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Abstract

Gasless single-port RoboSurgeon surgery combines gasless single-port surgery with robotization of the surgeon. This surgery, which employs a minimum of disposable devices and does not require extremely expensive instruments, is affordable and usually carried out in the wide retroperitoneal working space made along the anatomical plane, while sparing the intraperitoneum, through a roughly coin-sized single port. The RoboSurgeon system consists of three components: a three-dimensional head-mounted display (3D-HMD), handheld robot-like devices, and an endoscope manipulation robot. Depending on the situation, part or all of this system is used for various urological surgeries, but the 3D-HMD, which provides six fields of vision (magnified vision, stereovision, panoramic vision, multivision, navigated vision and shared vision), is always used. Using the panoramic vision (direct vision) obtained by moving the angle of sight downward, surgeons can smoothly receive instruments and observe the operative field to ensure safety. Performing this surgery achieves four key “nos”: no high costs, no CO₂, no multiple ports, and no intraperitoneal injury. Direct vision and adjustable port size provide safety, ease in learning, and transition from open surgery without difficulty. Without the RoboSurgeon system, gasless single-port-like surgery, in which the port size is somewhat larger, can be performed using the procedures described in this book. This system is also applicable to various fields of surgery and medical care.

Keywords

Gasless endoscopic surgery • Single-port surgery • RoboSurgeon • Robotization of surgeon • Urologic minimally invasive surgery

1.1 Introduction

Laparoscopic surgery was widely performed during the 1990s as a less invasive alternative to open surgery. The subsequent advent, around 2000, of the master–slave robot system, the da Vinci system, has further improved

laparoscopic surgery, offering surgeons better visualization (by moving from two-dimensional to three-dimensional images) and improved dexterity (by moving from chopstick-like devices to multiarticular robot arms). One of the next challenges is to develop a form of minimally invasive retroperitoneal surgery that benefits the patient, surgeon, and society by providing an option that meets the multiple requirements of affordable cost, no CO₂ insufflation, a single-port procedure, and an intact peritoneum.

Since 1998, our department has been developing a form of retroperitoneal surgery that uses a minimum incision and permits narrow extraction of the specimen without gas insufflation, designated as a type of minimum incision endoscopic

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Fig. 1.1 Fundamental concept of gasless single-port RoboSurgeon surgery

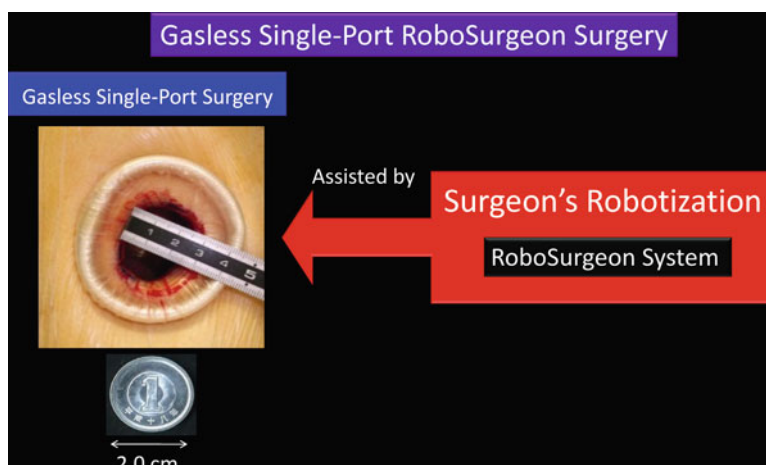
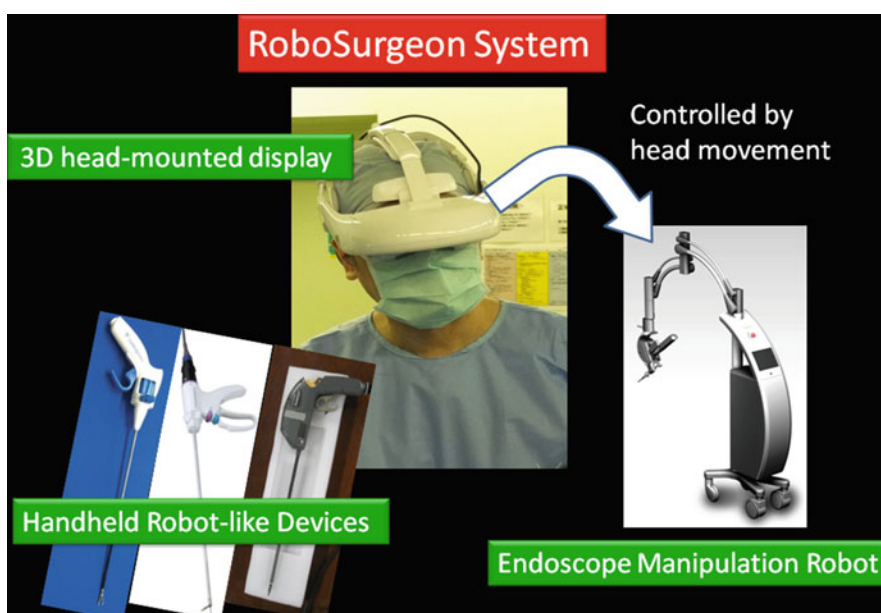


Fig. 1.2 RoboSurgeon system. Three dimensional (3D)



surgery [1–6]. From this surgical technique, we developed a form of gasless single-port surgery by introducing a system (RoboSurgeon) that involves the robotization of the surgeon, which makes it possible to safely minimize the port size to approximate the size of a coin [7–14] (Fig. 1.1). The current version of the RoboSurgeon system consists of three components: a three-dimensional head-mounted display (3D-HMD), handheld robot-like devices, and an endoscope manipulation robot (Fig. 1.2). Although part or all of this system may be used depending on the situation, the 3D-HMD is always used (Fig. 1.3). Robotization of the surgeon is being steadily and continuously improved.

This surgery may overcome some of the disadvantages of existing laparoscopic and robotic minimally invasive surgeries, while retaining their major benefits and possibly adding some unique advantages.

1.2 General Concept

This surgery is carried out in the wide retroperitoneal working space made along the anatomical plane without gas insufflation, through a roughly coin-sized single port, assisted by a system (RoboSurgeon) that involves the robotization of the surgeon (Figs. 1.1, 1.2, 1.3, and 1.4).

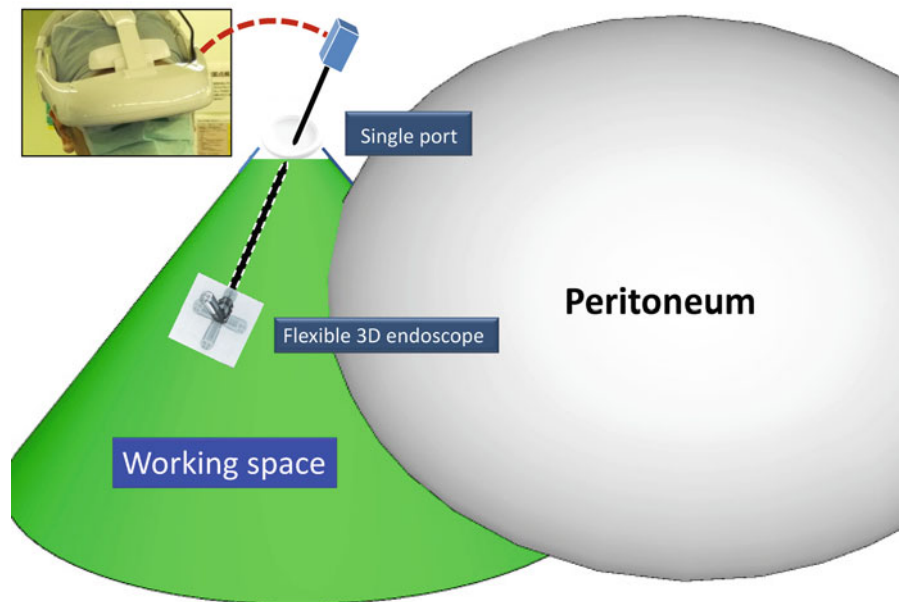
Performing this surgery achieves four key “nos”: no high costs, no CO₂, no multiple ports, and no intraperitoneal injury (Fig. 1.5).

High costs are avoidable because most of the devices are reusable, and highly expensive instruments are not necessary. The cost of surgery is nearly the same as that of open surgery, and hospitalization expenses are nearly the same as those associated with laparoscopic or robot-assisted surgery.

Fig. 1.3 Single port and 3D head-mounted display that all surgeons wear



Fig. 1.4 Wide retroperitoneal working space



Adverse effects due to CO_2 insufflation are prevented (Table 1.1), and careful care required by the anesthesiologist during operation is minimized. For patients with underlying low cardiopulmonary or renal function, no CO_2 insufflation may be preferable. The CO_2 -free nature of the surgery may create an eco-friendly association from the standpoint of global CO_2 elevation.

Adverse effects of the transperitoneal approach (e.g., postoperative intestinal obstruction) are avoided, and patients with extensive prior abdominal surgery can undergo this procedure.

No prophylactic antimicrobial agents are needed in most of the operations due to the minimal incision, effective washing of the operative field, effective protection of the edge of the incision, and no insertion of fingers, which may contribute to reduction of drug-resistant bacteria [15–18].

Safety is also guaranteed by easy, instant, and precise inch-by-inch extension of the port size tailored to the patient's situation, including, but not limited to, obesity, performance status, comorbidity, or the operator's experience. Conversion to open surgery, which almost never occurs, can also be accomplished swiftly. Based on these safety features, learning this operation is rather easy, as described below.

