Robotics

Cutting edge for new generation pediatric surgeons

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Prologue

Since year 2000 when the da Vinci surgical system (Intuitive Surgical Inc) was approved by FDA, it dominated and was the most frequent published platform. After ZEUS Surgical System (Computer Motion Inc, CA) stopped, da Vinci is the only robotic system worldwide used and that is why in this thesis any robotic procedure always refers to Intuitive Surgical da Vinci system. Robotic systems for minimally invasive surgery (MIS) have arguably been the most dominant technological innovation to be introduced to pediatric surgery in recent years. A scenario of inadequate evidence was automatically imposed and still hasn't vanished as happens every time something new is introduced. Still, even from 2003, North American pediatric surgeons reported that 71% felt robotics would play at least an important role in the future, with 47% also reporting that a greater emphasis should be placed on robotic surgery training during residency (Schimpf 2003)

Nearly after 10 years of robot-assisted pediatric surgery, evidence is building up and despite the high cost more pediatric surgeons proceed to robotic assisted operations. Gradually more and more papers are being published involving mainly limited case series. Unfortunately randomized controlled trials are still lacking in robotic pediatric surgery. Nevertheless, we stand beyond the point of no return as pediatric surgery (PS) has moved to the minimal invasive era. Beyond dogmatic assumptions, robotic assisted surgery will be in the forefront.

Goal of this thesis is to briefly record and analyze current training programs for trainee pediatric surgeons and point out the lack of standarized validated training curricula.

Introduction

It was 1982 when real time high resolution video camera was developed to be attached to the endoscope that allowed clear magnified image of the operating field to be shown on a monitor.

From that time limitation to minimally invasive surgery was instantly shifted to the imagination and willingness of the surgeons. First laparoscopic cholecystectomy represented the breaking point that led to the modern era of minimal emergency surgery. Soon after laparoscopy became everyday practice even for major surgery such as colectomy, nephrectomy adrenalectomy and more.

Laparoscopy continued to advance even today as experience and skills continue to grow allowing surgeons to overcome previous contraindications and limitations.

Since then, the increasing usage of robotic surgery has been espoused and promoted in recent literature. It is not surprising, but no less impressive, that 1.5 million robotic surgeries have been performed throughout the world over the past decade or that 83% of prostatectomies were performed robotically in 2011 compared with just 17% only 6 years earlier (Intuitive Surgical, 2015). In the few years following 2007, the number of robotic-assisted procedures nearly tripled worldwide from 80.000 to over 200.000. The number of da Vinci robotic surgical consoles grew 75% between 2007 and 2009 (from 800 to 1,400 in the US and from 200 to 400 abroad). In 2014, total US procedure volume was approximately 449.000, of which 20% was in urology, 52% was in gynecology, and 24% was in general surgery. International procedure volume was ∼121,000 in 2014, of which most procedures were in urology (Ahmed K 2013).

Reaching 2019 when according to Intuitive Surgical Inc annual report, more than 1.229.000 robotic procedures were performed, a 18% increase compared to 2018, with more than 1.119 da Vinci surgical systems shipped all over the world.

New technology new techniques make it clear that gross adoption and implementation of those respectively is associated with more complications and devices failure. Thus, it becomes imperative to minimize this risk first by identifying the causes, and of course by increasing surgical skills to ensure proficient surgical skills and patient safety.

History of Minimal Invasive Surgery

From the 400BC of Hippocrates when a primitive anoscope was used to examine hemorrhoids and the ruins of Pompeii (AD 70) when a three bladed speculum was used similar to one used today, fifteen centuries passed without a major advance. Until 1585 when Tgulio Caesare Aranzi projected sunlight into the nasal cavity through a flask of water.

Two hundred years later, the first endoscope with a light source was produced in 1806 by Philip Bozzini. His revolutionary development involved a series of mirrors to reflect light from a burning wax candle inside an aluminum device to the point of focus. His tool, which he termed the Lichtleiter (light conductor) was used as a cystoscope and vaginoscope and is considered to be the first true endoscope.

The concept of image projection on a screen would unlock the vast potential of minimally invasive surgery. At that time Pierre Salomon Segalas introduced the urethro-cystique (a cystoscope), a variation of Bozzini's instrument, to the Académie de Sciences in Paris in 1826. Simultaneously, the American John Fisher was using a similar instrument clinically for vaginoscopy in Boston. His development was driven by the necessity to evaluate the cervix of shy young women for whom standard exposure would be traumatic.

