Evaluation of a Navigation System for Minimally Invasive Esophagectomy in a Porcine Model

F. Nickel[1], HG. Kenngott[1], J. Neuhaus[3], A. Kolb[1], C.M. Sommer[2], T. Gehrig[1], B. Radeleff[2], HP. Meinzer[3], C.N. Gutt[1], B.P. Müller-Stich[1]

[1]Department of General, Abdominal and Transplant Surgery, Ruprecht-Karls-University, Im Neuenheimer Feld 110, 69120 Heidelberg, Germany
[3]Division of Medical and Biological Informatics, German Cancer Research Center, Im Neuenheimer Feld 280, 69120 Heidelberg, Germany
[2]Department of Diagnostic and Interventional Radiology, Ruprecht-Karls-University, Im Neuenheimer Feld 110, 69120 Heidelberg, Germany

`corresponding author: felix.nickel@med.uni-heidelberg.de`

Abstract:

The Navigation System aims to facilitate Minimally Invasive Esophagectomy by intraoperative real-time information about the exact localization of instruments in relation to tumour and lymph nodes. The Navigation System has high accuracy in a static environment and was tested for accuracy and different sources of error in an animal model with similar organ size to humans. The System with Optical Tracking, an immobilization device, preoperative CT-Imaging and Navigation software in MITK on a PC was tested on targets in different esophageal levels in a porcine model. The mean FRE and TRE were 1,75+/-0,83 and 7,4+/-3,2 mm. The Navigation System had lower accuracy with errors caused by different sources of soft tissue deformation that need to be compensated for.

Key words: Minimally Invasive Surgery, Esophagus, Navigation

1 Introduction

The minimally invasive surgical approach to esophagectomy for malignant esophageal lesions aims to improve patient outcome by reducing intraoperative trauma, invasiveness and blood loss. The totally laparoscopic transhiatal approach does not require single lung ventilation. This can be of advantage for patients with restricted lung capacity that would otherwise not be eligible for surgical treatment. The minimally invasive and the transhiatal laparoscopic approach to esophagectomy are however more difficult to perform than the open approaches. Additional difficulties are the restricted view and difficult manipulation of the instruments in the narrow mediastinal space and the difficult orientation [1]. Thus the exact localization of lymph nodes, height estimation of the instruments in the thorax and the estimation of adequate resection margins can become more difficult. Navigation systems could help overcome these difficulties by providing additional information to the minimally invasive surgeon during the procedure about the exact localization of the instruments in the patients body in relation to lymph nodes, tumor margins and risk structures. So far Navigation systems with real-time information have failed to establish in visceral surgery mostly due to soft tissue deformation [2]. This study aims to evaluate the performance and accuracy of a self developed navigation system for minimally invasive esophagectomy in a large animal model. In accuracy tests in a static environment with a static phantom the navigation systems reached high accuracy with a mean error rate below 1 mm [3]. We aim to test the accuracy of the navigation system in a living organism with similar organ size to human patients under real life operating room conditions. The evaluation of the overall error and accuracy of the navigation system is the primary goal of this study. The secondary goal is the identification of the different sources of error and inaccuracy of the navigation system during operations to identify possible mechanisms of compensation for these errors that can be implemented in the navigation system to improve the accuracy.

2 Methods

Initial landmark based patient registration with Optical tracking (Polaris™, NDI) is combined with intraoperative tracking of optical markers on a self-developed navigation instrument. The patient is fixed in a vacuum mattress on a stretcher with additional optical markers to minimize repositioning error. Gastroscopic hemoclips were used as targets(n=14) in the middle and lower thoracic, abdominal esophagus and at the gastroesophageal junction (GEJ) for the accuracy evaluation of the navigation system in a porcine model (n=4). High resolution CT-Imaging of the pig was imported into the navigation system on a conventional PC. CT-data segmentation and target definition was done with MITK (Medical Imaging Interaction Toolkit [4]). After the initial registration the Fiducial Registration Error (FRE) was measured. Laparoscopic preparation of the esophageal hiatus with the pig in the 25° Anti-Trendelenburg-position was then performed. The navigated instrument tip was positioned at each target clip under fluoroscopy control. Target Registration Error (TRE) was measured in the navigation system as off-set from the target to the tip of the navigated instrument.

