Learning Curve Using Robotic Surgery

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The da Vinci (Intuitive Surgical, Inc., Sunnyvale, CA) surgical system is being used by an increasing number of surgeons across several surgical specialties. The robotic interface is different not only to open surgery, but also to laparoscopy because it involves remote surgical control, stereoscopic vision, and lack of haptic feedback. As the transition is made from traditional open to robotic surgery, factors such as learning of robotic skills, assessment of proficiency in robotics, and structured training for urologists in practice and residents assumes importance. Understanding how the robotic surgical technique is learned and how such learning can be best assessed will enable us to define protocols for training and set standards for proficiency. Learning curve and surgical dexterity are two parameters that are used to compare surgical learning and training. This article presents the current gold standard for assessing skill training and compares surgical skill acquisition and proficiency using conventional laparoscopy and robotic interfaces.

Introduction

Following the emergence of the da Vinci robotic system (Intuitive Surgical, Inc., Sunnyvale, CA) as a preferred tool for performing minimally invasive surgery across several surgical specialties [1••,2–4], attention is now being focused on the learning curve and use of the robot as a teaching tool [5]. One of the limitations of laparoscopic surgery, especially reconstructive laparoscopy, has been its steep learning curve [6] and the use of the da Vinci system is expected to mitigate this disadvantage. The da Vinci system offers intuitive movements, tremor filtration, stereoscopic vision, and motion scaling, all of which are thought to contribute to making robotic-assisted surgery easier to grasp and master. Skilled robotic surgeons think that robotic surgery will soon bring advanced reconstructive laparoscopic procedures within the repertoire of the average urologist by using robotic technology that better mimics open experience. Because robotic surgery has been subjected to scrutiny throughout the past 3 years, several peer-reviewed reports have been published addressing the impact of the robot on performance of standardized surgical tasks, skill training, and the learning curve and comparing these results with laparoscopy and open surgery. Training surgeons in robotics will assume additional importance, as this technology is gaining greater acceptance and surgical trainees are being exposed to innovations in the field. Therefore, it becomes vital to define, standardize, and validate training protocols if this technology is to be seamlessly integrated into the current schema of urology residency training. This review aims to discuss the current role of robotics in learning and teaching minimally invasive surgery. Furthermore, it provides a synopsis of the available literature on the subject.

The Need for Structured Learning Curve Assessment

The use of any new technology raises several important issues; principal among them being: skill development, skill assessment, teaching, and translation into the operating room. Robotic surgery encompasses these challenges, as the robotic environment is different from conventional open and laparoscopic surgery. A significant difference is the loss of haptic feedback. Therefore, understanding how surgeons can implement, develop, and master their skills with robotic systems is the order of the day. This will enable the creation of structured training protocols that may ensure a safe incorporation of robotics into clinical practice.

Assessment of the Learning Curve

The term learning curve is being used increasingly to denote the process of gaining knowledge and improving skills in performing a surgical procedure [7••]. It also provides an objective assessment of technical ability and a benchmark to compare surgical approaches and technologies. It has been variably defined as the number of cases required to achieve technical competence at performing a particular surgery [7••]. When used to compare two surgical approaches, it also may be defined as the time required to achieve a comparable level of technical expertise in the two approaches [8]. The learning curve is commonly assessed using operative time as a surrogate, when it is assumed that operative times improve as the surgeon becomes more facile. Although this end point is easy to measure and compare, it is largely inaccurate. Other parameters that have been suggested to be important in assessing technical expertise include intraoperative and postoperative complications [9], conversion rates, intraoperative blood loss, functional outcomes [10], and the surgeon's comfort with the procedure [8]. Watson et al. [11] used the incidence of complications to define their learning curve following laparoscopic fundoplication. The time taken to develop a training curve plateau is another indicator of basic mastery of a surgical task and the time required [12••]. In fact, a single indictor may not be useful and many or all of the aforementioned end points may provide the most accurate evaluation of the learning curve.

