Synchronized Visualization of Bone Cutting to Support Microendoscopic Discectomy

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ABSTRACT

This presentation introduces a new concept of augmented reality (AR) assisted bone cutting to support Microendoscopic Discectomy. The designed system dynamically updates volume rendered images of patient's CT data while synchronizing with intraoperative cutting procedures, and contributes to precise and rapid cutting as well as reducing perceptual difficulties in micro-endoscopic operation.

1. INTRODUCTION

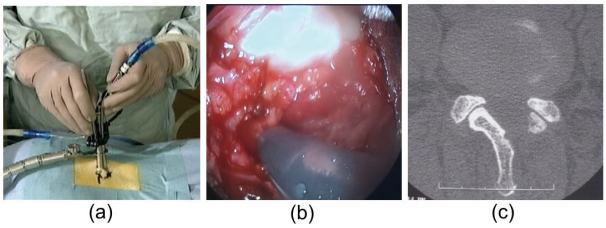
In the field of orthopedic surgery, lumbar disk disease has recently been treated by minimally invasive procedures such as Microendoscopic Discectomy (MED) [1]. In the surgery of MED, all procedures including bone cutting are performed through a microendoscopic view (see Fig. 1). In spite that surgical navigation products provide the 3D position of the tip of the drilling tool, MED still has the following difficulties: the surgeon tends to lose the orientation of the image because of the small surgical field within 16mm diameters provided from the endoscope. High technical skills and anatomical expertise are required because nerves must be carefully avoided. For these problems, we focus on visualization techniques to enrich intraoperative visual information and to quantify patient-specific cutting procedures.

In this presentation, we introduce a new concept of augmented reality (AR) assisted bone cutting to support Microendoscopic Discectomy. Unlike conventional navigation systems, the designed system 1) supports preoperative planning of 3D cutting regions on the rendered image of the patient's CT volume, 2) provides local views that simulate microendoscopic images, and 3) dynamically updates the rendered image while synchronizing with real cutting procedures. Intraoperative visualization of the cutting plan and the current cutting state makes possible of precise and rapid cutting while reducing technical difficulties of MED.

2. METHODS

2.1 AR-assisted Cutting

AR-assisted cutting aims to enhance intraoperative endoscopic images by extrapolating time-varying anatomical states as well as the surgeon's expertise on MED. Specifically, the designed system provides volumetric visualization of A) the pre-defined cutting plan, B) the current cutting state (or cutout region) and C) occluded risk tissues such as nerves and blood vessels using patient's CT and MRI volumes.



(a) (b) (c)

Fig. 1 Microendoscopic Discectomy
(a) Surgical setup and tool manipulation (b) endoscopic view and (c) postoperative CT image

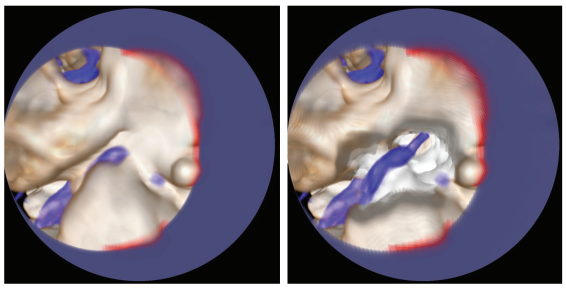
The cutting plan is preoperatively defined on the volumetrically rendered image of patient's CT volume in the planning software [2]. The surgeon proceeds cutting operation while comparing the cutting plan and the current cutout state that are visualized on the screen. The next two sections briefly explain the planning software and the synchronized visualization system for performing AR-assisted bone cutting.

2.2 Planning Cutting Procedure

In the preoperative planning, the developed software allows mouse-based virtual cutting on volumetrically rendered microendoscopic views (see Fig. 2). We obtain the depth information to the surface of the volume and implement a bone-cutting framework in which the user can cut the arbitrary 3D region at an interactive rate. Stable depth control to prevent drilling of unintended regions by the user is also implemented. The cutting procedure simulated on the rendered CT volume is stored in volumetric label as the pre-defined cutting plan. Please see [2] in details of algorithms and rendering schemes.

