ESPES Manual of Pediatric Minimally Invasive Surgery

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Philipp Szavay
Editors

European Society of Paediatric Endoscopic Surgeons

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To my wife, partner, and best friend, Marina, for her precious support and encouragement every day in the last 35 years

I love you

Ciro Esposito

I want firstly to dedicate this MIS book to the older generation of colleagues and friends who pioneered MIS in children and took us with them on board very early. But I will not forget all the sick children all over the world hoping that this book will help them to recover a beautiful smile.

Henri Steyaert

To all my friends and colleagues in pediatric surgery, many of them also authors of this book, who have been so inspiring, enriching, and supporting me.

Philipp Szavay

It was a pleasure to contribute to this book that will help us to clarify the state of the art for video surgery in children.

Next step will be robotic assistance for surgeons. New tools are and will be created to secure our procedures.

François Becmeur

Foreword

It is a pleasure for me to write the preface of this manual of pediatric MIS for two main reasons: first of all because I was involved in the field of Pediatric MIS Surgery from the beginning of its development in Europe at the beginning of the 1990s and second because one of the editors of this book, Ciro Esposito, was my trainee between 1991 and 1993, whom I also consider as my "surgical son."

Since nearly 10 years, the main goal of ESPES (European Society of Pediatric Endoscopic Surgeons) is education, and for this reason, to publish a manual of pediatric MIS techniques is an excellent idea.

At the beginning of laparoscopic area, we had to prove that pediatric laparoscopy offered some benefits to our patients. While some of you, as pioneers, paved the way and ignored the criticism of their colleagues, the others choose to watch with interest. And over the last 25 years, pediatric MIS made the transition from the "look what I can do" phase to a real validation of the MIS approach by randomized trials and comparisons of the open versus the scopic approach. Today, nearly everything, in pediatric surgery, can be done laparoscopically, retroperitoneoscopically, thoracoscopically, and even using robotic surgery.

The technique has evolved to a standard of care in many centers around the world. Even if many senior surgeons haven't learned the technique and therefore don't offer it to their patients, most surgeons in their team and in training are as confident with laparoscopy as they are with the open approach. Of course, the approaches have evolved over the years as well as the learning curve, but we can say now that MIS procedures are cost-effective operations that rarely take extra time to perform, even in some cases save time, and more importantly are part of our current practices.

This manual, then, serves as both an update of current practices and a real guide to the most common operations in pediatric. It covers the basics of anesthesia, instrumentation, and ergonomics and then reviews many of the more commonly performed laparoscopic, thoracoscopic, retroperitoneoscopic, and robotic pediatric procedures, including a review of the possibilities of prenatal treatment. While any book written about such a rapidly evolving technique may miss some of the very newest twists or modifications of technique, I am sure that most of the content will serve as a reference for many years. The format is designed to be readily accessible, and it will be certainly a must and a real opportunity for the new generation of pediatric surgeons.

CHU la Timone, Marseille, France Jean Michel Guys

Preface

The field of minimally invasive surgery in children and infants is rapidly growing and currently is considered the new frontier of pediatric surgery.

ESPES Manual of Pediatric Minimally Invasive Surgery (MIS) provides practicing pediatric surgeons and pediatric urologists with authoritative chapters that were written by recognized experts and cover all the aspects of pediatric MIS. The goal of the editors and the authors is simple: to provide the readers a unique resource consisting of practical and technically oriented chapters focused on all the aspects of pediatric laparoscopy, retroperitoneoscopy, and thoracoscopy.

ESPES Manual of Pediatric Minimally Invasive Surgery is based on a simple but important philosophy: give a practical and up-to-date resource for the practicing surgeon detailing the specific needs and special considerations surrounding the minimally invasive care of children.

We especially wanted to convey this information in an accessible and pleasing format.

Written by expert surgeons, each chapter has been carefully edited to maintain continuity in style and format while preserving the unique voice of the experienced and knowledgeable contributing author. In addition, this manual will serve as a useful reference for pediatric surgeons, pediatric urologists, general surgeons, and gynecologists. *ESPES Manual of Pediatric Minimally Invasive Surgery* is also specially designed to be used by surgical residents in pediatric surgery and urology rotation and chief residents who have chosen to obtain further specialized training in a pediatric surgery fellowship program.

This ESPES Manual is concise and easy to read, containing detailed and relevant information that can help you in taking care of the patient in your surgical practice using the more advanced MIS techniques. To cover all the aspects of minimally invasive surgery from the basis of MIS to the more advanced procedure as robotics or fetal surgery, the manual is divided into six parts: basics, chest, abdomen, urology, gynecology, and miscellanea.

The chapters give advice about room setup, patient positioning, as well as step-by-step descriptions of how each surgical procedure should be performed, including all technical aspects of the procedure, complications, and tip and tricks.

We are very impressed by the material present in this manual, and we are sure that the concepts outlined, if followed by the reader, will add to the value of minimally invasive care that we provide to our pediatric patients.

Enjoy this lecture and remember minimal incision, easy decision.

Naples, Italy Ciro Esposito
Strasbourg, France François Becmeur
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Basics

1 Equipment and Instruments

Raimundo Beltrà Picó

1.1 Introduction

Today, minimally invasive surgery (MIS) in paediatrics (MIPES: minimally invasive paediatric endoscopic surgery) is a consolidated and universally accepted surgical tool of indispensable use in our daily work.

The great, successful progress that this discipline has experienced in the last 20 years has been fundamentally due to the:

- Improvement of specialized anaesthetic techniques for paediatric endoscopic surgeries

Incessant achievement of highly sophisticated technological equipment and the continuous development of instruments designed specifically for these surgical techniques [1].

Equipment and instruments are designed to allow safe access to the child's anatomic cavity, to get and maintain a good working space, to see neatly inside the operating field and to perform all conventional manoeuvres in surgical techniques (grasping, dissecting, cutting, suturing, haemostasis, tissue sealing, etc.) with the same safety and efficacy as in open surgery.

MIPES surgeons must learn the principles and technical characteristics of the instruments and equipment at their disposal, without always depending on their technical team should an emergency arrive.

The next section will provide an overview of the basic equipment and instruments that should be available [2].

1.2 Description

1.2.1 Access: Cannulae and Trocars

Cannulae and trocars are used to pierce the anatomical cavity to enable the placement of telescope and surgical instruments.

Access by puncture with the well-known Veress needle (Fig. 1.1), while widely used in adult MIS, is generally discouraged in MIPES and even banned in many paediatric surgery services due to the high risk of damaging underlying structures.

The author discourages using this manoeuvre—and any other blind manoeuvres—in children and strongly recommends performing the first access through an open small incision. This allows for the safe introduction, under direct vision, of the first cannula, always with a blunt trocar inside (removable puncheon). By doing this, we create the first working port, preventing life-threatening complications of vascular or hollow viscus perforation [3].

