Opinion

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Synopsis of surgical training & simulation

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Introduction

Historically, surgeons learn new surgical procedures through observation, practicing skills, techniques, and then performing the procedure on patients under the supervision of an experienced surgeon. Successful implementation of robotic programs requires development of a dedicated team and training using a structured approach. Today, training continues to be a serious safety issue for surgeons, hospitals, credentialing departments, surgical Associations and perhaps most importantly, the patients. If a surgeon expresses interest in robotic surgery, training is often conducted by a one-day basic training course involving simple tasks but no emphasis on technique or in-depth knowledge of the individual steps required. Although this is sufficient to gain familiarity with the controls of the robotic system, it is inadequate to perform a complex and technically demanding techniques in operations such as radical prostatectomy with any degree of precision and expertise. In order for a fighter pilot to fly a jet, he or she must complete technique and task oriented flight simulation to gain sufficient skills captured through metrics. Simulators for open surgery have never really been practical and surgical residencies are a graded and structured environment for surgeons to develop their skills under constant supervision and guidance. The advent of laparoscopic and robotic surgery, which depends on imaging using video-scopes inserted into the body, allow for the very real possibility of simulation. Inadequate or suboptimal training is a serious safety concern and has yet to be adequately addressed via current day simulators. In addition, current robotic training lacks any objective metrics with which to gauge a surgeon's skills. Development of task and technique driven simulated training programs will address serious safety concerns in the Operating Theater.

Although many complexities in American Health care contribute to the changing landscape in surgical practice, nothing causes such dramatic change as the introduction of a revolutionary, and perhaps disruptive, technology. Using contemporary thinking to understand the power of technology and to try and predict the future is entirely futile. With the advent of robotic-assisted surgical platforms for predominantly pelvic and cardiac surgery, the possibility to continue to expand technology seems almost limitless. Perhaps one of the greatest issues that exists currently is the training required for a skilled open surgeon to learn and new skill which requires a human-machine interaction like he has never experienced before. As young surgeons expand their skill set, technology will further allowing for training to include: tele-surgery and surgical simulators as well as an introduction to numerous other new technologies that may significantly impact upon the practice of surgery. Currently the gaming industry has employed complex software to allow the user to experience a virtual world more similar to "real action' than ever before. The implications of using gaming technology for surgical application has tremendous benefit: decreased costs of training, less complications to patient, less ethical dilemmas, improved skills and of course improved surgical outcomes.

Background

The "Flexner Report" is a study of medical education in the United States and Canada, written by the professional educator Abraham Flexner and published in 1910 under the aegis of the Carnegie Foundation. The Report called on American medical schools to enact higher admission and graduation standards, and to adhere strictly to the protocols of mainstream science in their teaching and research. Training in surgical skills and surgical certification has not changed very since then. In 1904, the Surgeon-In-Chief of the new Johns Hopkins Hospital is credited with having pioneered surgical training as we know it today. The paradigm set and used today is that time and repetition will allow a surgeon to gain skills. Using robotic and computer-assisted systems in medicine, we should be able to develop a quantifiable 'signature' of skills assessment which accurately distinguishes the performance of a novice from an expert and which provides quantifiable information on how to improve performance. With the ability to so accurately quantify performance, a virtual, surgical simulator must incorporate the performance of experts as the benchmark criteria to which students much achieve. Traditional training programs have existed and thrived as chronology (time) based training. We must alter the focus towards proficiency-(criterion-)based training; the student no longer trains for a given time and then begins operating, instead the student continues training on the simulator until they achieve the benchmark 'criteria' of an expert before they operate upon their first patient. This dramatically decreases the amount of time a student will 'practice' on a patient. A Yale University study demonstrated that criterion-based training on a simulator can decrease operating time by 30% and decrease errors by 85%.

For decades, simulation has been established as a critical methodology for education, training and assessment in aviation and military domains. Simulation has been shown to improve performance, increase readiness, decrease costs and improve safety. In the military, contemporary simulation systems go far beyond learning and performance evaluation and are of such sophistication that they can be used for operational planning, force structure and doctrine. Indeed, recent military operations are a testament to force readiness directly resulting from thousands of hours of mission simulations.

