Design of a PVA liver phantom with respiratory motion for simulation of needle interventions

de Jong, Tonke L.; Adrichem, Don; Dankelman, Jenny; van den Dobbelsteen, John

Publication date
2018

Document Version
Final published version

Published in
International Journal of Computer Assisted Radiology and Surgery

Citation (APA)
de Jong, T. L., Adrichem, D., Dankelman, J., & van den Dobbelsteen, J. (2018). Design of a PVA liver phantom with respiratory motion for simulation of needle interventions. *International Journal of Computer Assisted Radiology and Surgery*, *13*(Supplement 1), S66-S67.

prediction of the post-operative jaw morphology was simplified and readily visualized, which was especially helpful for patients with facial asymmetry. By means of try and error, the optimal individual surgical plan was conformed. Then virtual surgical splint and guide was 3D printed.

Using surgical splints and guides, corrective surgeries were performed successfully in all selected cases with facial asymmetry. The facial contour was checked using postoperative CT, and it matched well with preoperative planning. Good coincidence with preoperative planning was achieved for osteotomy lines, the location of distraction device and resection amount. The maximal deviation between our surgical plan and the final surgical result was less than 2 mm.

Conclusion

Advancements in computer-aided design and manufacturing (CAD/CAM) technique have revolutionized the treatment of facial asymmetry. Fusion of relatively new technologies and techniques such as virtual surgical planning and 3D printed surgical guide can make surgery more efficient and effective for both patients and surgeons. Patients with facial asymmetry will benefit from the combination of these techniques. Virtual technology has a numerous clinical applications and shows extensive application potential.

Design of a PVA liver phantom with respiratory motion for simulation of needle interventions

T. L. de Jong[1], D. R. Adrichem[1], J. Dankelman[1], J. J. van den Dobbelsteen[1]

[1]Delft University of Technology, BioMechanical Engineering, Delft, Netherlands

Keywords Phantom · Liver · Breathing motion · Polyvinyl alcohol (PVA)

Purpose

Realistic physical liver phantoms are needed in interventional radiology for validation of novel instruments and for training of medical residents, because the use of biological tissues is not always a feasible option. Most research on liver phantoms focuses on the imaging mimicking qualities (e.g. [1, 2]). However, an ideal liver phantom should also mimic liver motion related to respiration and mechanical properties, such as instrument-tissue force interactions. A recent study indicated the suitability of polyvinyl alcohol (PVA) as a realistic liver mimicking material in terms of needle-tissue interaction [3]. The purpose of the current study is to design a PVA liver phantom with respiratory motion, to be used as a physical training model and/or a validation set-up for novel instruments in interventional radiology.

Methods

Phantom design: The developed phantom is a real size PVA liver phantom and consists of a support PVA abdominal cavity, a rib cage phantom, and a skin phantom (Fig. 1). To obtain the design requirements, we used MeVisLab 2.7 to segment the liver from a CT scan of a patient, with a resolution of 1 mm between subsequent slices. Data were saved as a point cloud and imported in SolidWorks to create a solid. A negative liver mold was created from this solid and 3D printed in Polylactid Acid (PLA) with 0.25 mm printing resolution. This mold was filled with 6 m% PVA-to-water (Selvol PVOH165, Sekisui Chemical Group NJ, USA), undergoing two freeze–thaw cycles for 40 and 20 h, to create the liver phantom. The abdominal cavity phantom was also made of PVA (4.0 m% PVA-to-water, 3 freeze–thaw cycles, 40 h/20 h), and used to support the liver phantom. The rib cage phantom was cut to size from an off-the-shelf skeleton. The skin phantom was made of a 2.5 mm layer of silicone (Ecoflex 00-30, Smooth-on Inc., Macungie, Texas, USA).

