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Stereotactic navigation for TAMIS-TME: opening the gateway to frameless, image-guided abdominal and pelvic surgery

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Abstract
Background Frameless stereotaxy is an established method for real-time image-guided surgical navigation in neurological surgery. Though this is capable of providing sub-millimeter accuracy, it has not been used by other surgical specialists.
Methods and procedure A patient with locally advanced, distal rectal cancer and tumor abutting the prostate was selected for transanal TME using TAMIS, with intra-operative CT-guided navigation to ensure an R0 resection.
Results The use of stereotactic TAMIS-TME was successfully performed with an accuracy of ±4 mm. The surgical specimen revealed an R0 resection, and this new approach aided in achieving adequate resection margins.
Conclusion This is the first report of the use of frameless stereotactic navigation beyond the scope of neurosurgery. Stereotactic navigation for transanal total mesorectal excision is shown to be feasible. Stereotactic navigation may potentially be applied toward other pelvic and fixed abdominal organs, thereby opening the gateway for a broader use by the general surgeon.

Keywords TAMIS · Stereotactic surgery · Transanal stereotaxy · Transanal TME · Image-guided surgery · Navigation

Introduction

There has been a renewed interest in the application of intra-operative imaging for anatomic navigation, with most of the interest in near-infrared fluorescence [1]. Neurosurgeons in collaboration with industry engineers have created a functional and highly precise "frameless" stereotactic navigation system which has been in clinical use for more than 20 years [2–7]. This approach was originally described by DW. Roberts et al. [2] in 1986. Surprisingly, this well-known adjunct for providing precision and accuracy in neurological surgery has not been applied to other surgical specialties. This is the first report of using frameless stereotaxy for pelvic surgery, specifically to perform transanal minimally invasive surgery for total mesorectal excision (TAMIS-TME).

Methods and patient characteristics

A 73 years male patient (BMI 29 kg/m^2) was diagnosed with locally advanced, cT3/T4N0 distal rectal cancer and received 5,400 cGy external beam radiotherapy with concomitant 5-FU for 6 weeks. However, the patient was non-compliant, and was lost to follow-up for 6 months after completion of neoadjuvant therapy. He finally agreed to radical surgical resection. Preoperative work-up 2 weeks prior to surgery revealed a bulky anterior mass at 4–6 cm from the anal verge anteriorly. Computed tomography revealed the lesion to abut, but not involve, the prostate

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gland anteriorly. There was no evidence of metastatic disease. The planned operative resection was laparoscopic resection with TAMIS-TME. This step-by-step approach to TAMIS and TAMIS-TME has been described by our group elsewhere [8, 9] and this approach has also been described by other investigators [10–13]. The TAMIS-TME portion of the operation was to be completed using frameless stereotaxy. Special approval was granted for this approach from our institution. It would be performed as a pilot study. This patient was selected because it was felt stereotactic navigation could help achieve negative margins, particular with the tumor intimately adjacent to the prostate gland.

General operative approach

This operation included a combined hand-assisted laparoscopic approach with TAMIS-TME. The abdominal portion of the operation did not involve stereotactic navigation. The patient had undergone full mechanical bowel prep and was taken to the operating room, where a systemic antibiotic (1-g ertapenem) was administered. Bilateral ureteral lighted stents were placed and the abdomen and perineum were prepped and draped with the patient in modified lithotomy. The abdominal portion of the operation was completed prior to proceeding with stereotactic TAMIS-TME. This included division of the inferior mesenteric vein and artery, as well as mobilization of the splenic flexure. Once the stereotactic TAMIS-TME was completed, a diverting ileostomy was created in the right lower quadrant, a 19 Fr Blake drain was positioned in the pelvis, and the abdominal cavity was closed.

Technique for stereotactic navigation for TAMIS-TME

With the abdominal portion of the surgery completed, preparation was made for stereotactic navigation for TAMIS-TME. The patient was kept on the operating table, where the operating theater had been equipped with an intra-operative CT-scanner (Fig. 1). The patient was taken out of lithotomy, and skin-fixed fiducials were placed on portions of the patient's body were there was predicted to be nominal movement after scanning. While an intra-operative scan is not mandatory, it is best to have recent imaging and the scan must include the fixed fiducials for patient tracking. The CT scan protocol requires inferior to superior 1-mm slices and the gantry has to be set at 90° (no tilt). Next, the scan was processed by the frameless stereotactic navigation system (Stryker Navigation, Kalamazoo, MI, USA).