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Fig. 1.1 Cannulae. From left to right: reusable. Disposable. Thoracoscopic

Once the first access port is created, we add as many working ports as strictly necessary, but limiting its number to the fewest possible.

Under direct vision through the lens placed in the first cannula, we can introduce any type of cannula with any type of trocar inside it, blunt or sharp, controlling at all times the entrance into the anatomical cavity, thus preventing accidental injuries.

As it happens with many other instruments used in MIS, cannulae and trocars are available in disposable, non-disposable or partially disposable forms (Fig. 1.1).

1.2.1.1 Disposable

Advantages

1. Clean, sterile, effective mechanisms
2. Easy storage, widespread, immediate availability
3. Later reuse in experimental surgery

Disadvantages

1. Purchase costs
2. Requires proper waste disposal after use

1.2.1.2 Reusable

Advantages

1. Allows multiple uses and thus can be amortized, implying a lower cost

Disadvantages

1. Needs to be cleaned, sterilized and packed.
2. Less availability units in stock.
3. Reliability decreases with each use.

1.2.1.3 Size

Diameter

- 2 mm
  The 2 mm instruments are fragile and bend easily, and grasping them firmly is difficult. Its use is quite limited and has few and very selected indications.
- 3.3 mm
  It is highly recommended in MIPES and its use is very widespread. There is a large choice of 3 mm instruments, both disposable and reusable. They are technically very reliable and allow performing in children most of the endo-surgical operations with complete safety. Handling of tissues is very delicate, and the scars left are aesthetically very satisfactory.

  On the other hand, vision with a 3 mm lens is not as accurate as with a 5 mm lens. Therefore, on many occasions it is more convenient to combine 3.3 mm cannulae with 6 mm ones.
- 6 mm
  Most 5-mm-diameter surgical instruments and accessories can be found nowadays.
- 11–12–15 mm
  They are sometimes necessary because some instruments such as staplers and retrieval bags are not available yet in a 5-mm-diameter size.

Length

- Cannulae of 60, 75, 100 and 110 mm are available.

The chosen length depends on the thickness of the wall of the child's anatomical cavity. It is advisable to insert the sheath as little as possible, so it occupies less space in an already limited working field, therefore allowing for a better instrumental manoeuvrability without interference.

1.2.1.4 "Luer" Lock Adapter

There are cannulae with and without an adapter to connect to the source of gas insufflation. There are also cannulae with a stopcock or with a rubber stopper that occludes the "luer" connection.

The heads of the cannulae that do not have a connector for the gas are less bulky than those that have it. Therefore, combining cannulae of both types helps to reduce the space occupied by them on the surface of the child.

1.2.1.5 Valve

There are cannulae with and without a valve to prevent gas leakages when the instrument is not inside the cavity. The valve should be easy to open for the removal of tissue samples.

1.2.1.6 Trocar

There are several types of awl tips:

- Sharp pyramidal. Very traumatic. Leakage of gas occurs easily.
- Sharp conical. Less traumatic as it dilates the tissues.
- Eccentric. Makes a slit-like hole and requires less force for insertion.
- Blunt conical. Ideal when a cannula is inserted using an open technique.
- With a small blade of a knife at the end of the trocar, which retracts as soon as the piercing resistance is lost.

1.2.1.7 Cannula Fixation

Dislodgment of cannulae due to the thinness of the child's body wall happens very often and becomes a great problem in MIPES.

Some cannulae have a screw-like structure on the outer surface. After a long operating time, they are not very effective and can often enlarge the diameter of the porthole.

There is a disposable cannula with an inflatable balloon at its end and a synthetic plate at the outside to be compressed against the wall. The disadvantage is that the part of the cannula inside the abdominal cavity is rather long, thereby limiting the working space.

A simple and useful way to fix the cannulae is to place a ring made from a silicone catheter, which fits well but can slide on its surface. It should be placed at the precise distance that we want the cannula to enter the cavity and should be fixed to the body wall with a suture, which can also be passed around the stopcock.

There is a type of cannula called Step™, available in 3–6–10–12 mm and in different lengths, which includes the cannula (with valve and stopcock), a blunt puncheon, a Veress needle with a length according to that of the cannula and a sheath formed by a mesh with 2–3 mm of outer diameter.

The mesh can be inserted through the first hole in its "open" mode or over the Veress needle in the next ports and under direct vision. Once the sheath is inside, the Veress needle is then removed leaving the sleeve in place. The cannula with the awl is then inserted through the sleeve, thereby radially dilating the sheath and stretching the orifice without tearing it.

Its advantages are:

- The tip of the cannula and trocar are protected by the mesh and don't damage the anatomical structures.
- The distended mesh adapts very well to the hole, providing a firm fixation.
- Cannulae of higher calibre can be introduced through the mesh, enlarging only the skin incision by a few millimetres.

1.2.1.8 Single Incision Laparoscopic Surgery (SILS)

For this MIPES modality, there are devices that consist of two rings, external and internal, connected to each other with a membrane in the shape of an hourglass. These devices can accommodate 3–4 ports and have a lateral connection for gas input. The device is normally inserted through the umbilicus [4] (Fig. 1.2).

1.2.2 Working Space: Insufflator

Both in the thorax and in the abdomen, the best way to get a good working space is through the insufflation of carbon dioxide (CO_2), the most commonly used gas.

CO_2 has the advantage of being rapidly absorbed by blood, is non-toxic and cost-effective and can be used with cautery.

Although in the thorax the simple entry of air through the cannula with the open stopcock

Fig. 1.2 SILS devices

collapses the lung, the positive pressure of the patient's ventilation reverses the collapse. Therefore, the working space is compromised, not allowing a comfortable and safe surgery.

Sufficient space in the chest can be created by inducing a pneumothorax with 3–6 mmHg CO2 pressure.

In the abdominal cavity, a good working space can be created using a pressure of maximum 8–10 mmHg and lower in small babies.

The main risks that appear when insufflating children's anatomical cavities with CO_2 arise from its high pressure and a maintained high flow [5, 6]:

- Negative effects on systemic and local hemodynamic, lung compliance and intracranial pressure (decreases venous return and cardiac output, increases heart rate, mean arterial pressure and systemic and pulmonary vascular resistance).
- A high flow rate when the pneumoperitoneum is created with the first cannula produces a sudden reduction of the venous return and compromises the adaptation of the cardiovascular system. Therefore, it is recommended using less than 1 L/min at the beginning.
- More than 2 L/min increases the tension of the diaphragm and produces scapular pain.
- High consumption of CO2 causes hypothermia.

The safety of the procedures depends on the quality of the insufflator. The surgeon must know well the characteristics of the insufflator before deciding which one to choose.

