# ROBOT SURGERY IN CHILDREN: WHERE WE STAND AND WHERE WE AIM

**Boia ES[1,2], Popoiu MC[1,2], Iacob RE[1,2], David VL[1,2]**

**Abstract**

Roboticsis the most advanced technology used in surgery nowadays. The international trend is towards the development of pediatric robotic surgery programs but as per novel technologies, there are still a lot of issues that must be solved. This study focused on the status of robotic surgery in children and over the issues that has to be address in order to make a pediatric robotic program feasible

**Key words:** robotic pediatric surgery, minimal invasive surgery, children

**Introduction**

First robotic minimally invasive surgery in children was reported in April 2001 (1). Since than an incising range of surgical procedures were performed in children, pediatric urological procedures being prevalent. Najmaldin et all 2007, Mehan et all, reported first large series. al 2008 (2, 3). Cundy et al. published a comprehensive meta-analysis of the robotic procedures in children in 2013 after a decade of robotic surgery in children (4). Until that date, they found over 130 studies and over 2300 pediatric robotic surgery procedures including genitourinary, gastrointestinal and thoracic procedures (4). Nowadays the international trend is towards the development of pediatric robotic surgery programs but as per novel technologies, there are still a lot of issues that must be solved.

This study focused on the status of robotic surgery in children and over the issues that has to be address in order to make a pediatric robotic program feasible.

**The Equipment:**

First robotic surgical systems were developed during the Nineties by two independent programs: Intuitive Surgical developing the daVinci System and Computer Motion developing the Zeus System. At the being of the 21st century, the two companies merged. While Zeus program was discontinued in 2003, the da Vinci program was approved for human use by the FDA in 2001 and was until recently the only robotic surgical system available on the market. Even though several models of the DaVinci System were developed since its introduction there are no special models designed for pediatric use. Even the current (XI model) has been a major improvement and has clear benefits over the former SI model (5); there are no specific futures or specially designed instruments for pediatric use (6). The system is composed of surgeon console, a vision cart and a patient cart. There are available 300 and 00 8 mm endoscope and a variety of 8 mm diameter surgical instruments. The major advantages of the robotic equipment over laparoscopy are the better visualization and magnification, tremor filtering and the instruments 7 degrees of motion range (7, 8, 9). Not to forget the improvement over surgeons comfort and fatigue during procedures (10). There drawbacks in pediatric surgery are mainly related to the size of the endoscope and the trocars, procedures in children less than 10 kg being currently very difficult, even impossible to be performed.

**Surgical team:**

Even though the basic principles of the surgery does apply in robotic surgery as well, the transition from open or laparoscopic surgery towards robotic surgery requires the acquisition of specific knowledge and skills. The surgical team includes a console surgeon, a scrub in assistant, a scrub in nurse and an anesthetist. Intuitive Surgical offer at the being of any robotic surgical program a training pathway for the console surgeon and the scrub in assistant that includes online training and certification, simulator training, clinical observershipp in a medical center with experience in pediatric robotic surgery followed by certification for both surgeons in a designated training center. The first procedures are to be made with the assistance of a proctor and for the following 90 days, the surgical team has to perform at least nine procedures. Learning curve has not yet been clearly defined most of the authors stating that 30 – 40 procedures are required to overpass it (11). It seems to be influenced by factors like proctoring, previous experience with minimal invasive surgery or adequate selection of cases to begin with (11, 12, 13). Strategies to reduce this learning curve are proposed. It has been proved that training in virtual reality increase the surgical skills of the surgeon and reduce the learning curve (14).