Fig. 1.5 Key features of gasless single-port surgery

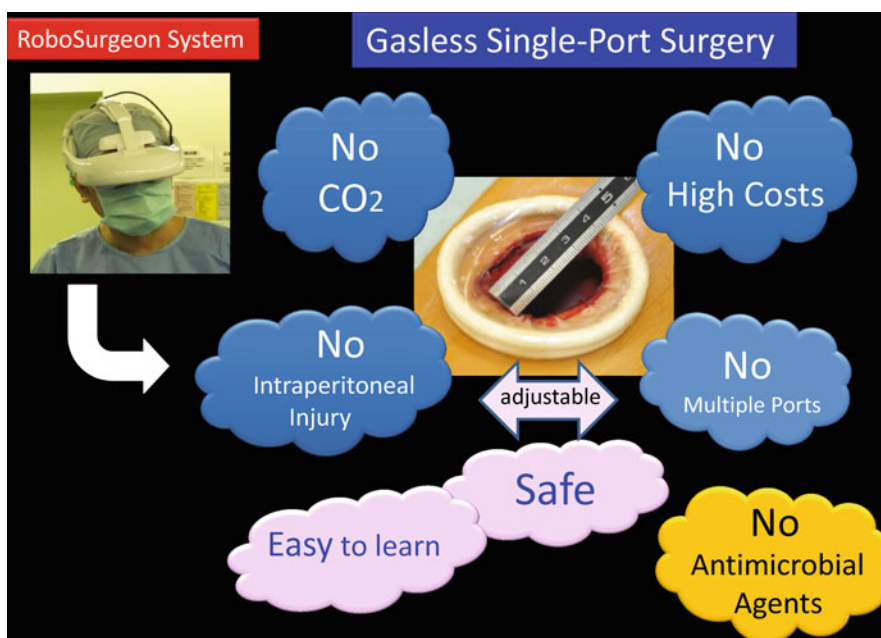


Table 1.1 Adverse effects due to CO₂ insufflation

Hypercapnia
Hypertension/hypotension
Decline of lung compliance
Reduction of urine volume
Gas embolism
Subcutaneous emphysema
Shoulder pain
One lung intubation

1.3 Gasless Single-Port Surgery

1.3.1 Approach and Positioning of the Patient

The retroperitoneal approach through a flank port in the flank position is the standard in surgeries for the adrenal gland, kidney, and upper urinary tract (Fig. 1.6). In cases with low cardiopulmonary function, severe osteoporosis, and horseshoe kidney and for cosmetic purposes, the retroperitoneal approach through a pararectal port (Chap. 2) or an umbilical port (Chaps. 3 and 4) in a supine position is chosen (Figs. 1.7 and 1.8). For a large pheochromocytoma, the transperitoneal approach, which usually spares muscles, is frequently selected (Fig. 1.7 and Chap. 5).

As for intrapelvic organs, the retroperitoneal approach through a lower abdominal port in a supine position is used (Fig. 1.9).

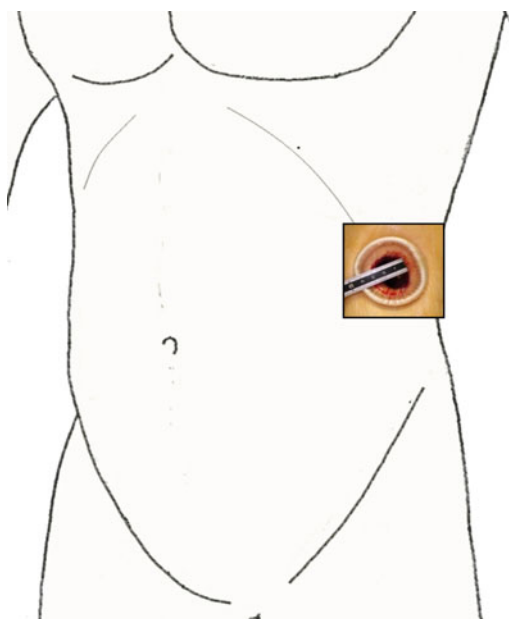


Fig. 1.6 Standard port site for the adrenal gland, kidney, and upper urinary tract

1.3.2 Working Space

A wide working space is created extraperitoneally through a single port as an initial step by creating separation along the anatomical plane. For the adrenal gland, kidney, and upper urinary tract, the space is made by dissecting along Gerota's fascia, usually through a port around the tip of the 12th rib (Figs. 1.10 and 1.11).

Fig. 1.7 Various retroperitoneal approaches through a single-port in the supine position. (a) Pararectal retroperitoneal radical nephrectomy; (b) transnavel retroperitoneal partial nephrectomy; (c) pararectal retroperitoneal partial nephrectomy; and (d) transperitoneal adrenalectomy for large pheochromocytoma

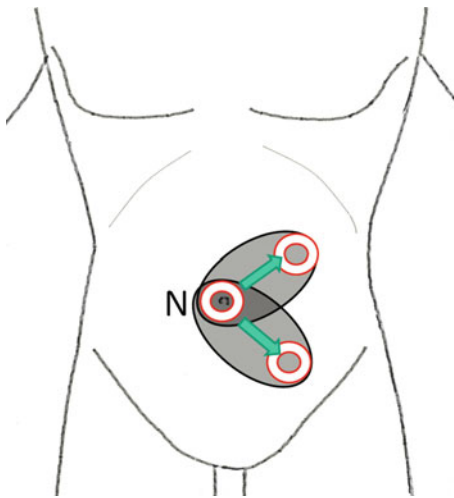
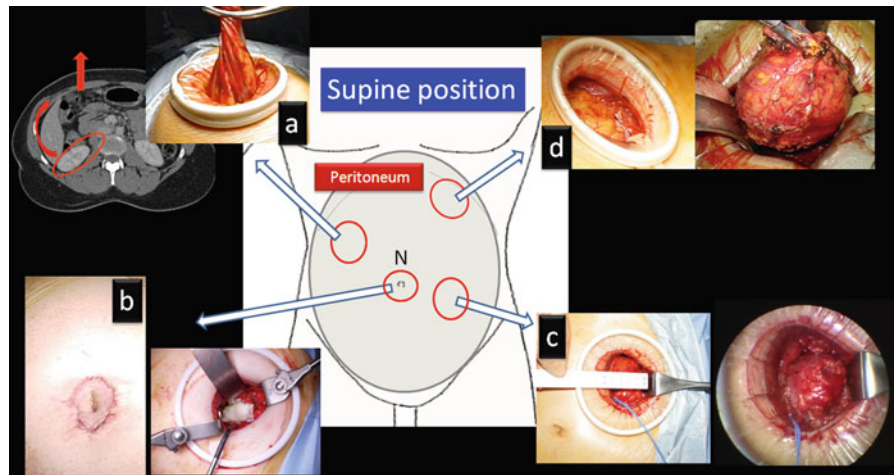


Fig. 1.8 Transnavel retroperitoneal approach. The skin hole at the navel site is shifted to the pararectal portion where a single-port is made. Navel (N)

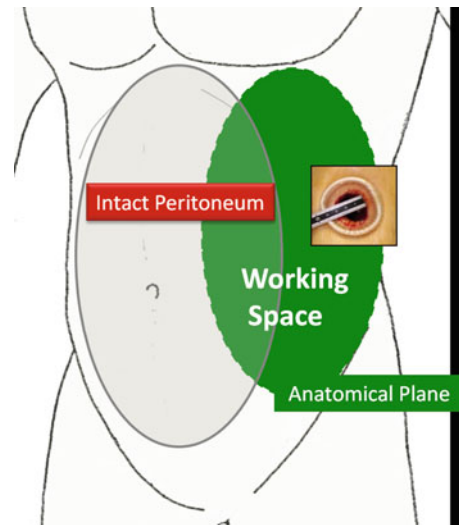


Fig. 1.10 Working space in the adrenal gland, kidney, and upper urinary tract surgeries

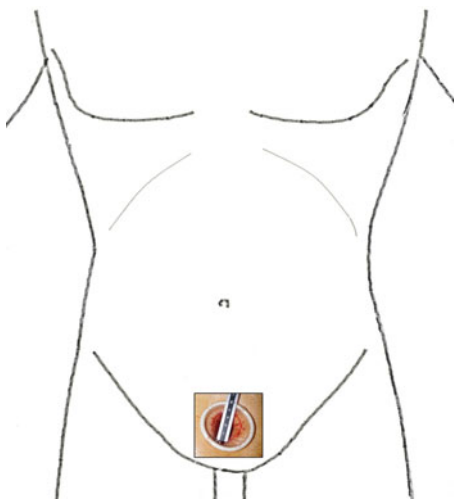


Fig. 1.9 Standard port site for intrapelvic organs

For the intrapelvic organs (i.e., prostate, bladder, and pelvic lymph nodes), the working space is created by dissecting along the fascia covering the perivesical fat through a port in the lower abdomen (Figs. 1.12 and 1.13).

When both working spaces are required, such as in nephroureterectomy, two single-port surgeries are combined (Fig. 1.14).

1.3.3 Single Port

The standard size of the single port in the flank or the lower abdomen is usually around 2–4 cm, approximately the size of a coin. The sizes for major urologic surgeries are presented in Fig. 1.15. The port size is adjusted based

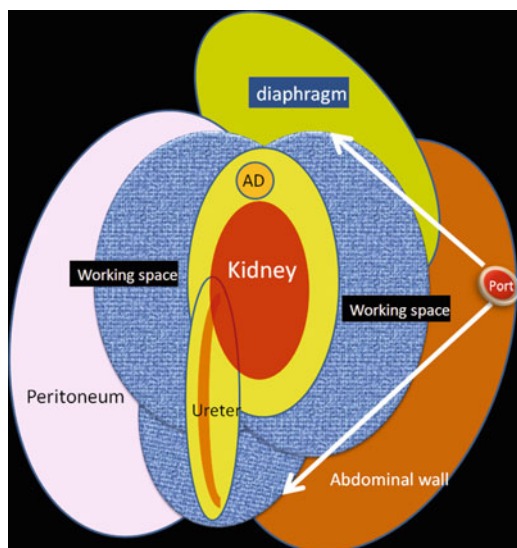


Fig. 1.11 Working space (shown in blue) made through a flank port along Gerota's fascia. Adrenal gland (AD)

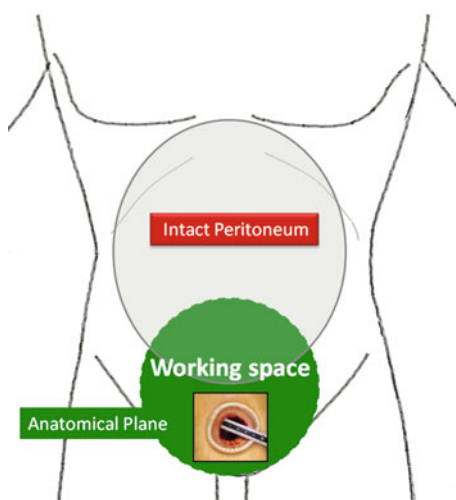


Fig. 1.12 Working space in the intrapelvic organ surgeries

on the patient's situation and occasionally on the surgeon's experience. Precise inch-by-inch adjustments are possible before or during the operation. Through the port, which can be extended to facilitate extraction, the targeted specimen is extracted as shown in Fig. 1.16.