At mid1800s a French surgeon named Antoine Jean Desormeaux began using a technological modification of the Lichtleiter for urologic procedures. In 1868, Adolf Kussmaul viewed the esophagus and stomach of a professional sword swallower, being much likely the first esophagoscopy. However, endoscopy was advanced more substantially by Johann Mikulicz, a surgeon in Vienna with a keen interest in the treatment of gastric cancer. He began performing clinically useful esophagoscopy in 1881 on an attempt to discover gastric tumors at an earlier stage. In 1901, the first experimental laparoscopy was performed in an animal model. A German surgeon, George Kelling, made a small incision in the abdomen of dogs, insufflated the peritoneal cavity with sterile air, and investigated the abdomen with a cystoscope. He created the term coelioskope for his visionary procedure. Although his work found little support, his research established the importance of a sterile pneumoperitoneum to allow visualization, an anchoring principle for future laparoscopy (Shawn P 2009)

The first large case series on the clinical use of laparoscopy appeared in 1920. An internist from Chicago, B. H. Orndoff, described 42 cases of diagnostic peritoneoscopy. He described the use of a sharp pyramidal trocar for an access port. The next substantial step occurred in 1929 when Heinz Kalk, a German gastroenterologist, developed a 135-degree lens system and described the addition of a working port. He used laparoscopy effectively in the diagnosis of hepatobiliary disease. Ten years after his invention, demonstrating remarkable confidence in his instrumentation, Kalk published a series of 2000 liver biopsies under local anesthesia without any mortality. During this time, in 1934, John C. Ruddock, an American internist, claimed laparoscopy to be a diagnostic technique superior to laparotomy. His work produced an important instrument in modern minimally invasive surgery, forceps with electrocoagulation capacity. Another modern tool of laparoscopy was introduced in 1938 when Hungarian Janos Veress developed a spring-loaded blunt-tipped needle for draining ascites and evacuating fluid and air from the chest. His innovation was used to create a therapeutic pneumothorax for tuberculosis. Although he did not foresee application of this tool in minimally invasive surgery, the Veress needle has become an indispensable instrument for many laparoscopic surgeons. Although the device was, and still is, considered unsafe by some surgeons, an alternative approach, using the cut-down technique, would later be published in 1971 by H. M. Hasson, a gynecologist in Chicago.

In 1944, Raoul Palmer used an umbilical port with insufflation and a rigid optic lighting system. Notably, his patients were placed in the Trendelenburg position to facilitate a view of the pelvis by passively allowing air into this space. Palmer monitored the intra-abdominal pressure during the procedure. Concepts that are now known to be important to modern laparoscopy. The technical key that unleased Pandora's box was in 1982 when a real-time, high-resolution video camera was developed that could be attached to the endoscope. This miniature electronic camera (4 ×4 mm) had a charge-coupling device (CCD) that could convert the incoming optical image into electrical impulses that be sent to a monitor, a recording device, or elsewhere. This development allowed a clear magnified image of the entire operating field to be shown on a monitor.

Five years after this critical innovation, the revolution in minimally invasive surgery began. The first laparoscopic cholecystectomy was reported in 1987 by Philippe Mouret in Lyon, France.

Since then, MIS experienced great advancement. The presentation of robotic surgical systems in late 90's really pushed the technical limits of laparoscopy.

History of robotics in pediatric surgery

The first case of robotic minimally invasive surgery in children was a Nissen fundoplication that was published in April 2001 (Meininger DD 2001). Since then robotic procedures have been tentatively adopted by selected pediatric surgical specialists. In the following decade, there were a total of 2393 procedures reported in 1840 patients in the published literature. The most common gastrointestinal and thoracic procedures were fundoplication (424) and lobectomy (18), respectively. Pyeloplasty was the most common procedure overall (672). Of the 137 reviewed publications, 122 (89%) utilized the da Vinci Surgical System (Intuitive Surgical, Inc.), making it by far the most prevalent and most studied robotic platform (Cundy TP 2013). In comparison, there were over 400,000 procedures performed in adults on the da Vinci system in the last year alone. Thus, adoption of robotic surgery is decidedly less common in the pediatric surgical specialties relative to the adult surgical disciplines

In general, wide adoption and implementation of the robotic platform occurs despite the high costs and until now quite uncertain benefits (Li H 2014). Except from the numerous technological innovations and advantages of the robot, local competitive pressures may be a motivation for many hospitals to purchase a robot. Contrary to adult medical facilities, Children Hospitals have been much slower in embracing the surgical robot. Some don't even have one and some others borrow them from the adult operating room within the same hospital (De Lambert G 2013).

What is not uncertain as far as the robotic console is concerned are all these technological features that improve dexterity, motion scaling, tremor filtration, optical magnification up to x10, stereoscopic vision, operator controlled camera movement, elimination of fulcrum effect compared to laparoscopic surgery (Kant AJ 2004,Chandra V 2006).

Added the wristed instruments used that provide 7degree freedom allows the surgeon to be more precise as if in ''open" fashion.

