A Haptic-enabled Toolkit for Illustration of Procedures in Surgery (TIPS)

Minho KIM [a,1], Tianyun NI [a], Juan CENDAN [b], Sergei KURENOV [b], and Jörg PETERS [a]

[a] *Dept. CISE, University of Florida*
[b] *Dept. Surgery, University of Florida*

Abstract. Good surgical training depends greatly on case experiences that have been difficult to model in software since current training technology does not provide the flexibility to teach and practice uncommon procedures, or to adjust a training scenario on the fly. The TIPS kit aims to overcome these limitations. To the expert, it presents visual and haptic tools that make illustrating procedures easy and can model unusual anatomic variations. For a non-specialist, it provides a locally customized learning environment and repeated practice in a safe environment. We used the toolkit to illustrate removal of the adrenal gland.

Keywords. medical illustration, haptic rendering, haptic authoring, teaching, virtual surgery training,

1. Introduction

Medical illustrations are the standard for publishing and documenting medical procedures in biological textbooks, teaching illustrations, instructional films, and legal proceedings involving medical documentation. Presently, the hurdles for taking descriptive text to illustration involve long hours between a trained medical illustrator and the documenting physician to illustrate even the simplest procedure. Subsequent "views" are generated by the illustrator with many attempts needing to be reworked before the results are satisfactory.

2. Tools and Methods

The toolkits' goal is to remove the intermediary and empower the *specialist surgeon as author* by placing advanced media conveniently at the surgeon's disposition. Like word processing software, but including haptic forces and 3D models, this allows the specialist to create customized instructional illustrations. The learner, typically a resident or non-specialist surgeon, can follow the instructions 'hands-on' by having the haptic stylus guide the hand (Figure 1, *left*) as key moments of a procedure are replayed in

[1]Correspondence to: SurfLab, Dept. CISE, CSE Bldg E325, University of Florida, Gainesville, FL 32611. Tel.: +1 352 392 1255; Fax: +1 352 392 1220; E-mail: {mhkim,jorg}@cise.ufl.edu.

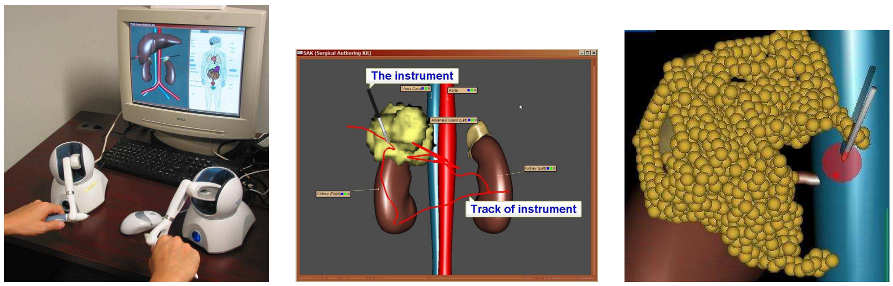

Figure 1. (*left*)Replay of (*middle*) 3D motion (red) to remove fatty tissue (*right*).

the virtual environment. At any point in the procedure, the illustration can be paused to explore the environment, and then continue or repeat the process until the skills are understood. Conversely, the learner's skills can be compared to the metrics laid down by the specialist.

Currently, TIPS modules are being validated by specialist surgeons at the Department of Surgery University of Florida. Modules and their associated metrics undergo peer review and are validated by a metric-driven validation of residents.

3. Results

3.1. The Authoring Kit

We created two types of the toolkit: an authoring toolkit and a learning toolkit. The authoring toolkit is an environment for a specialist surgeon to create a multimedia experience, and authoring consists of four stages.

The *Conceptual* stage consists of storyboarding and mapping steps to media. That is, the surgeon breaks the procedure into steps and decides on the simplest means of conveying the idea. In increasing order of complexity the available media are: (i) scanned sketch (Figure 2, lower left), (ii) photographic or textbook image (Figure 2, upper right), (iii) video of life procedure, (iv) animation, (v) haptic simulation.

In the *Anatomic Layout* stage the author populates the virtual 3D scene with objects from an extendable database of predefined 3D models (organs, vessels, surgical tools) and interactively generated fatty tissue (Figure 1, *middle*). When instantiating the objects, a simple interface allows adjusting their parameters: position (scaling, orientation), visual properties (base color, color when touched, transparency, etc.) and haptic properties (elasticity, extent of deformation). The properties are adjusted by touching the object with the haptic device and adjusting the value by mouse motion. Since typically, layouts will be downloaded from a database or shared from colleagues and then loaded, both conceptual and layout stages are not expected to be revisited frequently. Rather, a particular surgical scenario is established so that the main work reduces to creating variants by adjusting properties.