Recommended features:

- Automatic exsufflation valve in case of excessive pressure. External, to avoid cross-contamination.
- Safety maximum pressure adjustment with sound alarm.
- Automatic flow rate management according to leakages.
- Insufflation rate from 1 L/min.
- Current pressure, flow rates, volume and CO_2 remaining level of tank permanently displayed on screen.
- The gas used must be preheated and humidified under sterile conditions.
- Disposable filter between insufflator and sterile tube system towards the patient.

1.2.3 Visualization: Imaging System (Telescopes, Light Source, Cables, Camera Control Unit, Monitors, Video Recorder)

1.2.3.1 Telescopes

The telescope itself consists of an outer ring of optical fibres used to transmit light into the body and an inner distal-mounted core of rod lenses through which the images are relayed back to the camera where they get magnified for the surgeon. Different types of laparoscopes are available, different in terms of overall length, number of rods, diameter and angle of view.

Rigid telescopes are available in 2–3–5–10–12 mm with an ending angulation varying from 0° to 70°. The quality of visualization and light transmission of the telescope are inversely related to its diameter. 5 mm size is the most common choice in paediatrics. The author recommends starting MIPES with 5-mm-diameter telescopes and instruments of the same width. After gaining additional experience, the surgeon can decide whether smaller telescopes give them sufficient vision.

Regarding the angulation, it is advisable to use 30° telescopes for most operations because angled tips allow looking behind structures, around corners or below the surface of the abdominal wall.

There are new-generation rigid telescopes that enable three-dimensional (3D) procedures in conjunction with a 3D and high-definition (HD) camera.

5–10 mm HD telescopes with a flexible tip containing the chip are nowadays available.

To perform certain surgeries through a single port, there is the possibility of using a 10 mm, 0° operative laparoscope with a 6 mm working channel.

During surgery, fog, blood, saline or other materials can frequently obscure the scope lens. Various devices have been developed to solve this problem, including lens flushing systems, mechanical wipers, continuously flowing jets of air and mechanically spooled reels of transparent tape. A good alternative approach involves the use of a stainless steel shaker (sterilizable) with wet and warm gauze in the bottom with which one can effectively clean the tip of the telescope without damaging it. Angled lenses can also become dirty quicker due to increased contact with the intra-abdominal organs.

1.2.3.2 Light Source

Light may be the essence of endoscopic imaging, and it is the starting point of the imaging chain. HD endoscopy generally relies heavily on surgical light sources. Because HD cameras have lower sensitivity due to smaller pixel size, a powerful 300 W Xenon light source is frequently recommended. The light source should be set at maximum capacity in its non-automatic mode as modern cameras have a fast and automatic shutter built in. These HD cameras make use of the luminance signal derived from the video output to determine if the image is overexposed and adjust the intensity of the light source accordingly.

Ideal performance characteristics of the lighting system:

- Optimum intensity must adequately illuminate the operative field.
- Must ensure true-colour properties and brilliant image presentation.
- Sufficient brightness and contrast to discriminate healthy tissue from suspect ones that require treatment.

It should be noted that cold light does not exist. The temperature at the end of the light cable rises up to 225 °C within seconds and at the end of the telescope up to 95 °C within 15 min. A heat filter to reduce the amount of infrared light transmitted to the laparoscope is therefore required. The cable should therefore always be attached to the telescope, and one should never wipe the lens clean against surrounding tissues.

1.2.3.3 Cables

Light Cables

It is important to have good quality light cables adapted to the telescope that is being used, as the cables will provide the amount of light needed to illuminate the entire abdomen through a very small opening. The thickness of the cable should match the thickness of the light inlet of the telescope. Thick cables will not produce more light but more heat, while thin cables will not transport enough light.

A condensing lens is used to concentrate light from the bulb down into a narrow beam at the cable input, where it is transmitted to the laparoscope via a gel or fibre cable.

- Gel cables consist of a metal sheath filled with liquid crystal gel, terminated at each end with a quartz crystal.
- Fibre-optic cables are formed from tightly packed bundles of optical fibre, surrounded by several layers of protective flexible sheathing.

Both types of cable offer very high levels of light transmission but are somewhat fragile, and while gel cables can provide superior results in terms of brightness and colour temperature, they are also more prone to breaking due to the rigidity of the outer metal sheath.

Video Cables

Video cables have a great importance in video system of MIPES. They carry digital image data between the camera head, camera control unit (CCU), monitor(s) and recording devices.

The introduction of optical fibre provides an optimum cable solution as it has sufficient bandwidth for transmitting HD signals over long distances. This offers the opportunity to transmit other HD signals from imaging sources in a picture archiving and communication system (PACS).

An optical fibre for HD signal transmission can also be necessary for the development of HD imaging technology into integrated operating room systems.

1.2.3.4 Camera Unit

Camera Head

The camera consists of a lens, a prism and three sensors for acquiring the primary colours of the image. Some camera heads also incorporate an optical zoom for adjusting the image size (magnification). Due to better image performance, triple chip cameras have been generally accepted as the industry standard for endoscopic surgery. The primary advantage is the fact that colour reproduction is much more natural.

Image quality, however, will depend on the camera acquisition standard that’s been put on a given system. Nowadays, we are moving from standard definition (SD) to HD video formats.

- Typical SD formats offer a 4:3 aspect ratio in 640 × 480 pixels image resolution.
- The 1080 HD format provides a 16:9 aspect ratio and 1920 × 1080 resolution. The speed at which the camera captures the images is expressed in frames per second (fps). In laparoscopic operations for HD endoscopy, 1080p60 (1080p at 60 fps) may be the highest standard readily available for acquiring and displaying images, and it offers a superior viewing experience for surgeons.

  Instead of circular images created by SD video camera lenses, with HD cameras surgeons can operate watching a monitor with full-screen images, as if they were watching movies, shows or sports events on a modern HD TV set. Wide-screen image acquisition increases the horizontal field of view (panoramic image) and decreases the vertical field of view. With laparoscopic instruments primarily entering the concept of view laterally, wide-screen 16:9 aspect ratios seem advantageous. Another positive effect is the fact that a telescope positioned further away from the site of surgical interaction catches less debris and smoke on the front window, improving image quality.

The quality of the cameras has been greatly improved over the years. Instead of a single chip that contains sensors for red, green and blue light embedded on a single silicon chip called a charge-coupled device (CCD), triple chip designs use a prism located in the camera head unit to split the incoming image into its red, green and blue components and direct those beams of light into three separate CCD chips. The resulting image can offer superior quality in terms of colour definition and clarity, but triple chip cameras are more expensive and heavier than single chip versions. Weight is a significant factor as the camera is typically mounted directly on top of the scope, so a heavier camera can make the instrument more difficult to manoeuvre.

