Preoperative Surgical Planning Using Virtual Laparoscopic Camera

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1 Introduction

Minimally invasive surgical procedures require the surgeon to operate based on a 2-dimensional (2D) image visible through the laparoscopic camera. Laparoscopic virtual reality simulators have not been designed to represent individual patient's anatomic characteristics but rather ideal body or single volunteer based simulation. The utility of patient specific simulation lies in preoperative surgical planning that is tailored to the variations in anatomy and body habitus of individuals. Preoperative CT imaging allows the surgeon to identify this pathology and plan operative correction. Whereas organs and vessels can be accurately rendered in 3D, the surgeon is required to visually interpret these relationships to a 2D laparoscopic perspective. The objective of this study is to generate a 3D laparoscopic simulation of peritoneal surface anatomy based on abdominal CT scanning and physically based modeling of organ displacement after abdominal insufflation. This will allow surgeons to combine anatomic data with visual cues of a 2D laparoscopic environment in preoperative surgical planning.

2 Method

2.1 Data

Thin cut stack of abdominal CT images was obtained on a normal volunteer. The data consisted of 56 slices with resolution 512x512 each.

2.2 Subdivision

We started with atlas based human organs designed using geometric modeling tools. The coarse organ models were then subdivided using interpolating modified Butterfly subdivision of Zorin et al. [Siggraph96]. Regular Laplacian smoothing was applied to subdivided meshes to improve triangle aspect ratios.

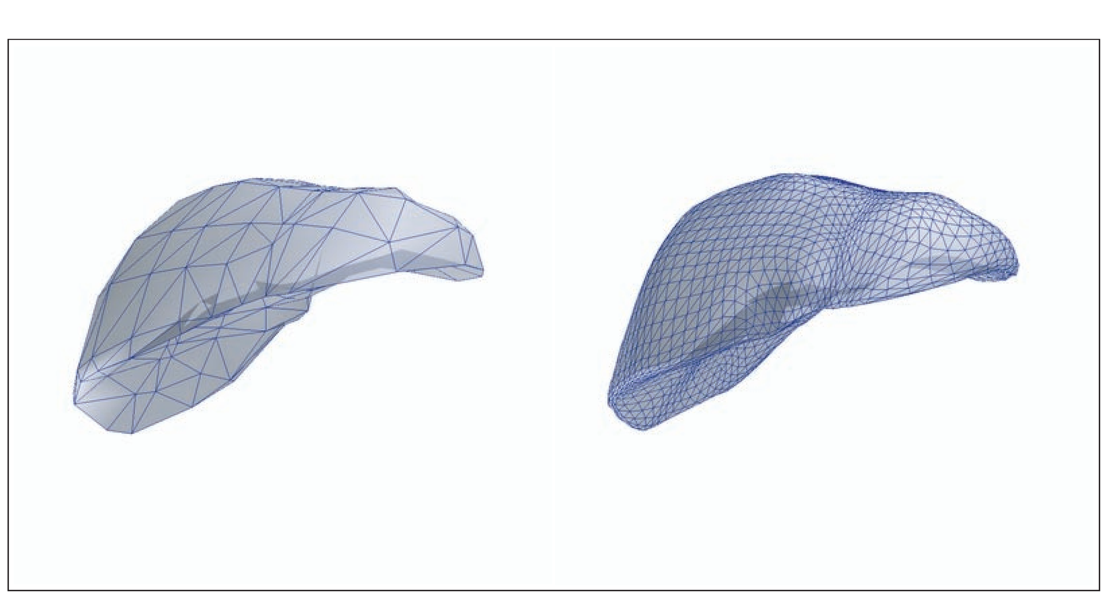

Fig.1 Coarse and subdivided liver models

2.3 Segmentation

Internal organs were segmented based on tissue density through the deformable model approach. Initially the model is manually scaled and approximately positioned and oriented within the scan. Final fit is accomplished by using image and elastic forces. Image forces attract the model to the image features and elastic forces due to deformation energy of the model ensure its smoothness. Additionally, user can provide control points on the scan to ensure quality of segmentation.

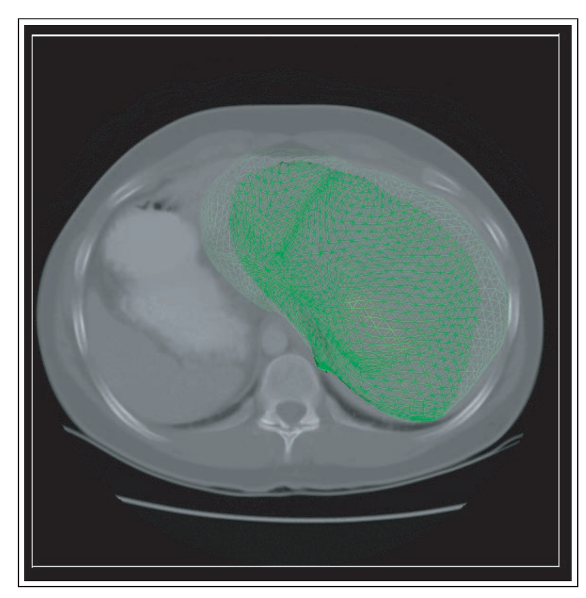

Fig.2 Deforming model on top of CT scan

2.4 Deformations

To simulate the deformation of abdominal cavity insufflation, we consider the abdominal wall as an elastic membrane and compute its motion under pressure. It is described by the Laplace equation with fixed boundary conditions and external forces due to insufflation. Numerical computations are then performed using 2D linear Finite Element Method.