The past ten years have seen the growth of medical simulation that parallels the early days of aviation and military simulation. The uptake of medical simulation technologies by civilian and military schools of medicine, nursing and allied health is indicative of the face validity and benefit opportunities for student learning and assessment. Moreover, with accrediting organizations mandating that students meet specific competencies for clinical practice, recently published peer-reviewed studies of medical simulation are showing measurable and quantifiable educational validity for learning and evaluating clinical performance. The Institute of Medicine (IOM) of the National Academies published a report entitled To Err is Human: Building a Safer Health System. This report examined that preventable medical errors result in the deaths of at least 44,000 people in hospitals each year. One of the report's main conclusions is that the majority of medical errors do not result from actions of individuals or a particular group. "More commonly, errors are caused by faulty systems, processes and conditions that lead people to make mistakes or fail to prevent them." A key recommendation by the IOM is for health care organizations to undertake the application of simulation for interdisciplinary team training.

The benefits of surgical simulation and virtual reality

Reducing serendipity in education and training

First, there are an ever-increasing number of surgical procedures to be mastered by surgical residents in the finite timeframe that a residency constitutes; a timeframe that has been further constrained by the 80-hour work week limitation for residents and by an increasingly ambulatory patient population. The reason residencies are so lengthy is because the variability in training experiences is reduced the more time one spends in a residency training situation. For example, the likelihood a surgical resident will be faced with a particular surgical situation "x" increases as the time "t" spent in a residency is increased. Residency accrediting bodies increasingly want to ensure that each resident has had a specific portfolio of experiences during their training. Simulation affords the opportunity to provide a simulated experience for the resident should the genuine experience not happen to present itself during the time that the particular resident is on-duty. The result is that simulation provides a more uniform educational experience for the resident.

Practice and rehearsal without patient consequences

Second, the use of simulation allows the individual to practice their procedures or skills in a non-threatening environment and multiple times under varying conditions there by fulfilling the key tenet of the Hippocratic Oath which is to "first, do no harm". New visualization technology will make it possible for an individual to practice the particular operation or procedure they will perform multiple times on a volume-rendered three-dimensional, haptically-enhanced simulator that exactly matches the anatomy of the patient undergoing the procedure. Practice can continue until the individual feels comfortable with their skill level performing the procedure or until some pre-defined objective metric is achieved. In addition, simulation allows the introduction of team-based training opportunities and allows one to introduce such rare but challenging conditions as an electrical power outage during the simulated procedure.

Reducing medical errors

Third, Institute of Medicine reports on patient safety, now several years old, have increased awareness that a significant number of medical errors occur each year by otherwise well-meaning practitioners and that of this number there are a large number of deaths that result from such errors. Simulation allows the deliberate practice of procedural skills to achieve a defined level of competency to reduce procedural errors and is increasingly allowing for the training of interdisciplinary teams to reduce errors related to the breakdown of communications among group members. Simulation also has the potential to identify and reduce errors that can occur within health care systems when, for example, a particular health system purchases two different models of patient care equipment, monitors for example, each of which operates somewhat differently, which can contribute to errors by users of the equipment.

Reducing reliance on animal models

Fourth, there has been an increasing ethical imperative in recent years to curb the use of animal models for medical training purposes as well as the use of human patients as "guinea pigs" as it were for the purposes of medical education. Publicity in recent years concerning medical device sales personnel performing medical procedures in the operating room, the increasing visibility of organizations such as the People for the Ethical Treatment of Animals and the patient advocacy and patient rights movements have all played roles in this area, as has the ever-increasing difficulty in obtaining a sufficient number of cadavers and other necessary body parts to support education and training. Simulation offers the potential for decreasing reliance on animal models and "practicing" on human patients in the medical education process.

Reducing healthcare costs

Fifth, the percentage of the U.S. gross domestic product spent on health care services continues to grow and simulation can help temper this cost growth. Simulation offers the potential to improve utilization of operating rooms and a consequent reduction of costs by reducing the time it takes practitioners to perform procedures in the operating theatres. These time reductions will be the result of the efficiencies to be gained by rehearsing the procedures in advance utilizing simulation as discussed above. In addition, the field of anesthesia has already demonstrated that the use of simulation can reduce errors and subsequent malpractice liability. The use of simulation has been credited with a reduction in the cost of malpractice insurance for anesthesiologists.

