MINIMALLY INVASIVE SURGICAL TECHNOLOGY

JAY R. GOLDBERG
Marquette University
Milwaukee, Wisconsin

INTRODUCTION

Most surgical procedures involve the invasion and disruption of body tissues and structures by surgical instrumentation and/or implantable medical devices, resulting in trauma to the patient. Diagnostic imaging procedures, such as magnetic resonance imaging (MRI), computed tomography (CT), X ray, positron emission tomography (PET), and ultrasound do not require disruption of body tissues, and are thus considered to be noninvasive. Extra corporeal shockwave lithotripsy (ESWL) used to disintegrate kidney stones is an example of a noninvasive therapeutic procedure. As shown in Fig. 1, it focuses acoustic energy, generated outside of the patient's body, on kidney stones. No trauma to the patient occurs during this procedure.

Open heart coronary artery bypass and organ transplantation surgery are examples of highly invasive surgery. These procedures require a high level of invasion and disruption of body tissues and structures. Bones, muscle tissue, and blood vessels are cut, and tissue from other parts of the body may be grafted, resulting in a high level of surgical trauma to the patient.

Minimally invasive surgical procedures are less traumatic than corresponding conventional surgical procedures. The use of small instruments placed through intact natural channels, such as the esophagus, urethra, and rectum, is less invasive than conventional open surgical approaches requiring large incisions, significant loss of blood, and trauma to tissues. The use of small instruments, such as biopsy guns and angioplasty balloons placed through small incisions, results in minor trauma to the patient, but is much less invasive than open surgical procedures used to accomplish the same goals. Procedures using small instruments through intact natural channels or small incisions are classified as minimally invasive.

A minimally invasive surgical procedure can be defined as surgery that produces less patient trauma and disruption of body tissues than its conventional open surgical counterpart. For example, conventional appendectomies require a 4 cm long incision made through layers of skin, muscle, and other tissues to gain access to the appendix. Once the appendix is removed, the layers of the wound are sutured together to allow them to heal. This invasive procedure requires a significant level of invasion and disruption of tissues and other structures. The minimally invasive appendectomy is performed with small surgical instruments placed into small incisions in the patient's abdomen. Once the appendix is removed, the small incision is closed with sutures. This procedure results in much less trauma to the patient than the open surgical approach.

Minimally invasive surgery (MIS) is performed with small devices inserted through intact natural orifices or channels, or small incisions used to create an orifice. Some procedures are performed with devices located outside the body, and thus are noninvasive. The MIS procedures are an alternative to open surgery. The benefits of MIS include reduced patient trauma, postoperative recovery time, and healthcare costs.

INSTRUMENTATION FOR MINIMALLY INVASIVE SURGERY

Many MIS procedures involve flexible or rigid fiber optic endoscopes for imaging surgical sites and delivering instrumentation for diagnostic or therapeutic applications. The term "endoscope" is a generic term used to describe tubular fiber optic devices placed into the body to allow visualization of anatomical structures.

Endoscopes consist of a fiber optic light guide, high intensity light source, coherent fiber optic bundle, steering mechanism, and various working channels for insertion of endoscopic instrumentation and infusion of irrigation fluids or insufflating gases. Glass fibers comprise the fiber optic light guide and coherent bundle and are surrounded by a flexible polyurethane sheath or rigid stainless steel tube. Figure 2 shows the components of a typical endoscope. The light source provides light that is transmitted through the light guide and projected onto the anatomical site to create an image. The coherent fiber bundle transmits the image back to the focusing eyepiece and into the surgeon's eye. The surgeon can move the endoscope proximally (toward the patient) and distally (away from the patient) by pushing and pulling the endoscope into and out of the body, respectively. Steering is accomplished with a handle attached to a cable that pulls and bends the tip of the endoscope in the desired direction. The proximal (closest to the patient) end of the endoscope (shown in Fig. 3) contains lumens for the fiber optic light guide and coherent fiber bundle, and one or more working channels for passage of instruments and irrigation fluid into and out of the operative site. Some endoscopes contain video cameras that display endoscopic images on a video monitor in the operating room, as shown in Fig. 4.

Specialized endoscopes have different names depending on what part of the body they are used to image. Table 1 lists the names of various endoscopes, the procedures for which they are used, and the anatomical location where they are used.

Endoscopic Procedures and Instrumentation

To perform an endoscopic procedure, the surgeon inserts a sterilized endoscope into a natural channel or orifice, such as the urethra, rectum, esophagus, bronchial tube, or nose. If there is no natural channel to provide access to the operative site (as in abdominal surgery), then the surgeon will create one with a small incision, and may insert a hollow trocar into the incision, as shown in Fig. 5. The trocar is left in the wound to provide access to the abdominal cavity. The endoscope is inserted into the access site (natural channel, incision, or trocar) and as it is advanced toward the operative site the surgeon monitors the image produced by the endoscope, either through the objective eyepiece or video monitor (as shown in Fig. 4). Rigid endoscopes are typically used when access is obtained

Encyclopedia of Medical Devices and Instrumentation, Second Edition, edited by John G. Webster

