucial point on which our teams should concentrate their efforts in the immediate future.

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