Robot-assisted Pediatric Surgery: experience of a single center and review of the international Literature.

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INTRODUCTION

Historical origin of the "robot" and curiosities

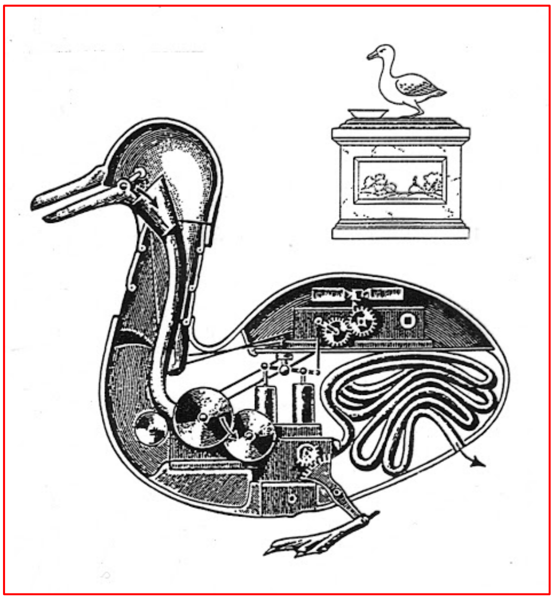
The idea of building a machine, able to replace some of the activities of man, is ancient: the origins can be found in Egyptian and Greek mythology.

The first "automata" (robot-like creature) described in "ancient" literature (1300 BC) can be considered the statue of Memnon, king of Ethiopia killed, according to Homer, by Achilles "the Pelis", and erected "majestic" on the banks of the Nile, which was activated by the rising of the sun and was able to emit sounds.

In Greek mythology, Hephaestus, the God of fire, of volcanoes, of all the artisans who worked metals, and of sculpture, was a very creative God; was known for creating automata and robots, also mentioned in Homer's Iliad, to make them work as slaves in his workshops, and for Talos, an invulnerable giant, "killer robot", entirely made of copper given as a wedding gift to Europa and Jupiter, her husband, and placed in the service of the king of Crete, Minos, with the task of protecting the island from enemies by throwing fiery stones.

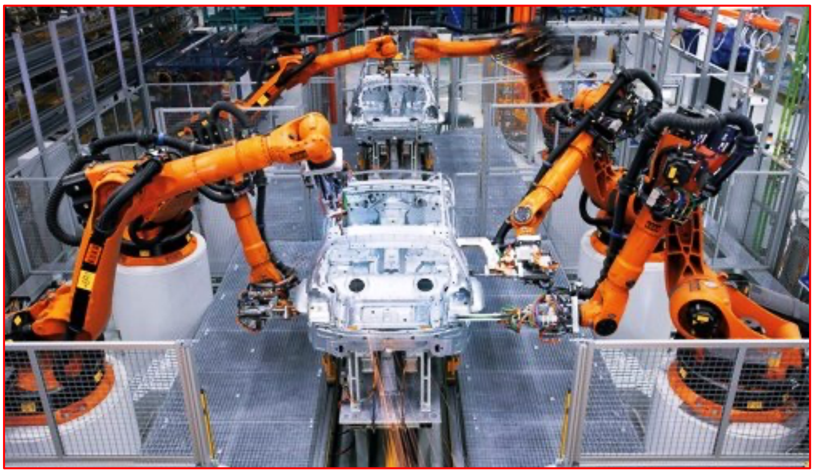
The ancient Greeks had a strong interest in technology, starting with Thales of Miletus (624 - 546 BC) philosopher, engineer, astronomer up to Aristotle, who was mainly interested in biology and zoology, but in the book of "Mechanics" reflects on what happens to art with the help of science, at the service of man. In the book of "Politics", however, he asserted how slavery is necessary to economically support cities and legitimized war as a tool to find slaves, adding that if each tool was able to work alone, and if the shuttle of a loom could weave alone, there would be no need for slaves.

Archite of Taranto (428 - 347 BC) was a mathematician and philosopher of the Pythagorean school, and he created a mechanical bird called "the Pigeon" powered by steam.



A few years later Ctesibius (285-222 BC), a Greek engineer, built a pipe organ and the first hydraulic clock with moving figures.
Also in other cultures of Middle-East there was the idea of creating moving machines or something near to the concept of a robot.
In the Jewish tradition, we speak instead of the "Golem", an anthropomorphic being, created from inanimate matter; and Adam himself, created in the image and likeness of God, points to man's ancient idea of creating humanoids. Before the real Renaissance, St. Albert the Great (1206 - 1380), created a bronze statue, able to speak for itself, while Leonardo Da Vinci, created a robot-humanoid, used in battles able to stand up, move the arms and neck (1).
Anymay the term "robot" comes from the Czech word "robota" which means slave, person subjected to forced labor, a term "used" for the first time by the writer Karel Čapek, in his play R.U.R. (acronym of *Rossumovi univerzální roboti*, translatable as "The universal robots of Rossum" 1920). At the origin of the historiographical plot, there is the discovery of the scientist-philosopher Rossum (rozum means "reason"), who finds the formula of that chemical substance that is needed to give life to matter. Rossum's grandson, an engineer, then decides to “use” the discovery to start the industrial production of automata. Thus he created the factory of "Rossum's Universal Robots", artificial beings destined to eliminate work from human life.

When robots, due to a design error, become too similar to men, they manage to rebel, they kill the holders of power and the formula that underlies their creation.
Passing from the Literature to the history, fifty years later, the first industrial robot becomes reality and in 1972, the Robot Institute of America defines the robot as "a multifunctional and reprogrammable manipulator, designed to move materials, parts, tools or specialized devices through variable programmed movements, for the performing a variety of tasks" (2). The industrial robot has therefore become, with the passage of time and the technological progress that has seen it protagonist of many innovations and evolution, the technological means of production par excellence in the most varied market segments; in fact, its use is now essential and of fundamental importance.
Currently, robotics research and application areas can be divided into different categories:
-Industrial robots, the first in order of application, are today widely used in all sectors of production. In fact, they make it possible to reduce production costs and times and to be able to modulate costs based on the necessary production volumes. In the field of industrial robotics there are manipulators for dozens of different applications, just to name a few: painting, assembly, cleaning, inspection, welding, assembly, handling, cutting, quality control, and detection; and the number of applications seems destined to increase with time and the autonomy achieved by these devices.



-Social robots identify a new application of robotics destined to be a tool for social interaction in the future. Once the security barrier has been eliminated, through an accurate series of standards and certifications, robots can become part of social life. To date, the development of social robots is still limited, ranging from some commercial examples to mostly experimental results. Robots for the game (the Sony Aibò, Mitsubishi Wakamaru, the Lego Mindstorm), for the cinema (animatronics) and assistance for the elderly (home automation), are now widespread. More recent research, on the other hand, are robots for artistic interaction, sport and music.