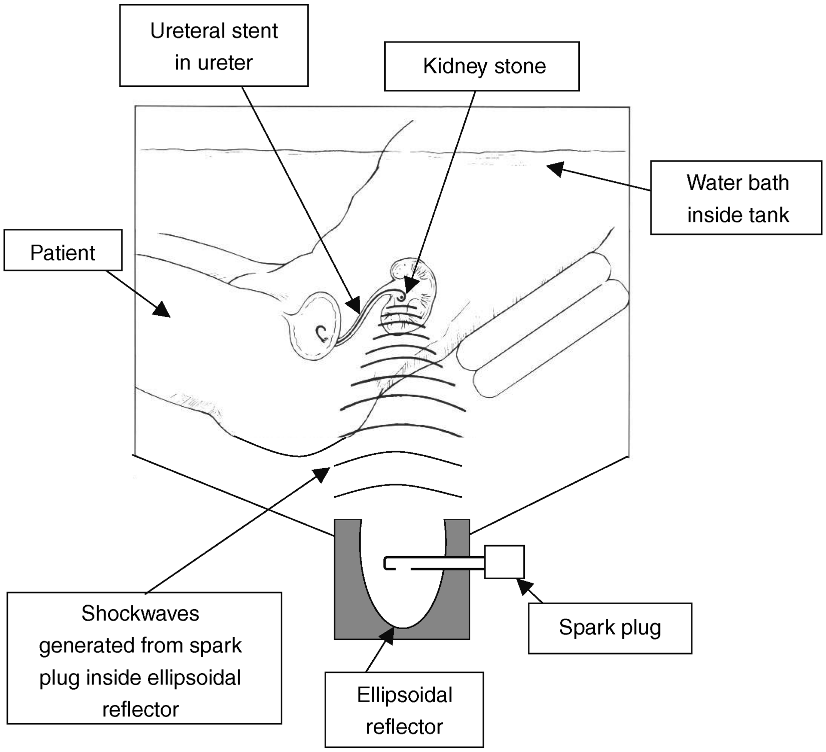

Figure 1. Schematic diagram of noninvasive extra corporeal shockwave lithotripsy (ESWL) procedure used to disintegrate kidney or biliary stones. Acoustic waves generated from spark plugs are focused with ellipsoidal reflectors on the kidney stone.

through an incision. Flexible endoscopes are used when access is obtained through natural channels (2). Once in position, the surgeon can then manipulate the endoscope to inspect tissues and anatomical structures (Table 1).

If a procedure other than visual inspection is required, the surgeon has a variety of instruments available to grasp, cut, remove, suture, and cauterize tissues, and remove debris through the endoscope. Forceps (Fig. 6) and graspers are used to grasp tissue and other objects such as kidney stones. Scalpels and scissors (Fig. 7) are used for cutting tissue. Suturing devices are used to repair internal wounds resulting from endoscopic procedures such as appendectomies, cholecystectomies (gallbladder removal), and arthroscopies. Morcellators are used to reduce the size and change the shape of a mass of tissue, such as a gallbladder, allowing it to be removed through a small incision. Electrohydraulic lithotriptor (EHL) and laser probes are used to disintegrate objects, such as kidney

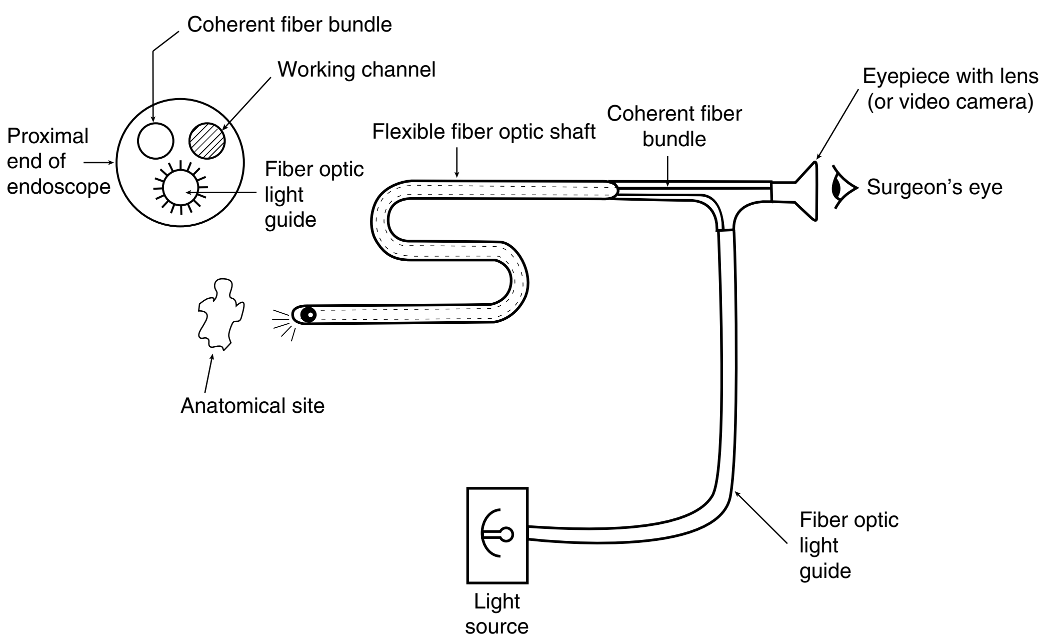

Figure 2. Components of a typical endoscope.

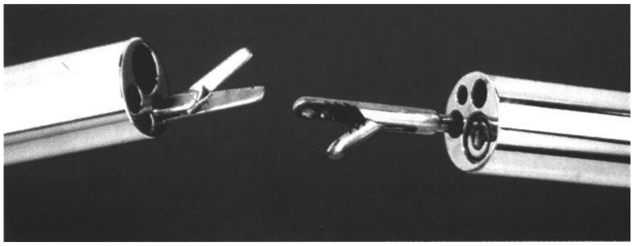

Figure 3. Proximal ends of typical endoscopes. Endoscopic instruments (left:scissors, right:forceps) are shown placed through working channels. Two other channels contain the fiber optic light guide and coherent fiber bundle, respectively. A fourth channel can be used for instrumentation or delivery of irrigation fluids to operative site (1). (Reprinted from Endoscopic Surgery, Ball, K., page 62, Copyright 1997, with permission from Elsevier.)

stones, with acoustic and laser energy, respectively, allowing the debris to be passed through the ureter. Stone baskets are used to trap kidney or ureteral stones for endoscopic removal, as shown in Fig. 8. These instruments are placed through the working channel of an endoscope or trocar and are operated by manipulating handles and controls located outside the patient.