It is not often feasible nor practical to evaluate the learning curve during actual surgery. Evaluating the performance of standardized, non-patient tasks such as threading a hole, stacking coins, suturing, and knot-tying also may be used to assess a learning curve [13]. These provide a degree of objectiveness to the evaluation because they are not limited by the variations in patient anatomy during actual surgery and they may be used across a cross-section of individuals, from the surgically naïve medical student to the experienced senior consultant.

Learning Curve and Surgical Dexterity

When a new procedure is incorporated into practice, there is a period of learning as the practitioner becomes facile with the procedure. Learning curve denotes the period during which inexperience of the surgeon makes a procedure more difficult, lengthy, and often causes less satisfactory results compared with that performed by an experienced surgeon. There is no accepted standard for measurement of learning curve, nor is there a definition of the point at which learning is said to be complete. It typically is the surgeon who decides when he or she is comfortable performing the procedure [8]. Hence, the learning curve can vary considerably depending on surgeon-related, procedure-related, and operation-related factors. The ambiguity in defining and assessing learning has spawned the development of standardized, objective parameters to assess surgical performance and is known as surgical dexterity [14].

Tools to Assess Surgical Dexterity

Traditionally, the learning curve has been assessed using "proxies" such as operative time, complication rates, and functional outcomes. These measures of training are currently thought to be inadequate by some researchers because they do not provide objective definitions of learning and are not a direct indicator of learning [15]. To directly and objectively measure learning, new tools to assess surgical dexterity have been and continue to be developed. Two such validated methods are the Objective Structured Assessment of Surgical Skills (OSATS) and Motion Analysis [16,17,18••]. The OSATS includes eight parameters to assess surgical performance: 1) respect for tissue, 2) time and motion, 3) instrument handling, 4) suture handling, 5) flow of operation, 6) knowledge of procedure, 7) overall performance, and 8) quality of final product. Each parameter is scored from 1 to 5 and then a global score is tabulated; a score higher than 24 indicates competence.

Motion analysis includes three parameters: 1) path length, 2) distance traveled, and 3) time taken to completion. These are evaluated using a software program that extrapolates data from the da Vinci system. Dexterity then may be determined by evaluating economy of movements, lack of unnecessary movements, and time taken to perform tasks. Analysis of dominant and non-dominant hand movements also is included in the analysis. A score then may be assigned to facilitate comparison between subjects. Recent studies and protocols of surgical trainee learning and surgical skills assessment primarily use surgical dexterity as their end point [14,15,17].

Learning Curve: Laparoscopy Versus Robotics

To study the difference between learning curve of conventional laparoscopy and robotics, two types of studies have been performed: performance of standardized tasks in the dry lab and perioperative patient outcome evaluations. The former includes threading rings, knot-tying, and stacking coins and the latter involves comparing outcomes of individual surgeons between their early (first 25–50 cases) and later (100–150 cases) experience.

Performance of standardized tasks

Sarle et al. [19] evaluated the time taken to perform four drills using standard laparoscopy and the da Vinci robotic system. After a 10-minute acclimatization period, three groups of surgeons of varying experience performed these drills, which were designed to provide increased technical difficulty to the participants. The mean time to perform the drills was significantly less using the robot compared with laparoscopy, except for the first drill, which was technically the easiest. As the technical difficulty of the drill increased, the difference in mean time increased in favor of the robot. Furthermore, the advantage for the robot was maintained across all levels of surgeon experience. The authors concluded that the robotic system provided an advantage to surgeons over conventional laparoscopy, the magnitude of which increased as the degree of difficulty of the task increased.

Maniar et al. [12••] performed a similar experiment using the Zeus Robotic system (Computer Motion Inc., Goleta, CA). In their more extensively analyzed study, they asked the subjects to perform the same drill 15 times and studied interval improvement (percentage improvement from 1st to 5th repetition, 6th through 10th, and so on) for both groups. They also defined a curve plateau, drill consistency, drill precision, and drill speed. They found that for both platforms, improvements in performance were greatest during the first five repetitions and that participants reached the learning curve plateau earlier with the robot. However, the slope of the learning curve was similar for laparoscopy and robotics, which is remarkable given the fact that the robot lacks haptics. Perhaps this disadvantage is compensated by the improved degrees of freedom, tremor filtration, and motion scaling. Other investigators have provided similar results [20–22].