-In the medical field, the use of robotics is revolutionizing both surgical (Computer Aided Surgery) and clinical practice (physiotherapy, technological assistance). Over the last few years, various robotic systems have been designed and marketed to complete the minimally invasive surgery equipment, with robotic instrumentation capable of making the intervention process natural and intuitive. The Da Vinci (Intuitive Surgical) system, for

example, allows a surgeon sitting in a position close to the patient to operate as if his hands were really pliers inside the patient's body. A complex robotic system collects the movements of the surgeon's fingers and transmits them to a robotic system of minimally invasive surgery that operates on the patient's body. A stereoscopic camera system also allows the surgeon to see directly inside the patient's body. The system produces significant positive effects: it reduces recovery times, reduces complications due to post-operative infections, limits physical stress; however it requires a highly specialized medical team (3).
However if we want to understand how we reach the important milestone of robotic surgery, we have to know how the idea of minimally invasive surgery was born. Infact, the origins of robotic surgery are based on the "strengths" and "weaknesses" of its predecessors: laparoscopy.

Minimally invasive surgery: from laparoscopy to robotic surgery

The term laparoscopy derives from the Greek λαπάρα that is "abdomen" and σκοπέω "I observe", thus indicating the action of exploring the abdominal cavity, through a small opening in the wall.
The first attempts to explore the natural cavities of the body date back to the ancient Greek doctors, and in "representation" of all, to Hippocrates, who reported using a "speculum" to visualize and cut a rectal condyloma (4).
However, the origins of laparoscopy are traced back to the beginning of the last century, in particular to a German surgeon from Dresden, Georg Kelling, (1866-1945): interested in the anatomy and physiology of the gastrointestinal tract; at the beginning of the twentieth century he focused his attention on the problem of digestive bleeding, which at the time was fatal and not always clinically evident. The only method to establish a certain diagnosis and provide treatment was to perform an exploratory laparatomy, which, Kelling noted, often led to a worsening of the patient's condition. For this reason, he proposed a non-surgical solution to the bleeding problem: insufflation of high pressure air inside the abdominal cavity; a technique he called "Luffttamponade" (rear-end collision). It was then in 1901 that he performed the first laparoscopy which he called "coelioscopy" as a method for studying the reaction of internal organs to the pneumoperitoneum created by his "coelioscope" in the abdomen of a dog (5).
However, it was Hans Christian Jacobaeus (1879-1937), a Swedish physician, unaware of Kelling's research, who carried out a more extensive research using laparoscopy and who made the method famous. Professor of medical clinic (since 1916) at the Karolinska institute in Stockholm, he dealt for a long

time with Paget's disease and linked his name to studies on the therapeutic treatment of cavitary pulmonary tuberculosis using pneumothorax. This led to interest in thoracoscopic and laparoscopic procedures; his technical equipment was similar to that used by Kelling and consisted of a cystoscope that he used for both the thoracic and abdominal cavities and a special "trocar"; the "trocars" were and still are devices consisting of a "cannula" at the outer end of which there is an inlet valve for the gas and a retention valve that prevents it from escaping. This "cannula" is "inhabited" by a pointed or blunt-tipped mandrel, which allows the instrument to penetrate through the abdominal or chest wall. He published the first results in 1910 in the journal "Münchener Medizinischen Wochenschrift": in 17 patients with ascites, after local anesthesia on the abdominal wall, he inserted a "trocar" and, after having partially drained the liquid and blown filtered air, examined the cavity by inserting a cystoscope in a trocar; in 1912 he then specified how operations in patients with ascites were simpler and without complications, while in those without ascites the risk of intestinal damage was much higher (6).

Over the next 50 years, specific instruments were developed to allow accurate exploration of the peritoneal cavity: Richard Zollikofer, a Swiss gynecologist, (1924) instead of oxygen or filtered air, used CO2 to obtain pneumoperitoneum , by virtue of its rapid absorption and the minimum risk of "explosion" (7).

Heinz Kalk, German gastroenterologist and founder of the German school of laparoscopy, devised a system of lenses (1929) that allowed to have a better oblique vision at 135 °: up to that moment in fact some of the best endoscopes in circulation allowed an between 80 ° and 85 °; in the 1950s, however, he routinely introduced the use of the double trocar method, of which he is considered the founder. Currently several are used: the first "trocar" is used to create a "port", that is an access, into which a laparoscope is introduced, while a variable number between one and three additional "trocars" is used to create accesses for surgical instruments (scissors and forceps) or to drain liquids.

John Ruddock, an American physician from Los Angeles, in 1934 presented his first "peritoneoscope" which consisted of a fluid evacuator equipped with a valve that blocked air, a needle for pneumoperitoneum, a scalpel with sheath and obturator that acted from "trocar", a "Telescope" (14-inch, pre-oblique optics) and biopsy scissors. Ruddock borrowed the idea of combining biopsy scissors with a peritoneoscope from urologists. Thus he successfully obtained samples from different organs (the liver, spleen, stomach, omentum and peritoneum) (8).

In 1937 the Hungarian doctor Janos Veress developed an atraumatic needle for the introduction of gas into the abdomen, derived from a model previously used for pneumothorax; at the same time, the Parisian gynecologist Raoul Palmer recommended monitoring intra-abdominal pressure.

In the early 1960s, the use of the cold light source was introduced which would have greatly reduced the risk of intestinal burns from contact with conventional incandescent bright surfaces; then followed the advent of optical fibers and optical vision systems.

Thanks to the German gynecologist Kurt Semm (1927–2003), the boundary between diagnostic and surgical laparoscopy was crossed: in the 1970s he led a research team at the University of Kiel and began treating some pathologies with a laparoscopic approach. In this regard, he developed an automatic insufflation device, an instrument for irrigation and aspiration, one for thermocoagulation and laparoscopic scissors; he then described techniques for performing ovariectomy and myomectomy. One of his major contributions was the execution of the first laparoscopic appendectomy in 1983 (9).

Inspired by Semm's success, the German surgeon Erich Mühe was convinced of the possibility of performing a laparoscopic cholecystectomy: in particular collaborating with Hans Frost, employee of the German company WISAP, manufacturer of medical instruments, he developed the so-called "Galloscope" a unique instrument complete with optics, operative channels, light and valves capable of maintaining the pneumoperitoneum. With this, on 12 September 1985, within two hours, he performed for the first time a laparoscopic cholecystectomy, erroneously attributed to the French doctor Philippe Mouret who performed it only two years later (1987) at the Lyon hospital (10). The French experience continued at the end of the 1980s with the surgeon François Dubois of Paris, who, unaware of Mouret's surgery, performed, with great pride, a cholecystectomy through a mini-laparotomy. He shared his experience with the room nurse, Claire Jeaupitre, who was not surprised by the size of the engraving, which she had already seen performed by Mouret in Lyon.