1.4 RoboSurgeon System

The RoboSurgeon system comprises three components: a 3D-HMD, handheld robot-like devices, and an endoscope manipulation robot that works with air pressure (Aerovision® [initial version], EMARO® [second version], Riverfield, Inc.).

1.4.1 Three-Dimensional Head-Mounted Display

The 3D-HMD for medical use (SONY Corp.) has $1,280 \times 720$ resolution from the two 0.7-in. organic light emitting diode (OLED) panels that process 256 levels colors each for red, green, and blue (Fig. 1.17). Separate OLED display panels for left and right eyes offer a smooth, natural 3D view. The 3D-HMD is connected to an image processor to provide clear, high-quality 3D images in front of the eyes regardless of head position (Figs. 1.17 and 1.18). Via the processor, the 3D-HMD is connected to a flexible (Olympus) or a thin (Shinko Optical) 3D endoscope (Fig. 1.18). The digital zoom function works by pressing a button on the 3D flexible endoscope (Fig. 1.19).

The 3D-HMD provides six fields of vision (magnified vision, stereovision, panoramic vision, multivision, navigated vision, and shared vision) (Fig. 1.20). Clear magnified stereovision enables the surgeon to perform complex maneuvers, especially in deep sites (Fig. 1.21). Panoramic vision (direct vision), which is obtained by moving the angle of sight downward, is helpful in maintaining safety throughout the operation. Each surgeon can change the direction of the images on the display according to his or her position and share a common direction with other surgeons (Figs. 1.22 and 1.23).

Various images of X-ray, ultrasound, computed tomography, magnetic resonance imaging, positron emission tomography, etc. are seen on the 3D-HMD (Fig. 1.24). Navigation using ultrasonography via the port or the rectum aids the process (Figs. 1.24 and 1.25). Two images in the original set, and four images when a multiplexer is applied, are seen simultaneously on the 3D-HMD (Fig. 1.26). Images are shared among all participating surgeons. The images can be controlled by a foot switch or via finger movement when a camera is set on the HMD (Figs. 1.27 and 1.28).

Instructors, students, nurses, or others who instruct or learn from the operation can see the same images as the surgeon and communicate with him or her directly (Fig. 1.29). They can also view these images and communicate with the surgeon from another room (Fig. 1.30).

Scrub nurses sometimes use a see-through-type 2D-HMD (AiRScouter, Brother Industries, Ltd.) showing a transparent image through a crystal panel in front of the eyes. They can view illustrated steps of the operation and prepare equipment in a timely manner. The images are changed by a foot switch (Fig. 1.31).

1.4.2 Handheld Robot-Like Devices

Handheld robot-like devices are used, such as Thunderbeat® (Olympus), which combines the functions of an ultrasonic

Fig. 1.13 Working space (shown in *blue*) made through a single port in the lower abdomen along the perivesical fatty tissue

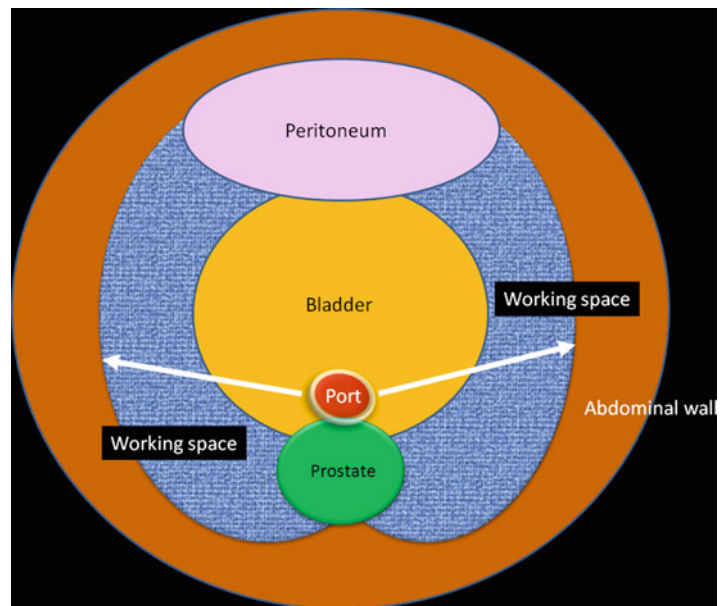


Fig. 1.14 Combination of the two single-port surgeries

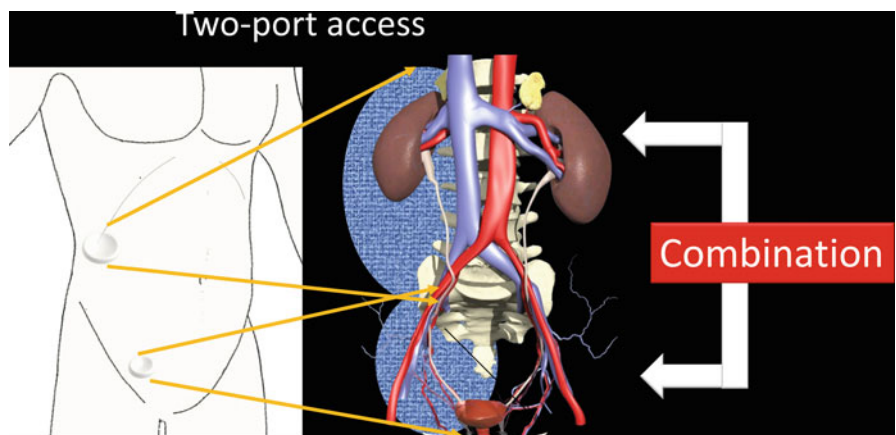


Fig. 1.15 Standard sizes of the single port for major urological surgeries



Fig. 1.16 Typical images of extraction of the specimen through a port

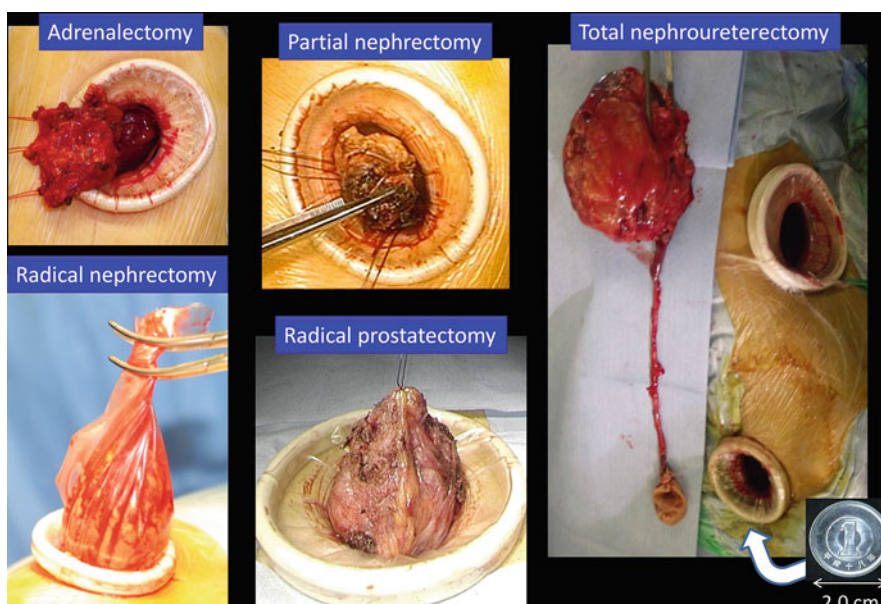
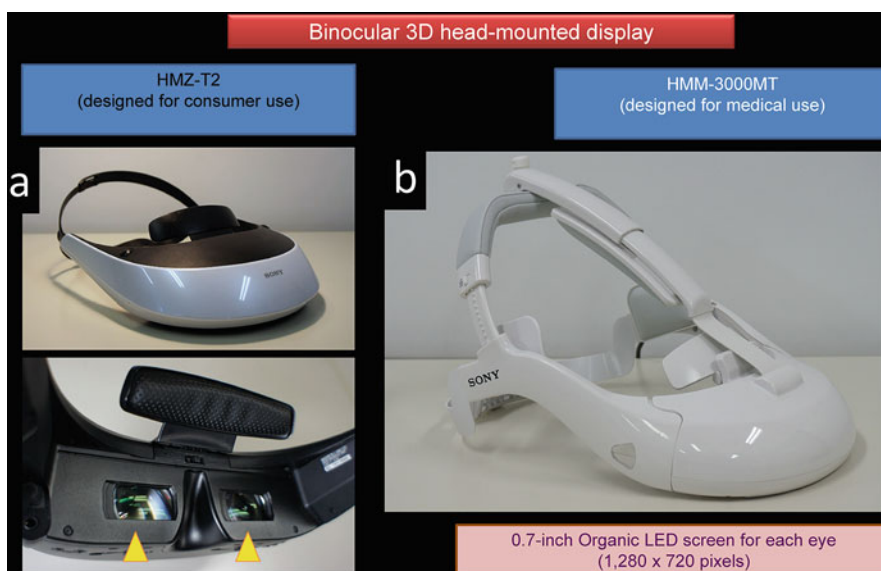


Fig. 1.17 3D-HMD for (a) consumer use and for (b) medical use modified from (a)



coagulator and a vessel sealing device (Fig. 1.32), flexible clip applier, ultrasonic coagulator, vessel sealing device, bipolar forceps, and monopolar coagulation system (Fig. 1.33).

Thin forceps or scissors are useful when the surgery is performed through a 2–3 cm port (Fig. 1.33).

Since the devices are held in the hand, indirect tactile feedback is obtained through the hand.