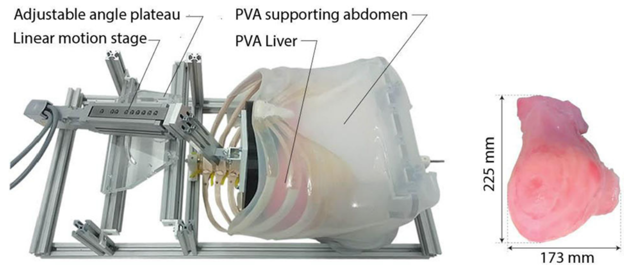

Fig. 1 The developed PVA liver phantom—A sinusoidal motion pattern is imposed upon the liver phantom by the use of the linear motion stage

Liver motion: First, we determined liver motion due to respiration in real patients. Livers from CT scans obtained during inspiration and expiration of five patients were segmented. The centers of mass of the reconstructed livers were used to calculate displacement vectors. The displacement vector of one patient was chosen as an input for the sinusoidal motion pattern imposed upon the liver phantom. The motion pattern was generated using an EMMS-ST-28-L-SE linear motion stage (Festo BV, Delft, the Netherlands), representing the sinusoidal movement of the diaphragm upon the liver.

Results

Phantom design: The PVA liver phantom is shown on the right side of Fig. 1. The maximal dimensions of the liver are 225 × 173 × 119 mm, with a total volume of 1.19 dm^3. Different motion patterns can be applied to the phantom by use of the linear motion stage. In addition, the direction of the applied motion can be changed by altering the angle of the motion stage, with respect to the liver, indicated by the adjustable angle plateau.

Liver motion: From the state of expiration to inspiration, the centers of mass of the livers of the five patients moved towards the right (range − 0.8–15.4 mm), anterior (range 2.7–21 mm) and caudal (range 9.3–31 mm) direction. The movement of the liver of one patient during inspiration and expiration is shown in Fig. 2. Liver motion is more apparent than liver deformation. The displacement vector of this liver was used as an input for phantom motion, being 5.3 mm towards the right, 17 mm towards the anterior and 22 mm towards the caudal direction. The resulting total stroke of 28 mm was applied to the phantom using a sinusoidal motion pattern with 12 and 18 strokes per minute, to simulate breathing motion.

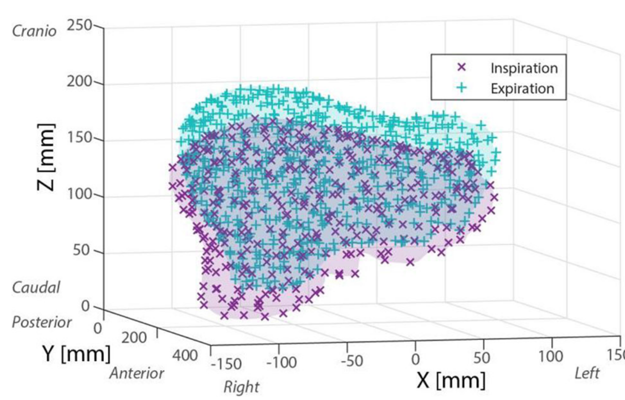

Fig. 2 Example of a segmented liver during inspiration and expiration. Calculated motion of the center of mass from expiration to inspiration was 5.3, 17 and 22 mm in the right, anterior and caudal direction, respectively

Conclusion

In the current study, the design of a PVA liver phantom with respiratory motion based on CT imaging data was presented. The developed liver phantom is capable of mimicking liver motion induced by breathing as seen in a real patient, and, due to the intrinsic properties of PVA, is ultrasound compatible and matches human liver in needle-tissue interaction.

Future work for this ongoing research project includes three developments. First, several liver motion patterns and liver phantom shapes will be added, as found on the CT scans, by altering the magnitude of the stroke of the linear stage and its angle. Secondly, a thorough validation of these phantom liver motions will be performed. We used the motion of the center of mass of the liver as an input for the movement of the linear stage. However, the livers not only show displacement due to respiration, but also deformation, dependent on the location inside the liver. Thirdly, the movement of the ribs with respect to the liver will be included. This relative motion is especially important for needle puncturing using an intercostal approach. As a start, the relative motion of the liver with respect to the ribs can be calculated from CT scans. Subsequently, a compliant rib cage will be used to mimic this motion.