Easing introduction of new surgical procedures

Sixth, simulation can speed the introduction of new surgical procedures, especially among those practitioners who no longer are in an active training environment. When new surgical procedures are introduced, such as was the case with laparoscopic cholecystectomy, it is often difficult for community practitioners to gain these new skills. Simulation could substantially shorten the learning curve for acquiring these new skills and reduce reliance on animal models.

Ensuring career-long procedural competence

Seventh, simulation offers the opportunity to incorporate a "hands-on" component to recertification examinations that currently are paper and pencil based. The addition of simulation to the recertification process can provide added safety for the public and assurance that there has not been a degradation of the surgeon's skills since they were initially trained.

The challenges

To date, the adoption of robotic surgery has many challenges all of which center upon training on new technology and lack of understanding of the surgical procedure using new technology. Unlike other paradigms, use of a robotic system for most procedures has required surgeons to learn new techniques and a different approach to the anatomy that focuses on visual cues rather than tactile ones. Skills such as dissection, suturing and tissue handling, which are honed during residency are challenged when the instrument is no longer a scalpel and replaced with a complex surgical robotic system. Other known challenges that deal with costs, operating room logistics, as well as process issues also add to the difficulty with respect to training.

A robotic training curriculum?

To date, most of the laparoscopic and robotic trainers lack sophisticated simulation and are limited to task-oriented (eg. placing a ring on a cone) simulation. Furthermore, the "school-house" concept of training as is conducted with aviation training does not exist. Currently, robotics training is unstructured and relies on varied credentialing criteria established by hospitals in conjunction with Intuitive Surgical (Figure 1).

Figure 1 A robotic training curric.

What is needed?

A curriculum that emphasizes:

i. Familiarity with the surgeon's console, the "control panels", actuators, foot pedals, etc.

ii. Familiarity with the instruments necessary for a given procedure

iii. Familiarity with multi-tasking (processing visual cues/displays, using both hands to operate, concurrently using your feet)

iv. Classroom instruction of the above+video review of the system, tasks and the surgical steps of a given procedure

v. Graduated task simulation (from beginners to intermediate to advanced) training to learn how to use the instruments and tools

vi. Simulation-based Immersive Reality-based Virtual Training (SIRV) where surgeons actually perform the intended procedure grasping advanced knowledge of the surgical steps, the anatomy and perform complex tasks. In addition, metrics can be added to gauge performance as well as Safety-training.

vii. LINK (courtesy of E Pollack, 2015) employs such training for Pilots in a so-called training suite.

Next steps

i. Accrue the funds needed to implement a strategy to build a training program and simulator (see proforma below) (Table 1).

ii. Develop the program: edit video to make a teaching video with dubbed instruction; course outline, classroom curricula, etc.

iii. Develop task simulator–hardware and software.

iv. Develop procedure specific training simulation (Figure 2).

Table 1 Proforma for simulation & training facility

		Per unit	Monthly $ non-recurring $
		Costs	**Recurring**
Salaries			
Manager			-
Developers (Incl. Taxes, Medicare)			
Part-time 20-25hrs/week		$30/hour	$2,500
Part-time 20–25hrs/week		$30/hour	$2,500
Part-time 20-25hrs/week		$30/hour	$2,500
Temp - Admin			$1,000
Rent (at UCF) - Awaiting $ Confirmation			$1000
Utilities/internet incl. in rent			$0
No phones			$0
Furniture			
2 long tables	2	$250	$500
4 chairs	4	$425	$1,700
1 low cabinet for printer + supplies	1	$150	$150
1 high file cabinet for supplies	1	$250	$250
2 bookcases	2	$200	$400
Equipment			
4 PC's w/ Microsoft software	4	$3,000	$12,000
1 Laptop	1	$2,500	$2,500
1 Printer	1	$750	$750
1 Network Server	1	$1,500	$1,500
Phantom Omni Joystick	1	$2,500	$2,500
3-DOF Omega Haptic Device (like DLR)	1	$7,500	$7,500
Software			
c++	4	$425	$1,700

Table Continued

		Per unit	Monthly $ non-recurring $
		Costs	Recurring
3D Studio Max	2	$3,500	$7,000
Photoshop	3	$1,500	$4,500
Mathlab Simolink	2	$5,000	$10,000
Adobe Flash	2	$400	$800
Additional software			$7,500
Service contracts for pc's/printer			$250
Licences or addi. unknown requirements	2, 3 or 4	???	???
Other			
Insurance - Workers' Comp			$250
Insurance - Property/Casualty			$125
Suppliers			
Paper, pens, staplers, etc.			$1000
Unforeseen Expenses (Approx. 10% of Annual rec. exp.)			$2,000

Figure 2 Training suite.