Other investigators have shown contradictory results, especially for simple standardized tasks and in experienced surgeons [23–25]. One criticism of these studies is that they did not allow any "acclimatization time" for the participants. Unfamiliarity with the robot controls could have introduced a bias that may have affected results in these studies. It may be that simple tasks do not require the advantages that the robot provides and that these advantages are manifest only for more complicated, technically demanding surgical tasks.

Impact of three-dimensional vision

A distinct advantage of current robotic systems is the presence of stereoscopic vision. Jourdan et al. [26] and Moorthy et al. [14] evaluated the impact of stereoscopic vision on the learning curve. Jourdan et al. [26] asked five experienced laparoscopic surgeons to perform five standardized tasks using two-dimensional first and then three-dimensional. They measured time taken to complete the task and the number of errors committed. All of the tasks were performed quicker using three-dimensional vision and the number of errors was significantly fewer than that noted using the two-dimensional vision. Similar results were shown by Moorthy et al. [14]; task times were 30% faster when stereoscopy was used.

Ambidexterity

In an attempt to assess dominant versus non-dominant hand skills, Hanna et al. [27] asked subjects to perform tasks individually with the dominant and non-dominant hand and assessed the time taken to perform the task. Hernandez et al. [7••] assessed time and errors committed in their similarly designed study. Both studies concluded that with conventional laparoscopy, the dominant hand performed significantly better than the non-dominant hand with regard to time and errors; however, this was not observed with the robot. Using the robot created equivalence between the dominant and non-dominant hand.

Operative data

Many studies have evaluated learning curve of robotics by comparing outcome data as the experience of the surgeon increased. Ahlering et al. [28] showed a statistically significant decrease in operative times, robotic set up times, and blood loss when the first 100 robotic prostatectomies (0–100 cases) were compared with the 50 cases performed later in the learning curve (300–350 cases). Frede et al. [9] demonstrated that surgeons who had performed more than 100 laparoscopic radical prostatectomies had better outcomes in terms of intraoperative complications, conversions rates, postoperative strictures, positive surgical margins, and continence compared with surgeons who were less experienced. Patel et al. [29] showed that the learning curve for robotic radical prostatectomy in a community setting was 20 to 25 cases and that operative times and blood loss improved steadily in the first 100 cases when analyzed in quartiles.

In a study performed at our institution, operative times and learning curves were drawn for three groups: an experienced laparoscopic surgeon who had performed more than 1000 procedures (A); an experienced open surgeon who was performing his or her first robotic radical prostatectomy (B), and a fellow who started performing robotic radical prostatectomies after having assisted and observed during more than 100 robotic procedures (C; Fig. 1; unpublished data). Several conclusions may be drawn from the graph. The robot decreased the learning curve for surgeon B such that by case 7, the operative times using the robot were faster than those of surgeon A, who had experience with more than 1000 laparoscopic procedures. Surgeon C, who was mentored in robotics, performed his first robotic case faster than surgeon A and B, both of whom were far more experienced surgeons. We may conclude that prior open or laparoscopic surgical experience is not required to develop competence in robotic procedures and that mere observation of robotic cases may decrease the learning curve for robotic procedures.