Laparoscopic cholecystectomy (LC) was carried out by a third front in France, in Bordeaux: Professor Jacques Perissat used intracorporeal lithotripsy, introducing the instrument directly into the gallbladder and was fascinated by the idea of performing it alternatively or together with the LC.

The success of the French spread quickly and in 1989 Perissat presented the video of his operation to the American Society of Endoscopic Gastrointestinal Surgery (SAGES) in Louisville, Kentucky, attracting great attention.

Thus it was that the "Bordeaux School", which he founded, that began organizing refresher courses and helping to spread laparoscopic cholecystectomy throughout the world, making it the "Gold Standard" for the treatment of various organ pathologies (11).
From this moment on, the list of surgical procedures performed laparoscopically has grown considerably, hand in hand with technological innovations and the technical skill of the surgeons.
In a very short time, numerous studies have shown how this type of technique allows the patient a faster post-operative course, with less pain and earlier re-feeding, a considerable aesthetic advantage, provided by the minimal scars, and faster recovery times (12, 13).
Pioneering was the beginning of the use of laparoscopic surgery (MIS) in the early 1970s in Pediatric Surgery; and for more than two decades the "potential" of the minimally invasive approach was not exploited from a surgical point of view but only from a diagnostic point of view. Among the most important obstacles were the size of the instruments which required very large incisions and such as to prefer the execution of the intervention with the open technique (14).
Between the late 1990s and early 2000s numerous "innovators" emerged: Steven Rothenberg, pediatric surgeon, active for over 30 years in Denver, Colorado and considered one of the pioneers of MIS, Keith Georgeson, general and later pediatric surgeon at Spokane (Washington), George W. Holcomb for over 35 years pediatric surgeon in Nashiville, who passed away on June 28, 2019. They applied laparoscopic surgery in children and then even in newborns, obtaining good results in the treatment of atresia and esophageal achalasia, in execution of antireflux gastroplasty (funduplication), of extramucosal pyloromyotomy for hypertrophic stenosis of the pylorus, of the Ladd procedure in intestinal occlusions due to malrotation (15).
The "qualitative" but above all "quantitative" development of the classic elements of MIS (telescope, trocars, staplers, instruments for insufflating CO2), made the procedures safer and more applicable also in the pediatric population; later when the same techniques were applied to infants and weighing even less than 5 kg, minimally invasive Neonatal surgery was born (16).
Today the laparoscopic or thorascopic approach is described and applied to countless pediatric diseases, with advantages similar to those found in adults: better visualization and "amplification" of the various anatomical structures, reduction of post-operative pain, risk of infections, dehiscence of the wound,

less propensity to create post-operative (intraperitoneal) adhesions and a decrease in the length of hospital stay (17, 18, 19).
However, both in adults and children, there are limits to the laparoscopic technique, which the "scientific community" has tried over the years to overcome or to make less evident (20):

• Lack of tactile "feedback".
• 2D vision with loss of stereoscopic vision.
• Loss of "eye / hand coordination": the surgeon has to coordinate two axes, that of the eyes with the monitor and that of the hands and instruments with the patient: moving the laparoscopic instruments while looking at a two-dimensional monitor placed on a different axis is not very intuitive.
• Presence of fixed fulcrums (so-called "fulcrum effect") on which the instruments move with consequent:

  - Restriction of degrees of freedom: the main characteristic of mechanical systems is that of being made up of several bodies (members), connected together in an appropriate way. As a consequence of these bonds (constraints) the possibilities of movement of each member relative to the others are limited. By virtue of the fulcrum effect created by the trocar inserted into the abdominal cavity, the movements of the tip of the instrument are limited to 4 degrees of freedom (DOF): i.e. 3 degrees of freedom of rotation at the insertion point and one degree of freedom of translation through the insertion point. In other words, the instrument has the ability to rotate along three perpendicular axes (defined as yaw, pitch and roll) and a single possibility to translate.
  - Discrepancy in the amplitude of external (external lever) and internal (internal lever of the trocars) movement
  - Difficulty in achieving technical dexterity, especially in complex interventions also for the enhancement of physiological tremor

• Ergonomic conjunctions at times unfavorable.

Outline of the evolution of robotic surgery
Several authors disagree in identifying the first robot-assisted surgical procedure performed in an operating room, but for many the honor goes to Dr. Yik San Kwoh and his team at Memorial Medical Center in Long Beach, California: in 1985 during a percutaneous brain biopsy, he used the Programmable Universal Machine for Assembly (PUMA ®, version 560), an evolution of the industrial robot from Unimation Inc. developed by Victor

Scheinman in 1978 (PUMA 200). For surgical use, it was interfaced with a tomographic scanner: once the target of the biopsy was identified on the scanner image, a program calculated the movements of the robot to position the probe and take the tissue sample. Compared to the manual procedure, the use of PUMA resulted in a less invasive, more accurate and faster intervention (21). Despite its accuracy, the system did not appear to be suitable for surgery due to some drawbacks, such as safety, the time required for its set up, and limited workspace (22).
In 1988, on the basis of the accuracy and success achieved with PUMA, urologist B.L. Davies and his team performed a transurethral prostate resection (TURP) using the same system (23): this ultimately led to the development of the PROBOT, a robot designed by Integrated Surgical Supplies Ltd specifically for the execution of TURP. Basically, it made it possible to specify the volume of tissue to be removed, and then automatically remove it without the intervention of the surgeon.
In fact, as early as 1983, the "Arthrobot," system was developed at UCB Hospital in Vancouver by the biomedical engineering team led by Dr. James McEwen as a tool to manipulate, on voice command, the position of the limb during arthroscopic operations.
Shortly thereafter, many total hip arthroplasty surgeries were performed using the first robot approved by the Food and Drug Administration (FDA), the ROBODOC (Integrated Surgical Systems, Sacramento, CA) or ACROBOT: this system was developed for the preparation of the femoral cavities, based on data obtained from intraoperative scans. The images were then transformed into spatial coordinates, which formed the path of the robot. The advantage to be obtained with this system was identified in the greater stability of the prosthesis in the long term, due to the better adaptability to the bone (24).
However, none of these systems were developed to integrate laparoscopic procedures, until the concept of "telepresence" was born. The more general meaning of the term “telepresence” (literally presence at a distance) is “communication in real time with a physically remote place”. In the most restricted, commonly accepted meaning, "telepresence" is defined as the ability to "see and operate at a distance": for which "presence" is not intended in an artificial environment generated by the computer (what is commonly called 'virtual reality '), but' presence 'in a real and remote physical place (25). The term was coined by Scott Fisher, a well-known artist and designer who worked for years at NASA for the development of advanced virtual reality systems: he defined telepresence "a technology that would allow remote operators to receive sufficient sensory" feedback "to feel on the spot and able