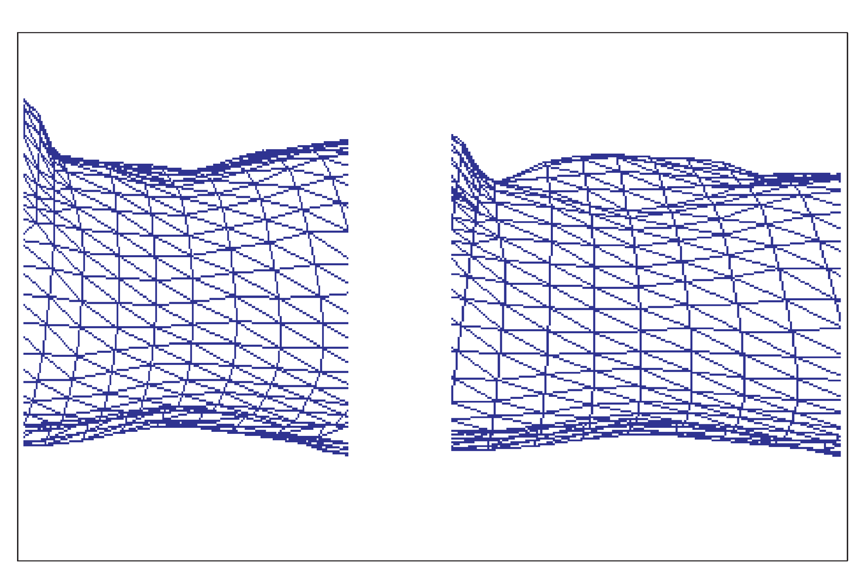

Fig.3 Modeling of insufflation of the abdominal cavity.

2.5 Texturing

Models used in our visualization tool are represented as triangular meshes. In order to achieve visual realism we texture the models with characteristic patterns coming from images of real human organs. The texturing is performed using the methodology of lapped textures introduced by Praun et al. in [Siggraph 2000]. The basic idea of lapped textures is to cover a mesh with a number of overlapping patches and texture each of these patches independently; when rendering the patches are drawn successively on top of each other. Since each single patch does not have much curvature the textures appear without distortion.

3 Results

Snapshots of fly-through laparoscopic simulation.

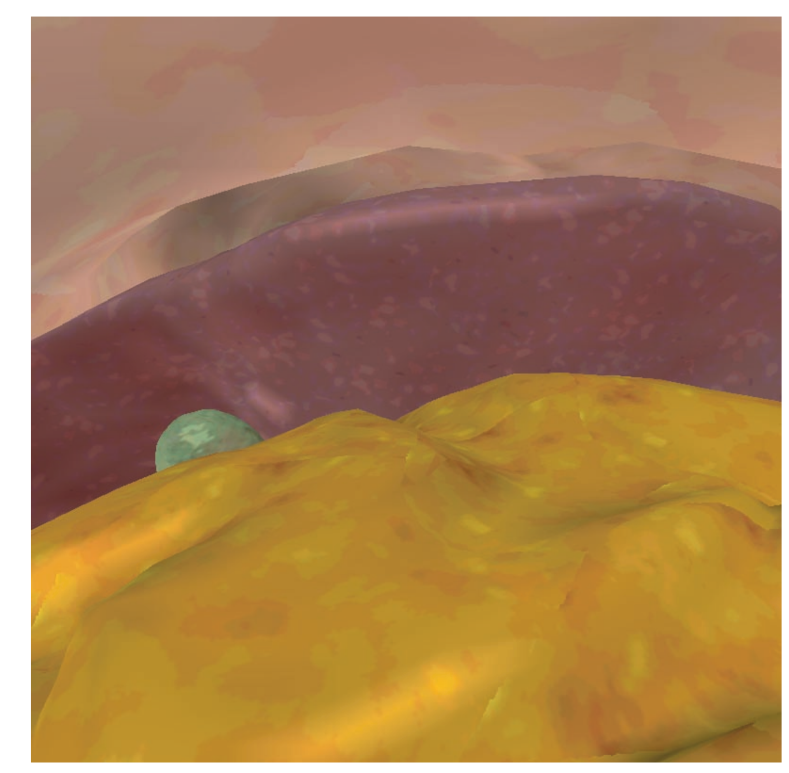

Fig.4 Simulated laporascopic view of liver and gallbladder.