By all these technical abilities it seems that robotic MIS can be optimal for small operative fields in most challenging reconstructive procedures in neonates, infants and toddlers, where delicate tissue handling and intracorporeal suturing is required. However, its technical requirements can make it problematic or even nor feasible for small size patients. Necessary distance between ports, optics diameter of 8-12mm are too big for narrow intercostal spaces and instruments of 8mm reduce the ergonomic efficiency. In addition to this, limited variety in 5mm instruments make it is clear that current robotic platform is disincentive for the use in small children and therefore limits the use in pediatric population even if we put aside the high purchasing and running costs.

But despite the drawbacks, an increasing number of pediatric surgeons and urologists are adopting robotic technology and use the platform to assist in several surgical procedures

Current status of robotic minimal invasive surgery (RMIS)

Current use in pediatric surgery and especially in urology is increasing especially in North America and Europe since most surgeries are considered reconstructive. I summarize most common procedures where the robot is used.

Pyeloplasty

Ureteropelvic junction obstruction (UPJO) is one of the most common congenital anomalies that is present in nearly 1:2000 live births.The gold standard intervention for UPJO is the Anderson-Hynes dismembered pyeloplasty, traditionally performed with an open flank approach. Laparoscopic pyeloplasty (LP) was first described in 1995 and subsequently shown to be a safe and effective minimally invasive treatment option for UPJO. However, conventional laparoscopy, due to the need for intracorporeal ureteropelvic anastomosis has a steep learning curve, which makes it technically challenging for many surgeons. Conversely, the robotic platform enhances the laparoscopic approach by providing several advantages, including high-resolution 3D view and enhanced dexterity. As such, utilization of robot-assisted laparoscopic pyeloplasty (RALP) has increased steadily since the initial case reports published in 2005 (Mon MF 2013). Since then, RALP has been shown to have sufficient outcomes. A 2011 article from Minnillo et al. showed a 96% success rate at a median follow-up of 31.7 months (Minnillo BJ 2011). A meta-analysis performed by Cundy et al. found no difference in success rate between RALP, LP, and open pyeloplasty (OP). This meta-analysis included 12 observational studies with a total of 384 RALPs, 131 LPs, and 164 OPs. The cumulative success rate among studies was 99.3% for RALP and 96.9% for LP, with no significant difference detected between the two groups. A more recent multicenter study included 407 pediatric patients treated with RALP and found an overall complication rate of 13.8%. Most of them being low grade Clavien–Dindo (CDG) I or II (8.8%). The remaining complications were grade III, (4.9%) and there were no grade IV or V (high-grade) complications. (Dangle PP 2016)

However, RALP for infants still remains in its early stages and further randomized studies are needed to validate the use of this approach for smaller patients.

Partial Nephrectomy and Nephroureterectomy

Renal benign diseases, such as atrophic kidney, multicystic dysplastic kidney, and renovascular hypertension, often require a nephrectomy which can be easily accomplished with conventional laparoscopy. Robot-assisted nephrectomy or nephroureterectomy has been described and reported by some study groups (Bansal D 2014). The robotic approach is clearly feasible, but whether the robot offers a real advantage is still questionable. Nephrectomy and nephroureterectomy do not belong to reconstructive procedures, and there is no high risk of harm to adjacent structures such as in the heminephrectomy. Therefore, the use of the robot for those cases mostly depends on local financial settings and the availability of the robotic system.

Ureteral Reimplantation

The ideal management of vesicoureteral reflux (VUR) is to protect the upper urinary tract in patients who fail conservative measures. In an effort to reduce morbidity, treatment options, which are less invasive than the standard ureteral reimplantation, have been developed. As a consequence, the total number of surgical procedures has dropped during the last decade. Recently, with the advent of robot-assisted laparoscopic ureteral reimplantation (RALUR), the surgical approach has been revisited, leading to a latest increase in utilization. RALUR is usually performed through a transperitoneal, extravesical approach, mimicking the Lich-Gregoire procedure. This technique offers several advantages, such as decreased postoperative narcotic pain requirements and shorter length of stay. Since RALUR was first described by Peters in 2004, an increasing number of extravesical cases have been reported. A review by Savio and Nguyen showed that the overall surgical success rate of open ureteral reimplantation exceeded 95%. (Savio LF 2013) Therefore, as a surgical treatment option for VUR, the open approach remains the gold standard. Conversely, a review by Baek and Koh showed VUR resolution rates after RALUR ranging between 77% and 100%. (Baek M 2017) This variability in success rates may be attributed to case selection and surgeon’s learning curve. The major complications after RALUR were found to be urinary retention and ureteral injury due to obstruction or leakage urinary retention being the most common one. (Gundeti MS 2017)

Although it remains unclear whether the robotic approach reduces the morbidity associated with a ureteral reimplantation, there is evidence that RALUR is associated with a shorter hospital stay and reduced need for narcotic pain medications. Further studies are needed to identify specific patient populations that experience the greatest benefit of RALUR over alternative approaches. (Boysen WR 2018)