The camera is attached via a rotating coupler, allowing the scope to be turned independently during use. This requires the camera to be held in the correct orientation throughout the procedure.

Lastly, a short mention about robotic 3D systems (discussed in more detail in Chap. 10). These systems use a pair of cameras and two different lenses working almost in parallel, but with a slight difference, to capture a stereoscopic image. Ocular disparity is the difference between the position between the left and the right eye in the human vision.

Camera Control Unit

The CCU connects various elements of the HD imaging chain, capturing and processing video signals from the camera head for display about the monitor, as well as for transfer to existing recording and printing devices.

The HD CCU must offer flexible output choices to ensure that the unit can continue to be used with HD equipment. The CCU should be able to accommodate both SD and HD inputs, and, conversely, it will have two digital video outputs:

- Digital video interface for the HD signal
- Serial digital interface for the SD signal

1.2.3.5 Monitors

The author recommends 26″ HD flat-panel monitors displaying images acquired in 16:9 format. Images in these characteristics enable surgeons to experience a more natural, panoramic vision, and, perhaps more importantly, visualization is much more in tune with human anatomy.

Our horizontal field of view is wider than our vertical field of view. Therefore, it is more natural and less fatiguing during procedures. Additionally, while we are viewing full-screen endoscopic images, trocars and hand instruments that normally approach the surgical area laterally are visible earlier with a 16:9 monitor than with 4:3 or 5:4 monitors.

1.2.3.6 Video Recorders

There is little doubt that with time all surgical operations recordings will have to be stored for a defined period of time as part of the patient's electronic chart.

Recording will also enable its use for studying, teaching and training of younger surgeons.

Normally, the recordings of endoscopic surgeries are made digitally on the hard disk of a computer. From there they can be organized for studying, reviewing or exhibiting.

Images can also be routed to a mounted screen, as it happens with 3D systems. In addition, video output can also be recorded and even viewed remotely through a live web stream, opening a range of opportunities in terms of remote and collaborative work.

At present, the trend in hospitals is to use modern and sophisticated systems that allow jointly storing data from different hospital units (recording of surgical interventions, electronic imaging studies). It is also possible to store non-image data, such as scanned documents that may be incorporated using standard formats like PDF.

Known as *picture archiving and communication system* (PACS), this medical imaging technology provides economic storage and convenient access to images from multiple modalities (source machine types). The universal format for PACS image storage and transfer is DICOM (Digital Imaging and Communications in Medicine).

A PACS consists of four major components:

- Imaging modalities such as X-ray plain films, ultrasound studies, computed tomography or magnetic resonance imaging
- Secured network for the transmission of patient information
- Workstation for interpreting and reviewing images
- Archives for the storage and retrieval of images and reports

Combined with available and emerging web technology, PACS has the ability to deliver timely and efficient access to images, interpretations and related data. PACS reduces the physical and time barriers associated with traditional film-based image retrieval, distribution and display.

1.2.3.7 What Will the Immediate Future Offer to Is?

Newer developments in laparoscopic technologies include virtual reality (VR) and augmented reality (AR) systems. VR systems rely solely on computer-generated images, while an AR system provides the surgeon with computer-processed imaging data in real time via dedicated hardware and software. The projection of AR is made possible by using displays, projectors, cameras, trackers or other specialized equipment. In AR systems, images of the patient, captured using X-ray, volumetric computerized tomography (CT) or other types of medical imaging technique, are overlaid onto the live feed from stereoscopic surgical cameras to create an enhanced 3D image that the surgeon can refer to during a procedure without the need to look away from the operating site. Although the technique has been used successfully in neurosurgery for a number of years, live AR laparoscopy is still in its infancy. However, both AR and VR systems have been used successfully in laparoscopic training applications [7].

1.2.4 Surgical Manipulation: Basic Working Instruments

1.2.4.1 Suction and Irrigation

The surgeon's vision during an endoscopic surgery can be hindered due to bleeding or smoke coming from ablation and resection procedures. Since blood absorbs light, even in areas far from the direct area that is being operated on, blood has to be removed to provide a clean visibility on the endoscopic monitor.

Moreover, biological debris that may remain after a surgery can lead to threatening sepsis complications in patients. Surgical suction pumps are also used to extract tissue and leakage of organic fluids and to irrigate water to wash the area.

Irrigation is also very important in endoscopic surgery for general washing, mechanical debridement of tissues and rupture of clots. However, it is advisable to try to avoid an abusive use of irrigation because once the operative field has become thoroughly wet, it is difficult to dry it again and this interferes with vision and dissection. This device can help surgeons to seek bleeding points (haemorrhage) by irrigating and sucking normal saline.

As an irrigation fluid, usually NaCl 0.9% is used. It must be sterile, preheated and kept warm.

Suction-irrigation pumps are available in one single device. They come in 3- and 5-mm-diameter and different lengths. They can be disposable o reusable.

Endoscopic suctioning instruments are relatively small, as they have to fit in the cannulae, yet they should be able to remove blood clots. The aspirating instrument therefore should have the largest possible opening at its end. Larger blood clots have to be mechanically fragmented before they can be aspirated. This means that the aspiration force should be quite high, but this will interfere with the working space by concomitant removal of the insufflated gas. High aspiration pressures will also result in aspiration of the surrounding tissues, thereby blocking the suction opening. This can be prevented to a certain extent by using short bursts of suction or by using a suction apparatus that has an automatic interrupter. The suction force should be easily adjustable.

There should be a control panel indicating:

- Suction pressure
- Rest volume of the suction bottle
- Irrigation pressure
- Rest volume of the irrigation bottle
- Temperature of the irrigation fluid

1.2.4.2 Retraction

Retractors used in adult MIS are not ideally suitable for MIPES due to their size once they are deployed within the anatomical cavity. As endoscopic retractors are not always within the viewing field, they can easily damage the surrounding tissues, particularly the liver and spleen.

The most popular is the one that opens like a fan, although its blades can be quite dangerous.

There is another less dangerous retractor, articulate and flexible, in the shape of a snake. Its main disadvantage is that a lot of its length has to be introduced in order to shape it properly and it thus takes up a lot of space.

The use of endoscopic swabs is usually useful and quite harmless to separate or move anatomical elements.

Sometimes an endoscopic grasping forceps can be used as a retractor. In anti-gastroesophageal reflux surgery, for example, the left lobe of the liver can be kept out of the way by inserting a grasping forceps through a cannula high in the epigastrium underneath the left lobe of the liver and grasping the most anterior part of the hiatus.

There are available internal magnetic graspers [DMG] (IMANLAP, Buenos Aires, Argentina) that grasp an intra-abdominal organ (gallbladder, appendix, gut) and, controlled by powerful external magnets, supply the necessary retraction/counter traction force to mobilize the organ. It can freely cruise the abdominal cavity according to the surgeon's need [8] (Fig. 1.3).