1.4.3 Endoscope Manipulation Robot

If necessary, an endoscope manipulation robot is used (Fig. 1.34). It is controlled by the operator's head movement using a gyro-system or by hand. It works smoothly and safely with air pressure and stabilizes the movement of

the endoscope. If this robot is not available, the operations described in this book can still be performed by replacing it with an endoscopist.

1.5 Commonly Used Devices

To prepare the port and protect the edge of the incision, a wound retractor (Alexis wound retractor®, Applied Medical Resources, Corp.) is used (Fig. 1.35).

To create and maintain the working space through the single port, certain types of long-and thin-neck retractors (PLES retractors®, Innomedics Medical Instruments, Inc.), thin spatulas, and a metal suction tube are used (Fig. 1.36).

Fig. 1.18 3D-HMD is connected to a flexible (Olympus) or a thin 3D-endoscope (Shinko Optical)

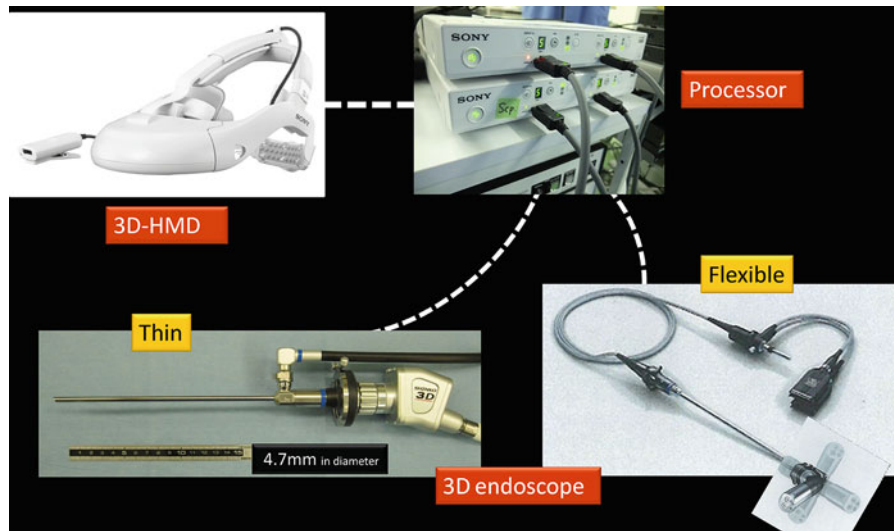


Fig. 1.19 Digital zoom function works by pressing a button on the flexible 3D endoscope

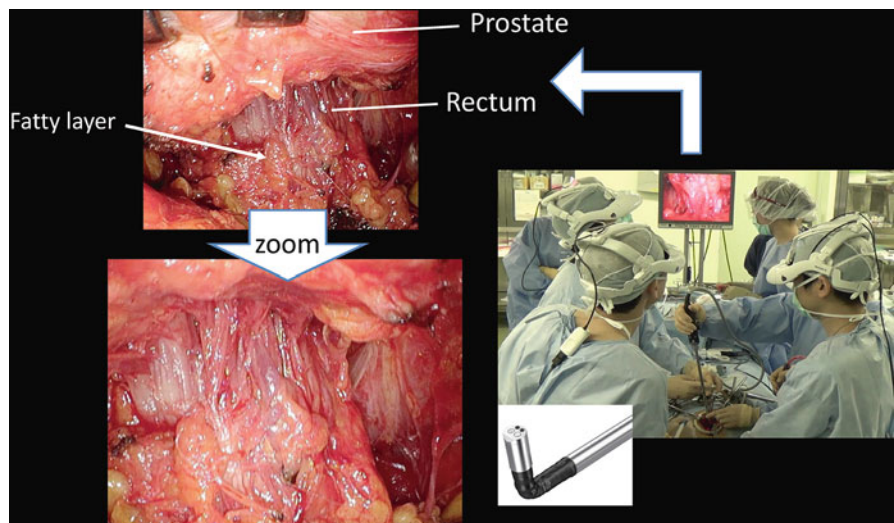


Fig. 1.20 3D-HMD provides six fields of visions in front of the eyes, regardless of head position



Fig. 1.21 Magnified stereovision and panoramic vision obtained by moving the angle of sight downwards

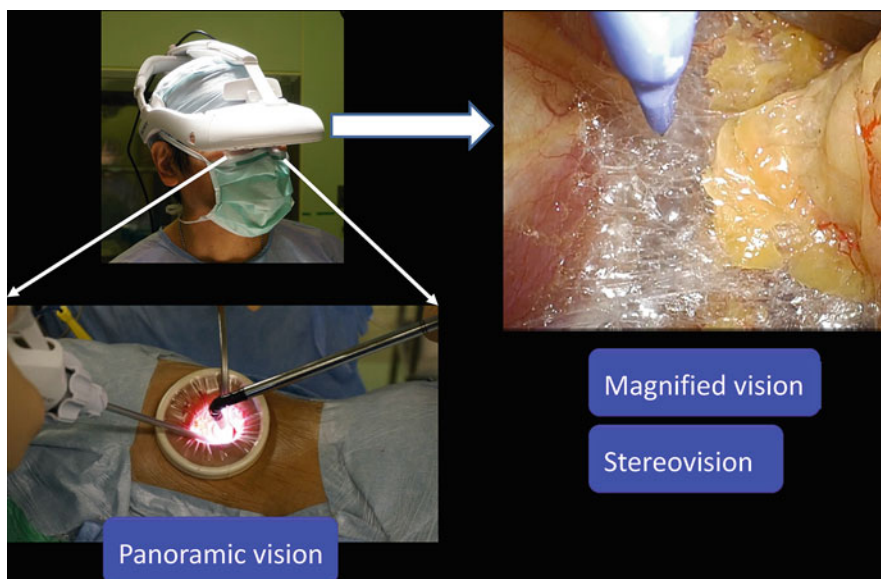
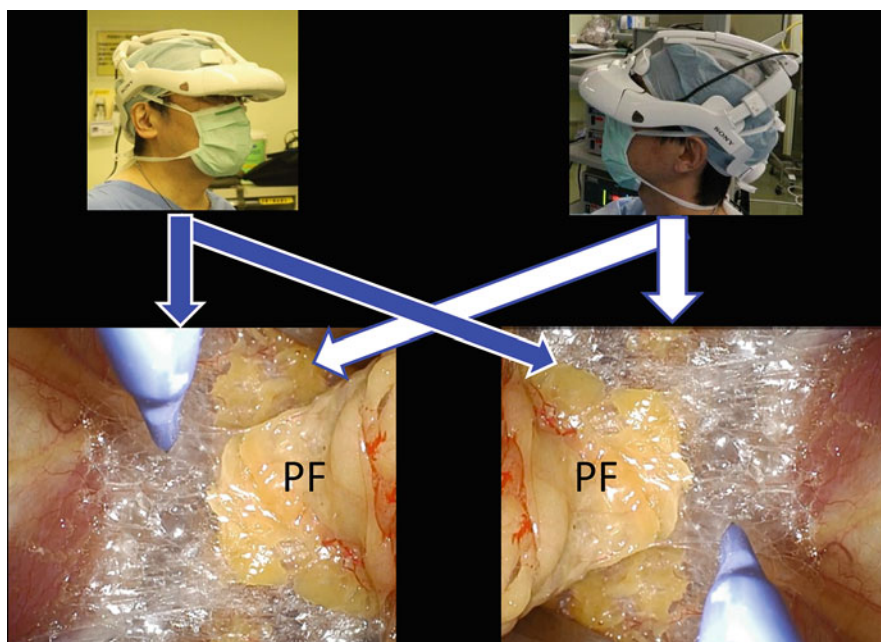


Fig. 1.22 Each surgeon can change the direction of the images on the display according to his or her position. Perinephric fat (PF)



To ligate with a thread through a single port, the Thread Pass® (Innomedics Medical Instruments, Inc.) and the Knot Slide® (Innomedics Medical Instruments, Inc.) are usually used (Fig. 1.37). A useful technique is to retract the tissue, tumor, or organ with a thread via the port.

To suture, Maniceps® (Mani, Inc.) and Geister Needle Holder (Geister Medizintechnik GmbH) are convenient choices (Fig. 1.38).

To extract the large specimen through the port, the Flexible Catcher® (Japan Medicalnext Co., Ltd.) is used (Fig. 1.39).

1.6 Advantages and Drawbacks of This Surgery

Major advantages of gasless single-port surgery and of the RoboSurgeon system are provided in Tables 1.2 and 1.3. This surgery is considered to be high quality, low cost, easy to learn, and safe.

The single-port, gasless, extraperitoneal approach is a high-quality technique and may be most beneficial for elderly patients or patients with various comorbidities. This surgery

Fig. 1.23 The endoscopist is positioned opposite the lead surgeon. The images on the lead surgeon's display are reversed from those on the endoscopist's display

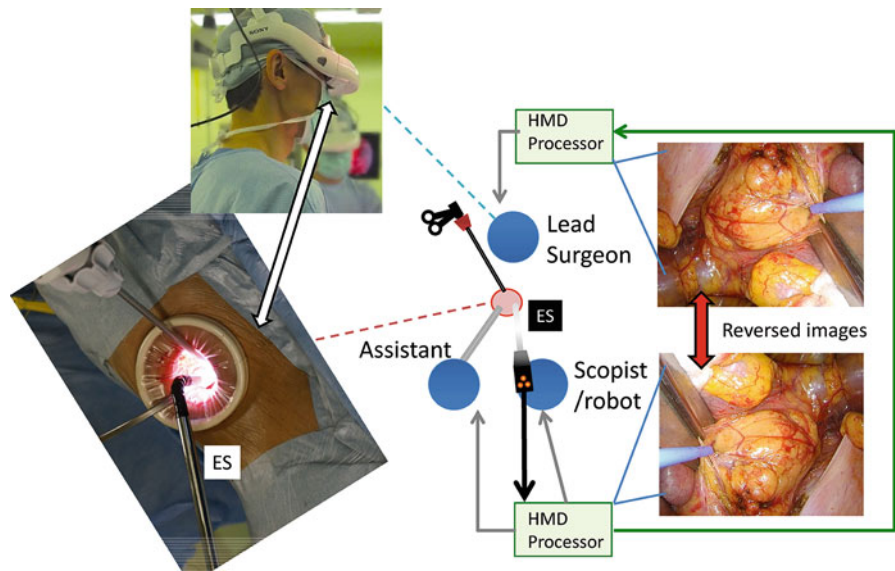


Fig. 1.24 Multivision and navigated vision using ultrasonography via the port. Peritoneum (*P*); working space (*WS*)