For stereotaxy, two navigational trackers were required. One tracker was assigned to the patient, and this must remain fixed with direct line of sight to a ceiling-mounted receiver. In this case, the patient-tracker was mounted to the bed rail with a special mount. Next, each of the fiducials is assigned a number which is programmed into the software. A special navigation pointer/wand is then used to "touch off" on each of these numbered fiducials (Fig. 2).

Fig. 1 Once the abdominal portion of the operation had been completed, the patient was scanned with an intra-operative, helical CT scanner. The patient was repositioned supine for the scan. Skin-fixed fiducials have been positioned overlying the pelvis. They are visible on reconstructed images of the scan

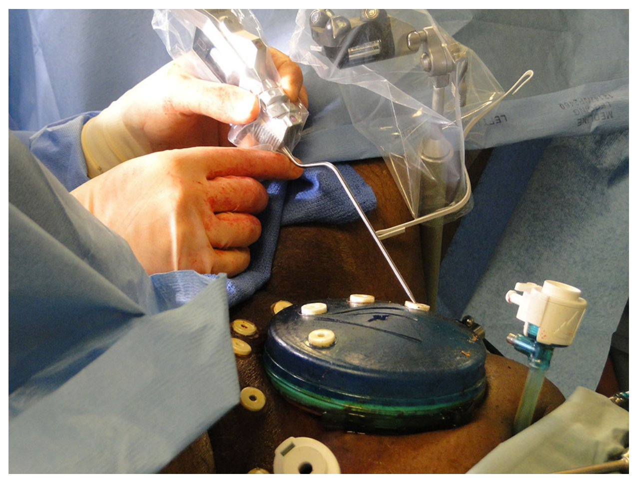


Fig. 2 A navigational device known as a "pointer" is placed on the skin-fixed fiducials for registration. This will allow the software to determine the position in space of the pointer, and other trackable devices. It relies on a fixed patient-tracker, which can be seen on an arm-mount secured to the bed rail. The position of the fiducials were chosen to be in relatively fixed areas and as close as possible to the region where stereotaxy is required. In this case, it was the anterior pelvis, overlying the pubic symphysis and extending laterally. Some of the fiducials were actually placed onto the hand-port device, and these positions being fixed provide accurate information and aided in calibration

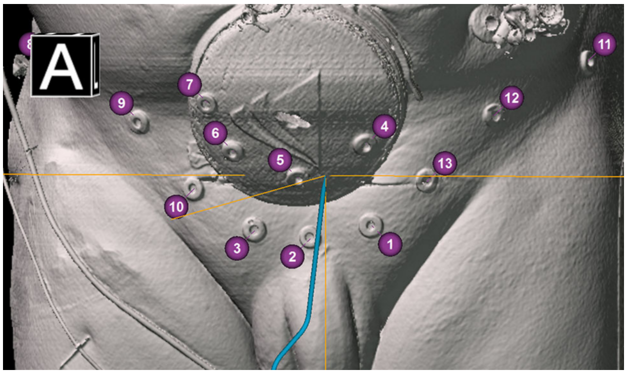


Fig. 3 Shown here is the 3D reconstruction from the CT scan that was obtained intra-operatively. Each of the fiducials was assigned a numeric value so that points on the image and points on the actual patient can be accurately defined. The pointer has been calibrated and is now being tested. The pointer appears as a "virtual" wand on the monitor, and can be clearly shown in *blue*. The surgeon has placed the pointer's tip of the corner of the triangle shaped logo of the hand port, and is able to visualize the virtual wand precisely at that point in real-time (Color figure online)

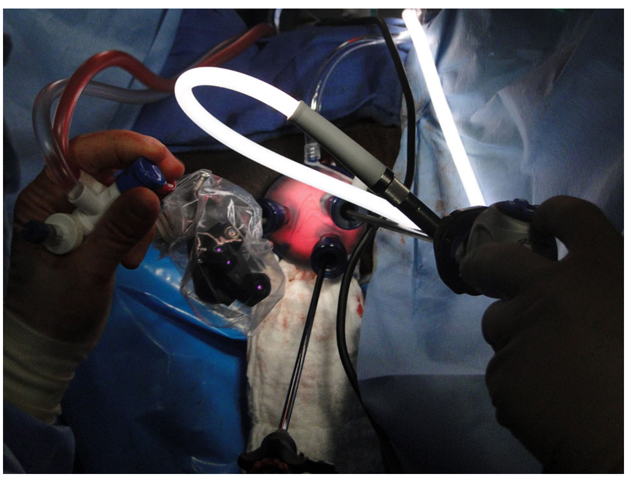


Fig. 4 TAMIS-TME is being performed and the dissection is being carried out with a navigation aided needle-tip cautery. The device is being tracked in real-time by the mounted navigation tracker. This must maintain line of sight with a ceiling-mounted receiver (not shown)