1.2.4.3 *Surgical Tools:* Dissect, Grasp, Hold, Cut, Suture

The MIS instruments are composed of a handle, the shaft and the specific work tip.

There are disposable and reusable instruments, usually high quality stainless steel made. The fundamental advantage of reusable models is their economic amortization with repeated uses. On the other hand, its main disadvantage is the difficulty to ensure adequate cleaning and sterilization since they could be a serious source of contamination and infections. Moreover, opening-closing mechanisms and scissors blades sharpness deteriorate with repeated uses and therefore lose their maximum effectiveness.

Fig. 1.3 (**a**) Dominguez magnetic graspers (DMG). (**b**) Thomas forceps are used to open the jaws of the DMG. (**c**) External magnet mounted on self-retaining retractor (By permission of Dr. M. Martinez Ferro)

There are different lengths, being the most appropriate in MIPES 24 cm and in older children 36. The two most used diameters in childhood are 3 and 5 mm.

There are many different handles, with the permanent idea of getting the best shape as possible for ergonomic rotating, grasping and locking abilities in a precise fashion. They are available with free opening mode or with an automatic ratchet that keeps them locked.

There are a wide variety of instrument tips available for multiple purposes, although not all have the same utility in terms of frequency and effectiveness. The following are the ones I consider the most commonly used:

1. Dissecting and grasping forceps
   - Kelly dissector
   - Maryland dissector
2. Grasping and holding forceps
   In MIPES, the use of atraumatic forceps is normally recommended. Traumatic clamps are limited to strong anatomic grasp, such as the diaphragm.
   To manipulate more delicate organs, such as exploring the intestine running through it, it is more appropriate to use a forceps with a broader atraumatic end.
   When forceps have to hold tissues for a longer period of time, it is advisable to use a handle with a ratchet in order to secure the holding grip.
   - Babcock
   - DeBakey
   - Standard
3. Scissors
   - Metzenbaum
   - Hook scissors (useful for cutting sutures and ligatures)
4. Needle holder
   Needle holders are usually made out of stainless steel and have straight axial designs that place the needle directly in line with the surgeon's hand to allow greater manoeuvrability and a more natural motion of the wrist when suturing. Various designs are available, but generally the jaws of the instrument are operated by means of an ergonomic spring-loaded palm grip on the handle. The grip is squeezed to open the jaws and released to close them. The needle is secured firmly in the jaws of the instrument by means of a ratcheted locking mechanism located in the handle.
   Needle driver jaws fall into one of four main categories: straight, curved left, curved right and self-righting.
5. Knot Pusher
   Normally, ligatures and tissue sutures are performed intracorporeally. In certain situations, for example, in the case of sutures with excessive tension, it may be advisable to externally make a self-slip Roeder knot or push a double knot inside until it is securely adjusted by means of a knot pusher.

1.2.4.4 *Haemostasis:* Clips, Staplers, Energy Sources

Clips

Clips are fast and effective for small- and medium-calibre vessels and for other small structures (cystic duct) (Fig. 1.4).

- Titanium [9]
  – 5 or 10 mm
  – Reusable one by one manual-pressure applier
  – Automatic single use device with multi-clip charges
- Non-absorbable polymer (Hem-o-lock™) [10]
  – Reusable one by one manual-pressure applier.
  – They are considered safer for larger vessels.

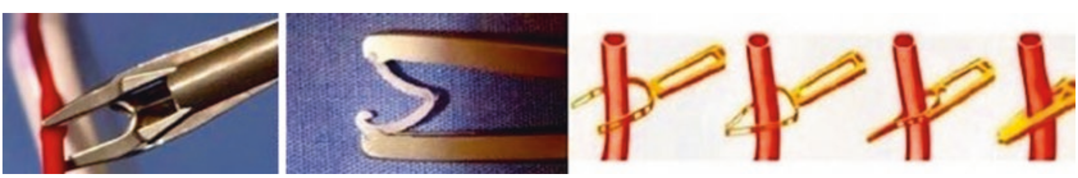

Fig. 1.4 Clips. From left to right: titanium, Hem-o-lock™ and Lapro-Clip™

Fig. 1.5 Left: linear cutter-stapler. Right: circular stapler

- Absorbable dual-layer clip lock mechanism (Lapro-Clip™) [11]
  - Polygluconate inner track and polyglycolic acid outer track
  - Degrades via hydrolysis in 180 days (inner) and 90 (outer)

The last two are inert, nonconductive and radiolucent. They do not interfere with CT, magnetic resonance images (MRI) or X-ray diagnostics.

Staples

Staplers are safer in cases of much larger vessels such as splenic or renal artery/vein. They are also used for resecting the intestine and before performing an anastomosis. There are even specific staplers for end-to-end circular intestine anastomosis available (Fig. 1.5).

Staples cartridge lengths can be of 30, 35, 45 and 60 mm. The most important factor in staples is the height of the closed staple, because it must be able to contain the relevant tissue when closed. Each height adapts to the different tissues, such as the mesentery, which requires smaller staples, and vessels or gastrointestinal tissues, which require larger staples.

There are many different, but similar, endolinear mechanical suture devices available. The devices can be found in 5 and 10 mm diameters. All of them have an external rotation mechanism that facilitates their placement, and some of them are also articulated at the end of the suture.

Energy Sources [12, 13]

Monopolar High-Frequency Electro-Surgery (MHFE)

It can be used both to dissect tissues and to coagulate small vessels at the same time. Therefore, it is a very efficient and used instrument.

Various monopolar ends are available. In the author's experience, the 90° hook end is the most frequently used and is a good one as it allows for good vision even when the manipulation angle is small.

Warning
- If too high energy is delivered, it could cause faster cutting before coagulation is achieved.
- Insulation failure can cause collateral damage.
- Electrical over-scattering can cause distant electrical injuries.

Bipolar High-Frequency Electro-Surgery (BHFE)

The passive electrode and the active electrode are both located in each of the branches of the forceps. It coagulates only between the two branches of the instrument, minimizing electrical damage and other potential hazards of MHFE mentioned above. It has the disadvantage of being a noncutting instrument, which means that after coagulation, another instrument has to be used for cutting.

Advanced Alternative Energy Sources

The need for meticulous haemostasis and the tedium of vessel ligation in advanced cases has propelled the development of new energy source devices that have proved to be remarkably helpful in MIPES. However, surgeons do not always agree with the choice of the device that would be optimal for a particular procedure.

- Ultrasonic energy (Harmonic® shears and scalpel; Sonosurg) [14]

  The high-frequency vibration of tissue molecules produces stress and friction in the tissue,

Fig. 1.6 Left: LigaSure™. Right: EnSeal®

which in turn generates heat and causes protein denaturation. Thus, coagulation and afterwards cutting are obtained.