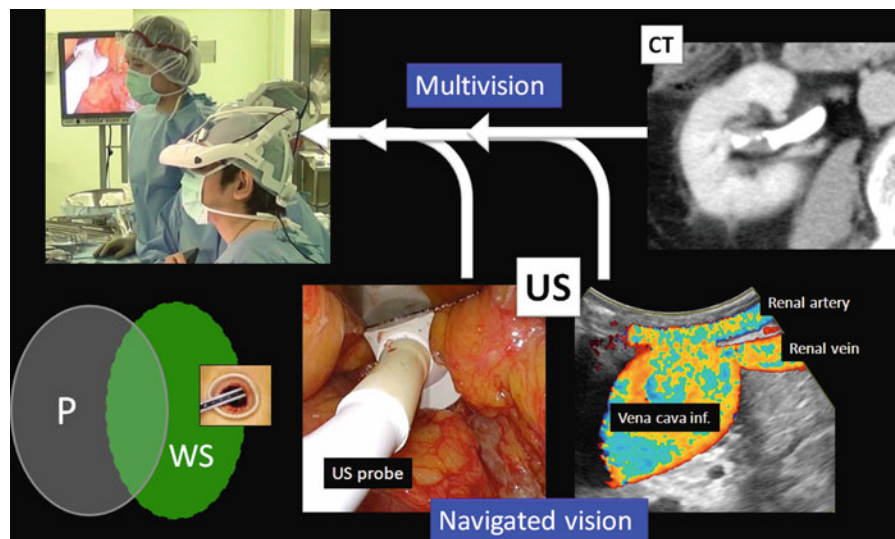


Fig. 1.25 Navigated vision using transrectal ultrasonography (*US*) in intrapelvic organ surgeries

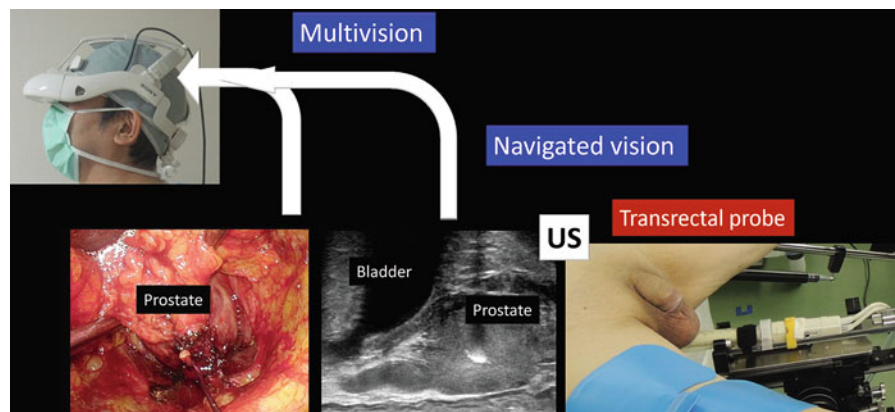


Fig. 1.26 Various images displayed on the 3D-HMD using the multiplexer are shared among all participants

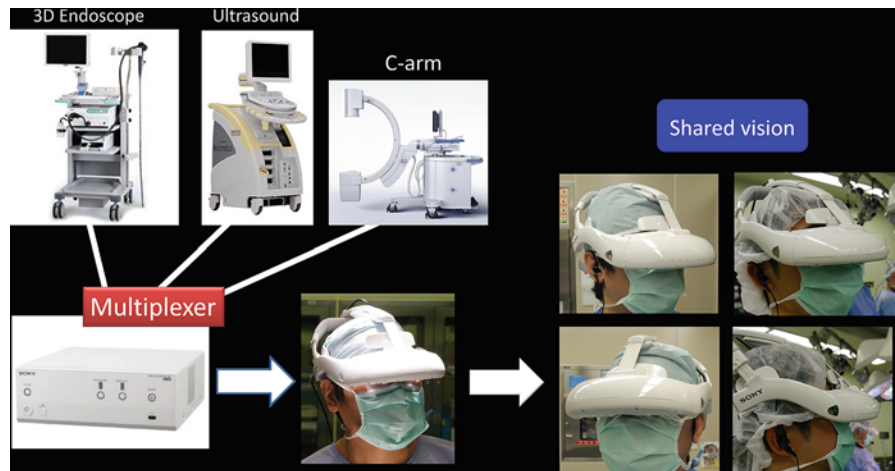


Fig. 1.27 Image control with a foot pedal. Magnetic resonance image (MRI)

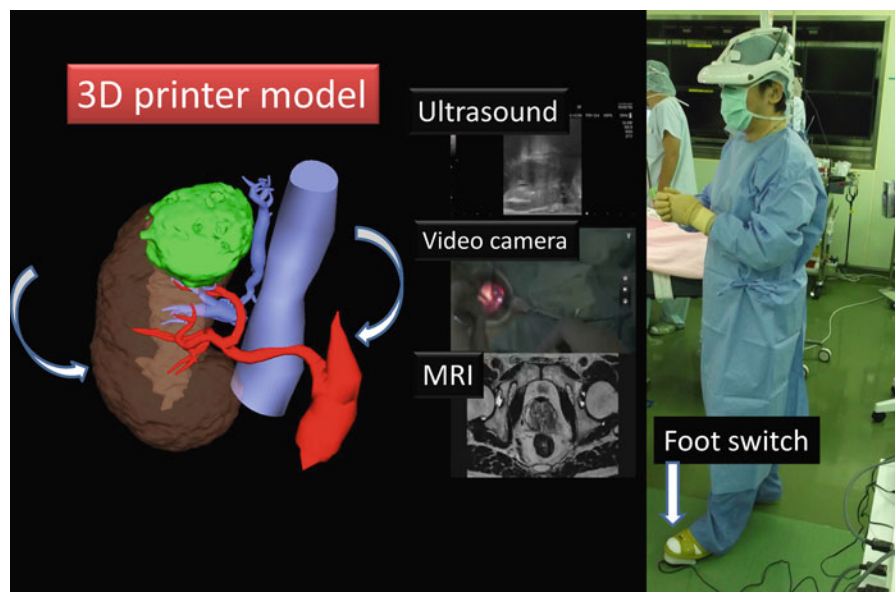


Fig. 1.28 Image control by finger movement (red arrow). Camera on the display (white arrow)

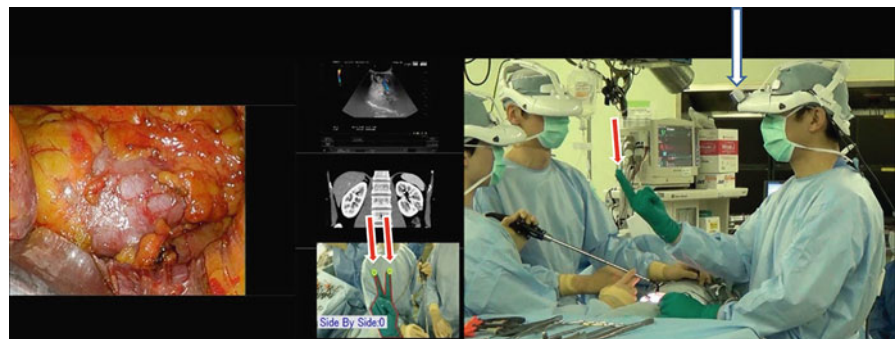


Fig. 1.29 Students, instructors, or others can see the same images as the surgeons and can communicate with the surgeon. Mic (arrow)