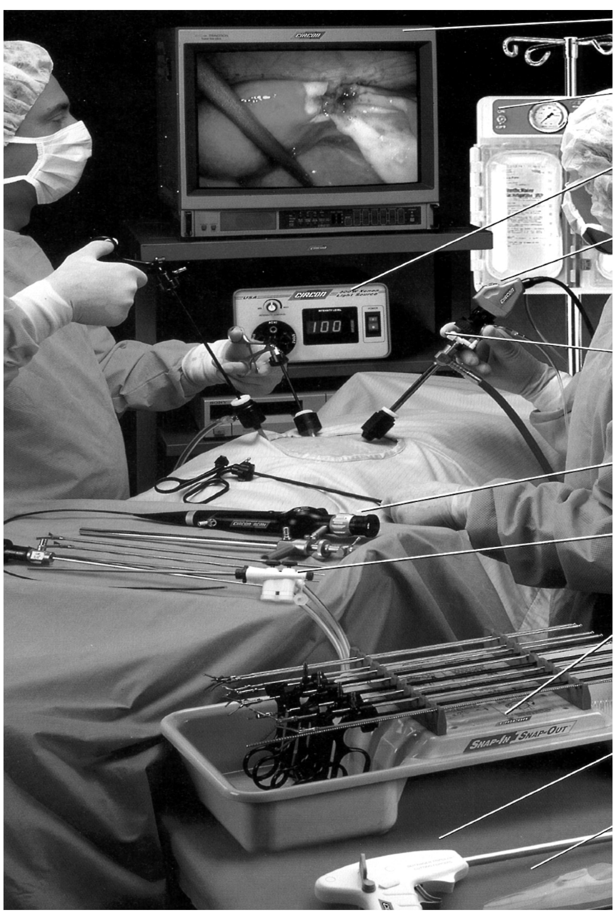

Figure 4. Surgeon viewing laparoscopic images of gallbladder on video monitor in operating room. Note use of three trocars in patient's abdomen; one each for video camera and two instruments. (Courtesy ACMI, Southborough, MA.)

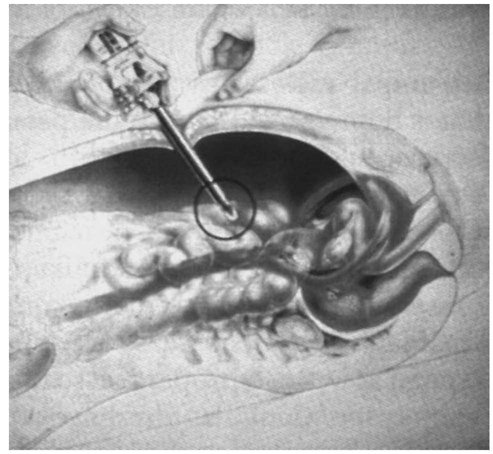

Figure 5. Trocar inserted into abdominal incision to provide access to abdominal cavity. Safety shield covers sharp end of trocar (circled) upon insertion to prevent damage to abdominal organs. (1) (Courtesy Ethicon Endo-Surgery Inc., Cincinnati, OH.)

Endoscopes may contain multiple working channels that allow for irrigation of fluids to irrigate and flush out clots and other surgical debris. The presence of the fluid improves visibility through the endoscope by keeping the visual field clear and the lens clean. Laparoscopic surgery requires insufflation of CO_2 or N_2O through the working channel or trocar and into the abdominal cavity to cause the cavity to expand, separating organs, and enlarging the operative site and visual field.

There are typically not enough working channels in a laparoscope to accommodate all of the instruments needed for a particular procedure. In these cases, multiple access sites are created with additional trocars. Typically, a camera is placed through one trocar and used to visualize the work being performed with instruments placed through other trocars.

When an endoscopic procedure is completed, the endoscope and instrumentation are removed from the patient via the natural channel or incision. When a laparoscopic procedure is completed, the laparoscope, camera, instruments, and trocars are removed from the patient. The wounds created by the trocars are sutured and the patient begins the recovery process. Although some of the CO_2 from insufflation may escape the abdominal cavity when all instrumentation is removed, some will be absorbed by body tissues and eliminated via respiration. Patients typically recover and are discharged from the hospital within 24–48 h.

Non-Endoscopic Procedures and Instrumentation

Not all minimally invasive procedures require endoscopic devices for imaging and placement of instruments. Some MIS procedures (listed in Table 2), such as stereotactic radiosurgery, use lasers or gamma radiation in place of scalpels. Others use small catheters to deliver medication, devices, or energy to specific anatomical locations. Balloons and stents, delivered via catheters, are used to access and dilate constricted vessels and maintain patency. Catheter mounted electrodes are used to deliver thermal, micro-

Table 1. Names of Endoscopes, MIS Procedures with Which they are Used, and Anatomical Location Where they are Used

Medical Specialty	Type of Endoscope Used	MIS Procedures	Anatomical Location
Urology	Cystoscope Ureteroscope Nephroscope	Cystoscopy, Transurethral resection of the prostate (TURP) Ureteroscopy, stone removal Nephroscopy, stone removal	Urethra, bladder ureter, kidney
Gastroenterology	Gastroscope Colonoscope Sigmoidoscope	Gastroscopy, gastric bypass Colonoscopy, Sigmoidoscopy	Stomach, colon Sigmoid colon
General surgery	Laparoscope	Laparoscopy, hernia repair, appendectomy, cholecystectomy (gallbladder removal)	Abdomen
Orthopedics	Arthroscope	Arthroscopy	Knee and other joints
Ob/Gyn	Hysterescope	Tubal ligation, hysterectomy	Female reproductive tract
Ear, nose, and throat	Laryngoscope, Bronchoscope Rhinoscope	Laryngoscopy, bronchoscopy Rhinoscopy, sinuscopy	Larynx, bronchus, nose, sinus cavities

wave, or radio frequency energy to selectively destroy tissue in ablation procedures used to treat cardiac arrhythmias (3), benign prostatic hypertrophy (BPH) (4), and other conditions. Many of these devices are guided through the body with the help of imaging or surgical navigation equipment.