Organ modeling, simulation & virtual reality

Thanks to an improved preoperative knowledge of each patient's internal anatomy, practitioners can today establish an improved diagnosis and a better planning of the best-suited therapy for a given case. Therefore, 3D modeling of a patient is generally used for diagnosis support or surgical planning tools. The other use is patient follow-up over time, easing visualization of therapy efficiency. However, surgical simulation still remains limited to virtual models, without really exploiting medical data of patients. Thus, to simulate an intervention on a virtual patient reconstructed from his/her medical image is a major enhancement, which would allow improved understanding of the procedure, improve safety and reduce medical mistakes (Figure 3).

Historically, intraoperative use, which allows improvement of the surgical gesture, has to be added to the preoperative use of 3D patient modeling. In this domain, augmented reality offers a more efficient steering of the surgical movement, by superimposing preoperative information on the patient. Most applications have been developed in neurosurgery and in orthopedic surgery, since non-mobile bone landmarks are very reliable and allow an eased registration of the virtual patient on the real patient. The few works that have been carried out on the abdominal or pelvic region are suboptimal, primarily due to organ movement from diaphragmatic breathing. In order to overcome limitations of 3D medical image analysis, preoperative simulation and augmented reality on organs and pathologies of the abdomen and pelvis, we propose a realistic simulator allowing to prepare and simulate a surgical intervention before actually carrying it out. Thus, our objective is to realize and validate a highly realistic simulator for robotic or laparoscopic surgery of the abdominal -pelvic viscera, including realistic physical and visual modeling of organs, real-time force feedback and the opportunity to change patient topology thanks to broad resections realized on any region of the reconstructed patient. In order to realize such a simulator, it is important to reproduce sensations linked to carrying out surgical maneuvers.

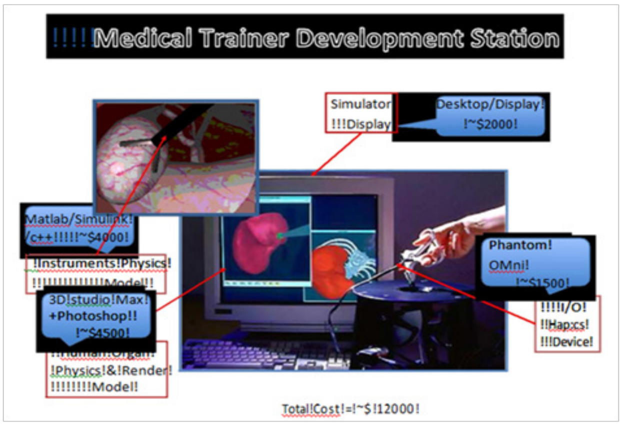

Figure 3 Organ modeling, simulation & virtual reality.

One of preoperative planning and simulation limitations is the difficulty of accurately reproducing the planed and simulated gesture on the real patient. This limitation can be overcome by superimposing preoperative data on the real patient during intervention. However, this superimposition is complex to achieve in practice since it requires the accurate correspondence of reference landmarks between the virtual and the real patient. We also propose to offer a view in transparency of the patient by superimposing the 3D virtual patient reconstructed from MRI or CT medical images, on the video image realized during the intervention (Figure 4-6).

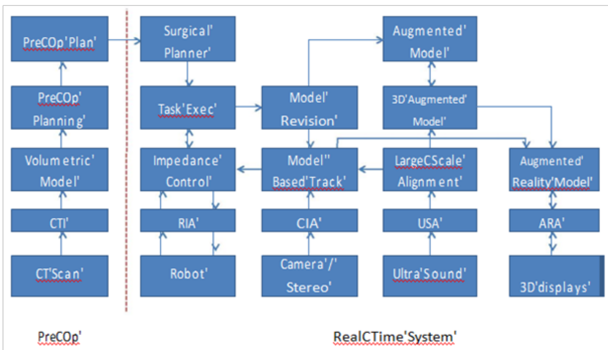

Figure 4 System architecture.