Kidney Stone Surgery

The wide availability and efficacy of endourological techniques have largely replaced open surgery for the treatment of renal stones. Recently, by gaining experience with robotic surgery in urology, the principle of open renal surgery is being revisited. In selected cases, robot-assisted pyelolithomy may be an excellent alternative to percutaneous nephrolithomy. This minimally invasive approach is ideally suited for synchronous renal reconstructive procedures as well as primary treatment of various renal and ureteral stones in patients with complex anatomy. This is best suited for large renal pelvic stones, partial staghorn stones, or complete staghorn stones. Until now, there is no strong evidence on the utility of robotic surgery for the treatment of renal stones in pediatric population since there is only available for the adult patient. (Madi R 2018)

Mitrofanoff Appendicovesicostomy

Mitrofanoff was the first to describe the principle of using the appendix as a continent cathetarizable channel in patients with neurogenic bladder (Mitrofanoff P 1980). Traditionally, Mitrofanoff appendicovesicostomy (APV) was accomplished with an open surgical approach, and to date it remains the most performed technique on these patients. As discussed above, RALS has shown to be safe and effective in infants and toddlers. Therefore, many pediatric surgeons and urologists are following the trend with increasing comfort and are now performing more complex procedures, including reconstructive surgery of the upper and lower urinary tracts. Pedraza et al 2004 were among the first to describe their successful experience with robot-assisted laparoscopic Mitrofanoff appendicovesicostomy (RALMA) in a7-year-old boy, born with posterior urethral valves. The authors performed the procedure in 6 hours, with an estimated blood loss (EBL) of 10 mL and no intraoperative complications.

Accordingly, Famakinwa et al. reported good outcomes in 18 patients undergoing RALMA. At a median follow-up of 24 months, 17 patients (94%) were continent. The overall rate of complications was17%, with 2 stomal stenosis and 1 parastomal hernia (Famakinwa OJ 2013). A more recent study by Gundeti et al., including multiple institutions, evaluated perioperative and functional outcomes of 88 patients undergoing RALMA (Gundeti MS et al 2016). Postoperative complications occurred in 26patients (29.5%), of which 11 (12.5%) required surgical revision. Overall, 75 patients (85%) were continent at a median follow-up of 29.5

months. In contemporary open series on Mitrofanoff, functional outcomes appeared comparable to RALMA, with revision rates ranging from 9% to 32%, and long-term stomal continence, stomal stenosis, and stomal revision rates being 91%–98%, 8%–10%, and 16%–24%, respectively (Veeratterapillay R 2013- Harris CF 2000).

Bladder Augmentation

Bladder augmentation is indicated in the management of patients with impaired bladder function secondary to neurogenic bladder or, less often, to non-neurogenic voiding dysfunctions, posterior urethral valves, Prune-Belly syndrome, and bladder exstrophy complex. Traditionally, this procedure was accomplished with an open approach, which is still considered the gold standard. As every major procedure, open augmentation ileocystoplasty (OAI) is characterized by long LOS and high rates of postoperative complications. In the available literature on OAI, LOS ranges between 9 and 14 days, and almost 15% of patients had a prolonged postoperative course due to ileus or urinary leak (Flood HD 1995). As discussed in the previous paragraphs, pediatric surgeons and urologists have started to push the envelope by using the assistance of the robot, even for more complex and technically challenging procedures, such as reconstructive surgery of the bladder. Early in 2008, Gundeti et al. reported their first successful robot-assisted laparoscopic augmentation ileocystoplasty (RALI) and APV. Murthy et al., in a large series published in 2015, compared RALI to the conventional OAI. The authors reported significantly longer OT and shorter LOS for the RALI cohort. The mean EBL, bladder capacity increase ratio, and narcotic use did not differ between the two groups. With a similar median follow-up, bladder stone formation and complication rates between RALI and OAI were similar (Gargollo PC 2015). Despite the high complications rate, OAI has proved to be a safe approach and remains the gold standard in these patients. However, RALI not only offers cosmetic advantages but also results in shorter LOS and decreased postoperative pain. Nonetheless, the complexity of this technique has limited the widespread adoption of the robotic approach.

Pediatric general surgery

As in adult surgery, inguinal hernia repairs are common place in pediatrics, although they are performed usually through a smaller open inguinal incision. The pediatric laparoscopic hernia repair is also far less involved than its adult counterpart and does not use a mesh, making robotic assistance an unnecessary technical addition in its current format.

Other more complex procedures have been carried out robotically.