We conclude that linear motion of the developed PVA liver phantom mimics appropriate respiratory motion as observed in a real patient. The developed phantom allows for applying several motion patterns and liver shapes/sizes, and is therefore suitable to mimic different motion patterns found among patients.

References

[1] Zell K, Sperl JI, Vogel MW, Niessner R, Haisch C (2007) *Acoustical properties of selected tissue phantom materials for ultrasound imaging*. Physics in medicine and biology **52**(20): p. N475

[2] Surry KJ, Austin HJ, Fenster A, Peters TM *(2004) Polyvinyl alcohol cryogel phantoms for use in ultrasound and MR imaging*. Physics in medicine and biology **49**(24): p. 5529

[3] de Jong TL, Pluymen LH, van Gerwen DJ, Kleinrensink GJ, Dankelman J, van den Dobbelsteen JJ (2017) *PVA matches human liver in needle-tissue interaction*. Journal of the Mechanical Behavior of Biomedical Materials, **69**(Supplement C): pp 223–228

Deformation matching of laparoscopic gastrectomy navigation based on finite element analysis

T. Chen[1,2], G. Wei[3], W. Shi[3], Y. Hu[1,2], J. Yu[1,2], Z. Jiang[3], K. Mori[4], G. Li[1,2]

[1]Nanfang Hospital, Southern Medical University, Department of General Surgery, Guangzhou, China

[2]Guangdong Provincial Engineering Technology Research Center of Minimally Invasive Surgery, Guangzhou, China

[3]School of Computer Science and Technology, Changchun University of Science and Technology, Changchun, China, Changchun, China

[4]Nagoya University, Graduate School of Informatics, Nagoya, Japan

Keywords Surgical navigation · Laparoscopic gastrectomy · Deformation matching · Finite element method

Purpose

Laparoscopy surgery as a minimally invasive procedure now is widely used in gastrointestinal surgery [1]. In spite of its benefits, the limited tubular vision of laparoscopy is not beneficial to observe the whole surgical field.

Image-guided surgery as a navigation can supplement the insufficient anatomical identification of laparoscopy [2].

However, vessels can be deformed due to pneumoperitoneum, surgical manipulation, heartbeat, respiration and other patient-specific changes [3]. But these deformations caused by heartbeat and respiration can be negligible because it is very mini. Additionally, some previous studies have reported how to correct the deformation due to the pneumoperitoneum in navigated laparoscopy [3]. The study about the deformation matching due to surgical manipulation has rarely been reported.

In our study, we aim to build Finite Element Method (FEM) model of gastric artery in the light of the deformation due to surgical manipulation. In addition, validate this model in animal experiment and surgical scene.

Methods

Animal experiment

Animal model and anesthesia

Our animal experiment was performed on a healthy male pig weighing 25 kg, which had received full approval by the Ethical Committee on animal experimentation. The pig was fasted for 24 h with free access to water before the study. 3% of thioethamyl (1 ml/kg) was injected percutaneously in the marginal vein of the ear. The pig was orotracheally intubated and maintained in a supine position (Fig. 1). The oxygen saturation and heart rate were monitored during the study.

Fig. 1 Simulation of laparoscopy surgery in an animal experiment

CT scans and images collection

The pig's CT images were obtained from CT scans with slice thickness of 1.25 mm, 120 kV, 167 mA and 512 $\times$ 512 matrix. There are two kinds of CT images for the experimental subject. The first one was taken with the pig in supine position before the operation. The second image was taken after pneumoperitoneum and the left gastric artery (LGA) was pulled up and fixed.

The ground-truth creating

CT images after LGA pulled up in the animal experiment were import to MIMICS 17.0 software (http://www.materialise.com) for visualization, including the threshold segmentation, semi-automatic segmentation and region-growing. Finally, the three-dimensional geometric model of LGA pulled up was established as a ground-truth.

Finite element model of animal

An ANSYS 17.0 software (http://www.ansys.com) was used to simulate the FEM model of the LGA after pulled up according to the need for the laparoscopic gastrectomy. The basic process of finite element analysis as follow: