Image-guided navigation surgery for pelvic malignancies using electromagnetic tracking

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ABSTRACT

The purpose of this study was to implement and evaluate a surgical navigation system for pelvic malignancies.

For tracking an NDI Aurora tabletop field generator and in-house developed navigation software were used. For patient tracking three EM-sensor stickers were used, one on the back and two on the superior iliac spines. During surgery a trackable pointer was used. One day before surgery a CT scan was acquired with the stickers in-place and marked. From the CT scan the EM-sensors, tumor and normal structures were segmented. During surgery, accuracy was independently checked by pointing at the aorta bifurcation and the common iliac artery bifurcations. Subsequently, the system was used to localize the ureters and the tumor.

Seven patients were included, three rectal tumors with lymph node-involvement, three lymph node recurrences, and one rectal recurrence. The average external marker registration accuracy was 0.75 cm RMSE (range 0.31-1.58 cm). The average distance between the pointer and the arterial bifurcations was 1.55 cm (1SD=0.63 cm). We were able to localize and confirm the location of all ureters. Twelve out of thirteen lymph nodes were localized and removed. All tumors were removed radically. In all cases the surgeons indicated that the system aided in better anatomical insight, and faster localization of malignant tissue and ureters. In 2/7 cases surgeons indicated that radical resection was only possible with navigation.

The navigation accuracy was limited due to the use of skin markers. Nevertheless, preliminary results indicated potential clinical benefit due to better utilization of pre-treatment 3D imaging information.

Keywords: Image-guided surgery; Electromagnetic tracking; Navigation; Abdominal surgery

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1. INTRODUCTION

Surgery of advanced tumors in the pelvis can be challenging due to the narrow space, the presence of surrounding organs, nerve bundles and blood vessels. High resolution anatomical imaging, such as CT and MRI, play an important role in staging and assessment of operability of pelvic malignancies. However, during surgery, utilization of the preoperative anatomical information is generally limited to the surgeons mind.

Navigation technology can be used to link preoperative anatomical information to the actual anatomical information of the patient during surgery. Surgical navigation has advanced to daily clinical routine in a variety of fields, such as neuro- and facial surgery, cochlear implantation and orthopedic oncology [1–5]. These fields have in common that the target area is relatively rigid due to surrounding bony structures.

Part of the pelvic anatomy, such as pelvic muscles, sacral nerves, ureters, and iliac vessels are reasonably rigid with respect to the pelvic bones. For these more rigid components of the pelvis, current navigation systems might improve the anatomical insight. Recently, Atallah et al. reported on the use of an optical tracking system during transanal minimally invasive surgery for total mesorectal excision (TAMIS-TME) [6]. In a pilot study report on 3 patients they claimed an accuracy of 2-5 mm, and an improved insight in selection of the actual anatomical planes for dissection.

We are currently developing a tracking system for abdominal surgery in which the standard view of the preoperative anatomy is combined with real-time data of implanted markers. The first step was to develop a navigation setup

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applicable for pelvic surgery, assuming rigid anatomy. The clinical usability and feasibility will be evaluated in a pilot study including 25 patients scheduled for pelvic tumor surgery. In this article we describe the navigation system and the clinical results of the first seven patients in the pilot study.

2. MATERIALS AND METHODS

2.1 Hardware and software

For tracking a NDI (Northern Digital Inc, Waterloo, Canada) Aurora V2 electromagnetic (EM) system with a tabletop field generator (TTFG) with a work field of 42x60x60 cm was used. For patient tracking a Philips Traxtal sticker sets were used, with three stickers containing each two 5 degree of freedom (DOF) EM-sensors (Fig. 1). During surgery a 6DOF sterile pointer was used. With the TTFG it is not possible to measure in the first 12 cm above the field generator. Therefore, a dedicated matrass was build, in which the TTFG was embedded, for patient setup (Fig. 2).

In-house developed navigation software was used. The user interface was developed in Embarcadere Delphi XE8, with an in-house developed C++ dynamic link library containing image processing modules based on the AVS interface. Sensor positions were read at 10 Hz using the PlusServer from the Plus Toolkit (https://www.assembla.com/spaces/plus/wiki), using OpenIGTLink TRANSFORM messages (www.igstk.org).

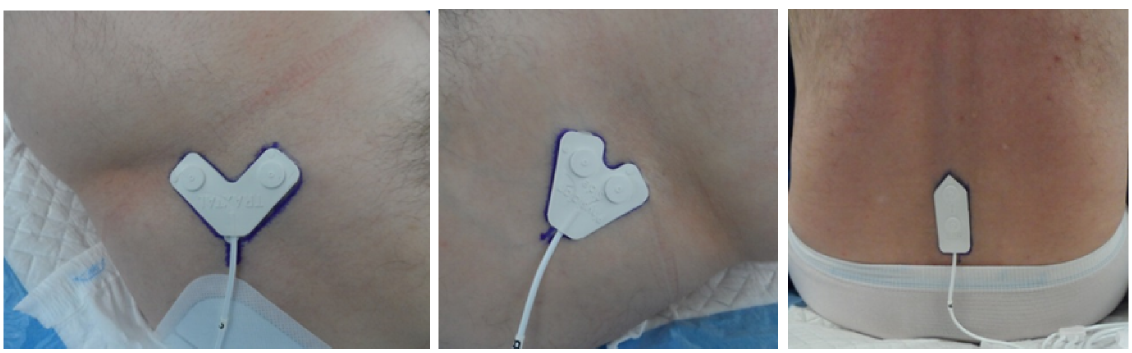

Fig. 1: Example of the patient localization stickers with EM-sensors placed on the right anterior superior iliac spine (left), the left anterior superior iliac spine (middle) and in the lumbar curvature (right). The stickers were placed and marked using a semi-permanent marker for the CT scan and were re-applied just before surgery.

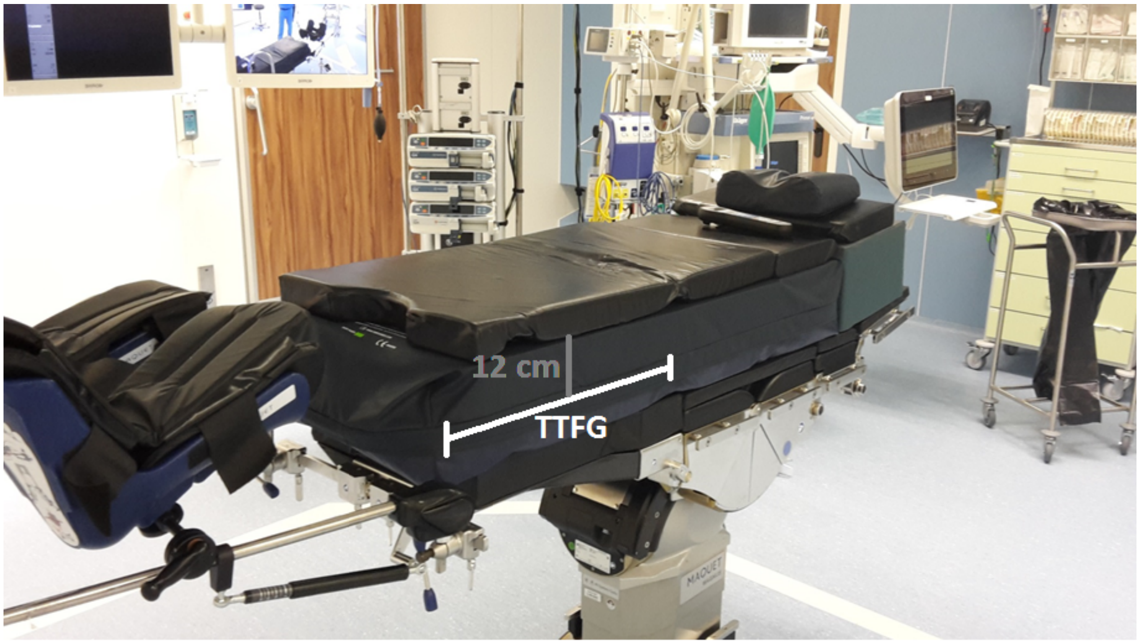

Fig. 2: A specialized matrass was developed, in which the tabletop field generator (TTFG) could be embedded (indicated by the white line). With the matrass the patient was positioned at a distance of 12 from the TTFG, which is the minimum distance needed for measurements.

2.2 Workflow

One day before surgery a CT scan was acquired with the stickers placed and marked at the lumbar curvature, and the anterior superior iliac spines. In the CT scans the pelvic bones, arteries, venous vessels, and ureters were segmented using in-house developed software (radiotherapy). The pelvic bones were segmented automatically using a threshold method, while the arteries were segmented using a region growing algorithm on the arterial phase scan. All other structures were segmented manually. For segmentation of malignant regions all present pre-operative imaging information (PET and MR) was rigidly registered to the bony anatomy of the arterial phase CT scan. Subsequently, the primary tumor and suspected lymph nodes were segmented manually. All segmentations were done by one observer (JN) and were checked before surgery by the operating surgeon. If needed for clarity, a radiologist was consulted. Finally, the positions of the six EM sensors in the three reference stickers were automatically determined using a thresholding method.

During surgery the patient was positioned and the stickers were re-applied. Patient setup during surgery was determined by the operating surgeon. For rectal cancer surgery, patients were positioned in leg-holders with bend knees, or in French position, while urological patients were positioned on a straight table. After general anesthesia, a registration was made between the EM-sensor positions derived from the NDI system, and the positions in the CT scan. The root-mean-square (RMS) error was provided to the users to indicate the registration accuracy. At each procedure, navigation accuracy was checked by asking the surgeon to point at the aorta bifurcation and the left and right common iliac artery bifurcation without viewing the navigation system (Fig. 3). Subsequently, the navigation system was made available for the surgeon, and the ureters (if needed for surgery) were localized and the pointed location was assessed by the surgeon. During surgery, surgeons had the navigation system at their disposal for localization of the tumor borders, and also for localization of suspect lymph nodes (Fig. 4).

2.3 Patients

All patients over 18, scheduled for open surgery of pelvic malignancies which were assumed to be rigidly attached to pelvic structures could be included in a prospective, review board approved pilot study. Patients had to be eligible for intravenous contrast enhanced CT scanning. Patients with metal implants in the pelvic area were excluded, due to the unknown influence on the EM-tracking accuracy. All patients signed an informed consent.

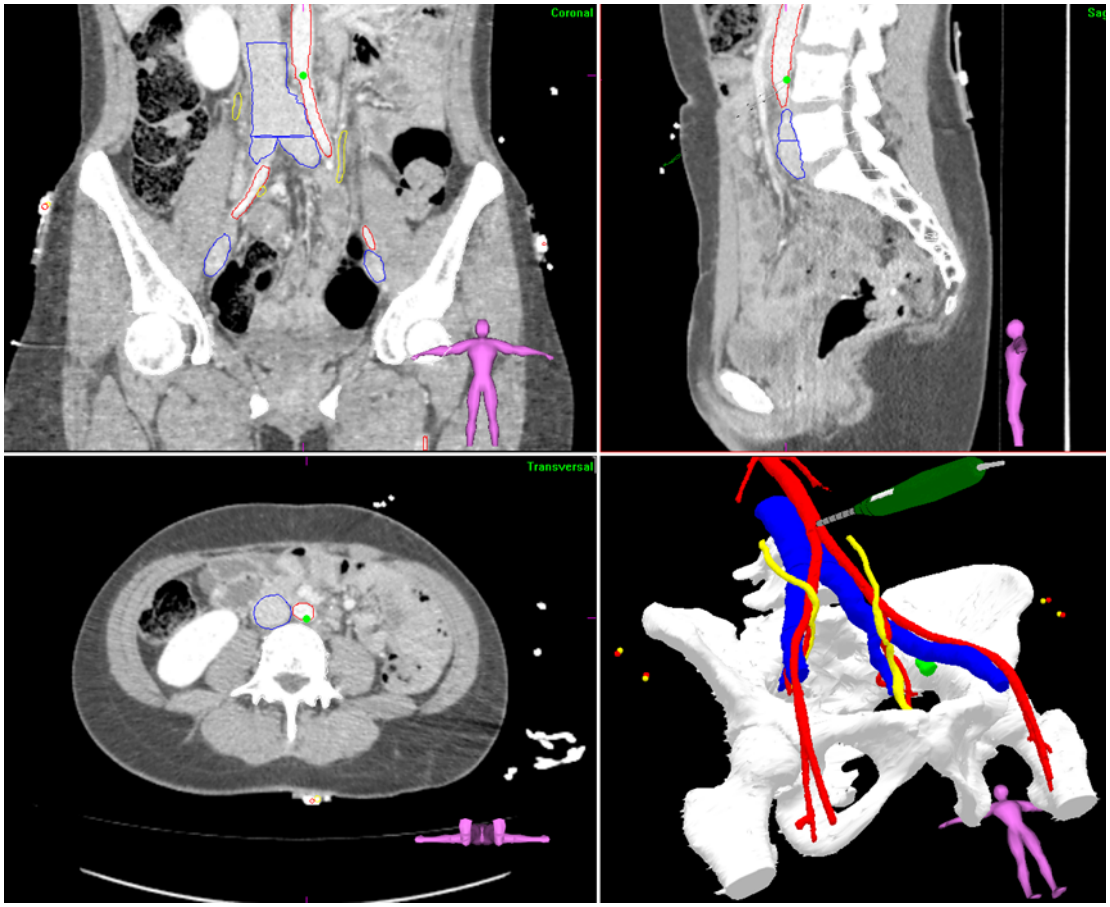

Fig. 3: Screenshots of the navigation system showing three orthogonal views plus a rendering of the segmentations. Arteries are shown in red, veins in blue, ureters in yellow, and a malignant lymph node in green. The dots on the lateral sides of the render view indicate the EM sensor positions derived from the scan (red) and from the tracking system (yellow). Here the aorta bifurcation was pointed by the surgeon without viewing the navigation system. In the orthogonal views the pointer tip is indicated by a green dot.

3. RESULTS

So far, seven patients were included, three primary rectal tumors with extra-mesorectal pathologic lymph nodes, three pelvic lymph node recurrences, and one rectal cancer recurrence at the sacrum (level S2-S3). Segmentation of all the structures for the 3D model took on average 85 minutes (range 54-175 minutes). The RMSE of the external markers registration was on average 0.75 cm (range 0.31-1.58 cm). In 6 out of the seven cases the legs were spread during surgery, which was different from the scanned setup. The average distance between the pointer tip and the segmented arterial bifurcations was 1.55 cm (1SD=0.63 cm). In the worst cases the surgeons indicated that it was hard to actually assess the actual location of the bifurcation, especially for the bifurcations of the common iliacs to the internal and external arteries. Part of the remaining distances was also due to the reluctance of surgeons to push the pointer very close to the arteries.

After making the navigation system available for the surgeons, we were able to localize and confirm the location of all ureters which were relevant for the surgical procedure. In none of the operations ureters were damaged.

All tumors were removed radically, and 12/13 lymph nodes were localized and removed. The missed lymph node was 2 mm in diameter on imaging after pre-treatment with chemo-radiation. In all cases the surgeons indicated that the system aided in better anatomical insight, and faster localization of malignant tissue. In two of the seven cases surgeons indicated that radical resection was only possible with navigation the navigation system.