Fundoplication

A meta-analysis in 2014 reporting outcomes of 297 children (Cundy TP 2014) found that despite a tendency towards conversion to open surgery in the laparoscopic fundoplication (LF) group (6.1% vs 3%), there was no significant difference in postoperative complications (RF 8.9% vs 8% LF) found. In one study the most common complication in the RF and LF was a tight wrap, requiring dilatation (8% and 6%), whereas in the open series

Hepatobiliary surgery

HPB surgery in children inevitably involves intricate and demanding MIS procedures. Choledochal cyst excision and reconstructive Roux-en-Y hepaticoenterostomy are technically complex and, with the exception of hospitals in South East Asia, open procedures are still relatively prevalent (Liem NT 2012). The laparoscopic technique often involves extending the umbilical incision to allow extra-corporeal anastomosis. Meehan et al describe a robotic approach outlining how additional degrees of freedom offered by the robot conferred a real advantage; a view shared by others with experience in the area (Meeham JJ 2007). This approach has also been repeated in small infants (<10kg) (although they use an extracorporeal anastomosis) and by the same group in a larger series (Dawrant MJ 2010); within this series they con-verted 19% of their cases, although only 1 patient had any complications (Alizai NK 2014). A similar rate of conversion is also seen in another case series (Chang EY 2012), which also used extracorporeal anastomosis for the Roux-en-Y loop. Recent evidence, however, suggests that laparoscopic Kasai portoenterostomies may have significantly worse outcomes than an open approach. This may reduce enthusiasm for further robotic work (Hussain MH 2017). Robotic-assisted cholecystectomies and splenectomies are relatively prevalent in the literature (Cundy TP 2013, Al-Bassam 2010). However, all authors emphasise that although these are useful training opportunities in the robot platform neither robotic-assisted splenectomy nor cholecystectomy seem to offer additional benefit over the laparoscopic approach. Indeed, there is no comparative research in the field. There are also case reports and series that document a diverse array of successful robotic general and gynaecological surgery such as robotic-assisted diaphragmatic hernia repair (Meehan JJ 2007-2008). Heller's cardiomyotomy for achalasia (Chaer RA 2004, Altokhais T 2016), duodenojejunostomy for SMA syndrome (Bütter A 2010), repair of duodenal atresia, anorectal pull-through for anorectal malformations, ovarian cystectomies and salpingo/oophorectomies (Nakib G 2013). Further study is needed to assess whether these procedures are indeed effective and whether they confer any benefit above traditional minimally invasive surgery (MIS).

Mediastinal

RATS has limited further examination in current literature. The largest series reports on 11 cases including mediastinal cyst excision, diaphragmatic hernia repair, Heller's myotomy, oesophagoplasty and oesophageal atresia repair via RATS. There were several conversions to open surgery in neonatal patients (Ballouhey Q 2015). As we mentioned before, the small neonatal thorax represents the greatest obstacle in adapting the large 5 or 8mm instruments of most robotic platforms into pediatric surgery, RATS seem only appropriate in patients with a weight >20kg.

Pediatric oncologic robotic surgery

Pediatric oncological surgery despite widespread use of MIS in adult oncological surgery and in non-oncological pediatric surgery, open surgery is the usual standard of care for resection of pediatric solid tumours. Pediatric oncological MIS and robotic assistance is a relatively recent development that is lacking high-level evidence, although there is a wide range of case literature (Van Dalen EC 2015, Chan KW 2007). There is a debate as to whether the fundamental oncological principles of no tumour spillage and clear surgical margins can be accomplished by robotic-assisted surgery; argument based on the absolute lack of haptics having an impact on the surgeon's ability to differentiate cancerous from healthy tissue. However, others have shown that loss of tactile feedback is very well compensated by the excellent optical system'. Cancer patients are necessarily followed up for recurrence and only prospective long-term studies of robot resections can give assurances of robotic adherence to oncological principles (Anderberg M 2008).

Training in robotics

While the complexicity of surgical techniques is increasing and the utilization of robotic surgical technology has experienced rapid growth in many parts of the world and across many specialities, training and credentialing of surgeons actually remains in embryonic state. Assisting robots for surgery are not just some new tools in the operating theatre. It is an evolutionary step that has new challenges for the novice surgeon, for example the detachment of the surgeon from the patient and loss of haptic effect. Young trainees and even experienced laparoscopic surgeons need time to adopt to new technology and new tasks, robot docking, instruments usage and exchange, unexpected platform malfunction etc. Those challenges need to be overcome with well-structured training programs. For now, lack of standarized global training curriculum causes serious disparity in the quality of robotic training and differs by trainee location and speciality.

Learning curve - current training modalities

This repeated task that make us improve was first described by German psychologist Herman Ebbinghaus and later, Bryan and Harter in 1909 called it learning curve. This curve has an initial phase of slow learning that is followed by a steep rise as this represents the phase of quick learning until it reaches a plateau which corresponds to expertise. Further progress afterwards is always slower and difficult.