- Electrical system with feedback (LigaSure™; EnSeal®)
  A low voltage is generated between the two branches of the instrument, which in turn is connected to a computerized system that measures the impedance of the tissue. The coagulation is produced by fusion of the collagen and elastin fibres (Fig. 1.6).
- Argon plasma coagulation
  It uses high-frequency electric current and ionized gas argon. The application of electric current on the gas releases a huge amount of heat resulting in a haemostatic jet. Its use is not too popularized and widespread.

1.2.4.5 Specimen Retrieval Bags

It is highly recommended to take anatomic specimens out of the body in an isolating bag in cases of:

- Infected tissue, to prevent contact with the body wall or in case of rupture during the manipulation, or gross contamination of the cavity
- Implantation of malignant cells in the port orifice or spilling of malignant or not malignant cells (splenic cells) inside the corporal cavity that may be hazardous

Currently marketed specimen retrieval bags can be found in diameters that range from 10 to 15 mm, with different capacity volumes and in their opening and closing technique [15].

1.3 Conclusion

There is generalized consensus that MIPES represents the recommended techniques for the majority of pathologies requiring surgical treatment, those settle in the abdominal, thoracic or retroperitoneal cavities.

Numerous breakthroughs in the design of instruments and advanced, highly sophisticated equipment make it essential for paediatric surgeons who want to advance safely in this field of surgery to know in detail the characteristics of the multiple devices and instruments that exist. In addition, surgeons should continuously learn about improvements and innovations of the most advanced endo-surgical techniques. That also requires being up-to-date on the continuous appearance of new products that outperform the previous ones.

The endoscopic surgeon should select a limited number of instruments to compose a standardized set. We cannot improvise or experiment during a surgery with the life or health of a child. From the first surgical use, we must already know perfectly the characteristics, proper use and, above all, possible risks or dangers derived from an inappropriate use or eventual collateral effect.

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2 Ergonomics in Minimally Invasive Surgery

Zacharias Zachariou

2.1 Introduction

Ergonomics is the science that studies human actions during labor. Results of ergonomic studies lead to the adaptation of the worker's environment by improving the work place, the equipment, and associated training programs. In minimally invasive surgery (MIS), ergonomics apply to the development of improved operational instruments, of optics with higher resolution, of the operating room (OR) environment, as well as of the surgeon's posture and workload [1, 2]. The number of MIS procedures is constantly increasing, and it is even expected that it will prevail open surgery. Although the clinical benefits of this technology are becoming more evident, the risk factors for the surgeon and her/his performance and the incidence of physical fatigue as well as the economic outcomes are still not completely clarified [3].

Since the introduction of MIS almost 30 years ago, this technique underwent advancements including improvement in instrument development as well as the resolution of cameras and monitors. Despite these significant advancements in MIS technology, ergonomics are still a big challenge, especially in conventional MIS, with a main issue remaining the disassociation between the visual and the working field. The lack of fixing tissues and the limited tactile sensations aggravate the working conditions. The strain on the surgeon due to operation theatre arrangements, instrument structure, operating table height, monitor position, etc. has a significant effect on the outcome of MIS in general. In addition, the evaluation of stress and strain to surgeons during MIS procedures is still technically very challenging. It is thus important that the awareness about these ergonomic challenges that MIS surgeons are facing today are addressed properly and serve as a basis before the actual training of the surgical procedures.

2.2 Operating Room and Its Components

The work in the OR has fundamentally changed since the development of MIS, and it is obvious that ergonomics had to be redefined in order to meet the requirements of this new technology. Lifting all equipment from the floor improves the functionality of the OR complex and minimizes occupational safety and health (OSH) risks as the movement of equipment towers is reduced and the floor is clear of cables and cords (Fig. 2.1). Additionally, the user controls all systems used from a central location within the sterile area reducing unnecessary movements in the OR.

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Fig. 2.1 Integrated operating room OR1™, KARL STORZ

During MIS procedures additional complex devices and complicated interfaces are placed in the OR between the patient, the surgeon, and the operation nurse. Appropriate ergonomics in the OR may increase safety, efficiency as well as comfort of the operating team, and by consequence the clinical outcome of the patient [1]. This can be achieved if the workplace organization ensures that every individual member of the surgical team has appropriate space and access to all equipment as the lack of balance in this respect leads inevitably to work overloads and injuries.

It is of utmost importance that the following considerations have to be taken into account when using the MIS equipment before and during surgical procedures:

- Operating table
  The operating table has to allow inclinations in the longitudinal as well as horizontal planes and enable tilts to the left and right. It should also enable kinking of the body on the level of the pelvis. The height of the operating table is essential and has to be adapted to the surgeon's individual height and position (standing or sitting). A table that is too high forces the surgeon to apply considerably more contraction of the body muscles in order to raise and hold the shoulders and elbows to compensate the high table. This can be tolerated for a short time, but if this position is maintained, it leads quickly to shoulder muscle fatigue.

  The table height that offers comfortable working conditions (about 64–77 cm above floor level) is when the MIS instrument handles are slightly below the level of the surgeon's elbows keeping the shoulders in a neutral position and the angle between the lower and upper arm during surgery is between 90° and 120° [4, 5] (Fig. 2.2).
- Monitor
  The monitor is the main visual contact between the patient and surgeon as the surgical scenarios are transmitted by this monitor. It is essential that the monitor is adjusted in its position already prior to surgery to avoid undesirable postures of the surgeon and the team in the whole for a long period of time. The monitor should be placed in such a manner that in the horizontal plane, it is in line

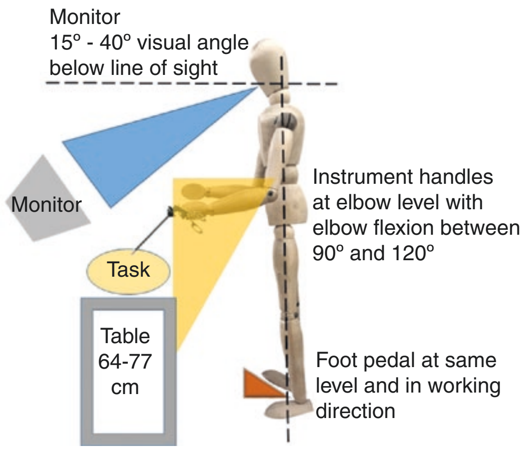


Fig. 2.2 Ergonomic position of OR equipment during MIS

with the surgeon and the forearm–instrument motor axis. In the sagittal plain, the monitor should be about 15° downward than the surgeon's eye level to ensure comfortable viewing, avoiding neck extension. The distance between the surgeon and monitor is highly dependent on monitor size, and it should be far enough to prevent extensive eye accommodation as well as extreme contraction of the extraocular muscles. It should be, however, close enough to avoid staring, resulting in loss of detail [6, 7]. An additional monitor near the operative field could offer additional benefits specially to accomplish precision tasks by improving hand–eye coordination [2, 7].