This will allow the system to correlate any point on the scanned portion of the patient with the corresponding (actual) point on the patient so that real-time CT-guided navigation can be performed (Fig. 3). Once this has been completed, the operating device must also be assigned a tracking device. In this case, we are using a suction-irrigator device with a needle-point cautery tip (Fig. 4). The instrument-tracker is mounted onto the shaft of the device and is calibrated so that the tracker can provide real-time information about where the tip of the device is in space. Like the patient-tracker, the instrument-tracker must

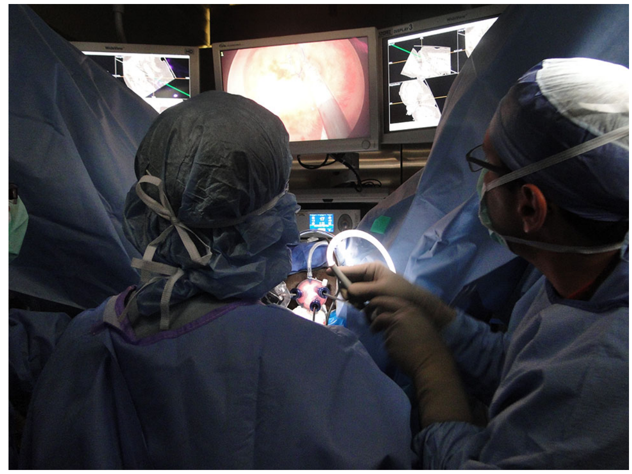


Fig. 5 The surgeon is able to utilize information from stereotactic navigation in real-time. Here, the video from the camera is on the center monitor. Monitors to the *left* and *right* are show multiplanar and 3D views of the scan, highlighting the dissector and its position relative to other pelvic organs

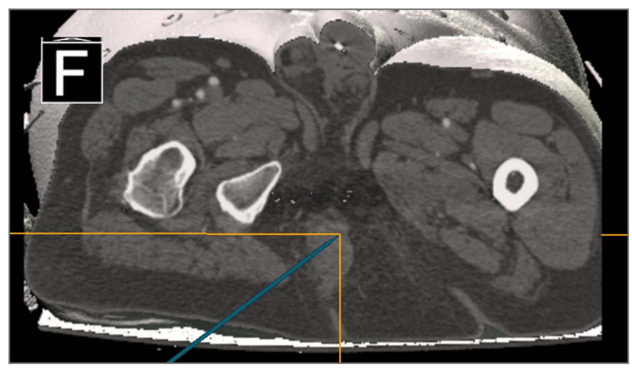
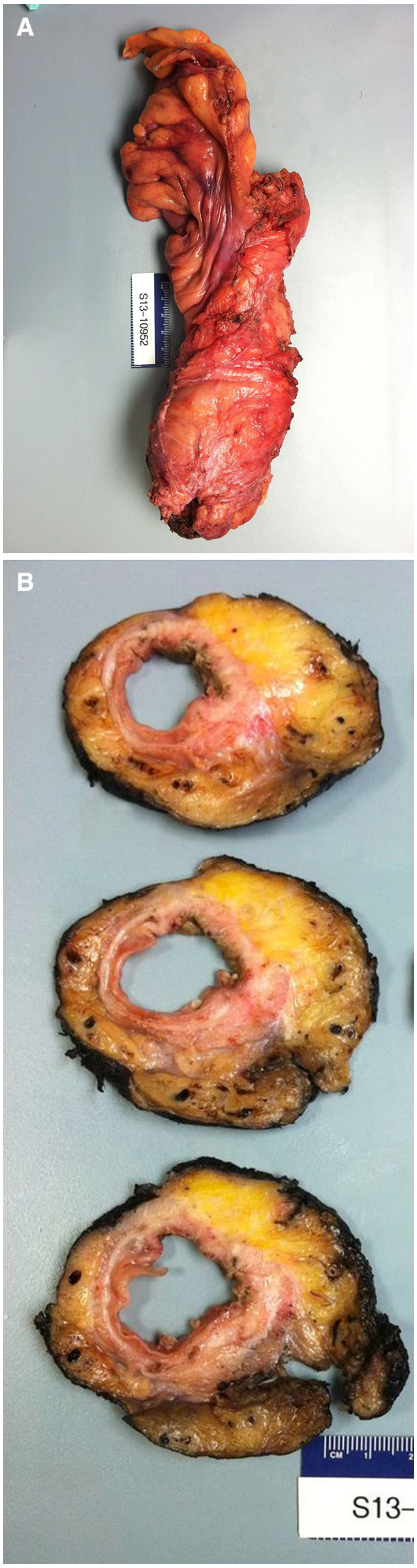


Fig. 6 The position of the operating dissector tip is shown. As the plane of dissection progresses cephalad, the software automatically advances the visible plane to where the surgeon is working

maintain direct line of sight with the ceiling-mounted receiver. The navigation software constantly gathers information from both of these trackers. While the patient-tracker must remain fixed, the instrument-mounted tracker can move, as long as its relation to the operating tip (in this case, needle-point cautery tip) does not change. Once these parameters have been set, stereotactic surgery can be performed (Figs. 5, 6). The step-by-step approach is illustrated in the supplemental video [v].