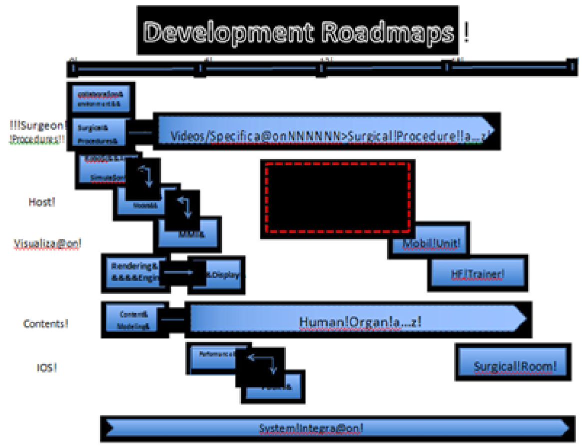

Figure 5 Timeline.

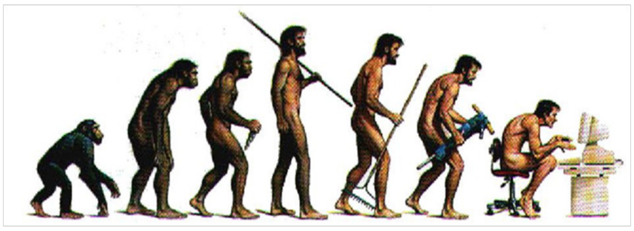

Figure 6

A review of the surgical steps – robotic prostatectomy

Patient positioning and preparation

Preparation of the robot: The robotic team includes console-side and patient-side surgeon(s). The surgeon sat at the console and was not scrubbed. Upon power up the system went through the self-testing process. The optics system required both black and white balancing as well as crossbar calibration of the stereo endoscopes. We draped the robotic arms in sterile plastic coverings, preparing them for later docking after patient positioning is completed. A nodule was detected at the left base on digital exam under anesthesia.

Patient positioning: The patient is placed in supine and extreme Trendelenburg position with adequate padding of the pressure points: shoulders, back, legs and arms. The patient is then to the table using cloth tapes over two egg-crate foams. An 18F foley catheter is placed in the bladder and connected it to a drainage bag. The patient receives IV antibiotics and DVT prophylaxis as per protocol. The abdomen and pelvis are prepared and draped in the usual sterile fashion.

Port placement

i. A Veress needle (Ethicon Endo-Surgery™, Albuquerque, New Mexico) is introduced from a left peri-umbilical incision for pneumo-insufflation to a pressure of 20 torr and is maintained during port insertion.

ii. The Veress needle is replaced with a 12-mm trocar and the 3-dimensional daVinci laparoscope is inserted.

iii. Two 8-mm daVinci trocars are placed 2.5cm below the level of the umbilicus at the lateral border of the rectus muscle on either side.

iv. A 5-mm trocar is placed between the umbilicus and the left robotic port.

v. A 12-mm trocar is then placed in the mid-axillary line approximately 2cm above the iliac crest on the right side.

vi. Finally, an additional 8-mm da Vinci trocar is placed in a mirror image symmetrical position above the iliac crest on the left side. In some cases, this port is substituted for a 5-mm port, in cases were an assistant is used in place of the 4th robotic arm.

vii. Following docking, the team evaluates the robotic arms and tower in relation to the patient's legs and hands to avoid inadvertent compression by the robotic system (Figure 7).

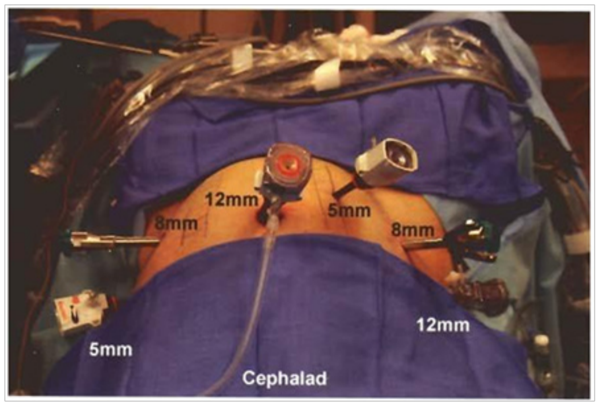

Figure 7 Port placement.