to perform various operations "allowing the subject to control not only the simulation, but also the reality, giving him the possibility to remotely manipulate the physical reality that is presented to him through images that are both representations of remote reality both tools to intervene on it. The teleoperator's body is transmitted, in real time, to another place where it can act (remote action), for example by repairing a space station, carrying out underwater excavations or bombing a military base. So thanks to telepresence you don't have to be physically present in a certain place to affect reality (26).
He developed the first Head Mounted Display (HMD), which “immersed” the viewer in a virtual reality in “3 Dimensions”.
At the suggestion of the plastic surgeon, Joseph Rosen, the biomedical engineer Phil Green developed a robotic "telemanipulation" system for micro-surgery at the Standford Reaserch Institute (SRI): Green already from the end of the 1960s was involved in the realization of numerous inventions that made ultrasound a full-fledged diagnostic tool (ultrasound). Then in the 1980s, in fact, he integrated the advances made in the field of micro-cameras, robotics and remote controlled systems to create a prototype capable of allowing the surgeon to have the tactile and visual sensation of being with the hands in the patient, although she was far from him (27).
The combination of these two ideas, i.e. telepresence and robotic telemanipulation, marked the beginning of remote surgery, a concept that the US military attempted to develop in order to perform remote surgeries, which are difficult in war zones.
In particular, Computer Motion, Inc. of Santa Barbara, CA, used the funds made available by the army to develop AESOP (Automated Endoscopic System for Optimal Positioning), a robotic arm controlled first by pedals or manually (AESOP 1000, 1994) and then from the surgeon's voice (AESOP 2000, 1996) to manipulate an endoscopic video camera: in laparoscopic interventions, in fact, the surgeon loses his correct vision, as the lens that transmits the image to the screen is manipulated by an assistant. AESOP was first used in 1993 and in 1994 was registered as the first surgical robot in history by the FDA (28).
Not satisfied, Computer Motion wanted to create a robot capable of reproducing the surgeon's movements: thus the ZEUS system was born, equipped with three arms, one of which represented by an endoscope, controlled by voice commands (such as the AESOP system); the other two with 4 degrees of freedom were manipulated on the console by a "joystick". (29)
The image of the surgical field was displayed either in 2D on a standard screen or in 3D through the use of polarized lenses. It was used for the first time in July 1998 at the Cleveland Clinic, Ohio to perform an anastomosis of a

fallopian tube (30), and in 1999 in Canada in an open heart coronary replacement surgery (31).
In 2001 in New York, using the SOCRATES software, the surgeon Jacques Marescaux performed a cholecystectomy on a patient in Strasbourg, in an operation known as "Operation Lindgberg" (32). Later, however, the procedures were always performed over short distances, as remote surgery requires a system capable of transferring data at high speed to obtain good quality images and with minimum delay between the start of the movement and the display of the feedback on the monitor.
In 2003, following a long legal battle, "Computer Motion Inc." merged with Intuitive Surgical Inc. and stopped development of ZEUS (33).
In 1997 Intuitive Surgicals Incorporated perfected the da Vinci, a "master slave" robot.
In the surgical field, there are three types of robotic systems: automatic (“active”), semi-automatic (semi-active) and master-slave. The former (eg. PROBOT and ROBODOC platforms) are equipped with artificial intelligence, which allows them to perform procedures independently, under the supervision of the surgeon. The semi-automatic systems have both autonomous components and those guided by the surgeon, while the master slaves totally depend on the latter's action (34).
The first Da Vinci was equipped with 3 arms, one of which for the camera and the other two for the instruments, which thanks to the presence of a physical joint, had seven degrees of freedom. This combined with 3D vision and "force feedback" technology, the surgeon has the impression of being immersed in the operating field.
It was with this "system" that Jacques Himpens and Guy Cardiere performed the first robot-assisted cholecystectomy in Brussels, while several cardiac revascularization surgeries were performed the following year at the University of Leipzig, Germany (35).
Although designed for cardiac surgery, the results obtained in this area were not as satisfactory as those in general surgery: around 300 interventions between cholecystectomy and fundoplication were performed in Europe over a period of 3 years to demonstrate the safety of this new technology, approved by the 'FDA for abdominal surgery on July 17, 2000 (36).
From the moment of its conception, the robot has gradually evolved from the first three-arm system to the lighter and more versatile 4-arm system defined as the “S model”.

DA VINCI ROBOTIC SYSTEM-Description of the system

The “da Vinci robot” is the most advanced platform for minimally invasive surgery on the market today. The flagship of robotic technology, it is available in two systems (37):

- **da Vinci Si:** considered since its arrival on the market (1999) the "gold standard" for medium complexity procedures in defined surgical fields, such as urology, gynecology and general surgery in a single quadrant.
- **da Vinci Xi:** innovation of the Si system, introduced in Italy in 2014, is proposed as the ideal tool for highly complex surgery in large and multi-quadrant surgical fields, allowing for extreme freedom of movement. These features make it suitable for interventions in urology, gynecology and complex general surgery, maximizing anatomical access and ensuring a 3D-HD view.

It consists of three main components: the surgical console, the patient trolley and the vision trolley.

1. Surgical Console: This is the control center of the da Vinci Xi system. Through the console, positioned outside the sterile field, the surgeon controls the 3D endoscope and the EndoWrist instruments by means of two manipulators (master) and pedals. The daVinci Xi EndoWrist® instruments have a diameter of 8mm and a length of approximately 60cm. They are equipped with a wrist that allows freedom of movement on seven axes and a rotation of almost 360 °. In the range of robotic instruments we can find needle holders, cauterized and cold scissors, grippers and bipolar dissectors of different types.

In the stereo viewer, the tips of the instruments line up with the surgeon's hands holding the manipulators

The operator at the surgical console also has the possibility to switch from full screen view to a multi-image mode (TilePro ™ view), which shows the 3D image of the operating field along with two other images (ultrasound, ECG) provided by auxiliary inputs.