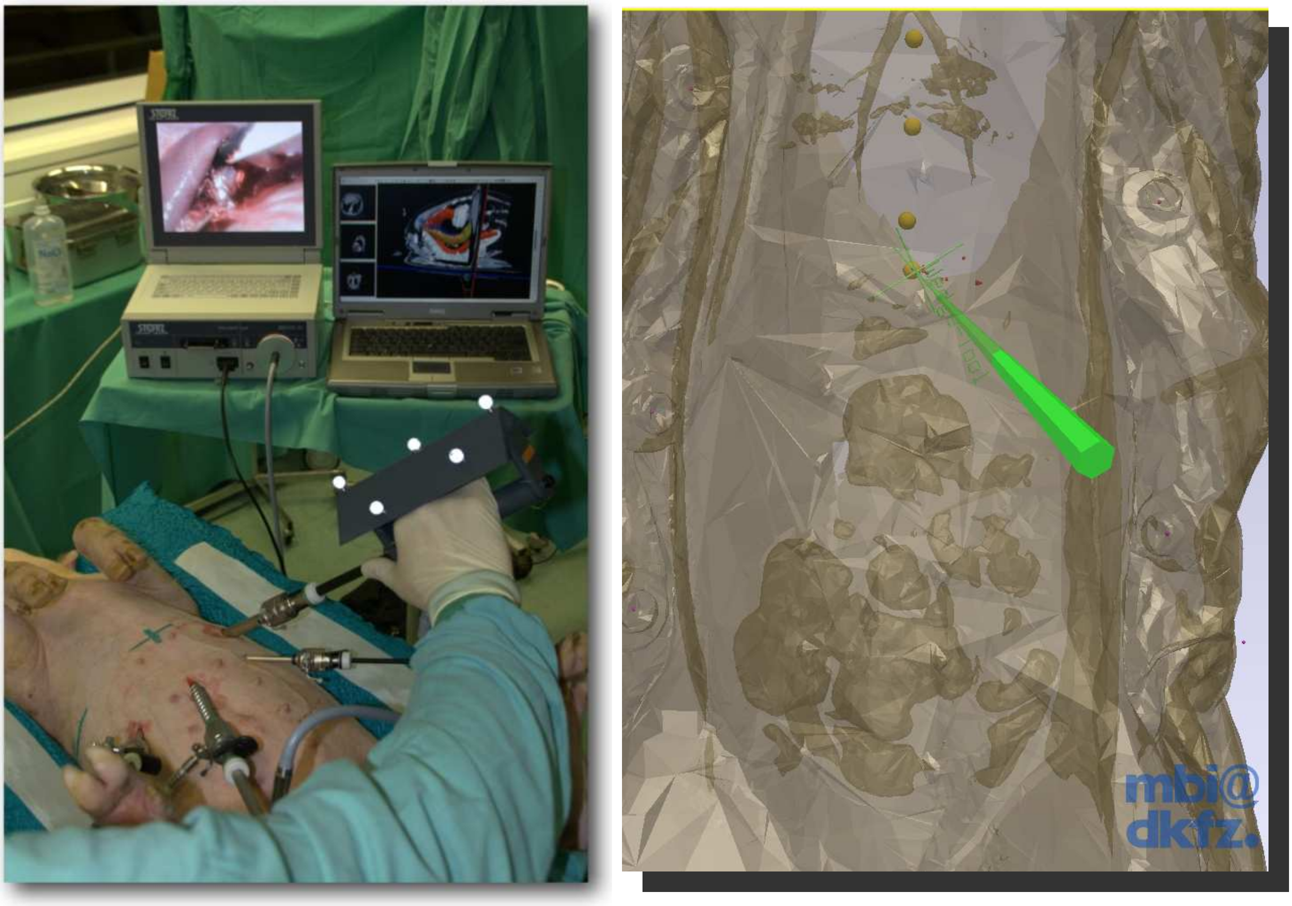

Fig. 1: Experimental Setup with the navigated instrument in the right hand of the surgeon and the Navigation System on a Laptop next to the laparoscopy unit on the left side. The instrument is displayed in the Navigation System in relation to the targets in the esophagus in real-time during the experiment.

3 Results

During the operation the instrument tip was successfully visualized in real-time in relation to the segmented organs by the navigation system at all times. In the accuracy evaluation the mean FRE was 1,75+/-0,83 mm standard deviation. The mean TRE in the accuracy evaluation was 7,4+/- 3,2 mm standard deviation. The error in the X-/Y- and Z-axis differed between the middle and lower thoracic, the abdominal esophagus and the gastroesophageal junction (GEJ) (see Table 1).