[1]"Victor Babeș" University of Medicine and Pharmacy, Timișoara – Department of Pediatric Surgery
[2] "Louis Țurcanu" Children's Emergency Hospital, Timișoara

E-mail: boiaeugen@yahoo.com, mcpopoiu@yahoo.com, radueiacob@umft.ro, david.vlad@umft.ro

**Costs:**

The main issue in making feasible a robotic surgery program are the costs. Compared to conventional and laparoscopic surgery there are higher acquisition costs for the equipment, instruments and consumables, high maintenance costs for the equipment and higher cost for anesthesia and for the use of operating room (15, 16, 17). Hospital stay and pain medication related cost were lower for the robotic surgery (15, 16, 17). Altogether the cost/ procedure is significantly higher for robotic procedures versus conventional and laparoscopic surgery and from an economical point of view, robotic surgery "may not make the cut" in pediatric surgery (18). The current debate is over the benefits of the robotic approach justify the higher costs. Unfortunately, this cost/ effectiveness has not been proved only for a few procedures like Pyeloplasty pelvic- ureteric junction obstruction (19, 20). This is mainly due to relatively small cohort of cases treated by the means of robotic surgery in the majority of pediatric medical conditions. However, there are a number of strategies to reduce the cost of robotic surgery in children and focusing on reducing the complication rate, reducing the OR time and the cost of anesthesia, reducing the maintenance cost/ procedure by increasing the number of procedures/ year (21). WE hope that in the nearby future competition on the producer market will increase and which will inevitably lead to lower prices for the consumables..

**Selecting the patients:**

Virtually all the procedures that could previously be done laparoscopically can be performed by means of robotic surgery. However, two main factors has to be considered when selecting the cases for robotic surgery:

1. Technical limitations of the equipment. The distance between the ports has to be at least 8 cm in order to avoid collision of the robotic arms. In addition, there has to be sufficient working space for the instruments inside the peritoneal or thoracic cavity considering that the current instruments available have 8 mm in diameter and the intra-abdominal section is slightly longer. This means that with current technology robotic surgery can be safely performed in children above 10 Kg and with a pubo-xyphoid distance of minimum 16 cm (3, 22). We hope that current technology will be upgraded soon and these issues can be overpass.
2. The pathological condition and the ability of the surgical team to perform the required surgical procedure. The international trend in pediatric robotic surgery was to perform surgical procedures with the robot only in complicate, very difficult cases mainly due to the high cost/ procedure. The common cases like cholecystectomy, fundoplication were left for cheaper conventional laparoscopic surgery (3). Unfortunately, this approach has a major drawback: there are simply insufficient cases for the surgical team to get sufficient experience. In addition, the potential of complication is higher for difficult cases. So probably, a safe approach at the beginning would be to perform also some easy cases as well as difficult procedures in order to get the sufficient experience and to consolidate the team (3).

Ultimately, the goal shall be patient's best interest and safety. The debate over advantages of the robotic surgery over laparoscopy or open surgery is still in progress mainly because of the lack of large series and meticulous comparative studies. For instance, there is evidence that robotic pyeloplasty is superior to laparoscopy or open surgery (18, 19, 20, 23, 24).

**Anesthesia:**

Robotic surgery requires general anesthesia with tracheal intubation (25). Special consideration to a large number of physiological modifications related to CO2 insufflation into the abdominal/ thoracic cavity, cardio-respiratory dynamics due to diaphragm elevation, increase duration of the procedure and the patient's position on the operating table should be consider (26). A systematic preanesthetic exam should be meticulous conducted over the renal, cardiac, respiratory and neurologic systems. Contraindication are related to cardiac malformations or impaired function (EF < 60%), Respiratory disease, hypertension, coagulopathy (25). Anesthetic technique usually involves intravenously induction and then carried out inhalatory (25). Adequate analgesia and muscle-relaxant must be provided. Nitrous Oxyde must be avoided due to gaseous distension effect over the intestine (26). Special attention should be considered over the position of patient and access to the airway, catheters and other monitoring devices during surgery. Due to the large space required by the patient cart and arms, there is limited access around the patient (25). In addition, changes in body temperature must be watched given the possibility of malignant hyperthermia reported in minimal invasive surgery (27). Monitoring of the following parameters is required: ECG, non-invasive blood pressure, pulse oximetry, capnography, inspiratory peak airway pressure, inspiratory oxygen, diuresis (25).