2. Patient trolley: it is the operating component of the daVinci system and consists of four arms dedicated to supporting instruments and endoscope. The daVinci system uses remote center technology, a fixed point in the space around which the arms of the patient trolley move. This technology allows the system to manipulate instruments and endoscopes within the surgical site while minimizing the force exerted on the patient's body wall. At the rear of

the trolley, in correspondence with the handling handles, the da Vinci Xi system has a touchpad and controls for the pre-operative selection of the type of intervention, based on which the arms are automatically positioned. It is also possible to carry out manual positioning, in terms of height and advancement with respect to the base and rotation of the group of arms, up to a maximum of 270 °.
3. Viewing cart: contains the central processing and image processing unit. It includes a 24-inch touchscreen monitor, an ERBE VIO dV electrosurgical unit for monopolar and bipolar energy delivery and adjustable shelves for optional auxiliary surgical equipment, such as insufflators. The da Vinci Xi system also includes a high definition (full HD) video system.

Advantages
Robotic surgery “shares” the well-known advantages of minimally invasive surgery including: fewer and smaller incisions, less pain, less risk of infection, less hospital stay, quick recovery times and smaller scars; others are added, including those that overcome the many obstacles of laparoscopic surgery:

- Restoration and improvement of eye / hand coordination;
- Increase in the number of degrees of freedom to 6, of which 3 for position and 3 for orientation, which increases the surgeon's ability to manipulate the instruments and therefore the organic tissues;
- Elimination of physiological tremor through appropriate hardware and software filters;
- Ergonomic position by the surgeon: surgeons often report pain or numbness in the arms, wrist or hands during laparoscopic procedures, while the console can reposition the hands without moving the ends of the instruments;
- Ability to modulate the range of the surgeon's movements through "downscaling": large movements made at the console can be transformed into micro-movements in the patient, making the surgical gesture more precise and fluid;
- Possibility of having a 3D view of the operating field;
- Facilitate those procedures that have always remained outside the surgeon's domain, such as, for example, the suturing of small bile ducts;
- Possibility of performing interventions in confined anatomical spaces such as in the pelvic cavity; (33)
- Ability to work remotely from the patient.

Limits

It is well established that robotic surgery has been greeted with great enthusiasm by many and has entered a wide variety of surgical fields.

However, there is still much discussion on the evidence of greater safety and better patient outcomes compared to laparoscopic procedures; furthermore, for these systems, the randomized clinical "trials" are still insufficient both from a qualitative and quantitative point of view (38).

As one of the most innovative technologies in the surgical field, it is not surprising that it is one of the most costly approaches (39,40). The costs depend both on the initial purchase cost, and on the duration of the operation, the instruments used, the technical assistance and are subject as in any free market, both to the availability of the buyers and to the presence or absence of competition, for which the antagonism between companies capable of developing new systems would greatly reduce costs on the one hand and could lead to technological improvements on the other (41) However, it is certain how costs can be partially offset by the reduction of perioperative morbidity and the fact that average hospital stays are decidedly shorter (42).

Other aspects to consider from a technical point of view are the size and the absence of tactile feedback. The bulk of the system, in fact, prevents easy transport: therefore, reducing the weight of the machinery would open up the possibility of offering it to distant environments (43).

Furthermore, the current platforms do not provide tactile feedback to the surgeon: this implies that the surgeon must make up for the lack of this through sight, which is accompanied by a greater workload from a mental point of view but above all it is added the aspects to be taken into account in the learning curve of the procedure. The hope is that the forces experienced by the machinery during the surgery can be converted into an electrical signal capable of changing the shape of the "joystick" in the surgeon's hand so that it can receive a sensation similar to that of touch. In reality, with experience, the human brain learns to compensate and the "high definition" image changes transmit all the information necessary to avoid errors caused by excessive traction or pressure (41).

The lack of specific training centers and programs is another important limitation. Many specialization schools, in fact, still do not provide for teaching the use of robots during the course years, however, in the face of interesting results as regards the learning curve (a term that is used to describe that process of acquisition of knowledge and skills in the surgical field, but not only) much faster and more adequate (44); in fact, in robotic assisted procedures, the latter varies widely and depends on the experience and expertise of the surgeon who "teaches", the type of intervention and the "volume" (quantity) of the procedures; the most extensive analyzes are those that derive for example from radical prostatectomy with robotic technique, in fact, and demonstrate rapid learning in the face of a conspicuous number of procedures (45)

The last aspect to consider is the need to contain the delay between the transmission of images and the motor response in less than 200 milliseconds, beyond which the safety of the intervention could be compromised. In any case, in the event of an "emergency", the "team" at the operating table can detach the robotic trolley and autonomously continue the operation in laparoscopy or with conversion to the "open" technique, through a maneuver that takes a few seconds. The incidence of conversion essentially depends on the intrinsic difficulty of the operation and the experience of the operating surgeon.

CLINICAL STUDY

Introduction

In 1859 Charles Darwin in his masterpiece “Origin of the species” stated that: "It is not the strongest of the species that survives, nor the most intelligent, but the most reactive to change." Thinking about this, the same law could be applied also to surgery, that during centuries passed through some important milestones until the improvements reached in present days.

One of the most important passage in this process of growth has been the development of minimally invasive surgery (MIS) that changed in a dramatic way the surgical approach either in adults either in children (46). Infact, with small instruments and a better magnification with a camera view it has been possible to perform a huge amount of surgical intervention with better outcomes, such as less postoperative pain, a minor time of hospitalization and a better aesthetic result.

Nowadays, the introduction of robotic surgical systems represents a further step in the evolution of surgery. These computer-enhanced systems offer three-dimensional (3D) visualization and significantly improved instrumentation dexterity coupled with motion scaling, allowing surgeons to perform complex reconstructive procedures (47). Robot-assisted surgery, with these advantages, overcame the laparoscopic approach in many surgical fields, becoming for specialities such as urology, gynecology and colorectal surgery a gold standard for many procedures (48). In pediatric surgery, instead, this kind of approach didn’t have the same wide adoption due to the difficulties of finding the right indications on a so much younger population. The use of the robot in children, infact, found limitations due to the need to work in small and constrained cavities with instruments developed for the adult, but also, some specific challenges such as patient and trocar position, anaesthesia and control of post-operative pain (49, 50).

Neverthless in the first years of 21th century (51) robotic surgery began to be applied also in pediatric procedures and slowly, in the last decade, started to be a first choice in selected procedures (52).

In this work our aim was to point out the state of art of the pediatric robotic surgery in our center, evaluating its growth and devolopment and comparing our experience with the most important case series found in the Literature.

Materials and Methods

This was a retrospectic study from 2016 to 2020. The study was carried out at the italian center of Salesi Children's Hospital, in Ancona. In our unit of pediatric surgery we have experience of robotic surgery and we collected data about patients, treated diseases, surgical procedures and operative time. We divided the surgical interventions in two groups, on the base of the anatomical district of interest: abdominal and genitourinary surgery.

We collected also data about complications and conversion rate.

