Interactive 3-dimensional reconstruction of simulated neurosurgical procedures

PhD Thesis

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Introduction

Cadaver dissection represents one of the most powerful tools to dexterity in micromanipulation. To obtain sufficient competency in surgery and learn various surgical techniques hands-on cadaver courses, handbooks and illustrated anatomical textbooks or atlases are available aside apprentice like training.

However cadaver based dissections are hardly accessible. Hand son courses are usually expensive and only accessible in major medical centers or universities. Access to cadaver is greatly restricted by medico-legal and ethical limitations. Dissection experience is not reproducible. Once the specimen has been dissected it is no longer available for further practical use. Despite all limitations lab dissection still remains the gold standard of anatomy education and surgical training.

The three dimensional architecture of the human body or steps of complex surgical procedures is hardly imaginable in lack of interaction and three dimensionality. Print atlases offer no interaction or spatial experience.

Advancement of novel image reconstruction technologies resulted in the developments of more efficient teaching tools offering advanced visualization of the human body and pathologies. Importance of CT and MR imaging is unquestionable in clinical diagnostics. They offer high-resolution display of anatomy and pathology. Major drawback of animated computer models and volumetric imaging such as CT or MR reconstructions is their appearance is artificial. They do not reflect true color shadow and texture their resolution lags far behind photography.

Anatomical QTVR (QuickTime Virtual Reality) reconstruction offered novel display of simulated surgical procedures and anatomy. QTVR reconstruction of specimens rotated on a turntable in front of a camera resulted in the ability to examine specimens from multiple viewing angles.

Rotation provides additional information compared to still photographs as hidden elements may be visualized.

The introduction of the MKM surgical robotic microscope (MKM) with QTVR reconstruction represented the next milestone of interactive image reconstruction. As the MKM was able to position its optics with high precision while maintaining focal lengths and focal point on spherical trajectory resulted an image grid providing not only horizontal but also vertical motion in the final reconstruction. The new technique proved to be suitable to capture and simulate single stages of intraoperative procedures. But the technology still lacked the ability to simulate dissection itself.

Goals

- Our goal was to develop an interactive three-dimensional image reconstruction technique for the simulation of anatomic dissections and surgical procedures.
- Our goals were to develop a simulation tool that enables users to virtually rotate tilt specimens to any selected angles and dissect them.
- Our goal was to develop a simulator that allows to study intricate anatomical details and steps of neurosurgical procedures.
- Our goal was to develop the simulation module of the frequently applied frontolateral orbitozygomatic approach, the interpeduncular fossa and the cavernous sinus-sellar region most often targeted by such exposures.
- We have analyzed the role of layering in simulating surgical procedures and anatomical dissections. We also examined the role of rotation to simulate changes of working trajectory and its effect

on the visibility of various anatomical structures located in working areas.

Method

There were 3 cadaver head and neck specimens we have prepared for dissections embalmed in 5% formaldehyde. The arterial and venous vascular system has been injected with silicon dye. The arterial system was colored by red and the venous circulation by blue silicone dye. The specimens have been immobilized in Mayfield head-holder for the entire lengths of the dissections. The orbitozygomatic approach and microsurgical neuroanatomical dissections of the interpeduncular fossa and the cavernous sinus-sellar region have been performed.

Stages of dissections have been captured with scanning using high-resolution cameras attached the robotic MKM microscope. Scanning was performed in spherical mode while neither the settings nor position of the specimen were changed. The resultant multilayer image grid system reconstructed into simulation modules using custom developed software (MIGRT)

Results

We have developed methods and tools of multilayer image grid reconstruction technology and computer software (MIGRT) for interactive spatial display of microsurgical neuroanatomical dissections. The software allows manipulating and dissecting virtual specimens. It simulates steps of neurosurgical procedures and changes of viewing angulation and helps to analyze their effects on the visibility of various anatomical structures located in working areas.

We created training modules of the orbitozygomatic approach, the interpeduncular fossa and the cavernous sinus-sellar region.

Intuitive manipulation tools such as rotation simulates changes in viewing angulation thus mimics preoperative head positioning as well while layering simulates dissection and steps of surgical procedures.

Discussion

Safe execution of neurosurgical procedures and obtaining sufficient dexterity in microsurgery require sound neuroanatomical knowledge and many assisted surgeries. Available simulation tools offer unrealistic environment in lack of interaction and three dimensions. Animated computer models appear artificial do not reflect true color texture and shadows in terms of details they lag behind photography.

Multilayer image grid reconstruction technology provides realistic visualization of anatomical dissections creating optimal simulation environment to analyze complex architectures such as the human body. The technology reproduces dissection experience in interactive and multidimensional fashion. Interactive tools such as layering helps to simulate dissection and provides opportunity to examine important operative nuances, steps of microsurgical procedures. Rotation generates three-dimensional experience and provides optimal simulation study viewing angulations or preoperative head positioning location and relationship of delicate neuroanatomical structures.

Simulation of the orbitozygomatic approach offers great opportunity to examine important nuances of skin incision muscle preparation size and shape of craniotomies. Layering helps to demonstrate place and extent of brain retraction or removal of the lesser wing of the sphenoid bone to achieve maximum exposure. Deeper layers of the simulation module help to explore the opto-carotid, interoptic and the oculo-carotid regions in frontal and frontolateral directions.

Modules of the interpeduncular fossa and the cavernous sinus-sellar regions were designed to help in studying important neurovascular elements in simulated surgical orientations.

The interpeduncular fossa module offers glimpse into the complex neuroanatomy of supra- and parasellar region. Layering helps to demonstrate origin of the posterior communicating and anterior choroid arteries. Removal of their perforators opens exclusive views into the posterior cranial ditch by visualizing structures such as the brainstem the proximal portion and branches of the basilar artery and origin of the oculomotor nerve.

Simulation module of the cavernous sinus-sellar region provides insight into the neuroanatomy of the region displaying course and content. Intraoperative orientations offer exceptional views of the nervous structures entering and exiting the cavernous sinus. Important anatomical details such as the proximal and distal dural ring, the intracavernous course of the internal carotid artery, the pituitary gland and the sphenoid sinus can be examined.

Conclusions

Important nuances of neurosurgical procedures can not be obtained solely learning illustrated textbooks. Development of Microsurgical dexterity requires extensive training assisted surgeries and exact neuroanatomical knowledge.

Cadaver dissection is a superior training modality to practice steps of neurosurgical procedures. As cadaver dissection is routinely not available justification of simulation tools that reconstruct realistic operative environment is undisputed.

The technology makes cadaver-based dissection available on computers.

Important issues of neurosurgical operative nuances can be analyzed such as surgical steps and their role in creating clear working area. It helps to address issues associated with preoperative head positioning or intraoperative viewing angle selection and their effect on the visibility of structures located in working areas.

Multilayer image grid reconstruction technology is a powerful simulation technique to reconstruct microsurgical dissections in interactive and three-dimensional manner. The photography based imagery reflect true color texture and shadow with the most possible detail as opposed to animated computer models or illustrations that lack depth of field and provide less detail. The training program is a powerful tool to train surgical techniques and study intricate anatomical details. The database has the potential to be extended to other surgical specialties as well.

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Publications

Publications related to present thesis

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