Conclusions

Current available literature demonstrates that surgical performance and dexterity can be objectively measured using the da Vinci robotic system and that this may have important implications in training future minimally invasive surgeons. The use of robotic assistance decreases the learning curve for both standardized tasks and actual operations. However, outcomes data to support these conclusions are scant and much of the data citing the benefit of robotic surgery lies in anecdotal testimony or from data pertaining to dry lab research. The results of such dry lab experiments have been shown to translate into better performance in the operating room. The future trend will be development of simulators to assess dexterity and its use to define a level of expert performance. An established definition for a learning curve then may be

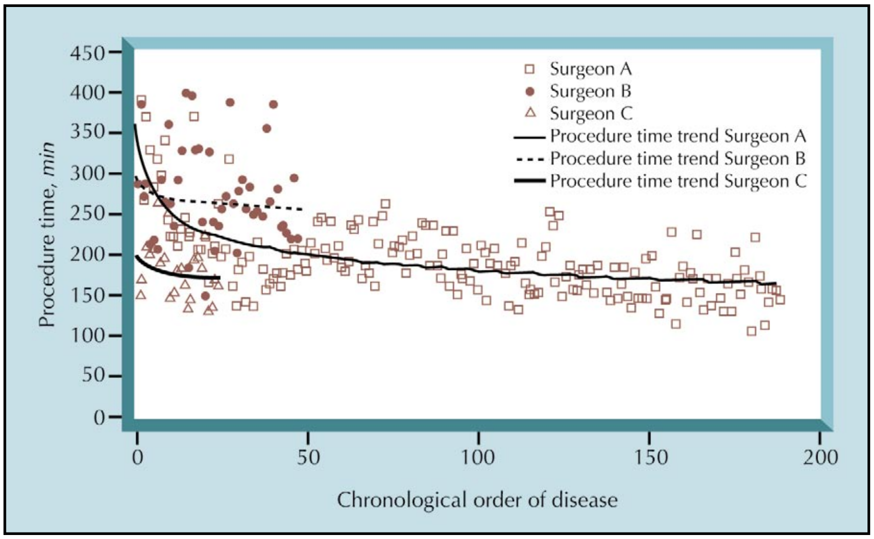

Figure 1. Learning curve of three surgeons: surgeon A for conventional laparoscopic radical prostatectomy, and surgeons B and C for robotic radical prostatectomy.

used to set competency standards for the clinical/surgical and laboratory arenas. The da Vinci system then would be used to mentor trainees to a predetermined level of competence and also as a quality-control tool for continued skills assessment.

References and Recommended Reading

Papers of particular interest, published recently, have been highlighted as:

- • Of importance
- •• Of major importance

1.•• Sanjeev K, Menon M: **Robotics in laparoscopic urology.** *Min Invasive Ther* 2005, **14**:62–70.
An extensive review of the current role of robotics in urology, including techniques of robotic-assisted urologic procedures and outcomes published in literature.

2. McLeod IK, Mair EA, Melder PC: **Potential applications of the da Vinci minimally invasive surgical robotic system in otolaryngology.** *Ear Nose Throat J* 2005, **84**:483–487.

3. Kariv Y, Delaney CP: **Robotics in colorectal surgery.** *Minerva Chir* 2005, **60**:401–416.

4. Bonatti J, Schachner T, Bonaros N, et al.: **Ongoing procedure development in robotically assisted totally endoscopic coronary artery bypass grafting (TECAB).** *Heart Surg Forum* 2005, **8**:287–291.

5. Di Lorenzo N, Coscarella G, Faraci L, et al.: **Robotic systems and surgical education.** *JSLS* 2005, **9**:3–12.

6. Bollens R, Sandhu S, Roumeguere T, et al.: **Laparoscopic radical prostatectomy: the learning curve.** *Curr Opin Urol* 2005, **15**:79–82.

7.•• Hernandez J, Bann S, Munz K, et al.: **Qualitative and quantitative analysis of the learning curve of a simulated task on the da Vinci system.** *Surg Endosc* 2004, **18**:372–378.
A very succinct paper explaining current gold standard in assessing surgical dexterity.

8. Herrell SD, Smith JA Jr: **Robotic-assisted laparoscopic prostatectomy: What is the learning curve?** *Urology* 2005, **66**:105–107.

9. Frede T, Erdogru T, Zukosky D, et al.: **Comparison of training modalities for performing laparoscopic radical prostatectomy: experience with 1000 patients.** *J Urol* 2005, **174**:673–678.