Image Guided Surgery–Surgical Navigation

Image guided surgery (IGS) allows surgeons to perform minimally invasive procedures by guiding the advancement of instrumentation through the patient's body with increased accuracy and better clinical outcomes. Preoperatively, an IGS system is used to produce computerized anatomical maps of the surgical site from MRI or CT images of the patient. These maps are then used to plan the safest, least invasive path to the site. During an image guided procedure, the IGS system provides surgeons with a three dimensional image showing the location of instruments relative to the patient's anatomical structures. It tracks the movement of surgical instruments in the body, correlates these movements with the patient's preoperative images, and displays the location of the instruments on a monitor in the operating room. This feedback helps the surgeon safely and accurately guide instruments to the surgical site, reducing the risk of damaging healthy tissue (4,5).

An IGS system includes a computer workstation, localization system, display monitor, and specialized surgical instruments capable of being tracked by the system. Image processing and surgical planning software are also used. Tracking of instruments is accomplished through optical, electromagnetic, or mechanical means. Optical tracking systems use a camera mounted to view the surgical field and optical sensors attached to surgical instruments. These systems required line of sight between the camera and sensor to function properly. Electromagnetic tracking systems include a transmitter located close to the surgical site, and receivers attached to surgical instruments. Line of sight is not an issue with these systems, however, nearby metallic objects may produce interference to signals used to track instruments (4).

To ensure that the patient's anatomical features (and location of instruments) are accurately displayed by the IGS system, actual anatomical locations must be registered to the preoperative images. This can be accomplished by touching a probe to a marker on the patient's body and then assigning the location of this marker to its corresponding point in preoperative images (4).

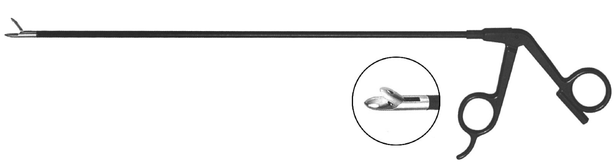

Figure 6. Endoscopic forceps. (Courtesy ACMI, Southborough, MA.)

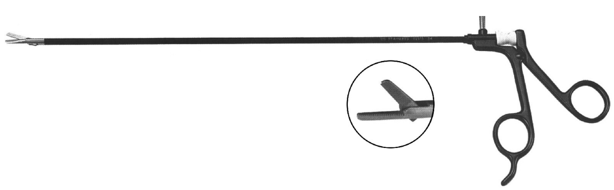

Figure 7. Endoscopic scissors. (Courtesy ACMI, Southborough, MA.)

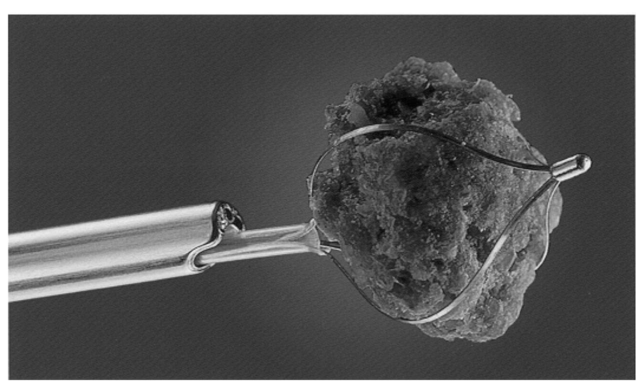

Figure 8. A stone basket used to trap and remove a large ureteral stone. (Courtesy ACMI, Southborough, MA.)

Table 2. Examples of Non-Endoscopic Minimally Invasive Surgical Procedures

Medical Specialty	Non-Endoscopic Minimally Invasive Surgical Procedure
Cardiovascular surgery	Minimally invasive direct coronary artery bypass (MIDCAB)
	Percutaneous transluminal coronary angioplasty (PTCA)
	Coronary stenting
	Radio frequency cardiac ablation
	Laser angioplasty
	Microwave catheter ablation for arrhythmias
	Chemical ablation for ventricular tachycardia
Ophthalmology	Laser photorefractive keratotomy (PRK)
	Laser ablation of cataracts
	Laser glaucoma surgery
Orthopedics	Total joint arthroplasty (hips, knees, and others)
Neurosurgery	Stereotactic radiosurgery
	Stereotactic radiotherapy
	Laser ablation of brain tissue, tumor tissue
Radiology	Clot removal
	Aneurism repair
	Cerebral arterial venous malformation repair
	Transjugular hepatic portal systemic shunt creation

Most surgical instruments must be adapted for use in image guided surgery by mounting sensors and other devices to allow detection of the instrument's position by the IGS system. Some medical device manufacturers are developing navigation-ready surgical instruments that contain small reflective spheres to act as reference arrays for cameras used in image guided surgery (5).

MINIMALLY INVASIVE SURGICAL PROCEDURES

This section contains a few examples of minimally invasive surgical procedures used in urology, orthopedics, neurosurgery, and general and cardiovascular surgery.

Ureteroscopy

Flexible ureteroscopy is used to perform a variety of diagnostic and therapeutic urological procedures. It involves entry into the body via intact natural channels (urethra and ureter) and does not require an incision. Local anesthesia and sedation of the patient are required.

Ureteroscopy is commonly used to remove ureteral or kidney stones. Initially, a cystoscope is inserted into the urethra. Next, a guidewire is placed through a cystoscope into the ureter, and advanced up into the kidney. While maintaining the position of the guidewire, the cystoscope is removed, and the distal end of the guidewire is placed into a working channel at the proximal end of the ureteroscope. The ureteroscope is then advanced along the guidewire into the ureter or kidney, as shown in Fig. 9. Active (controlled by the cable and handle) and passive deflection of the shaft, along with rotation of the flexible ureteroscope allows visual inspection of the renal calices as shown in Fig. 10. Ureteroscopic instruments are then placed through the working channel into the ureter or kidney. Figure 11 shows two devices used for ureteroscopic removal of ureteral stones. The stone grasper is used to physically grab the stone (Fig. 11). If the stone is small enough to fit into the working channel, it is pulled out of the patient through the ureteroscope. Large stones that will not fit into the working channel are pulled out with the ureteroscope. The laser lithotripter (Fig. 11) disintegrates the stone into small particles that can easily be passed naturally through the ureter, bladder, and urethra. Collapsed stone baskets can be placed alongside a stone and moved proximally and distally as they are expanded, until the stone is trapped in the basket (as shown in Fig. 8) and pulled out of the urethra.