Statistics

GraphPad Prism6 (GraphPad Software Inc., San Diego, CA, USA) was used for statistical analyses. Data were presented as mean ±SD, comparisons between groups were analyzed using Student's t-test for unpaired data. A p-value <0.05 was considered significant.

Results

The total number of patients included in this study was 65, of who 34 (52%) were males and 31 (48%) females. The demographic data about patients are shown in Table 1.

The number of perfomed surgical interventions was 65: 15 (24%) of abdominal and 50 (76%) of genitourinary (Figure 1).

The most performed surgical interventions of these two categories were respectively fundoplicatio (10%) and pieloplasty (43%). Total performed interventions for each anatomic district are shown in Figure 2 and 3.

Figure 4 showed the growth of robotic cases through our period of study.

Mean operative time was 224 minutes (165 minutes for abdominal surgery and 194 minutes for genitourinary surgery) (Figure 5).

Total complications were 10 (15%): 2 (3%) for abdominal surgery and 8 (12%) for genitourinary surgery (Figure 6). There was 1 (1.5%) conversions, in a case of genitourinary surgery.

There was no significant difference in terms of operative time, complications and conversions between the two groups.

Discussion

Robot-assisted surgery, at the beginning, was conceived as a military tool for remote surgical care of the injured soldier, and later, in the 90s, was introduced in the clinical practice (53). The first surgical robot to be approved from the Food and Drug Administration (FDA) was the AESOP® (Automatic Endoscopic System for Optimal Position; Computer Motion, Inc., Goleta, CA). It is composed by a voice-controlled robotic arm that actively manipulates telescope/camera, eliminating the need for a human camera holder and the associated difficulties in directing camera placement (54). In 1995 FDA gave approvation to the use of Da Vinci system and since then it has been used at many institutions in thousands of surgical procedures. This technology is a teleoperating system comprised of a surgeon's console and a patient's side cart. The console side contains the surgeon's control handles that direct movements of the robotic arms inside the patient's body, the stereoscopic visual display system, and the user interface panels. This system permits the remote control of the patient-side tower structure which consists of two to three arms that control the operative instruments and a separate arm that controls the video endoscope (55).

This final class of robot has been used in the fields of general surgery, urology, gynecology and cardiothoracic surgery, but only later and much slower in pediatric surgery. In fact, the size and variety of available robotic instrumentation remains limited compared with those offered for adults surgery, and the huge size discrepancy between the typical pediatric patient and the overall size of the robotic system can restrict the surgical indications (56). The first report describing the use of robotic surgical systems for abdominal procedures in children were published by Heller and colleagues in 2002 (57). They reported a series of 11 children who underwent Thal or Nissen fundoplication for treatment of gastroesophageal reflux disease using a Da Vinci system. Mean patient age was 12 years and no complications were reported. From that time the applicability of robotic surgery in pediatric fields has made important progress and the indications for the intervention have been extended to other pathologies and to patients of lower age and weight. A retrospectic study of 2019 (58) demostrated that weight cannot be considered an absolute limit for robotic surgery. The improvement of instruments permits to perform complex surgical procedures in low-weight children without additional difficulties. Also other studies (59, 60) reported case series that demonstrated the safety and feasibility of robot in pediatric surgery.

The results of our study confirmed this process of growth: in our center it's evident a progressive increase in the number of intervention every year. This finding not only certified the rise of pediatric surgical idications, but also an improvement in the learning curve. These data are confident with the results showed by the one of the most important study on this issue (7). This systematic review of 2013 showed an increase, through the years, either of case volumes of robotic surgical procedures in children, either of the published literature on this subject. In addition, another interesting result of this review is the percentage of each performed procedure for the main anatomic district (abdomen and genitourinary system). The main surgical interventions perfomed with robot are fundoplicatio and pieloplasty. This is confident with what we demonstrated in our work, and show a shared consent in considering robot-assisted surgery a gold standard for the treatment for gastroesophageal reflux and for ureteropelvic junction obstruction. In fact, several studies (61, 62) demonstrated no significant differences in outcomes and complications between laparoscopy and robot in the approach of these diseases.

In our case series emerges also the data that the two second most performed surgeries for abdomen and genitourinary system are resection of intestinal duplication and nephrectomy. In the past years there were no evidences that robot is the suggested approach for this kind of interventions, due to the fact that neither resection of duplication neither nephrectomy have any reconstructive part, and there is no high risk of harm to adjacent structures. Therefore the use of robot-assisted surgery doesn't present a significant advantage (63, 64). In our Unit this application of robot is explained by the fact that pediatric surgeons share the robotic system with general surgeons and urologists and this make possible to lower the costs related to the use of this technology. This situation permit us to widen the indications also to these diseases in order to increase the learning curve for robotic surgery. In addition, also without significant evidences, we believe that robot-assisted surgery can bring important advantages in these kind of interventions. Minimally invasive approaches have gained popularity, and in some centers, has replaced open surgery for the surgical management of urinary tract abnormalities. A study of 2018, analyzing a series of 18 robotic partial nephrectomies, showed good outcomes and confirmed the fact that this approach ia associated with decreased postoperative analgesia requirements, shorter hospital stay, less blood loss, and less use of drains in comparison to the open approach, while demonstrating efficacy and safety (65).

In our series we reported data also about ureteral reimplantation. Ureteral reimplantation was the initial surgical correction method for pediatric vescico-ureteral reflux (VUR). Laparoscopic approach for VUR was introduced as early as 1993, and robot-assisted laparoscopic approach followed about one decade

later. Although open ureteral reimplantation (OUR) is still the gold standard in surgical treatment of pediatric VUR, the application of robot-assisted laparoscopic ureteral reim- plantation (RALUR) has been growing in popularity (66, 67). With the development of robotic instrumentation, RALUR was applied in clinical practices and has been proven to relieve postoperative pain, shorten the recovery phase and have a shorter learning curve than the conventional laparoscopic approach (68).
Talking on the base of our experience we believe that robotic approach for ureteral reimplantation is feasible and safe. Paying the price of a longer operating time, the robot-assisted technique guarantees a better visualization of the anatomical structures, reducing the risk of bleeding or damage to the peri-ureteral and peri-vesical nerve structures. Furthermore, compared with OUR, RALUR should be considered as an effective surgical approach for primary pediatric VUR, since it has a similar success rate and could help patients shorten the time spent in the hospital.
Thoracic surgery, instead, presents a different situation, with no cases of intervention performed in our series and a few number described in Literature. This result can be explained by different reasons. Firstly, in pediatric population many of the thoracic diseases are congenital (CPAM, lobar enphysema, lung sequestration) and they needed an intervention in the first months of life, making impossible, until now, the use of robot. The other reason is that, in any way, also in older patients the thoracic cavity is small and make difficult the movements of the instruments and the positioning of the trocar, without mentioning the anesthesiological problems and the control of post-operative pain. From the point of view of the evolution of the robot, the problem of interventions in thoracic surgery is one of the limits that could be overcome with the implementation of smaller instruments with less impact on the anatomical structures of the pediatric patient.