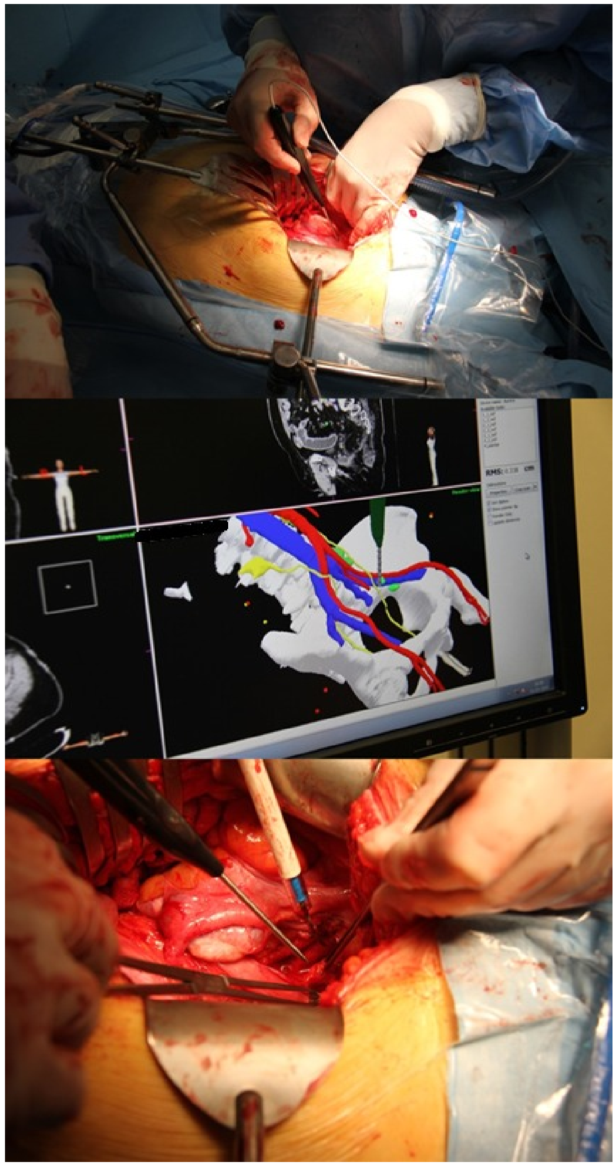

Fig. 4: Example of a navigated external iliac lymph node dissection. Top: localization of the lymph node using the tracked pointer. Note that the lymph node is located in the retro-peritoneal space, and that it is not visible for the surgeon. Middle: screenshot of the navigation system at the same time as the top image indicating the lymph node in green. Bottom, resection of the lymph node.

4. DISCUSSION

To the best of our knowledge, this is the first study using EM-tracking based surgical navigation for pelvic malignancies. In our setup we assume that the most important anatomy of the patient is rigid, and as such, we can use the pre-operative CT scan during surgery. The main error source in our setup is the reproducibility of the EM-sensor stickers with respect to the bony anatomy. A major cause might be the difference in setup between the CT scan with the legs straight, and the rectal operations with the legs spread has an impact on the sensors which are placed on the superior iliac spines. In our dataset only one patient was operated with legs straight, so the actual influence of setup could not be estimated. In 3 cases where the navigation system was used to assess lymph node positions, extra measurements on bony structures, such as the promontory and os pubis, indicated navigation inaccuracies of more than 5 mm. Here a manual adjustment of the registration was applied to minimize the miss-match and improve the accuracy for lymph node localization. After applying the correction, several bony anatomy landmarks were localized to assess proper correction. In the remainder of these procedures, surgeons indicated that the navigation system was accurate enough for lymph node localization.

Where we focused on the patients with rigid tumors and lymph nodes along the large vessels, the content of the pelvis can deform substantially, for example due to changes in bladder, bowel, and rectal filling [7], or by the surgical procedure itself. If anatomical discrepancies occur between preoperative imaging and the actual surgery, the accuracy of surgical navigation is limited. To overcome the changing anatomy challenge several options are available. For example, the anatomy could be reassessed frequently using intra-operative imaging in a hybrid operating room [8]. However, the application of intra-operative imaging can be limited due to the use of ionizing radiation, logistic challenges in a sterile environment, and substantial increase of operation time. As an alternative, the anatomical changes can also be monitored using implanted tracking markers. For example, in radiation oncology wireless tracking markers in the prostate can be used for real-time prostate tracking [9]. A similar approach for rectal surgery was suggested by Wagner et al., who showed in a phantom study that one electromagnetic sensor implanted in the rectal wall could be used to monitor and compensate for tissue shifts [10]. Unfortunately, these tumor tracking solutions are not yet available for clinical practice.