Post-operative course

The patient was discharged on post-operative day four on a regular diet in good condition. He was seen at 6-week



◀**Fig. 7** **A**, **B** The pathologic specimen is shown revealing a smooth mesorectal envelope and cross-sectional analysis reveals negative margins with the closed radial margin 1 cm

follow-up doing well and there were no operative or post-operative morbidity.

The surgical specimen (Fig. 7A, B) measured 26 cm and the tumor measured 5 × 5 cm, with a 2-cm thickness and was histologically consistent with invasive rectal adenocarcinoma, pT3N0 (19 tumor-free lymph nodes). All resection margins were negative with the tumor >1.5 cm from the distal margin and 1 cm from the radial resection margin. The mesorectal area was intact except for a "focal area of disruption" not involving the region of the tumor.

Discussion

For the first time, stereotaxy is applied outside of the field on neurosurgery on a human patient, paving the way for more generalized applications for pelvic and abdominal surgery—e.g., segmental liver resection and metastasectomy; uterine myomectomy, pancreatic resection; adrenalectomy; nephrectomy; image-guided intra-operative biopsy; and lymph node dissection. That this technology has not yet been transposed across specialties for 20 years not only underscores the chasm that (unfortunately) develops among different specialties, but it also reveals the potential to learn from one another.

While TAMIS-TME does not require real-time navigation, in select cases such as this one, it was helpful in assuring the correct plane of dissection, thereby allowing for an R0 resection of a difficult, locally advanced rectal cancer. Moreover, the dissection would have been quite challenging without navigation because the lesion was fixed anteriorly and because there was dense post-radiation changes to the pelvis which distorted the anatomic planes.

The approach used in this case required a recent imaging study. Both CT and MRI scans can be useful, depending on intra-operative availability. While MRI is preferable, our institution's intra-operative MRI system only allows for brain imaging, as it was designed for neurosurgical procedures.

While the stereotactic navigation used in this case was mostly the same as that used for neurosurgery, there were some important differences to our approach. First, the patient-tracker used in neurosurgery is typically drilled into a boney landmark near the area of the interest (for example, lumbar spine). However, instead of this, we attached the patient-tracker to an arm-mounted device obviating the need for the tracker to be drilled to the patient. Though this may result in slightly less precise navigation, it still provided accuracy of ±4 mm and this was within acceptable limits. Second, neurosurgeons do not track their dissecting instrument. They simply use the navigation tool as a pointer. By attaching the device tracker to our dissecting instrument, we were able to gain real-time information about our surgical plane and surrounding structures. At some points of the operation this was so accurate, that the operating surgeon was performing the operation based on the navigation software's-reconstructed images, rather than the optical camera feed. Overall, stereotactic navigation for TAMIS-TME was found to be accurate and aided significantly in our ability to maintain tumor-free margins.

Conclusion

Stereotactic navigation for TAMIS-TME is feasible, and this approach may have important applications for operating on other pelvic and abdominal organs. This new application of existing technology could have practical uses for liver resection, pancreatic surgery, uterine surgery, and for retroperitoneal "fixed" targets such as the kidneys and adrenal glands. While of proven value in neurological surgery, the role of stereotaxy for abdominal and pelvic surgery has yet to be fully realized, and as we consider the direction surgical innovation will take over the next fifty years, it seems clear that image-guided surgery, particularly with refinement, has a true potential to improve surgical outcomes. This is especially relevant for complex oncologic cases where the benefit of an R0 resection is proven, and where stereotaxy can help surgeons achieve greater certainty in their dissection so that a more complete resection is performed. Stereotaxy can also aide surgeons by improving safety. In particular, a stereotactic resection has the potential to improve recognition of vital structures during dissection so that they can be kept free of the plane of dissection, thereby decreasing the chance for injury. For these reasons, real-time stereotactic surgery is quite promising, and through the methods demonstrated in this TAMIS-TME case, a gateway to abdominal and pelvic stereotactic surgery has been opened.

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