**Operating room setup and patient positioning:**

All three components of the da Vinci robot are large pieces of equipment with patient cart being almost 2 m tall and 900 kg in weight. The OR must accommodate also the anesthetic equipment, the table for instruments and there shall be enough space for the medical personnel to work around the patient. So first of all OR must be cleared from the unnecessary equipment and the OR table shall be carefully positioned before surgery. In addition, when the setup is done, other team should keep in mind that the robotic arms must have adequate clearance in regard not only to the patient but also to the OR table and in relation to the other robotic arms (28). Patient positioning on the table is directly related to the surgical procedure and usually extreme positions are used in order to obtain the maximum exposure to the surgical site: Trendelenburg or reverse Trendelenburg up to 200, lateral position (6). Trocar placement is usually done before putting the patient in the definitive position. As per XI model, the trocars are place in a quasi-straight line. After placement of the trocar, the

patient is rotated in the desired position and the patient cart is docked. No further movement of the patient/ table is allowed afterward (6).

**Surgical procedure:**

As stated above, virtually all procedures could be perform by the means of robotic surgery and no clear contraindication exists except for the general contraindications of minimal invasive surgery. The debate over some procedures have greater benefits for the patients when done robotically over laparoscopy is still in course. There is clear evidence that in certain procedures, especially in pediatric urology, the robotic approach is better (23). For other procedures the benefits of the robotic approach is not yet demonstrated, but what can be stated is that the results are at least as good as with laparoscopy (29). There is a wide range of surgical procedures that have be done with the help of the surgical robot in children (Table 1).

There is also the perspective of non-scheduled robotic procedures in children (31). Procedures like Meckel diverticulum excision, intestinal occlusion even esophageal atresia or duodenal atresia could be performed in selected case in less than 24h after admission (31). This possibility would significantly expand the use of the robotic in pediatric surgery.

| | | |
|---|---|---|
| **Gastro-intestinal** | Cholecystectomy | Ileocecectomy |
| | Fundoplication | Right colectomy |
| | Heller myotomy | Sigmoid colectomy |
| | Pyloroplasty | Total proctocolectomy with pull-through |
| | Adrenalectomy | Kasai portoenterostomy |
| | Neuroblastoma | Choledochal cyst |
| | Splenectomy | Duodenal anomalies |
| | Splenic cyst | Duodenal atresia |
| | Small bowel resection | Duodenal web |
| | Crohn's | Annular pancreas |
| | Enteric duplication | Ladd's procedure |
| | Meckel's diverticulum | Jejunal or ileal atresia |
| | Partial colon | Gastrotomy with foreign body retrieval |
| | Left colectomy | Congenital diaphragmatic hernia (Morgagni) |
| **Genital** | Ovarian cystectomy | Ovarian teratoma |
| **Reno-urainary** | Pyeloplasty | Mitrofanoff procedure |
| | Nephrectomy | Bladder neck reconstruction |
| | Hemi nephrectomy | Urethral diverticula |
| | Ureteral reimplantation | Urachal remnant |
| | Bladder diverticulectomy | Utricle |
| | Bladder augmentation | |
| **Chest** | Pulmonary resections | Tumors |
| | CCAM | Ganglioneuroma |
| | Pulmonary sequestration | Neuroblastoma |
| | Thymectomy | Ganglioneuroblastoma |
| | Cystic hygroma | Germ cell tumor |
| | Mediastinal masses | Teratoma |
| | Congenital anomalies | Esophageal atresia with tracheoesophageal fistula |
| | Bronchogenic cyst | Congenital diaphragmatic hernia (Bochdalek) |
| | Esophageal duplication | Eventration of the diaphragm |

**Table 1**. Surgical procedures performed with the robot in children (3, 4, 28, 29, 30)

**Discussions and conclusions:**

Besides being the „trendy" new thing in pediatric surgery, the surgical robot is a step forward in the field of minimal invasive surgery. Almost all pediatric surgical operations have been performed successfully with the robot and most of the studies found that robotic surgery enables better vision, superior dissection and suturing skills, better dexterity and access to places hard to reach for the conventional surgery. Unfortunately, current robotic systems are not without drawbacks for pediatric surgery, with instrument size and high cost being the most cited ones. Market competition would probably drive medical companies into further development of this technology. For instance, the development and use of single port robotic surgery may overcome the limitation of port placement in small children (32). Several international centers are currently involved in the development and implementation of this technology in children. There are also a number of other robotic platforms under evaluation by the European Medicines Agency and FDA: flexible robotic arms ore dedicated robotic systems for ENT, brain or spine surgery, miniature in vivo robots (33). Undoubtedly the answer for Thomas P. Cundy's question "Adopt now, await or dismiss?" is: adopt (34). The future of surgery is in technology and robotic technology is promising new spectacular dawns.

**Aknowledgment**

The project "Implementation of robotic surgery in pediatric patients" has been funded by the FondationBotnar www.fondationbotnar.org

**References**

1. Meininger DD, Byhahn C, Heller K, Gutt CN, Westphal K. Totally endoscopic Nissen fundoplication with a robotic system in a child. SurgEndosc (2001) 15(11):1360.doi:10.1007/s00464-001-4200-3
2. Najmaldin A, Antao B. Early experience of tele-robotic surgery in children. Int J Med Robot. 2007;3(3): 199–202.
3. Meehan JJ, Sandler A. Pediatric robotic surgery: a single-institutional review of the first 100 consecutive cases. Surg Endosc. 2008;22(1):177–82.
4. Cundy TP, Shetty K, Clark J et alA. The first decade of robotic surgery in children. J Pediatr Surg. 2013;48(4):858–65.
5. Wilson TG. Advancement of technology and its impact on urologists: release of the daVinci Xi, a new surgical robot. Eur Urol. 2014 Nov;66(5):793-4. doi: 10.1016/j.eururo.2014.05.026
6. Pelizzo G. Operating Room Setting and Robotic Instrumentation. In Mattioli G, Petralia P. Pedaitric Robotic Surgery. Springer International Publishing; 2017, p 15 – 23
7. Ng AT, Tam PC. Current status of robot-assisted surgery. Hong Kong Med J. 2014;20:241–50.
8. Moorthy K, Munz Y, Dosis A, Hernandez J, Martin S, Bello F, Rockall T, Darzi A. Dexterity enhancement with robotic surgery. Surg Endosc. 2004;18:790–5.
9. Byrn JC, Schluender S, Divino CM, Conrad J, Gurland B, Shlasko E, Szold A. Three-dimensional imaging improves surgical performance for both novice and experienced operators using the da Vinci robot system. Am J Surg. 2007;193:519–22.
10. van der Schatte Olivier RH, van't Hullenaar CDP, Ruurda JP, Broeders IAMJ. Ergonomics, user comfort, and performance in standard and robot-assisted laparoscopic surgery. Surg Endosc. 2009;23(6):1365–71.
11. Bach C, Miernik A, Schönthaler M. Training in robotics: The learning curve and contemporary concepts in training. Arab J Urol. 2014 Mar;12(1):58-61
12. Mason MD, Herndon CDA, Herbst KW et al. Proctor environment facilitates faculty training in pediatric robotic-assisted laparoscopic pyeloplasty. J Robotic Surg (2014) 8:365–369
13. Bowen DK, Lindgren BW, Cheng EY, Gong EM. Can proctoring affect the learning curve of robotic-assisted laparoscopic pyeloplasty? Experience at a high-volume pediatric robotic surgery center. J Robotic Surg (2017) 11:63–67
14. Calatayud D, Arora S, Aggarwal R, Kruglikova I, Schulze S, Funch-Jensen P, et al. Warm-up in a virtual reality environment improves performance in the operating room. Ann Surg 2010;251:1181–5.
15. Mahida JB, Cooper JN, Herz D, Diefenbach KA, Deans KJ, Minneci PC, McLeod DJ. Utilization and costs associated with robotic surgery in children. J Surg Res. 2015;199(1):169–76.
16. Bennett WE Jr, Whittam BM, Szymanski KM, Rink RC, Cain MP, Carroll AE. Validated cost comparison of open vs. robotic pyeloplasty in American children's hospitals. J Pediatr Urol. 2016 Dec;12(6):408.e1-408.e6.
17. Geller EJ, Matthews CA. Impact of robotic operativ eefficiency on profitability. Am J Obstet Gynecol (2013) 209(1):.e1–5.
18. Bruns NE, Oliver S. Soldes OS, Ponsky TA. Robotic Surgery may Not "Make the Cut" in Pediatrics. Front Pediatr. 2015; 3: 10.
19. Silay MS, Spinoit AF, Undre S et al. Global minimally invasive pyeloplasty study in children: Results from the Pediatric Urology Expert Group of the European Association of Urology Young Academic Urologists