What is really awesome in robotic surgery is that there are big differences in the learning curve of various operations in several publications. For example, the learning curve for robotic assisted laparoscopic radical prostatectomy (RALRP) varies from 8-150 operations (Herrell SD 2005).

This wide variability is due to the lack of standard definition of the appropriate outcome measure. In other words, the end point. For example, in a recent publication the mean operation time (OT) for RALRP reached a plateau (4h) after 750 operations but took 1600 operations to reach a positive surgical margin rate of <10% (Sooriakumaran P 2011). On the contrary for much complex procedures as robotic assisted radical cystectomy the International Radical Cystectomy Concortium reported a mean of only 30 procedures needed to reach standard endpoints of OT, node counts and positive surgical margin rate (Hayn MH 2010).

Traditionally, the approach to training in robotic surgery usually begins from attending a training course to become familiar with the set-up of the system and to learn basic tasks, such as the safe manoeuvring of instruments, suturing and knot tying. Meanwhile, observation of several procedures and studying of fully videotaped operations is recommended. After this preclinical stage the trainee accompanies the procedure as a bed-side assistant before starting to perform entire procedures (or at least major parts) under the supervision of the mentor. Consequently, the early cases take usually significantly longer time than the desired 3–4 h OT and only highly selected patients are appropriate. After this initial period the surgeon is usually left to perform the procedures alone, with more or less frequent input by the mentor (Orvieto MA 2012, Kaul SA 2006)

Other institutions follow a more modern approach. That of following the concept of parallel learning. The underlying principle is that the procedure is divided into different steps, which need to be practiced repeatedly until the operator is proficient. However, the essential clarification is to specify the relative difficulty of each step and to define a sequential order of training, which should be strictly followed in a structured mentoring program (Dev H 2012). This allows sequential learning, following complexity rather than the linear order of the surgical procedure. In addition, trainees can begin practicing the several simpler surgical steps of the operation before proceeding to the more difficult parts, which themselves can be trained in parallel again. Once the trainee is proficient in all steps and can perform them in a timely manner, they can be put together and the whole procedure can be performed. According to the author's personal experience, such parallel learning, going from easy to difficult, can considerably accelerate the learning process (Bach 2014).

In the case of Pediatric robot-assisted minimally invasive surgery, there are many unique considerations that demand dedicated training opportunities in addition to generic specialty non-specific training resources that are emerging. Some examples of factors that deserve focused training in this field are the numerous operative indications that occur exclusively or predominantly in children, adaptation strategies for widely varied patient ages and sizes, and emphasis on reconstructive rather than extirpative surgical techniques (Orvieto MA 2012, Camps JI 2011). At present, there is no standardized validated training curriculum for pediatric surgery or urology that has been adopted.

A proper curriculum should be composed of theoretical knowledge (cognitive skill), the practical part (tactile skill) and the nontechnical skills which is mainly communication and team building.

A curriculum framework described by Chitwood et al seems to be a nice example of an approach to training. This educational model involves a 2-stage process that consists of preclinical and clinical phases. It was implemented at the original international training center for robotic surgery and has been replicated by many others since (Chitwood WR 2001, Lee JY 2011).

One of the best tools currently available for robotic training is surgical simulation. Simulators allow trainees to practice basic but transferable skills in a safe and controlled environment (Seymour NE 2002). Simulator training should dominate in the preclinical stage even if currently there are not in abandance.

Live simulators

There are numerous courses with inanimate exercises to be used by trainees to improve basic robotic skills, mainly dexterity and instrument control. Most important in these dry lab courses is the presence of external controls and proctoring feedback for surgeons to improve over time. Dulan et al validated a robotic curriculum simulation based on Fundamentals of Laparoscopic Surgery approach (Dulan G 2012). Arain et al used this model with 55 trainees and demonstrated significant improvement in performance as well as feasibility and reliability. Main drawback was the requirement of a robotic console and instruments (Arain N 2012)

Wet lab with animal or cadaveric subjects can be an invaluable training tool but they are currently expensive since they need a dedicated lab robotic console and expendables. Unlike open surgery or conventional minimally invasive surgery, all equipment items (instruments, staplers, clips and sutures) relating to robotic surgery are significantly more expensive and less transportable.

Apart from the high cost, there are inherent challenges in coordinating any practical training event in robotic surgery in addition to specific challenges in purposefully dedicating an event to the pediatric specialty.

The master-console based nature of existing robotic system means that only 1 person can actively be engaged with the master interface at any one time. This has a restrictive influence on the number of delegates that can be accommodated on a practical training event. Physical availability of more than one robotic system or virtual reality simulator is dependent on the available resources of the host institution or willingness of industry to support a training event with loan equipment.