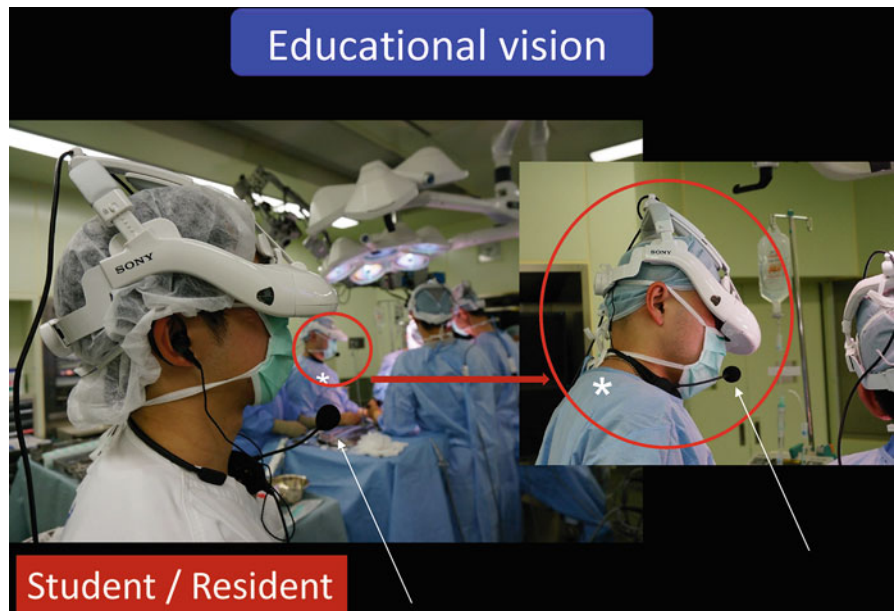


Fig. 1.30 Participants can see the same images from another room

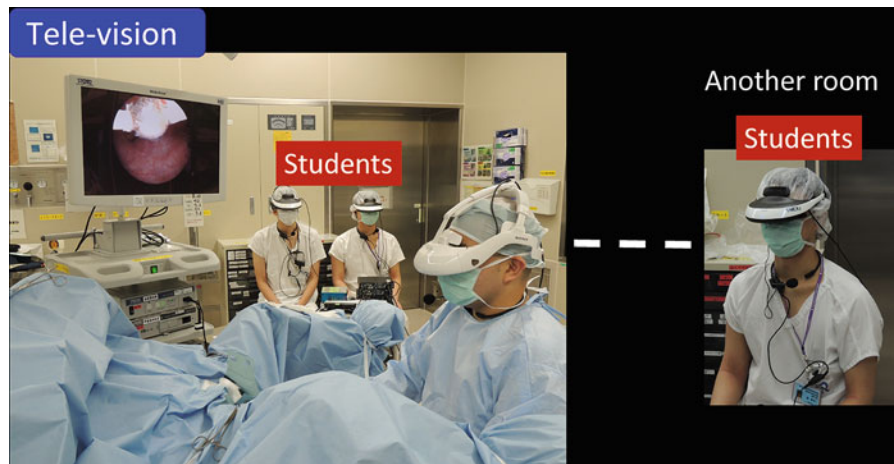


Fig. 1.31 See-through type HMD use for scrub nurse

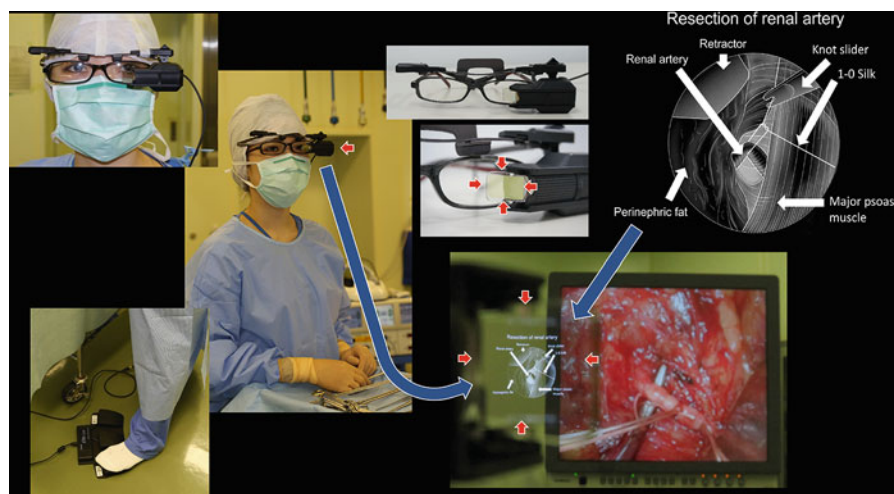


Fig. 1.32 (a) Thunderbeat® and (b) flexible clip applier as handheld robot-like devices

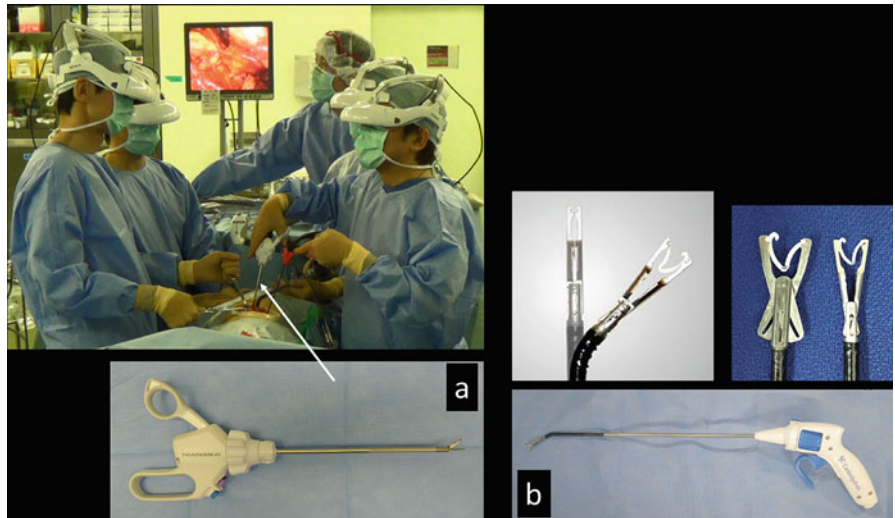


Fig. 1.33 (a) LigaSure®, (b) Harmonic scalpel®, (c) Bipolar forceps, (d) IO electrode, (e) thin forceps and scissors as handheld robot-like devices

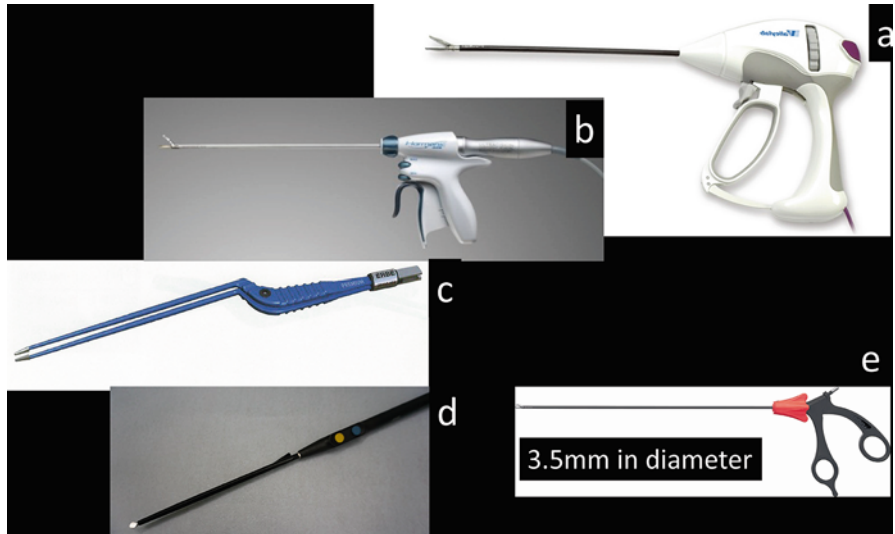


Fig. 1.34 Endoscope manipulation robot, which works with air pressure. (a) Initial version (Aerovision®; Riverfield, Inc.) and (b) second version

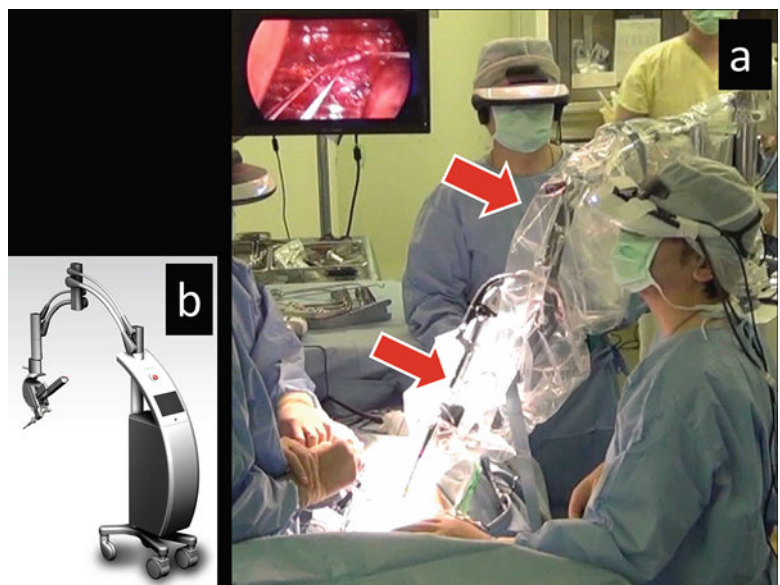


Fig. 1.35 Alexis wound retractor[®] used to make a single port

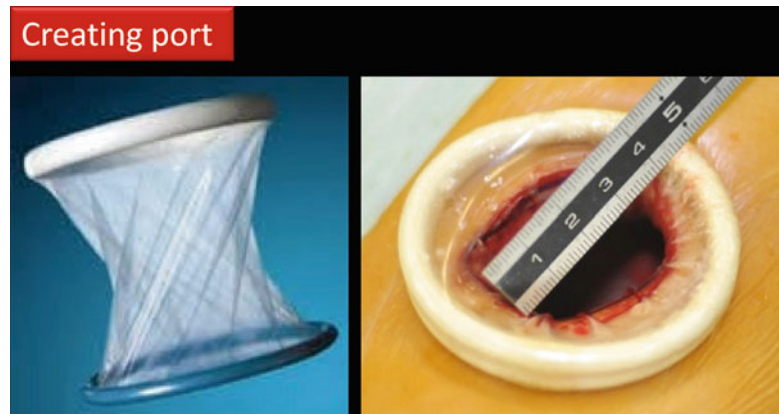
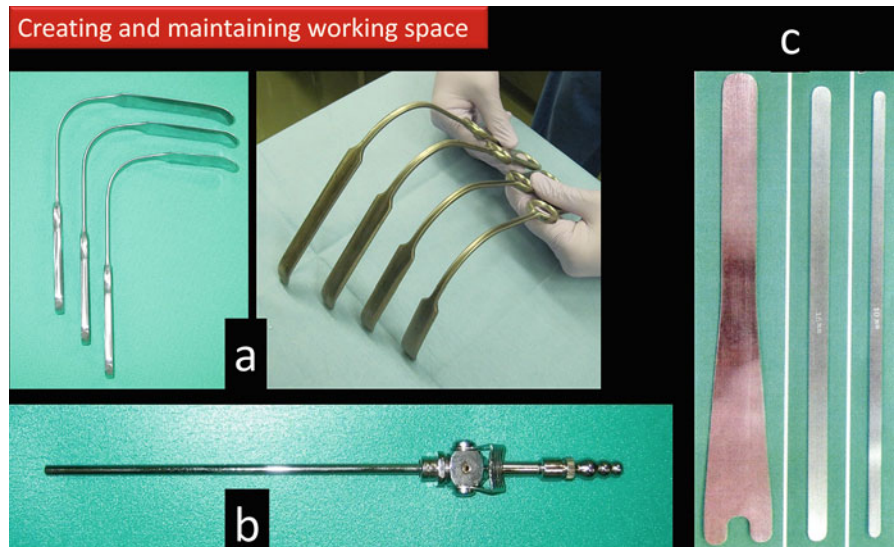


Fig. 1.36 (a) PLES retractor[®], (b) metal suction tube, and (c) various spatulas used to create and maintain the working space



does not compromise the oncological outcome and allows the patients to leave the hospital after a short stay, usually within two postoperative days [19–24].