- Foot pedals
  Equipment like electrocauters, ultrasonic shears, laser, or other tissue welding/dividing instruments commonly need foot pedals to activate the instruments used during MIS. The lack of visual contact to the pedal results in an unbalanced position of the surgeon making the situation more difficult especially if more than one pedal is in use. The best solution is to replace them with hand controls. If not possible the pedals should be placed near the foot aligned in the same direction as the instrument in use and the monitor, thus enabling the surgeon to activate the device without twisting the body or leg. Pedals with a built-in footrest should be preferred.

- Theatre lighting
  In order to increase the contrast on the monitor, the lights in the OR are only dimmed and not completely switched off as working even in relative darkness may have a negative impact on the appropriate choice of similar instruments and safe handling of needles and scalpels as well and increase the risk of collision.

2.3 Patient Position

The position of the patient during MIS is usually supine with the arms of the patient in a position that does not interfere with the visual axis of the surgeon. This implies that the arms are tucked along the body at least unilaterally. The legs of the patients may be spread apart with the thighs extended below the pelvis in order to avoid instrument clash. Despite the abovementioned complex patient position, it is essential to prevent any compression of nerves.

2.4 MIS Instruments

The majority of the first-generation MIS instruments was offered by the industry in one standard size, which transmitted lower force compared to standard instruments, demanding higher muscular activity and effort from the surgeon to handle the tissue [8]. Nowadays most MIS instrument development is technology-driven and less designed for the physical and emotional comfort of the users, potentially leading to a user-unfriendly product design. The design of surgical instruments influences the performance of MIS procedures as it dictates the position of the surgeon's arms, hands, and fingers. Mainly the shape of the handle and the tool length are of great significance as non-ergonomic designs lead to discomfort and even to paresthesias of the thumb [9]. A possible solution for this problem is to use powered instruments, similarly used in staplers; however these are more expensive. Although there are different handle designs, it seems that instruments with axial handle lead to a more ergonomic posture for the wrist compared to a ring handle. Different instrument handles influence the task to be achieved. Pistol-type handles enable better performance in tasks that require force, while precision-type handles enable tasks that require precision [10].

In recent years efforts are made to improve and overcome the ergonomic limitations of MIS. One essential parameter to achieve this is by increasing the instrument's degrees of freedom. New instruments are more of devices with precision-driven and articulating instrument tips which increase the triangulation, thus improving the performance of surgical maneuvers. However, this development requires new manual skills and complementary knowledge of how to use them.

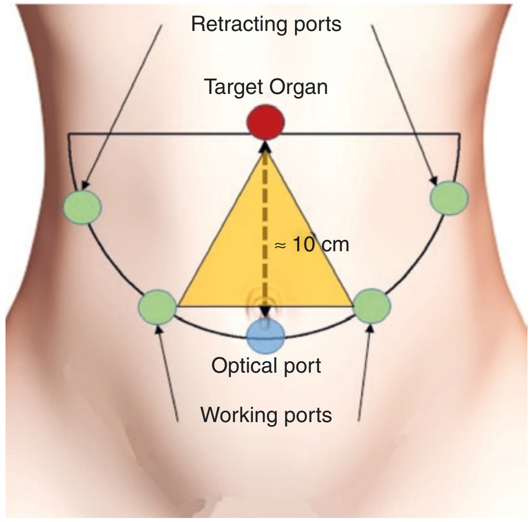


Fig. 2.3 Triangulation of the trocars

2.5 Trocar Placements

Although trocar placements are currently dictated by the surgeon's preference based on individual experience, defined ergonomic principles should be applied when possible. The trocars should be placed in triangular fashion as this configuration facilitates smooth instrument manipulation along with adequate visualization. In most of the procedures, the optical port should be placed about 10 cm from the target organ with two working ports on the same 10 cm arc on either side of the optical port allowing a working space at a 60°–90° angle. If necessary additional retracting ports could be placed more laterally to the working ports on the same arc (Fig. 2.3).

In certain cases, the target organ is on one side so that the optical port comes to lie on one side and the working ports on the other side of the target organ. This is defined as sectorization (Fig. 2.4).

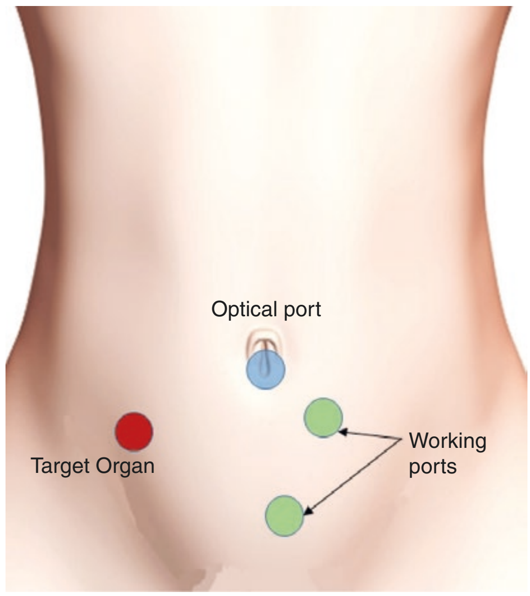


Fig. 2.4 Sectorization of trocars

Due to the limited length of the instruments, trocars have to be positioned in such a way that the tip of the instrument can reach the target organ without having to put the whole instrument in the trocar or sometimes to push the trocar all the way in the abdomen. This impairs the movement of the instrument making it less precise as well. The angles between the instruments are also a factor that, if chosen correctly, increases the performance and causes less fatigue for the surgeon. The trocars have to be positioned in defined distances from body landmarks in order to facilitate the optimal ergonomic manipulation, i.e., suture and knotting. The suggested positions within the triangulation principle are indicated in Fig. 2.5. Manipulation angles below 45° or above 75° are accompanied by increased difficulty and degraded performance. In addition, the intra-/extracorporeal (I/E) length ratio of the working instruments should be preferably close to 1:1. A direct correlation between the manipulation and the elevation angle influences ergonomics significantly. The optimal elevation angle which yields the shortest execution time and optimal quality performance is 60° (Fig. 2.6).