Laparoscopy

Laparoscopy is commonly used for removal of the gallbladder and appendix, hernia repair, and other abdominal procedures. The basic steps involved in laparoscopy have been previously described. The lack of natural channels located in the abdomen requires the use of trocars to gain access to the operative site. Laparoscopic procedures require insufflation of gas to separate organs and expand the visual field. This is controlled by a separate insufflator that controls the pressure inside the abdomen produced by the flow of insufflating gases (1).

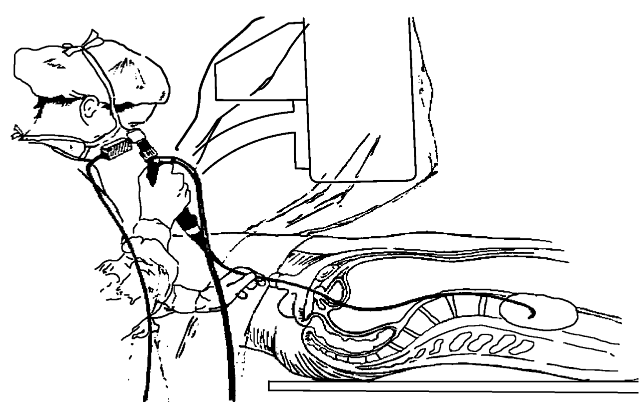

Figure 9. A surgeon views images through a ureteroscope placed through the urethra, bladder, ureter, and into the kidney. (Courtesy ACMI, Southborough, MA.)

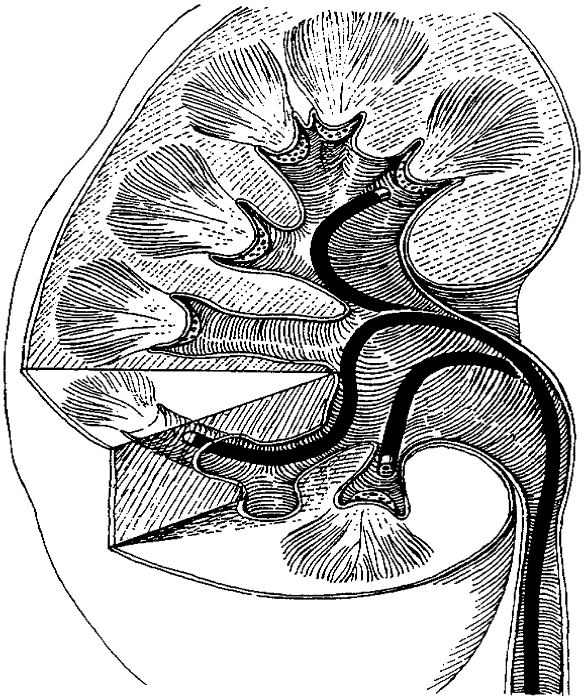

Figure 10. Flexibility and steerability of proximal end of ureteroscope allow inspection of upper, middle, and lower renal calices. (Courtesy ACMI, Southborough, MA.)

Total Joint Replacement

Total hip and knee replacements are typically performed with large incisions to expose the joint, allowing for complete visualization of and access to the joint and soft tissues. New surgical approaches using smaller incisions that result in less damage to muscles and other soft tissue limit the view of the joint. To compensate for the limited view, fluoroscopy and IGS systems are often used. Some existing surgical instruments have been modified to enable surgery through smaller incisions (6).

Traditional hip arthroplasty requires a 30–46 cm long incision, which is highly disruptive to muscles and surrounding tissues. Two different techniques can be used for minimally invasive total hip arthroplasty. One technique uses two 5 cm long incisions, one each for preparation and insertion of the acetabular and femoral components, respectively. The other technique involves one 8–10 cm long incision. Modified retractors and elevators are used to gain access and expose the joint. Fluoroscopy and IGS systems are used to provide the surgeon with a view of instruments and components (as shown in Fig. 12) and assist in positioning of instruments designed to enable accurate component alignment and placement. Minimally invasive hip arthroplasty results in less disruption of muscles and tissues, smaller and less noticeable scars, less blood loss and pain, and fewer blood clots and dislocations (6).

Most minimally invasive knee arthroplasties performed through smaller incisions involve a single compartment of the knee. These procedures typically use existing unicompartmental knee implants for resurfacing the medial or lateral femoral condyle and corresponding tibial plateau. Existing instrumentation has been modified to obtain

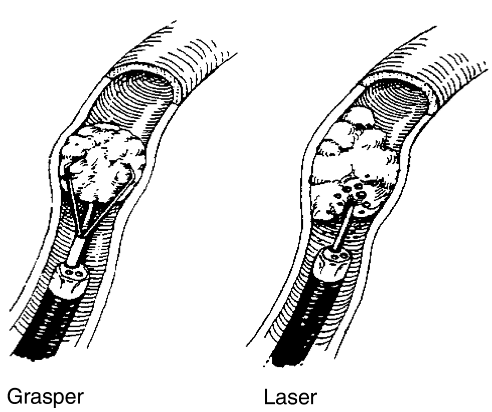

Figure 11. Devices used for endoscopic removal of ureteral stones. (Courtesy ACMI, Southborough, MA.)