working party. J Pediatr Urol. 2016 Aug;12(4):229.e1-7.
20. Bennett WE Jr, Whittam BM, Szymanski KM, Rink RC, Cain MP, Carroll AE. Validated cost comparison of open vs. robotic pyeloplasty in American children's hospitals. Robot Surg. 2016 Oct 20
21. Tedesco G, Faggiano FC, Leo E, Derrico P, Ritrovato M. A comparative cost analysis of robotic-assisted surgery versus laparoscopic surgery and open surgery: the necessity of investing knowledgeably. Surg Endosc. 2016 Nov;30(11):5044-5051.
22. Finkelstein JB, Levy AC, Silva MV, Murray L, Delaney C, Casale P. How to decide which infant can have robotic surgery? Just do the math. J Pediatr Urol. 2015 Aug;11(4):170.e1-4.
23. Boysen WR, Gundeti MS. Robot-assisted laparoscopic pyeloplasty in the pediatric population: a review of technique, outcomes, complications, and special considerations in infants. Pediatr Surg Int (2017) 33:925–935
24. Chan YY, Durbin-Johnson B, Sturm RM, Kurzrock EA. Outcomes after pediatric open, laparoscopic, and robotic pyeloplasty at academic institutions. J Pediatr Urol. 2017 Feb;13(1):49.e1-49
25. Disma N, Bonfiglio R, Montobbio G. Paediatric Anaesthesia in Laparoscopic and Robotic Surgery. In Mattioli G, Petralia P. (eds). Pediatric Robotic Surgery. Springer International Publishing Switzerland 2017, p 43 -52
26. Shah AB, Gundeti MS. Basic Principles of Robotic Surgery in P.P. Godbole et al. (eds.), Pediatric Endourology Techniques. Springer-Verlag London 2014, p 23-32
27. McHoney MC, Corizia L, Eaton S, Wade A, Spitz L, Drake DP, et al. Laparoscopic surgery in children is associated with an intraoperative hypermetabolic response. Surg Endosc. 2006;20(3):452–7. Epub 2006/01/25.
28. Mehan JJ. Pediatric robotic surgery. K.C. Kim (ed.), Robotics in General Surgery. Springer Science+Business Media New York 2014, p 339-361
29. Anderson JE, Chang DC, Parsons JK, Talamini MA.The first national examination of outcomes and trends in robotic surgery in the United States. J Am Coll Surg (2012) 215(1):107–14.
30. Howe A, Kozel Z, Palmer L. Robotic surgery in pediatric urology. Asian J Urol. 2017 Jan;4(1):55-67
31. Ballouhey Q, Fouracde L, Longis B et al. What are the prospects for non-scheduled robotic procedures in pediatric surgery? J Robotic Surg (2016) 10:117–121
32. White MA, Haber GP, Autorino R, Khanna R, Altunrende F, Yang B, Stein RJ, Kaouk JH. Robotic laparoendoscopic single-site surgery. BJU Int. 2010 Sep;106(6 Pt B):923-7
33. Peters BS, Armijo PR, Krause C, Choudhury SA, Oleynikov D. Review of emerging surgical robotic technology. Surg Endosc. 2018 Apr;32(4):1636-1655.
34. Cundy TP, Marcus HJ, Hughes-Hallett A, Khurana S, Darzi A. Robotic surgery in children: adopt now, await, or dismiss? Pediatr Surg Int (2015) 31:1119–1125

**Correspondence to:**
Vlad David
"Victor Babes" Universityof Medicine and Pharmacy
Timisoara, Romania
Phone: +40 757023237
Email: david.vlad@umft.ro