The cost of surgery is nearly the same as that of open surgery, and hospitalization expenses are nearly the same as those associated with laparoscopic or robot-assisted surgery.

Regarding training and safety, the surgery is easy to learn. The wide panoramic view that is available while wearing the 3D-HMD ensures safety along with an inch-by-inch adjustable port size. Inexperienced surgeons can gradually upgrade their skill using the procedures presented herein. In our hospital, the rate of conversion to open surgery is less than 1 %, which includes operations performed by inexperienced surgeons.

The key drawback to this surgery is that the surgeon needs to become accustomed to using several devices through a single port, which, fortunately, is usually accomplished in a relatively short period.

1.7 Application to Transurethral Examination/Surgery and Patient's Use

The 3D-HMD can be applied to the examination and surgery through the external urethral orifice, which is essentially a natural port [25–27] (Fig. 1.40). A newly developed transurethral 3D endoscope system can be used with the 3D-HMD (Figs. 1.41 and 1.42). The 3D-HMD can also be used as a 2D-HMD with an ordinary transurethral 2D endoscope system. In transurethral resection of the bladder tumor or benign prostate hyperplasia, transurethral ureteroscopy, transurethral biopsy of the upper urinary tract, etc., the 3D/2D-HMD serves the purpose, as outlined in Chap. 10.

A combination of approaches via an artificial port and a natural orifice is applied to partial cystectomy, as presented in Chap. 8 (Fig. 1.43).

Fig. 1.37 Thread Pass[®] (arrow head) and Knot Slide[®] (arrow) used to ligate

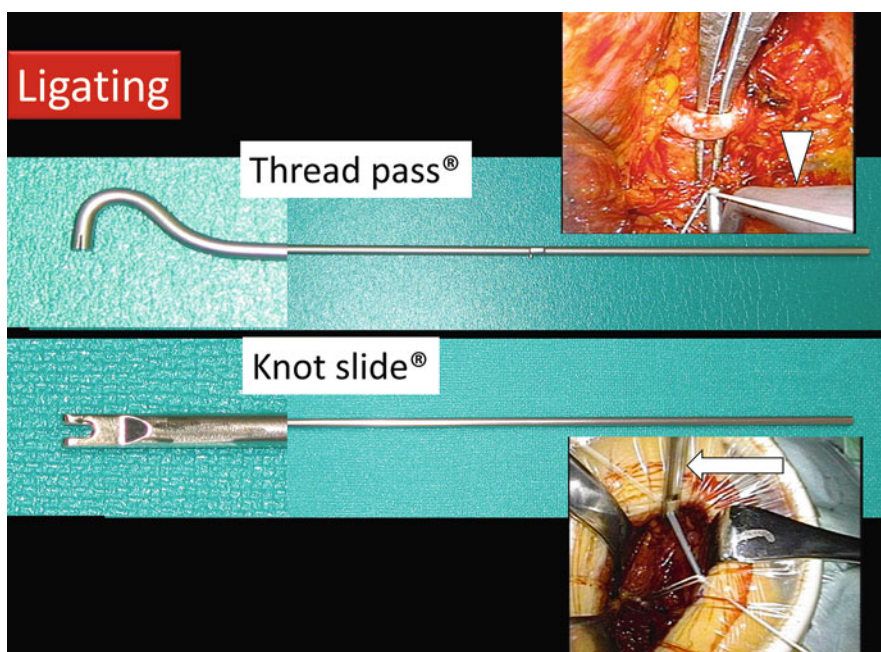
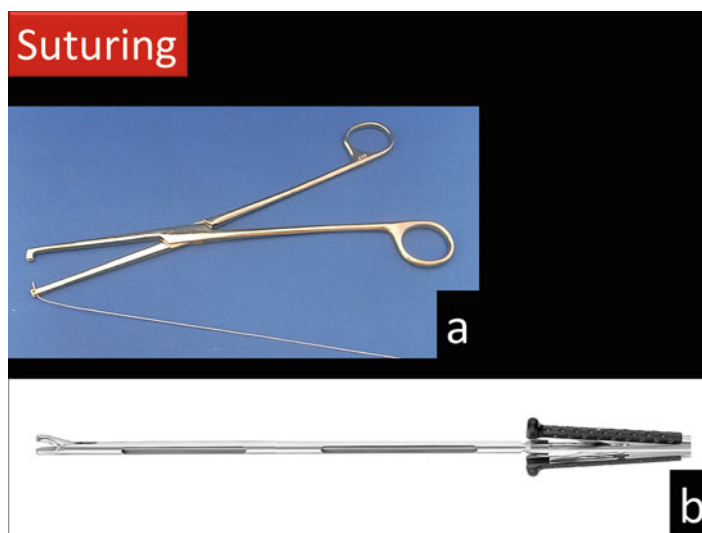


Fig. 1.38 (a) Maniceps[®] and (b) Valvate Geister needle holder[®] used to suture



Patients as well as various medical staff members can use the 3D-HMD effectively [28–31] (Figs. 1.44 and 1.45). It is also useful for telemedicine or in combination with the da Vinci system [32] (Chap. 10).

1.8 Surgery Without the RoboSurgeon System and Transition from Open Surgery

Without the RoboSurgeon system, gasless single-port-like surgery, in which the port size is somewhat larger, can be performed using an ordinary 2D endoscope combined with a 2D display (Fig. 1.46). Based on the procedures described herein, the surgeon can transition from open surgery to gasless single-port-like surgery without encountering much

difficulty by gradually adjusting the port size and utilizing the panoramic view with the naked eye to assure safety.

We made the transition from open surgery to minimum incision endoscopic surgery and then to single-port surgery in a gradual manner. Initially, a 2D endoscope combined with an ordinary 2D display was used. Next, a 3D endoscope combined with an ordinary 3D display was introduced. Subsequently, the 3D endoscope was combined with a 3D-HMD for consumer use (HMZ-T1, HMZ-T2, Sony Corp.) (Fig. 1.17) and then finally with the 3D-HMD for medical use, which we helped develop (Sony Corp.) (Fig. 1.17).

We are now well on the way toward realizing the ideal combination of gasless single-port surgery and the robotization of the surgeon (Fig. 1.47). We believe that this surgery could contribute to minimal invasiveness for the benefit of the patient, the operator, and society in general (Fig. 1.48).

Fig. 1.39 Flexible catcher[®] used to extract specimen

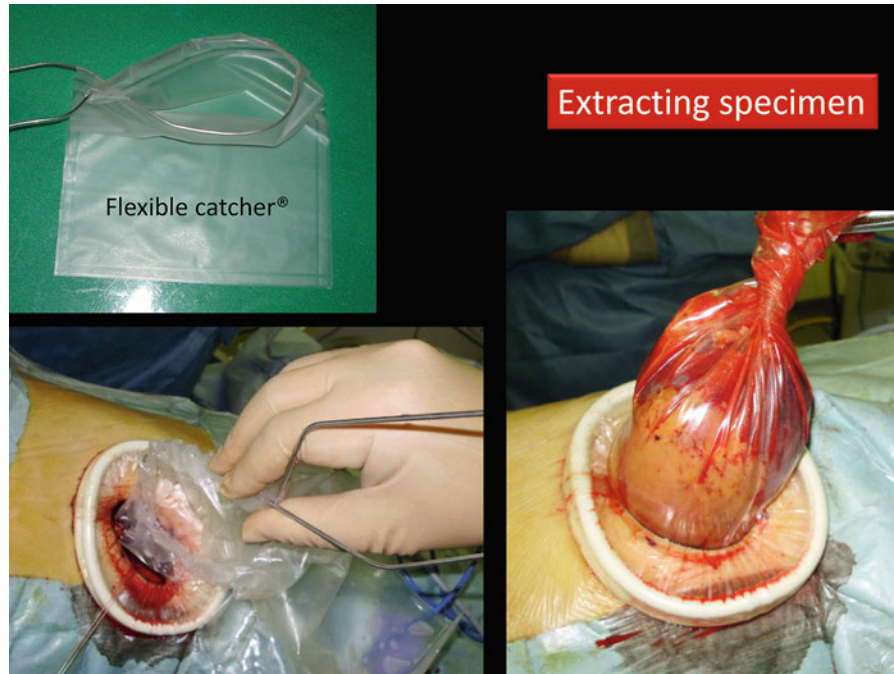


Table 1.2 Advantages of gasless single-port surgery

Better cosmetic results
Less pain
Early recovery
Safer
No adverse effects due to CO ₂ insufflation
No adverse effects due to transperitoneal approach
Possible reduction of drug-resistant bacteria
Affordable
Eco-friendly

Table 1.3 Advantages due to RoboSurgeon system

Magnified stereo-images are obtained in front of the eyes regardless of head position
Panoramic vision using the naked eyes is possible by moving the angle of sight downward
Multiple images are seen on the display simultaneously
All participants share the same images
Each surgeon can change direction of the images on the display and share common direction
Tactile feedback is possible through handheld devices
Endoscope is able to be controlled by operator's head movement safely
Affordable cost

Fig. 1.40 Usage of the 3D-HMD through the natural orifice, transurethral surgery, and examination