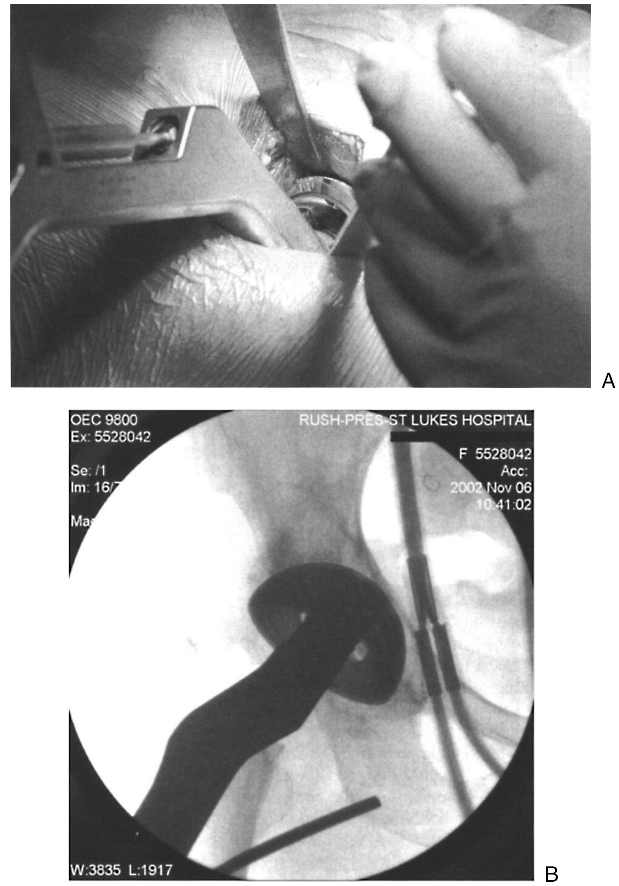

Figure 12. Acetabular component inserted with inserter through small incision (top image). Fluoroscopic image of inserter and acetabular component seated in acetabulum (bottom image). Images such as these allow surgeons to ensure proper placement of instruments and implantable components within hip joint when small incisions prevent viewing of entire device (6). (From MIS for the Hip and Knee: A Clinical Perspective, 2004, pg. 20, Minimally Invasive Total Hip Arthroplasty: The Two Incision Approach, Berger, R.A. and Hartzband, M.A., Fig. 2.11. Copyright 2004, with kind permission of Springer Science and Business Media.)

access to the joint and enable accurate placement and alignment of the unicompartmental knee components through smaller incisions.

Minimally Invasive Direct Coronary Artery Bypass

Coronary arteries may become blocked due to fatty deposits (plaque), blood clots, or other causes. This reduces blood flow to cardiac muscle, depriving it of needed oxygen and other nutrients. This condition can result in a myocardial infarction (heart attack) that can damage cardiac muscle.

Traditional open heart coronary artery bypass graft surgery has been used to restore normal blood flow to cardiac muscle. This procedure involves grafting a new vessel to points on both sides of the blocked coronary artery, thereby bypassing the blockage and restoring normal blood flow. It requires open access to a still heart to allow suturing of the graft to the blocked coronary artery. A sternotomy and separation of the sternum is required to provide access to the heart. The heart is stopped and the patient is attached to a heart–lung machine to maintain circulation of oxygenated blood through the body during the surgical procedure. This procedure is highly invasive and can result in a variety of complications, many of which are associated with use of a heart–lung machine. Inflammatory responses negatively affecting multiple organ systems have been observed in patients who were perfused with a heart–lung machine during traditional open heart coronary bypass surgery (7). These responses are due to reactions between circulating blood and material surfaces present in the heart–lung machine.

Minimally invasive direct coronary artery bypass is an alternative to open heart surgery. A small 5–10 cm incision made between the ribs replaces the sternotomy to gain access to the heart. A retractor is used to separate the ribs above the heart to maximize access to the operative site (8). Heart positioners and stabilizers (Fig. 13) are used to minimize the motion of the heart, allowing surgeons to perform the procedure on a beating heart, eliminating the need for the heart–lung machine. Some stabilizers grasp the heart with suction cups. Others use a fork like device to apply pressure to the beating heart to keep it steady for anastomosis of the graft (8). A thorascope and small endoscopic instruments are used to visualize the surgical site and perform the surgical procedure. The left internal mammary artery is commonly used as the grafted