During the *Anatomy Exploration* stage, the author traverses the 3D anatomy, and modifies it - for example, by removing fatty tissue, or displacing organs and vessels in preparation for ligation, etc. The system records the 3D motion of the surgical procedure via a feedback stylus (see Figure 1, *left*)

Figure 2. Editing the ‘pop-up’ time rail to add additional illustrations (e.g. recorded video, *top right*))

In the *Annotation* stage, the surgeon-author adds or deletes recorded motion sequences and adds other media using the timeline of the recorded motion (see Figure 2). This is similar to deleting or editing text on a page in a word processing or video-editing environment. Annotation is an important alternative to full simulation. The tags are non-occluding and attached to objects in the 3D scene. Each functions as a (computer) window and allows display of video clips, hand-drawn or book-scanned images and plain text.

3.2. The Learning Kit

The learning kit allows a non-specialist surgeon to retrace the recorded, annotated motion. In the *passive mode*, the haptic feedback interface guides the learner’s hands along a specific path while the computer screen shows the authored 3D scenario. Tissue or material resistance is experienced from acceleration or deceleration of the author’s hand motions and from the model settings. The replay can be adjusted to slow motion. An alternative view than the original can be selected.

While the author fixes the path, the forces that guide along this master path can be relaxed. In this *active mode*, the non-specialist can move more freely and make mistakes. The non-specialist’s motion in the active mode is recorded for comparison.

3.3. Case Study: Removal of the Adrenal Gland

As a test, we illustrated *laparoscopic adrenalectomy*. Here, safe dissection of the fatty tissue to expose the adrenal vein requires (i) correct 3D motion, adapted to the highly variable layout of organs, vessels and fatty tissue; and (ii) application of appropriate force conveyed by the haptic device, to lift the vein free of the surrounding tissue in preparation for ligation (Figure 1, *left*). Rupturing the adrenal vein or neighboring vena cava could result in catastrophic hemorrhage.

The specific anatomic relationships between the adrenal gland and the surrounding structures deserve special attention. There is an adrenal gland on each patient’s side; however, the relationship between the gland and the nearby organs differ significantly from cases to case. In particular, the vascular relationships are completely different between the right and the left gland. Each poses its unique challenges to the surgeon during surgery. At present there is no method for preparing for these anomalies and variations a priori. There is no road map for the surgeon, other than experience.

In the 3D surgical procedure illustration environment, we could emphasize and illustrate the following aspects in particular:

1. The right gland is attached via a short and frail vein to the largest vein in the body, the inferior vena cava (IVC). The adrenal vain is generally in a standard location but its wide to short caliber is particularly challenging for dissection. Undue tension in the process of surrounding the vein, prior to its ligation, can create brisk bleeding from the inferior-medial junction of the vein to the IVC. This type of bleeding can be catastrophic in the laparoscopic setting.
2. The procedure is applied behind the right lobe of the liver, and deserves a controlled environment for practicing.
3. The left gland also has its unique challenges. Although the vein on this side is longer and easier to manipulate, its location is more variable. The ability to construct multiple anatomic relationships, cover them with fatty tissues and impose dissection on the learner allows exploration of these relationships in a safe environment. The tail of the pancreas and the spleen must also be exposed to see the adrenal gland.

The Authoring kit allows representation of these relationships in a three-dimensional and tactile environment. These modalities are missing from videos and books. In particular, the authoring kit allows the author surgeon to, on the spot, create a number of variations. For example, there are a number of vascular relationships that are modeled simply by adjusting the gland (size, position, haptic feedback), relative position of the vessels and the distribution and character of the fatty tissue and covering peretoneum. The learning kit then allows a competent, but not expert, surgeon to review the procedure to prepare for surgery. The review reiterates the key anatomic relations and forces as defined by the expert.

4. Discussion and Future Work

A key point of our approach is that the specialist surgeon rather than a computer programmer will author the material. This makes the approach flexible and removes a level of indirection that easily leads to incorrect emphasis. This toolkit is not in competition but rather complements the rapidly advancing academic or commercial surgery training tools [1,2,3,4,5,6,7].

By placing the specialist surgeon at the center of the content generation, we follow a different paradigm. The toolkit brings together a number of state-of-the-art technologies: advanced graphics, both hardware (GPU acceleration of subdivision surfaces [8]) and software (novel surface representations, realtime shadows as depth cues, etc.) and makes judicious use of haptic measurement and feedback at key points of the illustration. Open-source development of the toolkit is expected to trigger further collaboration of computer and surgical specialists to develop libraries and shared repositories for continued education.

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