10. Poulakis V, Dillenberg W, Moeckel M, et al.: **Laparoscopic radical prostatectomy: prospective evaluation of the learning curve.** *Eur Urol* 2005, **2**:167–175.

11. Watson D, Baigrie R, Jamieson G: **A learning curve for laparoscopic fundoplication: definable, avoidable, or a waste of time.** *Ann Surg* 1996, **224**:198–203.

12.•• Maniar H, Council M, Prasad S, et al.: **Comparison of skill training with robotic systems and traditional endoscopy: implications on training and adoption.** *J Surg Res* 2005, **125**:23–29.
A very thorough comparison of learning curve using conventional laparoscopy and robotic interface.

13. Korndorffer J, Dunne B, Sierra R, et al.: **Simulator training for laparoscopic suturing using performance goals translates to the operating room.** *J Am Coll Surg* 2005, **201**:23–29.

14. Moorthy K, Munz Y, Dosis J, et al.: **Dexterity enhancement with robotic surgery.** *Surg Endosc* 2004, **18**:790–795.

15. Darzi A, Smith S, Taffinder N: **Assessing operative skill.** *Br Med J* 1999, **318**:887–888.

16. Ramsay C, Grant A, Wallace S, et al.: **Assessment of learning curve in health technologies.** *Int J Technol Assess Health Care* 2000, **16**:1095–1108.

17. Datta V, Mackay S, Mandalia M, Darzi A: **The use of electromagnetic motion tracking analysis to objectively measure open surgical skill in the laboratory based model.** *J Am Coll Surg* 2001, **193**:479–485.

18.•• Martin J, Regehr G, Reznick R, et al.: **Objective structured assessment of technical skills (OSATS) for surgical residents.** *Br J Surg* 1997, **84**:273–278.
This paper explains the current gold standard for assessing learning curve and details future developments in technology for assessing learning in surgery.

19. Sarle R, Tewari A, Shrivastava A, et al.: **Surgical robotics and laparoscopic training drills.** *J Endourol* 2004, **18**:63–66.

20. Garcia-Ruiz A, Gagner M, Miller J, et al.: **Manual versus robotic assisted laparoscopic surgery in the performance of basic manipulation and suturing tasks.** *Arch Surg* 1998, **133**:957–961.

21. Yohannes P, Rotariu P, Pinto P, et al.: **Comparison of robotic versus laparoscopic skills: Is there a difference in the learning curve?** *Urology* 2002, **60**:39–45.

22. Prasad S, Prasad S, Maniar C, et al.: **Surgical robotics: impact of motion scaling on task performance.** *J Am Coll Surg* 2004, **199**:863.

23. Obek C, Hubka M, Porter M, et al.: **Robotic versus conventional laparoscopic skill acquisition: implications for training.** *J Endourol* 2005, **19**:1098–1103.

24. Nio D, Balm R, Maartense S, et al.: **The efficacy of robot-assisted versus conventional laparoscopic vascular anastomoses in an experimental model.** *Eur J Vasc Endovasc Surg* 2004, **27**:283–286.

25. Sung GT, Gill IS: **Robotic laparoscopic surgery: a comparison of the Da Vinci and Zeus systems.** *Urology* 2001, **58:**893–898.
26. Jourdan I, Dutson A, Garcia T, et al.: **Stereoscopic vision provides a significant advantage for precision robotic surgery.** *Br J Surg* 2004, **91:**879–885.
27. Hanna G, Drew T, Clinch P, et al.: **Psychomotor skills for endoscopic manipulations: differing abilities between right- and left-handed individuals.** *Ann Surg* 1997, **225:**333.
28. Ahlering TE, Skarecky D, Lee D, Clayman RV: **Successful transfer of open surgical skills to a laparoscopic environment using a robotic interface: initial experience with laparoscopic radical prostatectomy.** *J Urol* 2003, **170:**1738–1741.
29. Patel V, Tully A, Holmes R, Lindsay J: **Robotic radical prostatectomy in the community setting. Learning curve and beyond: initial 200 cases.** *J Urol* 2005, **174:**269–272.