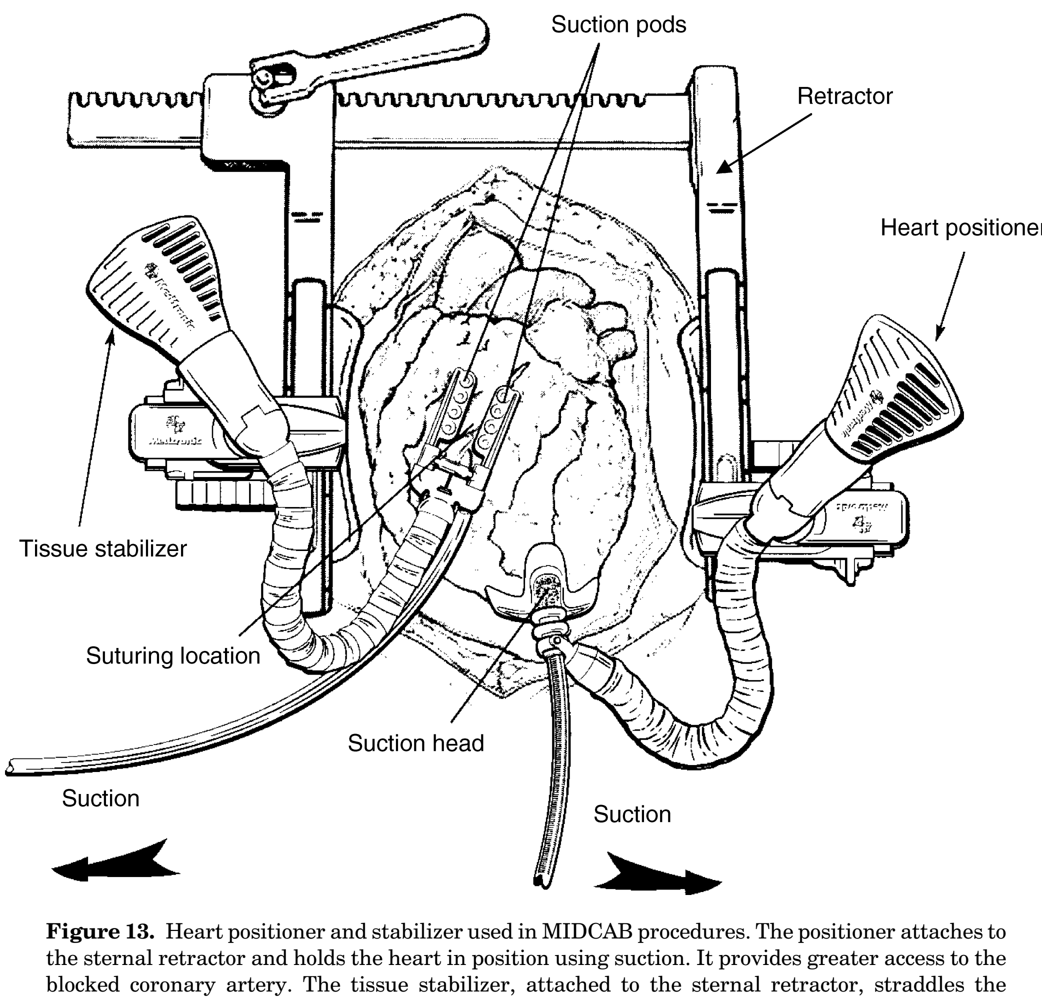

Figure 13. Heart positioner and stabilizer used in MIDCAB procedures. The positioner attaches to the sternal retractor and holds the heart in position using suction. It provides greater access to the blocked coronary artery. The tissue stabilizer, attached to the sternal retractor, straddles the blocked artery and holds the suturing site steady. This allows surgery on a beating heart, eliminating the need for a heart–lung machine along with its associated complications. (Courtesy of Medtronic, Inc., Minneapolis, MN.)

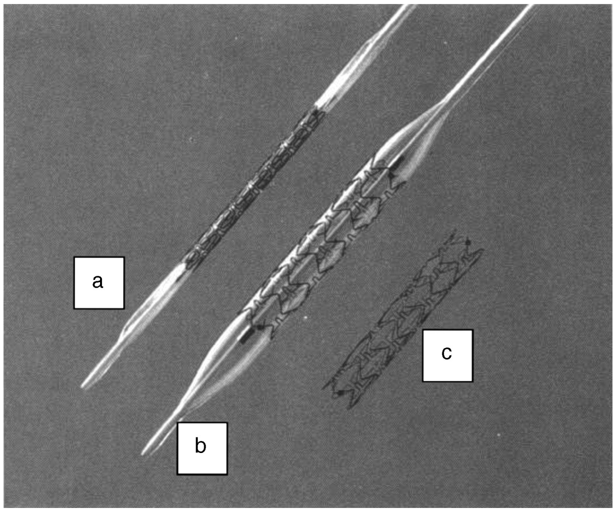

Figure 14. A PTCA catheter and stent. Stent and balloon in collapsed configuration for insertion and placement into coronary artery (a). Inflated balloon causing stent to expand (b). Expanded stent after collapse of balloon and removal of catheter (c). (Courtesy of Sorin Biomedica Cardio SpA, Italy.)

vessel to bypass the blockage of the coronary artery. The MIDCAB results in fewer complications, less blood loss, and shorter hospital stays.

Percutaneous Transluminal Coronary Angioplasty with Stent Placement

The PTCA method is used to open a blocked, constricted coronary artery instead of bypassing the blockage with a graft. Under local anesthesia, a steerable balloon catheter containing a stent mounted to the balloon (Fig. 14a) is inserted into the patient's femoral artery and guided to the constricted coronary artery under fluoroscopy. Once in position, the balloon is inflated to compress and flatten the plaque against the arterial wall, creating a larger opening for blood to flow through the coronary artery. The balloon is constructed with materials of different stiffness such that pressure from the inflating balloon is radially applied to the constricted area, and not to tissue outside of the constricted region (3). During balloon inflation, the stent is expanded to a larger diameter Fig. 14b, which is maintained after deflation of the balloon. The catheter is removed, and the expanded stent (Fig. 14c) is left in place to maintain a larger opening and prevent restenosis of the coronary artery.

Most coronary stents are made of stainless steel, nitinol, cobalt chrome molybdenum alloy, or gold (3). Some stents contain coatings to improve biological performance (biocompatibility and resistance to clot formation) and/or elute drugs into surrounding tissues to prevent restenosis of the coronary artery.

The PTCA method does not remove plaque from the coronary artery; it flattens it so it no longer restricts blood flow. Plaque removal methods involve lasers and rotational cutting devices (3).

Stereotactic Radiosurgery

In this noninvasive procedure, focused external beams of radiation are delivered to specific locations in the brain to treat tumors (9). The accuracy of the delivery prevents damage to healthy brain tissue. The patient's head is constrained in a mask or frame during the 30–45 min procedure.

Newer radiotherapy systems include robotic linear accelerators for delivery of radiation at any angle to the patient's head, a beam shaper to match the shape of the beam to the three-dimensional (3D) shape of the tumor, and imaging equipment to provide real-time tracking of tumor location and patient positioning (9).

Treatment of Benign Prostatic Hypertrophy

Benign prostatic hypertrophy causes the prostate to enlarge. An enlarged prostate applies pressure to the prostatic urethra that can occlude the urethra, reduce urinary flow rate, and make urination difficult. The enlarged prostate can be removed with an open surgical approach or less invasive transurethral resection of the prostate (TURP). The TURP procedure involves cutting and removing segments of the prostate through a cystoscope or with a resectoscope inserted into the urethra, and can result in complications, such as incontinence and impotence. Prostatic balloon dilators and prostatic stents inserted into the urethra have been used to expand the narrowed urethra. Transurethral laser incision of the prostate (TULIP) has been used to cut and remove prostate tissue. In this procedure, a catheter mounted laser facing radially outward toward the prostate delivers laser energy that cuts through the enlarged prostatic tissue, relieving pressure on the urethra.