Development of the retropubic space

i. The operation begins with the da Vinci 30° lens in the upward position. The left robotic arm is equipped with a bipolar cautery grasper or a Gyrus grasper. The right arm has a monopolar hot shear (scissor).

ii. Using these instruments, the extraperitoneal space is entered by incising the parietal peritoneum lateral to the medial umbilical ligaments and connecting these two incisions by incising at the level of the urachus. The internal inguinal ring can be seen medial to the external iliac vessels. The vasa are seen coursing obliquely and are divided in cases where a lymph node dissection is planned.

iii. As the peritoneal incision is deepened, visualization of the pubic bone serves as a landmark and the superior limit of dissection. The bladder is carefully taken down from the anterior abdominal wall exposing the extraperitoneal pelvic space of Retzius.

iv. As depicted below, the endopelvic fascia is then incised exposing the contour of the prostate from its apex to the base. In addition, the levator ani musculature is exposed.

v. At this point, suture ligation of the dorsal venous complex (DVC) at the apex of the prostate can be performed. Our current practice is to avoid opening the endoplevic fascia and proceed directly to division of the bladder neck (described below). Furthermore, we are also advocating selective suture control of the DVC just prior to urethral transaction (Figure 8).

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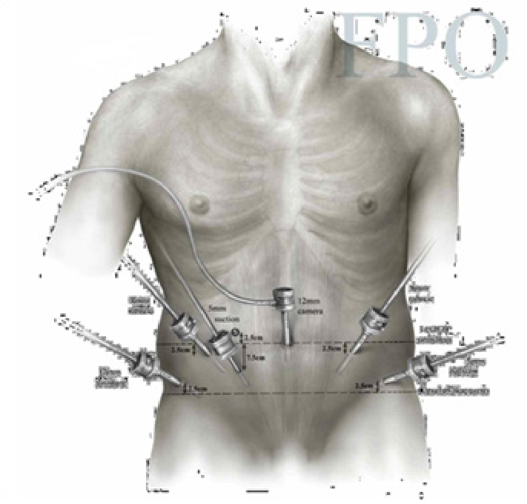

Figure 8 Development of the retropubic space.

Division of the bladder neck & posterior dissection

i. The 30° daVinci laparoscope lens is now placed in the downward position.

ii. At the midline, the bladder and prostate are contiguous as the bladder muscle is continuous with the mucosa of the prostatic urethra. A distinct fibro alveolar and fatty plane can be developed between the prostatovesical junction, especially under traction.

iii. We begin the division of the bladder neck anteriorly while the right assistant retracts the bladder cephalad. As the dissection ensues in the midline, the foley catheter is encountered.

iv. The foley catheter is deflated and the catheter is grasped by the 4th lateral robotic arm or the left assistant. Once grasped the catheter is pulled cephalad and up to the anterior abdomen, thereby raising the prostate for the posterior dissection.

v. The posterior bladder neck is carefully dissected free at the prostatovesical junction. The dissection is carried laterally. A fibro fatty tissue plane is encountered and the dissection is advanced and deepened until the anterior layer of Denonvillier's fascia is seen. This layer is incised there by exposing the vasa and the seminal vesicles.

vi. Once identified, the vasa are divided and the vesicular arteries are controlled with small titanium clips, the Gyrus or selective use of the bipolar cautery.

vii. Both seminal vesicles are freed and reflected superiorly along with the prostate by the left assistant, there by exposing the longitudinal fibers of the posterior layer of Denonvillier's fascia. This layer is sharply incised creating a plane between the prostate and the rectum. Visualization of perirectal fat confirms the appropriate level of dissection (Figure 9 & Figure 10).