Conclusion

The results of this work give the reason to believe that in Italy, as in the rest of Europe and in the US, pediatric robotic surgery is a field in development which present a progressive growth. Pyeloplasty and fundoplicatio are, to date, the most frequent surgeries performed in children, and the one where outcomes are recognized as at least equivalent to the open or laparoscopic procedures. Many other procedures have been reported, and still under evaluation with more data expected in the near future. A further increase of learning curve and improvements of robotic surgery can be the next step to do to widen the application of robot-assisted surgery.

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Figures and Tables

Patients	65
Males/Females	34 (52%)/31 (48%)
Mean age at intervention	90.9 months (11-207 m)
Mean weight at intervention	29.3 kg (9.5-68 kg)
Operative time	224.2 minutes (72-530 min)
Hospitalization	3.7 days (2-12 days)
Complications	10 (15%)
Conversions	1 (1.5%)

Table 1: Demographic data of the patients.

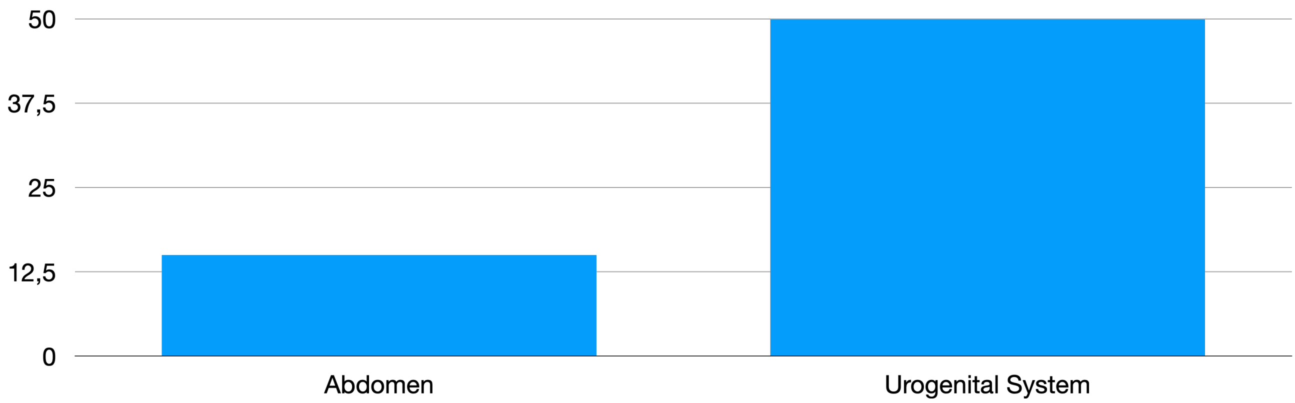

Figure 1: Number of intervention for each anatomic district.

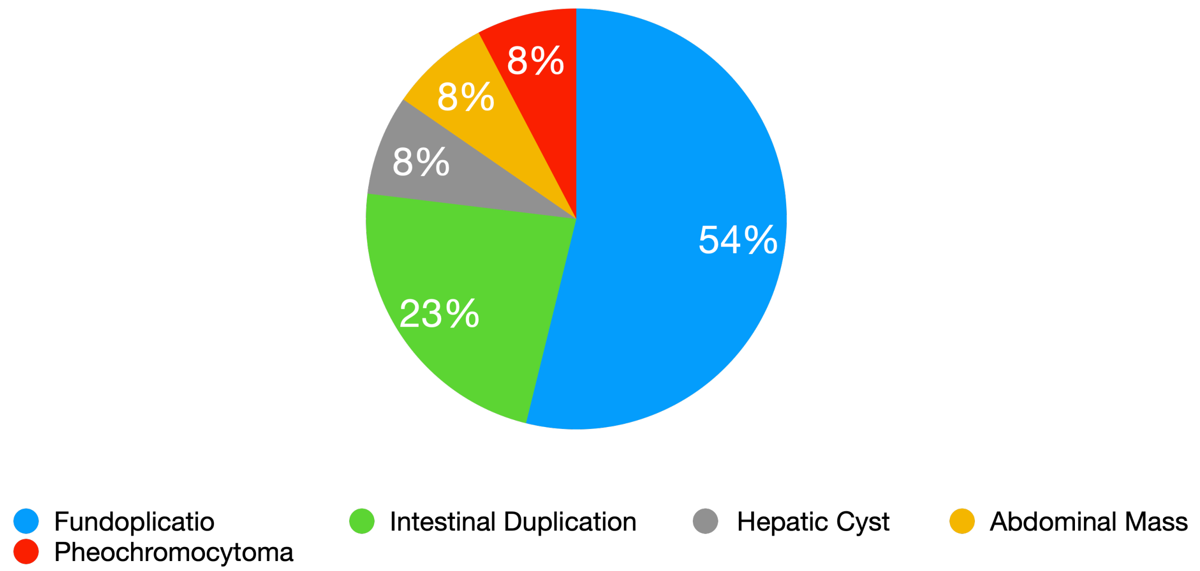

Figure 2: Main interventions performed about the abdomen.