The highest fidelity training resource will always involve the clinical da Vinci systems, although the fidelity of training tasks that they may be used for will evidently vary (e.g. simple abstract tasks, in vivo animal models, or cadavers). Assigning da Vinci systems for use in a training course or workshop obviously renders them unavailable for clinical use.

As an alternative, simulators are an excellent utility to make basic and intermediate level training more accessible and affordable.

Virtual simulators

Virtual simulators play a significant role in the learning curve of robotic surgery skills. Although robotic simulation is unsatisfactory to achieve a safe clinical practice alone, without doubt the positive role of virtual simulators is establish even from laparoscopic training. Seymour et al demonstrated that residents who were trained on a virtual reality platform were faster and less likely to cause injury during laparoscopic cholecystectomy compared to trainees who had only standard training.

Five simulator platforms are commercially available and these include the:

1) da Vinci Skills Simulator (Intuitive Surgical, CA)

2) dV-Trainer (Mimic Technologies Inc, WA)

3) Robotic surgical simulator "RoSS™" (Simulated Surgical Systems, NY)

4) SimSurgery Educational Platform "SEP-Robot" (SimSurgery, Oslo, Norway)

5) ProMIS Surgical Simulator (Haptica, Ireland, United Kingdom).

Although each has been validated to various extents, it is unclear which is more effective as a training and assessment tool. The costs for these simulators range from between 62,000-158,000USD (Buchs NC 2013, Abboudi H 2013, Hun AJ 2013)

The platform that gained popularity is the product of mutual effort of Intuitive Surgical and Mimic Technologies that created the Da Vinci Skills Simulator (dVSS). An Integration of the dv-Trainer software available on a "backpack" on the existing console that utilizes the hardware of the existing da Vinci console.

Hung et al demonstrated the validity of dVSS by studying 24 trainees on three exercises performed on ex vivo animal tissue. He concluded that there was significant improvement in the simulator group compared with the control group. (Hung AJ 2012). Later also verified by Crochet et al (. Crochet P 2011)

For now, Intuitive Surgical company seems to have the most experience in providing robot assisted surgery training.

But, robot manufacturer dependence and the missing credentialing of the trainees makes new official training programs necessary. The FRS and the ERUS initiative are the two main candidates to become the gold standard in robot assisted surgery training. The FRS, inspired by FLS, tries to solve the puzzle of curriculum creation by training the basic skills needed for robotic assisted surgery and tries to be the lowest common denominator to gain basic proficiency levels for robotic assisted surgery. The FRS therefore is meant as one part that can be integrated into existing trainings. The creation of the curriculum resembles most of the prototypical approach described above. The ERUS initiative, European Association of Urology-Robotic Urology Section, the second main contender to become the gold standard for robot assisted surgery training, tries to solve it by a more individualized, broader approach by mixing dry and wet lab, virtual reality and a 12-week fellowship stage that ends in live surgery (Fisher 2015).

Another curriculum, the Fundamental Skills of Robotic Surgery (FSRS), again a simulation based 1-3week training course has been validated at Roswell Park Cancer Institute in New York. Consists of dry and wet lab hands-on-tasks and bedside troubleshooting, but without in course live surgical training. Even though it has been shown to be acceptable to trainees and has an educational impact (Stegemann 2013).

Even with these major projects in development further research is needed to optimize curriculum creation.

Nontechnical skills (team building)

Nontechnical skills are an important element of training. Most important of all is the team building/communication but is often neglected when forming a training curriculum even by very advanced surgeons (Benjamin T 2017).

According to Yule et al six core skills are required by surgeons to be able to operate effectively and safely:

1. Communication
2. Situation awareness
3. Decision making
4. Task management
5. Teamwork
6. Leadership

Studies have shown that even experienced surgeons often lack insight into their own nontechnical behaviour, fact that make them suboptimal evaluators for trainees.

Consequently, puts barriers to the implementation of nontechnical skills in surgical curricula (Yule S 2009)

According to the authors of fundamentals of robotic surgery program traits of team building and communication are vital for safety and effectiveness in operating teams.by forming a checklist preoperatively, intraoperatively and postoperatively allows the formation of a check list communication skills in a variety of scenarios (Seymour NE 2008)

Existing programs such as team stragedies and tools to promote performance and patient safety (teamSTEPPS) can be used, but regardless of the program, checklist is a vital team function and should be formulated.

As mentioned before, preclinical training should be followed by clinical phase training.

One of the first priorities in clinical phase training is getting familiar with every procedure. Obviously, some procedures are more complicated than others and each operation has

individual learning curve.