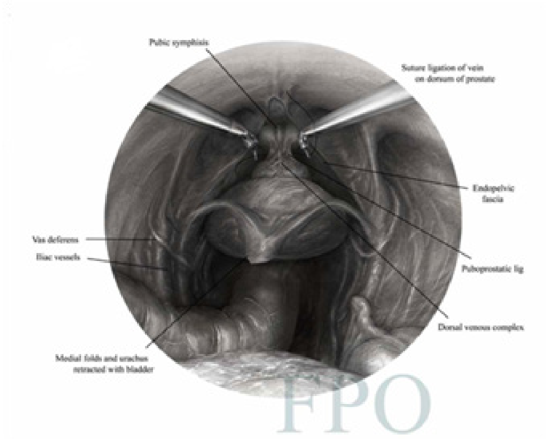

Figure 9 Division of the bladder neck & posterior dissection.

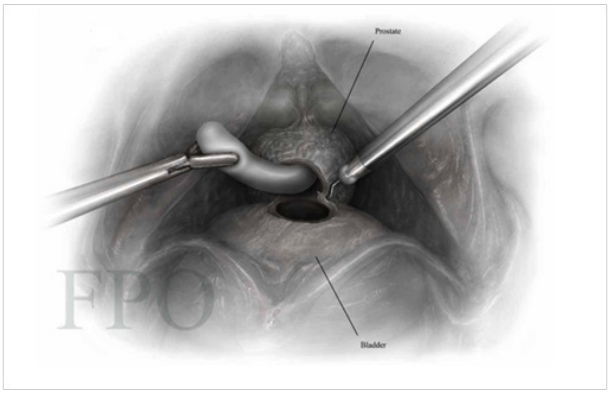

Figure 10 Visualization of perirectal fat confirms the appropriate level of dissection.

Pedicle control and nerve-sparing

i. Several animal laboratory and human cadaveric studies suggest that a lattice of accessory cavernosal nerves exists underneath the prostatic fascia but above the prostatic capsule. We believe these nerves play a role in erectile function, where preservation of this neural lattice on one or both sides of the prostate can lead to improved functional outcomes in selected patients.

ii. Continuing with the robotic articulated scissors in the right hand and the bipolar cautery forceps in the left hand (or the Gyrus), the lateral prostatic fascia is dissected away from the prostate.

iii. The vascular pedicle is controlled and divided with Weck clips. Use of Cautery is extremely limited here. The tissue posterolaterally is dissected free from the base of the prostate including the associated nerves, fat and blood vessels.

iv. The correct plane is between the prostatic venous plexus and the prostatic capsule. The neurovascular bundles are teased away from the prostate easily. Once the apical dissection has ensued, the resulting fascial planes appear as veils of tissue laterally, thereby creating a 'veil' of spared tissue (Figure 11).

v. **Note**: In my current practice, patients with focal disease are offered an extended fascial sparing procedure which creates the lateral 'veil'of tissue on each side. However, other patients are offered a standard nerve-sparing procedure which does not spare the lateral prostatic plexus.

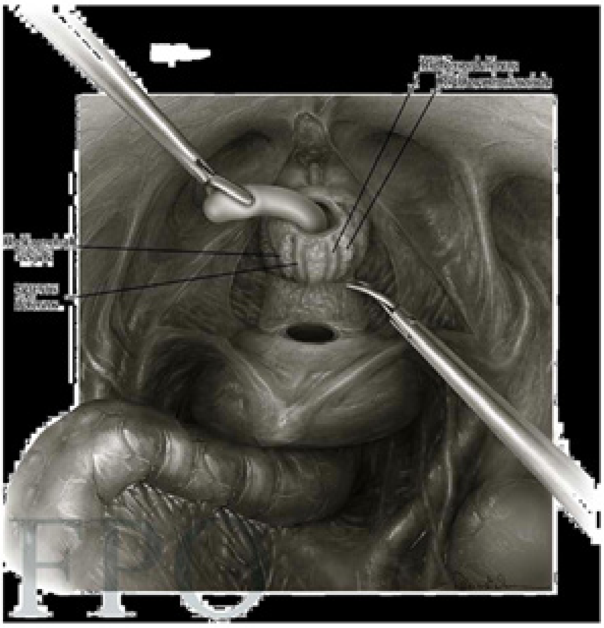

Figure 11 Pedicle control and nerve-sparing.