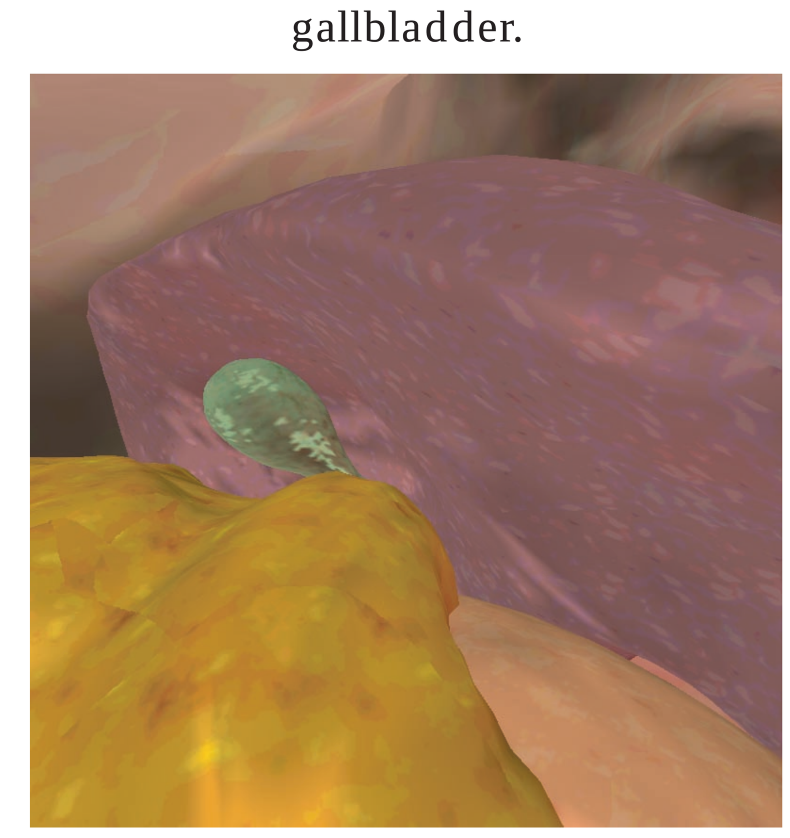

Fig.5 Simulated laporascopic view of liver and stomach.

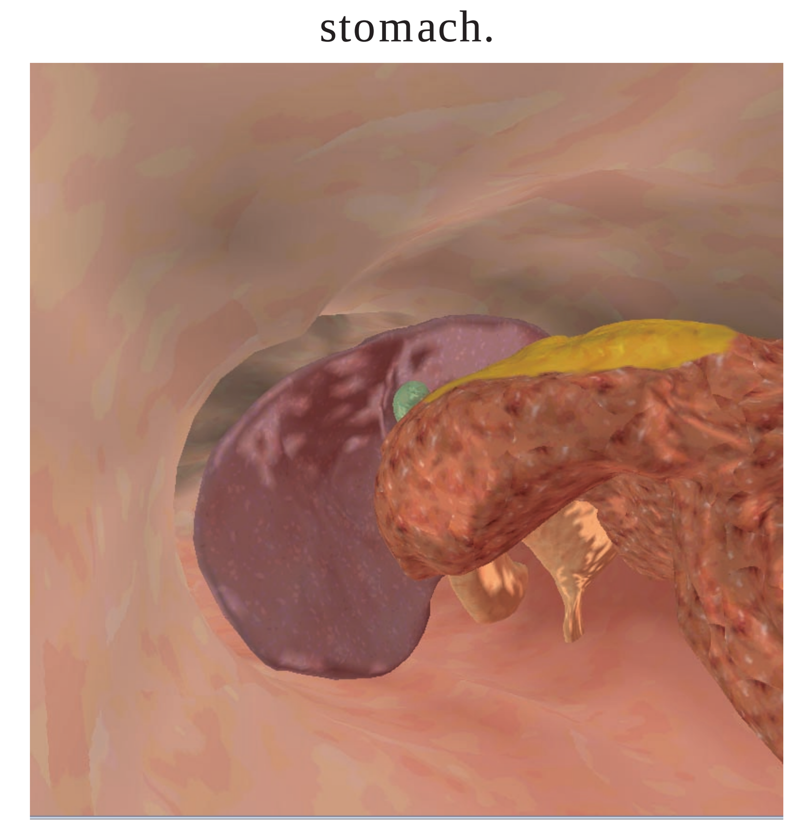

Fig.6 Simulated laporascopic view of intestines and right lobe of the liver..

4 Discussion

Preoperative planning with CT scan virtual laparoscopic simulation allows the surgeon to see anatomic relationships as they appear during the actual procedure. Complex surgical intervention can be practiced prior to the actual operation and used as a teaching aid for surgical training. Virtual reality preoperative planning allows patient specific data to be modeled in-order to allow the surgeon to practice a complex surgical intervention without actually operating on the patient.