Simulators are very helpful as we analyzed before but since they are not in great numbers, most learning occurs in the operating theatre. Traditionally the absolute number of operations serves as a substitute for clinical proficiency. In the absence of global curriculum, in order to achieve a safe clinical practice every hospital follows their own curriculum. For example, Fantola et al after 1000 robotic operation and 12 years of experience developed a step by step training model. Using the dual console of da Vinci SI the learning surgeon performs a part of the operation as one scheduled step of his/her own training program. Robotic steps are either dissection or reconstruction and he classified 3 surgical levels. Basic, intermediate and advance level. For his clinic he chose robotic Roux-en-Y gastric bypass as a procedure in high volume with both dissecting and reconstructing steps (Fantola G et al 2014).

Similar protocols have been published each with its own individuality. But is there a way to evaluate the learning curve at a way that can be universal and work as a standarized training curriculum?

The truth is no and that is why there are various validated tools to evaluate open and laparoscopic surgical skills (Vassiliou MC 2005, Hogle NJ 2009). For example, GOALS has been developed to assess intraoperative laparoscopic skills and is validated for use in multiple laparoscopic procedures (Martin JA 1997, Gumbs AA 2007). Similar with this is the GEARS

(Global Operative Assessment of Robotic Skills). A tool that allow trainees to identify weaknesses and objectively monitor the training outcome.

Goh et al studied GEARS in 25 trainees and 4 experts in seminal vesicle dissection during 6-port robotic prostatectomy. By examining performance scores revealed that GEARS can distinguish residents by training year and novice from expert robotic surgeons. It proved to be an assessment tool for providing specific and structured feedback to allow trainees to focus in specific weak procedural steps (Fig 1.). Could be also used in a curriculum in preclinical simulator practice and transfer all improvements in the operating theatre (Goh et al 2012).

Global Evaluative Assessment of Robotic Skills (GEARS)

Trainee: **Date of Surgery:**

Evaluator:

Depth Perception

1	2	3	4	5
Constantly overshoots target, wide swings, sow to correct		Some overshooting or missing of target but quick to correct		Accurately directs instruments in correct plane to target

Bimanual Dexterity

1	2	3	4	5
Uses only one hand, ignores non-dominant hand,poor coordination		Uses both hands, but does not optimize interactions between hands		Expertly uses both hands in a complementary way to provide best exposure

Efficiency

1	2	3	4	5
Inefficiently efforts;many uncertain movements ;constantly changing focus or persisting without progress		Slow but planned movements are reasonably organized		Confident efficient and safe conduct, maintains focus on task, fluid progression

Force Sensitivity

1	2	3	4	5
Rough moves,tears tissue,injures nearby structures,poor control,frequent suture breakage		Handles tissues reasonably well,minor trauma to adjacent tissue,rare suture breakage		Applies appropriate tension,negligible injury to adjacent structures,no suture breakage

Autonomy

1	2	3	4	5
Unable to complete entire task,even with verbal guidance		Able to complete task safely with moderate guidance		Able to complete task independently without prompting

Robotic Control

1	2	3	4	5
Consistently does not optimize view,hand position or repeated collisions even with guidance		View is sometimes not optimal.Occasionally needs to relocate arms.Occasional collisions and obstruction of assistant		Controls camera and hand position optimally and independently.Minimal collisions or obstruction of assistant

Use of Third Arm

1	2	3	4	5
Consistently does not use it or does not use it well when required even with verbal guidance		Mostly used 3rd arm in a safe and efficient manner with moderate guidance		Consistently uses 3rd arm in a safe and efficient manner without prompting

Figure 1. GEARS. 5-point Likert scale with performance anchors at 1-3-5. Rating 1 corresponds to lowest level of performance

Conclusion

Undoubtly, within the bounbaries of a very brief thesis not every area of the working field can be deeply discussed. Maybe I was lost trying to be as short as possible. The main focus was to highlight the great evolution of technology in the field of surgery, record all current training programs in robotic surgery and stand out the lack of validated training programs especially for pediatric surgery and not only. Young surgeons should be able to improve from novice to expert level in open, laparoscopic and robotic surgery. During writing, it was frustrating to realize that in the current literature I could not find anything regarding pediatric surgery and training in robotics.

It is a reality that usefulness and significance of pediatric robotic surgeries differs from adults, since anatomic and physiologic differences make implementation harder. Even though there are still no randomized control trials to prove the benefit of robotics in pediatric surgery it is a matter of time for robotics to be established as in the adult population and see the same popularity.

It the near future, the evolution of robotic procedures and the entrance of new platforms will result in reduction or instrument sizes and improvement in haptic feedback both necessary for pediatric patients especially the newborns.

The pediatric surgical community should remain engaged, be ready and work in educational resources and training curricula since nowdays are poorly provided for pediatric robot assisted surgery. New technology, new platforms, applied augmented reality will probably lead not only to a minimally invasive evolution like now, but to a surgical evolution too.

Pediatric surgery should follow this great potential, create new surgeon generation by better training that will enable to improve surgical care in children.

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