Urethral transection & control of the dorsal vein complex

i. Division of the apical urethra is performed using the 0-degree daVinci laparoscopic lens with 1:3 scaling.

ii. The urethra is encountered after division of the puboprostatic ligaments and control of the dorsal venous complex (DVC).

iii. The DVC is controlled with a combination of selective cautery and/or a suture ligature (2-0 Vicryl RB-1 needle).

iv. Using scissors, the puboprostatic ligament is incised where it inserts into the apical prostatic notch. A plane between urethra and dorsal venous complex is gently developed to expose the anterior urethral wall.

v. To minimize the possibility of a positive apical margin, the anterior wall of the urethra is transected with the scissors a few millimeters distal to the apex of the prostate.

vi. The freed specimen is then placed in an endo-catch (Ethicon®) specimen retrieval bag. The prostate is removed following the completion of the anastomosis (Figure 12).

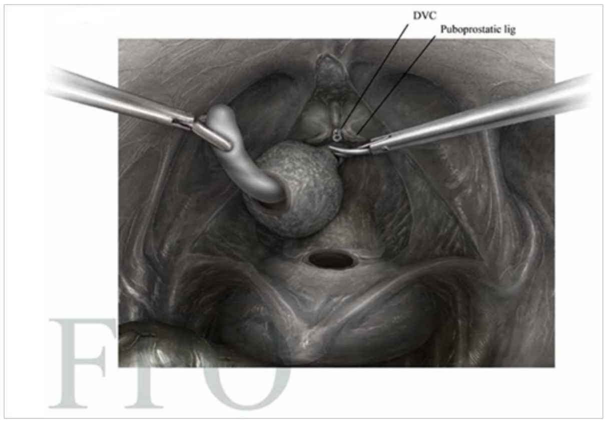

Figure 12 Urethral transection & control of the dorsal vein complex.

Vesicourethral Anastomosis

i. A continuously fashioned sutured anastomosis is performed using a modification by van Velthoven and colleagues.

ii. Two 15cm 3-0 Monocryl sutures (one dyed, the other undyed) are tied together to create a single double arm suture.

iii. The anastomosis is started by taking the needle of the dyed suture from outside the bladder neck at the 4 o'clock position. The needle of the dyed suture is then placed from inside at the corresponding position on the urethra. This technique is continued in a clockwise manner.

iv. At the 9 o'clock position, the suture is reversed at the bladder neck (Connell Stitch) and then run until the 12 o'clock point.

v. The undyed suture is then used commencing at the urethra from the outside to in at the 4 o'clock position and run in a counter-clockwise manner until the dyed suture is met. The needle of the dyed suture is cut and the two ends are tied. Once complete the other needle is removed.

vi. A new 20 French Foley catheter is introduced and inflated to 20 cc's. The integrity of the anastomosis is tested by instilling 200 ccs of Normal Saline into the bladder. The anastomosis is visually checked for any leak. If so, 2-0 Vicryl interrupted sutures are placed as needed (Figure 13).

Figure 13 Vesicourethral anastomosis.

Retrieval of specimen & completion of surgery

i. A suction drain is placed through the left lateral 8-mm daVinci trocar port.

ii. The System is de-docked. The patient receives a 1-liter bolus of 0.9% Normal Saline and 30-mg of Intravenous Ketorolac.

iii. The ports are removed and the entrapped specimen delivered after enlarging the umbilical port incision sharply. All incision are closed, only the 12-mm camera port is closed along with its fascial layers.

iv. After visual inspection of the prostate by the surgical team, the specimen is then sent off to pathology.

Postoperative considerations

i. Patients are taken to recovery and then to our Urology ward where they remain overnight.

ii. Five hours after surgery, patients are asked to drink clear liquids and ambulate the halls. Prior to sleeping for the night, patients are asked to ambulate ~20laps around the nurses station.

iii. Urine and drain outputs are recorded. Ketorolac 30-mg IV is given for two additional doses, 6hours apart. In addition, Ancef 1-gram and Heparin 5000-Units are given for 2 additional doses.

iv. On the first postoperative day, the drain is removed if the output is less than 100cc's over the prior 8 hour shift.

v. Patients are sent home with the foley catheter and urine drainage bags. Patients maintain their catheters for 8-10days after surgery.

vi. Removal is based upon a postoperative cystogram to determine the presence of an anastomotic leak.

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None.

Conflict of interest

The author declares no conflict of interest.