Several improvements can be made to our current pilot system. The main step that we are working on, is inclusion of intra-operative imaging (Philips Allura FD20 XperCT). The images will be used to better assess the EM stickers with respect to the bony anatomy, and also to assess if important structures and tumor tissue is moved with respect to the bony anatomy.

5. CONCLUSIONS

As expected, the navigation accuracy was limited due to the assumption of rigid anatomy, and the use of skin markers for patient localization. Nevertheless, preliminary results indicated potential clinical benefit due to better utilization of pre-treatment imaging information. Our surgeons are enthusiastic and we will further refine the system for future use.

REFERENCES

[1] Grunert P, Darabi K, Espinosa J, Filippi R, Computer-aided navigation in neurosurgery. Neurosurg Rev 26:73–99; discussion 100–1, (2003).

[2] Senft C, Ulrich CT, Seifert V, Gasser T, Intraoperative magnetic resonance imaging in the surgical treatment of cerebral metastases. J Surg Oncol 101:436–41, (2010)

[3] Langø T, Tangen GA, Mårvik R, Ystgaard B, Yavuz Y, Kaspersen JH, Solberg O V, Hernes TAN, Navigation in laparoscopy--prototype research platform for improved image-guided surgery. Minim Invasive Ther Allied Technol 17:17–33, (2008)

[4] Aschendorff A, Maier W, Jaekel K, Wesarg T, Arndt S, Laszig R, Voss P, Metzger M, Schulze D, Radiologically assisted navigation in cochlear implantation for X-linked deafness malformation. Cochlear Implants Int 10 Suppl 1:14–8 (2009)

[5] Wong K-C, Kumta S-M (2014) Use of Computer Navigation in Orthopedic Oncology. Curr Surg reports 2:47.

[6] Atallah S, Martin-Perez B, Larach S. Image-guided real-time navigation for transanal total mesorectal excision: a pilot study. Tech Coloproctol 19: 679-84 (2015)

[7] Nijkamp J, Swellengrebel M, Hollmann B, de Jong R, Marijnen CA, van Vliet-Vroegindeweij C, van Triest B, van Herk MB and Sonke J-J. Repeat CT assessed CTV variation and PTV margins for short- and long-course pre-operative RT of rectal cancer. Radiother Onlcol 102: 399-405, (2012)

[8] Kenngott HG, Wagner M, Gondan M, Nickel F, Nolden M, Fetzer A, Weitz J, Fischer L, Speidel S, Meinzer HP, Bockler D, Buchler MW, Muller-Stich BP. Real-time image guidance in laparoscopic liver surgery: first clinical experience with a guidance system based on intraoperative CT imaging. Surg Endosc 28: 933-940, (2014)

[9] Keall PJ, Aun Ng J, O'Brien R, Colvill E, Huang CY, Rugaard Poulsen P, Fledelius W, Juneja P, Simpson E, Bell L, Alfieri F, Eade T, Kneebone A, Booth JT. The first clinical treatment with kilovoltage intrafraction monitoring (KIM): a real-time image guidance method. Med Phys 42: 354-8 (2015)

[10] Wagner M, Gondan M, Zollner C, Wunscher J. J., Nickel F, Albala L, Groch A, Suwelack S, Speidel S, Maier-Hein L, Muller-Stich BP, Kenngott HG. Electromagnetic organ tracking allows for real-time compensation of tissue shift in image-guided laparoscopic rectal surgery: results of a phantom study. Surg Endosc DOI 10.1007/s00464-015-4231-9