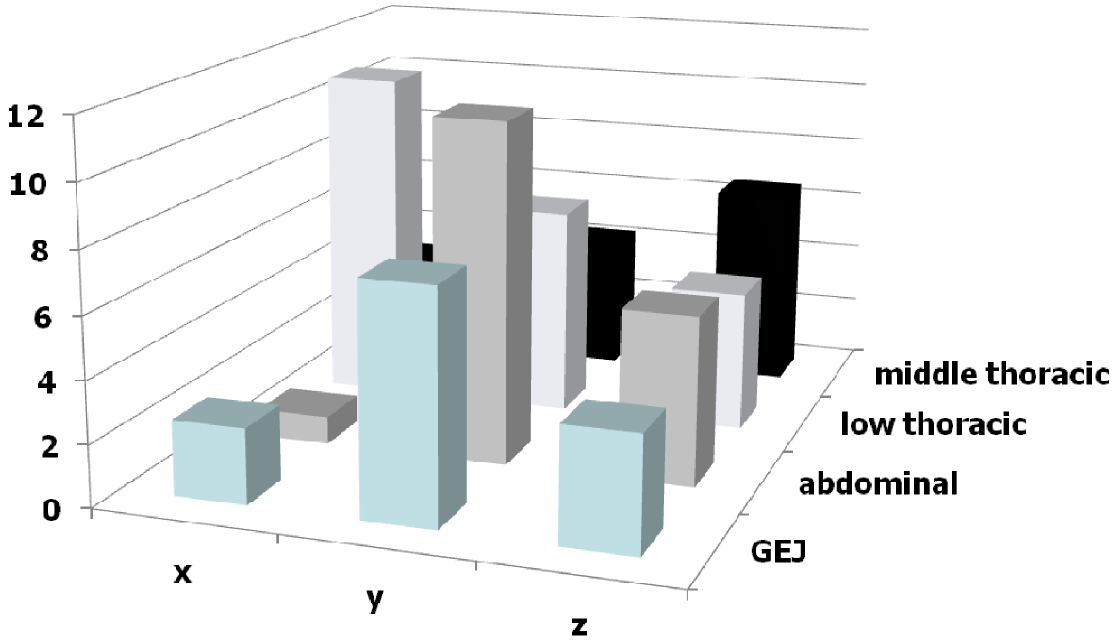

Table 1: Off-set error from navigated instrument tip to target in the Navigation System in the X-/Y-/Z-axis with instrument tip placed on the targets in the different parts of the esophagus in the experimental porcine model

4 Conclusions

In a live animal model with a foregut size that is comparable to human patients the navigation system obtains a mean error of less than 1 cm in a minimally invasive approach to esophagectomy. We believe that the obtained accuracy can help improve intraoperative orientation and identification of lymph nodes and adequate resection margins. The difference between the FRE and the considerably higher TRE can mostly be explained by displacement of the esophagus due to intraoperative iatrogenic manipulation, breathing and cardiac motion. The next step for improved accuracy of the navigation system is the implementation of compensation methods for breathing motion and iatrogenic manipulation. These methods are tested at our institution. Further studies need to approve the system prior to the use with patients.

5 References

[1] Gutt CN, Bintintan VV, Köninger J, Müller-Stich BP, Reiter M, Büchler MW. Robotic-assisted transhiatal esoph gectomy. Langenbecks Archives of Surgery, Springer, 2006
[2] Zhang H, Banovac F, Lin R, Glossop N, Wood BJ, Lindisch D, Levy E, Cleary K. Electromagnetic tracking for ab dominal interventions in computer aided surgery. Comput Aided Surgery, Wiley Interscience, 2006
[3] Kenngott HG, Neuhaus J, Müller-Stich BP, Wolf I, Vetter M, Meinzer HP, Köninger J, Büchler MW, Gutt CN. De velopment of a navigation system for minimally invasive esophagectomy. Surgical Endoscopy, Springer, 2008
[4] Maleike D, Nolden M, Meinzer HP, Wolf I. Interactive segmentation framework of the Medical Imaging Interac tion Toolkit. Computer Methods and Programs in Biomedicine, Elsevier, 2009