Newer approaches to treating BPH include transurethral microwave therapy (TUMT) and transurethral needle ablation (TUNA) (4). These procedures use microwave and radio frequency energy, respectively, to heat and destroy unwanted tissue without actually removing the tissue. The TUMT method involves insertion of a urethral catheter containing a microwave antenna into the bladder neck. Channels contained in the catheter carry cooling water to prevent thermal damage to the urethra while microwave energy is used to heat the prostate for $\sim$1 h. The TUNA method uses a cystoscope to insert two shielded electrode needles through the urethra and into the prostate. Radio frequency energy is delivered to the prostate, heating the tissue and destroying it. Thermal energy causes the prostate tissue to stiffen and shrink, relieving the pressure on the urethra caused by the enlarged prostate. Both TUMT and TUNA deliver controlled thermal energy to a targeted area to selectively destroy prostate tissue (4).

NEW DEVELOPMENTS IN TECHNOLOGY FOR MINIMALLY INVASIVE SURGERY

New devices and technologies are being developed and clinically evaluated for use in MIS. Robots can be used to enable surgeons to perform more intricate surgical procedures than can be done with endoscopic devices (10). In robot-assisted surgery, the surgeon operates a console to control mechanical arms positioned over the patient. The arms become an extension of the surgeon's hands. While observing the procedure on viewing screens (one for each eye) that produce a 3D image, the surgeon uses hand, finger, and foot controls to move the mechanical arms containing interchangeable surgical instruments through a small opening in the patient's body (10).

Other new technologies for MIS include 3D video imaging, integrated robotic and surgical navigation systems, devices for mechanical retraction of the abdominal wall (eliminating the need for insufflation), and telerobotics (8).

OUTCOMES OF MINIMALLY INVASIVE SURGERY

Comparison of MIS to Conventional Approaches

Minimally invasive surgical procedures result in reduced patient trauma, less postoperative pain and discomfort, and decreased complication rates. Hospital stays and postoperative recovery times are reduced, resulting in lower hospital costs and allowing patients to return to work earlier.

Studies comparing various MIS procedures to their traditional open surgical counterparts have been conducted. One such retrospective study compared the clinical and economic aspects of laparoscopic and conventional cholecystectomies (11). Results of 153 consecutive traditional procedures and 222 consecutive laparoscopic procedures performed in a German teaching hospital were evaluated. Researchers found that although laparoscopic cholecystectomies required longer operative times (92 vs. 62 min), they resulted in fewer complications (6 vs. 9), shorter hospital stays (3 vs. 8 days), and an 18% decrease in hospital costs, when compared to traditional procedures.

In a Canadian study, the direct costs of conventional cholecystectomy, laparoscopic cholecystectomy, and biliary lithotripsy were compared (12). Researchers concluded that laparoscopic cholecystectomy provided a small economic advantage over the other two procedures and attributed this to a shorter hospital stay.

In the United States, hospital stays following laparoscopic cholecystectomies typically ranged from 3 to 5 days. Now, many of these procedures are performed on an outpatient basis. This additional reduction in hospital stay further reduces hospital costs, resulting in a greater economic advantage over the conventional procedure.

A study comparing results of 125 consecutive off-pump coronary bypass (OPCAB) procedures to a matched, contemporaneous control group of 625 traditional coronary artery bypass graft (CABG) procedures was conducted (7). The OPCAB procedure is a beating heart procedure that does not involve a heart–lung machine. Partial sternotomies were used with some patients in the OPCAB group. Researchers found that the OPCAB procedure resulted in a lower mortality rate (0 vs. 1.4%), reduced hospital stays (3.3 vs. 5.5 days), 24% lower hospital costs, and a reduced transfusion rate (29.6 vs. 56.5%), when compared to the traditional CABG procedure. Excellent graft patency rates and clinical outcomes were also reported with the OPCAB procedure.

In another study of 67 MIDCAB patients, it was found that average hospital charges for MIDCAB were $14,676 compared to $22,817 for CABG and $15,000 for coronary stenting (13). The significantly lower charges for MIDCAB were attributed to shorter hospital stays, elimination of perfusion expenses, and reduction in ICU, ventilation, and rehabilitation times.

Limitations of Minimally Invasive Surgery

There are several problems and limitations associated with MIS procedures. First, some minimally invasive surgical procedures can take longer to perform than their more invasive counterparts (10). Second, open surgical procedures allow the surgeon to palpate tissue and digitally inspect for tumors, cysts, and other abnormalities. Tactile feedback also assists in locating anatomical structures. The inability of the surgeon to actually touch and feel tissue and structures at the operative site limits the diagnostic ability of some MIS procedures (10). Third, a two-dimensional (2D) image is produced by the endoscope and video monitor. The resulting loss of depth perception combined with restricted mobility of instruments through a small incision make manipulation of endoscopic instruments challenging. Fine hand movements are difficult due to the long distances between the surgeon's hand and working ends of these instruments. Fourth, there is a limit to the number of instruments that can be used at one time through trocars and working channels of a laparoscope. Finally, instrumentation for MIS procedures is more expensive.

Insufflation presents a small risk not associated with open surgical procedures (1,10). If the gas pressure inside the abdominal cavity becomes too high or there is a small defect in a blood vessel, then a gas bubble can enter the bloodstream and travel to the heart or brain, causing unconsciousness or death.

Laparoscopic removal of cancer tissue carries a very small risk of transporting cancer cells to other parts of the body. As tumor tissue is removed through the laparoscope, some cancer cells may remain in the body. They may be displaced from their original location resulting in the spread of cancer cells to other parts of the body (10).

SUMMARY

Minimally invasive surgery is made possible through the use of specialized devices and technologies. These include endoscopes, surgical instruments, imaging and navigation systems, catheters, energy delivery systems, and other devices. The MIS procedures tend to require more time, are more difficult to perform than conventional procedures, and present some unique risks not associated with conventional procedures. Compared to conventional open surgical procedures, MIS procedures demonstrate similar clinical efficacy and reduce trauma and disruption of body tissues and structures. Patients experience less pain and discomfort, fewer complications, and shorter recovery periods. Hospital stays are reduced, resulting in lower hospital costs.

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See also ENDOSCOPES; GAMMA KNIFE; MICROSURGERY; STEREOTACTIC SURGERY; TISSUE ABLATION.