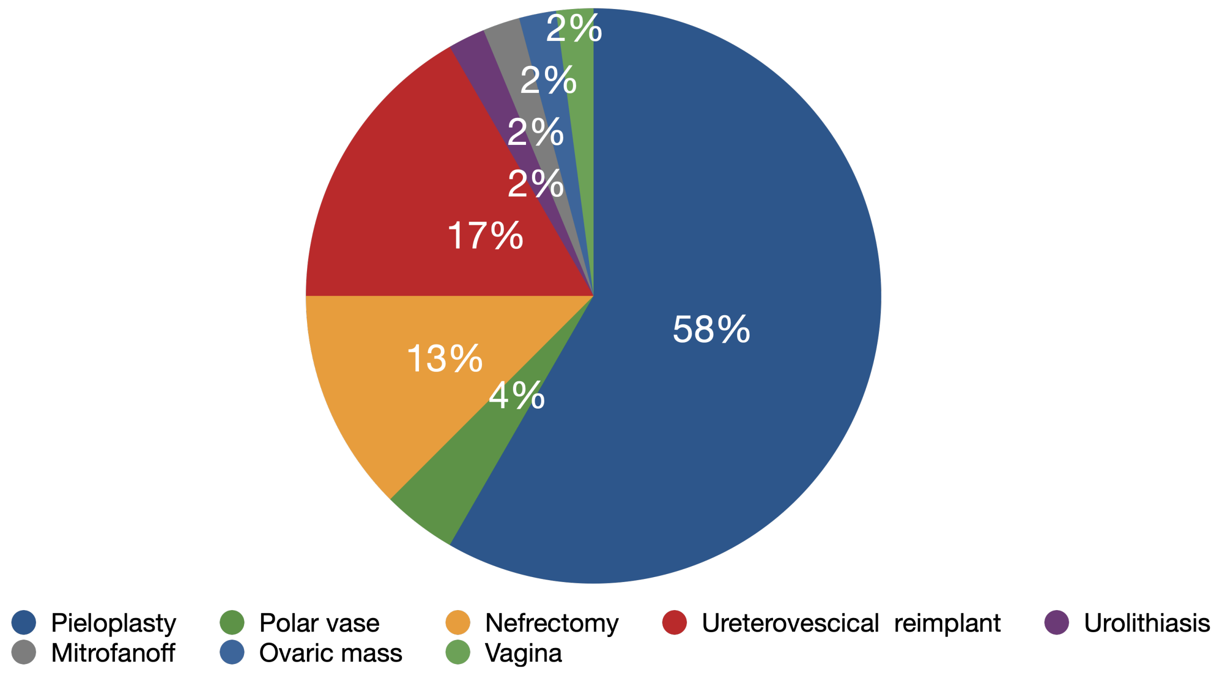

Figure 3: Main interventions performed about the genitourinary system.

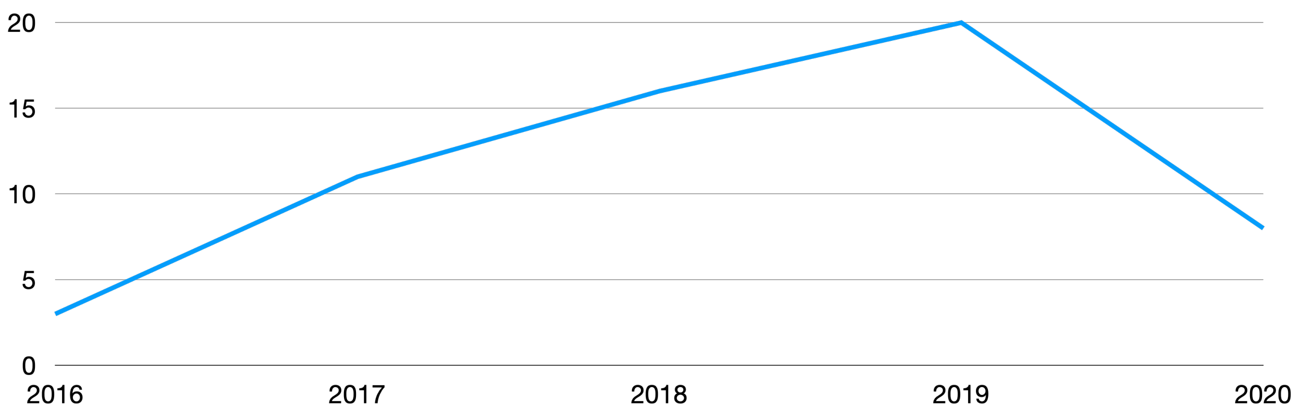

Figure 4: Curve of growth of robotic cases through our period of study (decrease in 2020 is due to the Sars-Cov-2 emergency that lead to a stop of the scheduled interventions).

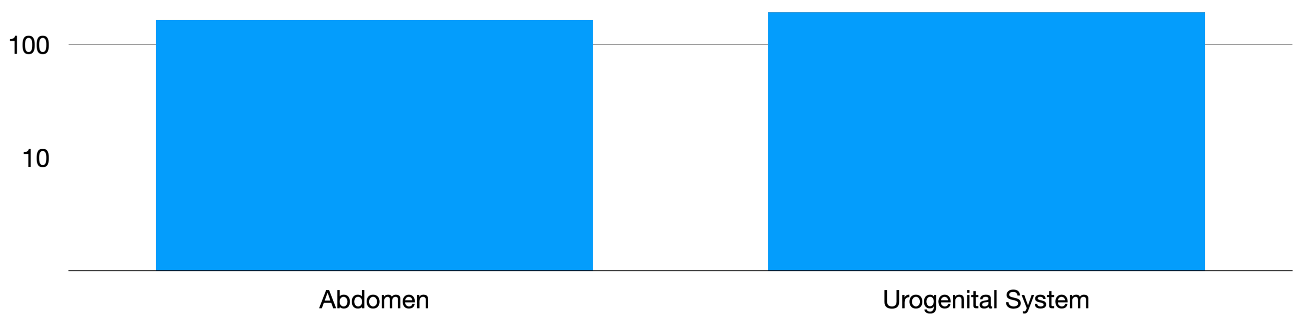

Figure 5: Mean operative time for each anatomic district.

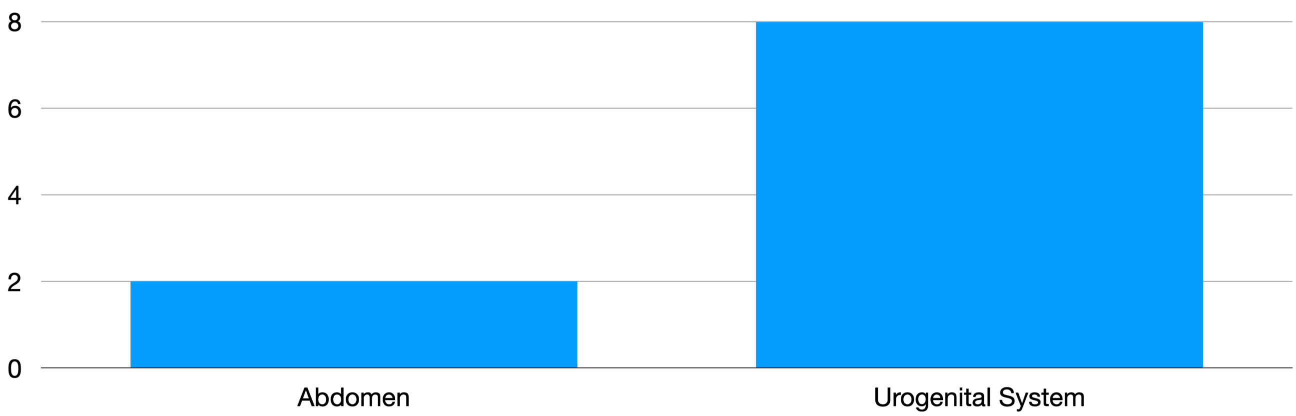

Figure 6: Surgical complications for each anatomic district.