2.3 Synchronized Visualization

In the surgery, the designed system provides a virtual image synchronized with the real-world cutting



(a) (b)

Fig. 2 Preoperative planning and preview of cutting procedure on the volume rendered image

(a) Endoscopic view of a CT spine fused with MR nerves (blue), (b) virtual cutting as a preoperative planning

procedure. The virtual image initially has the colored cutting plan given by the surgeons in the preoperative planning (see Fig. 3). During cutting operations, the tip of the drilling tool is measured in real time, and the 3D trajectory of the tip is stored in a volumetric label $\mathbf{L}$. The intensity volume $\mathbf{I}$ and the label volume $\mathbf{L}$ represent time-varying cutout region. When the tip of the drilling tool contacts with a real-world object, the corresponding voxels are removed on the rendered image. This makes possible of synchronized visualization on both the cutout region and the remained region that should be cut. Since the accurate measurement of the tool tip is required to realize this concept, we currently assume the optical 3D measurement system such as Polaris for clinical use.

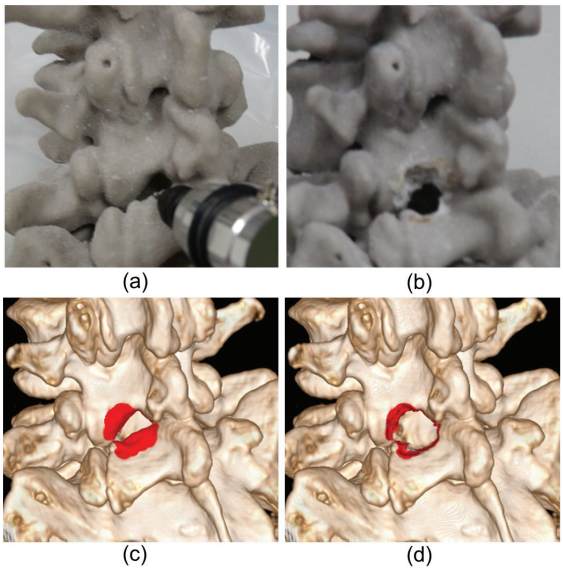
3. EXPERIMENTS AND RESULTS

3.1 Preoperative Planning and Preview Example

In the first test, we applied an abdominal CT and a MRI volume data to the developed planning software. The nerve structures around the spine were extracted from MRI data and then fused with CT data. Fig. 2 shows a planning example of the cutting region on the spine. The complex 3D cutting region can be intuitively defined on the rendered image by only a simple mouse operation, and the positional relationship between the spine and the nerve (colored blue in Fig. 2) can be previewed using the microendoscopic views.

3.2 Cutting Tests

We have also developed an experimental system for quantitative evaluation on the performance of AR-assisted cutting. A handy electric router is fixed on the stylus of the PHANToM haptic device (SensAble Inc.). In the experiment, the PHANToM is only used for 3D position measurement of the router, and not for force feedback. Fig. 2 shows the appearance of our first cutting tests. The plaster spine model was made from the patient's CT volume data using the Z Corp.'s 3D printer. The subject drills the spine model while observing the pre-defined cutting plan on the rendered CT volume. We have



(a) (b)

(c) (d)

Fig. 3 Visualization of time-varying cutout region

(a) Initial model (b) cutout result (c) cutting plan (d) rendered image synchronized with drilling procedure

confirmed the rendered image can be updated at an interactive rate (>10FPS), which performs synchronized visualization with the subject's drilling procedure. We also plan to evaluate the cutout results based on several visualization methods including the proposed AR assistance. The cutout models will be scanned using CT and quantitatively compared in 3D.

4. CONCLUSION

We have presented the concept of AR-assisted cutting to support Microendoscopic Discectomy. Unlike conventional navigation systems, the designed system achieved update of the volume rendered images while synchronizing with intraoperative cutting procedures. Further experiments and clinical trials are planned in order to quantitatively evaluate the performance of AR cutting. We believe the developed framework contributes to precise and rapid cutting as well as reducing perceptual difficulties in microendoscopic operation.

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