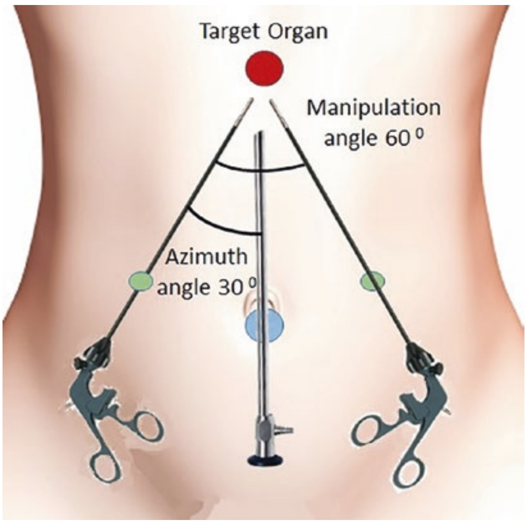


Fig. 2.5 Angles between instruments

2.6 Limited Degree of Freedom

A MIS procedure is performed by the surgeon using an instrument through a trocar. The movements of the surgeon's hand are transmitted through the incision point to the tip of the instrument. The degree of freedom (DoF) is defined by the potential for movement of the instrument either in one direction or around the instrument axis. While in open surgery the surgeon is allowed to work within the natural six DoFs (Fig. 2.7a), MIS instruments possess a motion constraint of four DoFs (Fig. 2.7b) [11]:

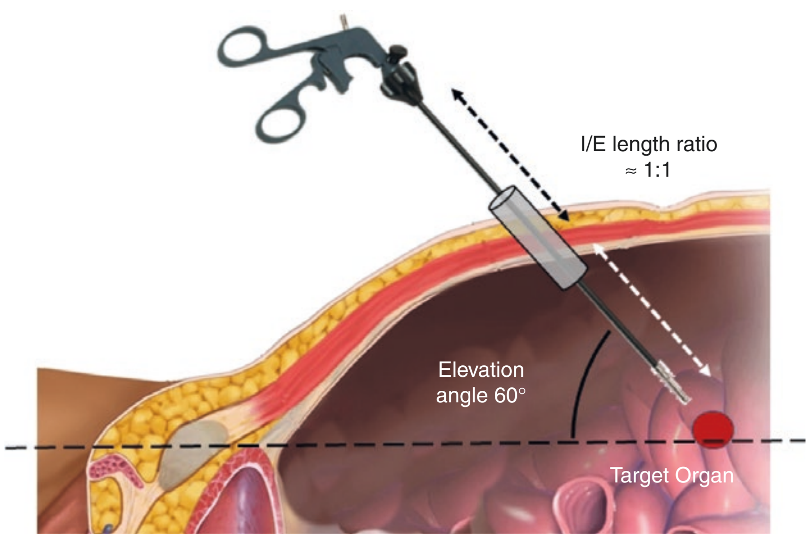
- 1st DoF—up/down (heave)
- 2nd DoF—rotation around instrument axis (roll)
- 3rd DoF—left/right (sway)
- 4th DoF—forward/backward (surge)

The limitation in the DoFs with MIS instruments makes handling of the target organ more difficult, which has to be compensated by experience and full application of ergonomic principles.

2.7 Disconnection of the Visual and Motor Axes

A three-dimensional spatial vision field and work performed in line with the person's visual axis are the features we naturally adopt during our

Fig. 2.6 Elevation angle, intra-/extracorporeal (I/E) length ratio



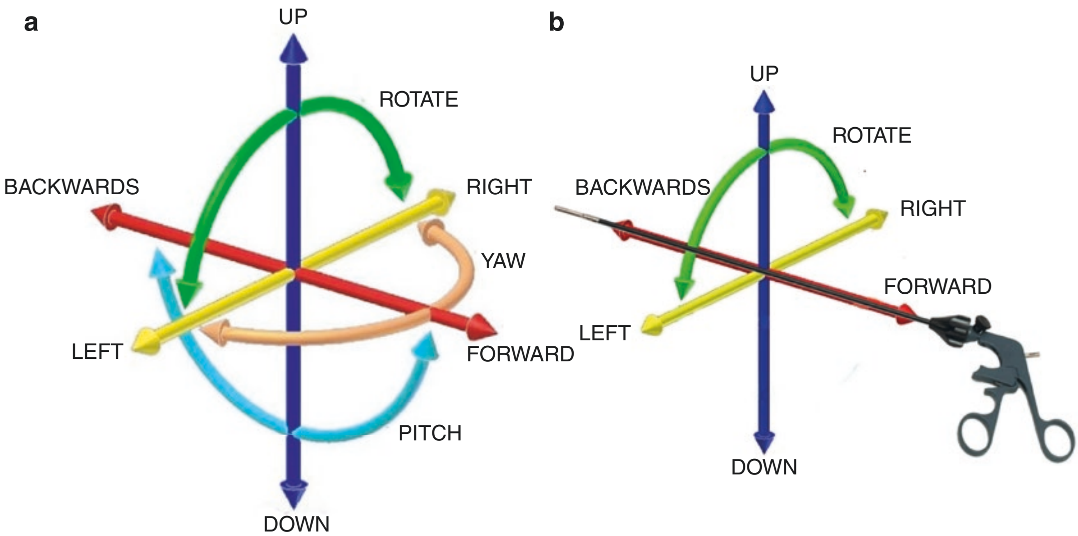


Fig. 2.7 Six degrees of freedom (**a**) vs four degrees (**b**) during MIS

actions. In MIS the visual field is reduced to bidimensional vision shown on the screen, causing confusion. This loss of the third dimension is associated with the loss of depth perception and reconstruction of space which is strongly limited especially if operating small children. During MIS the surgeon's motor actions are decoupled from the visual axis so that the surgeon is not able to directly look at the instruments. The hands and the surgical field at the same time and has to overcome the spatial separation of the axis of vision and the axis of the physical procedure by combining the two functions into one channeled approach. The surgeon has to concentrate more during MIS procedures, and this may decrease performance, leading to higher rates of error [1].

2.8 Diminished Tactile Feedback

Since childhood, we learn different skills and train to "see" not only with our eyes but also with our hands. We become competent and reach a high level of dexterity by achieving this dual job. During MIS procedures, the haptic and tactile feedback is conspicuously lacking as the long instruments manipulated through the access ports reduce the efficiency during the learning curve and result in an increased time of dissection [12]. However, through experience this tactile feedback can be partly regained by learning to "feel" using the instrument as an extended hand.

2.9 Hawthorne Effect

Since MIS was introduced, the Hawthorne effect was observed. It has been proven that every individual applies more caution and performs better whenever this individual is under observation of other people resulting in an immediate assessment of the performance. This results in a better score as compared with a situation where the person is unaware that an assessment is performed. This behavior contributes essentially to ergonomics; however, although beneficial for the patient, it results in a bias for the evaluation of ergonomics during MIS.

2.10 Body Posture

The specific arrangement of the equipment in the OR as the location of the monitor, operating table, foot pedals, and the design of surgical instruments determines to a large extent the surgeon's posture and the organization of the surgical team. The way surgeons interact not only in the operating