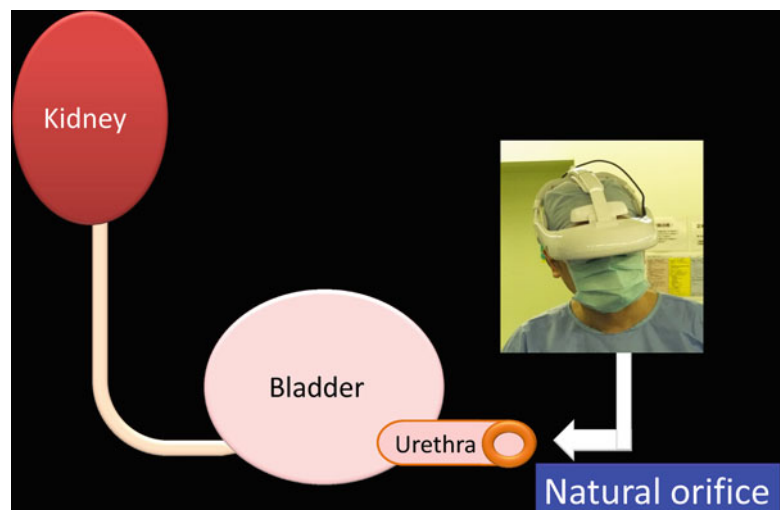


Fig. 1.41 Transurethral 3D endoscope system using 3D-HMD

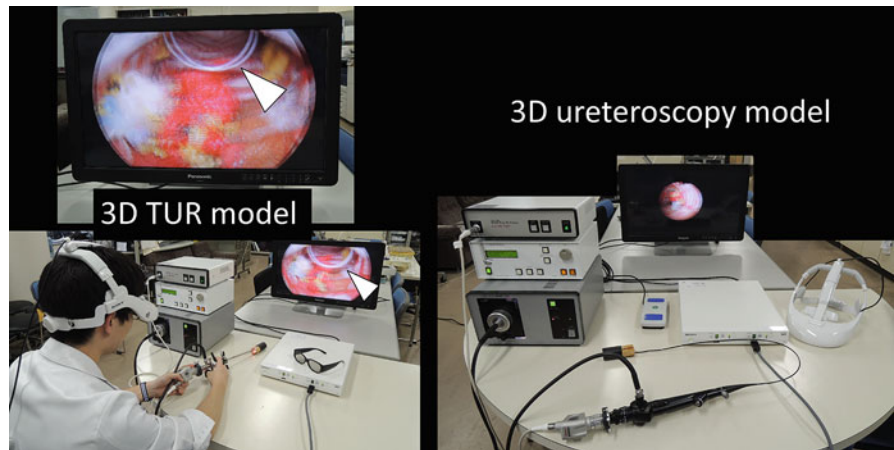


Fig. 1.42 Transurethral resection of the bladder tumor using 3D endoscope system

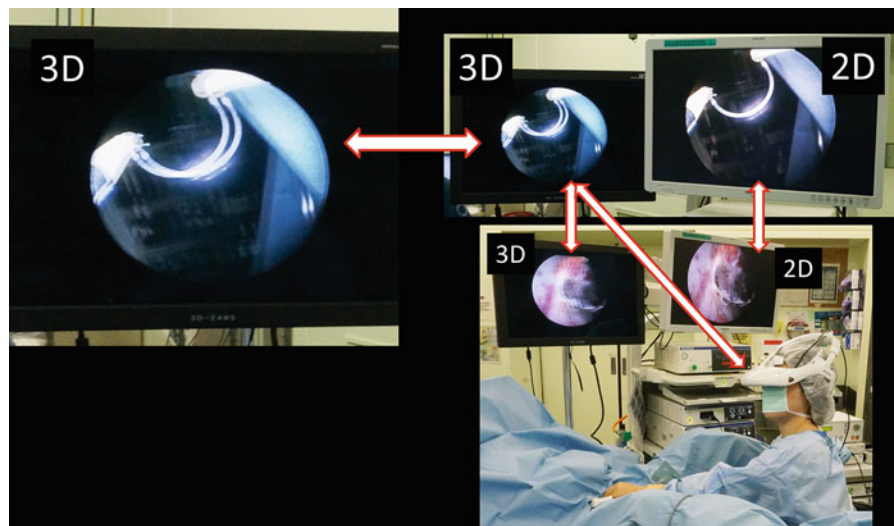


Fig. 1.43 Combination of artificial port and natural port

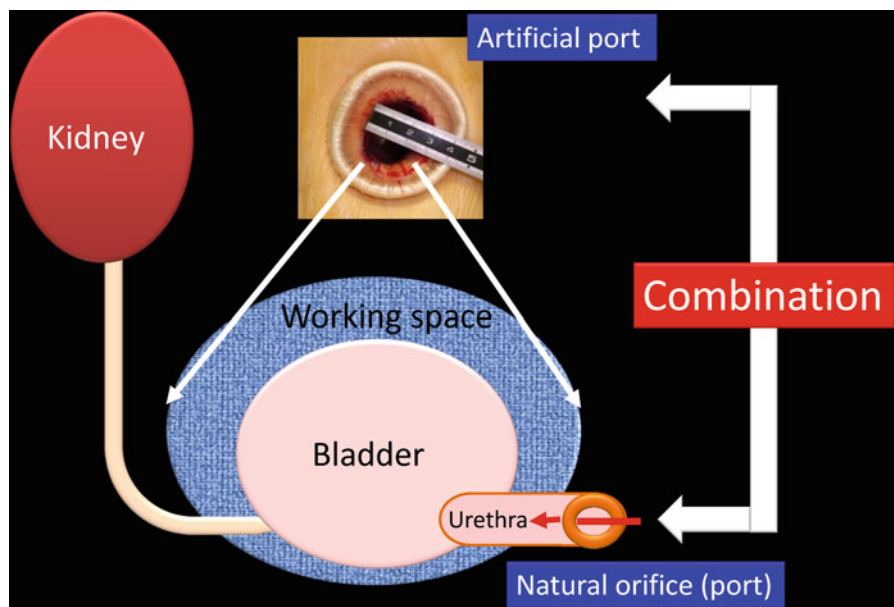


Fig. 1.44 3D-HMD used by a patient, (a) ultrasonography of the kidney, and (b) prostate biopsy

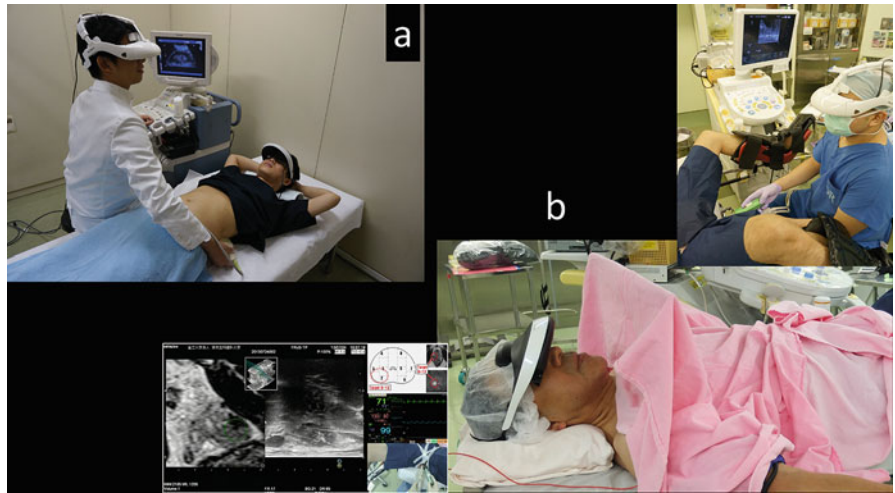


Fig. 1.45 Applications of 3D-HMD

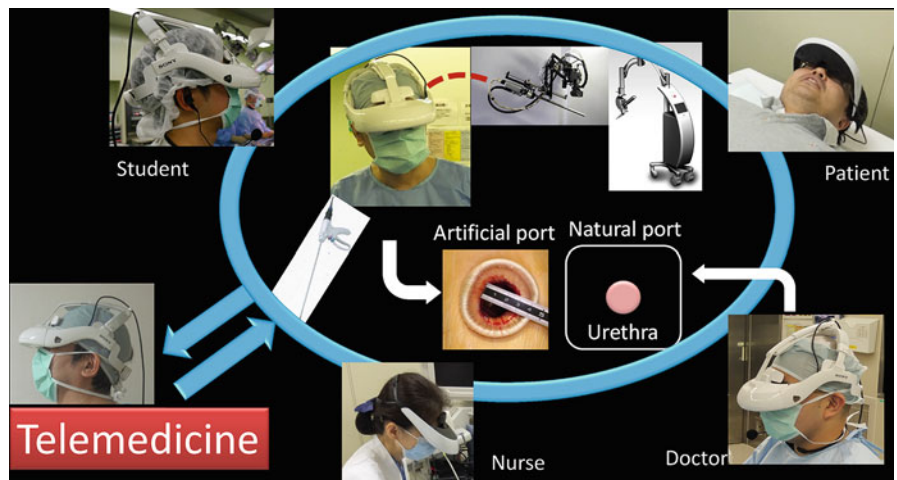


Fig. 1.46 Gasless single-port-like surgery, in which the port size is to some extent larger, can be performed without the RoboSurgeon system



Fig. 1.47 Each part of the RoboSurgeon system is being improved

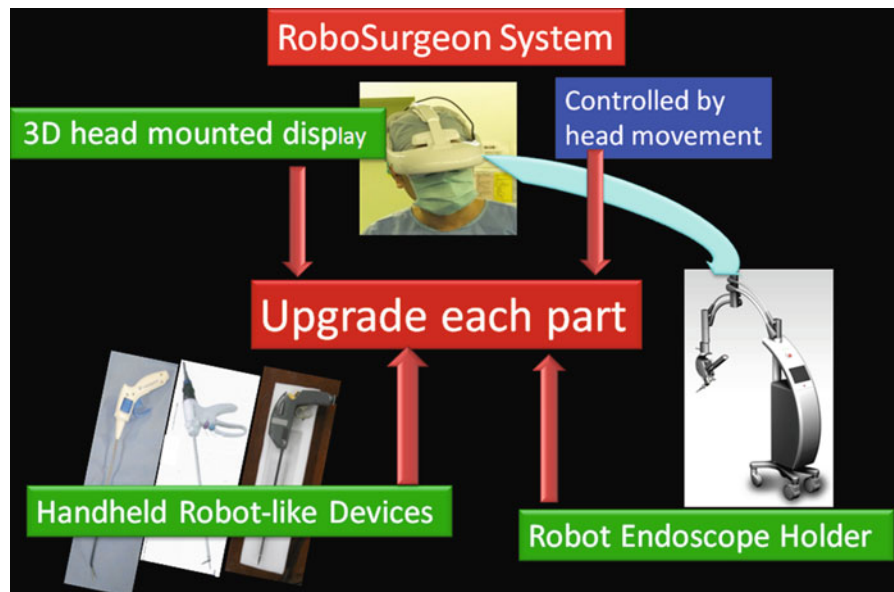
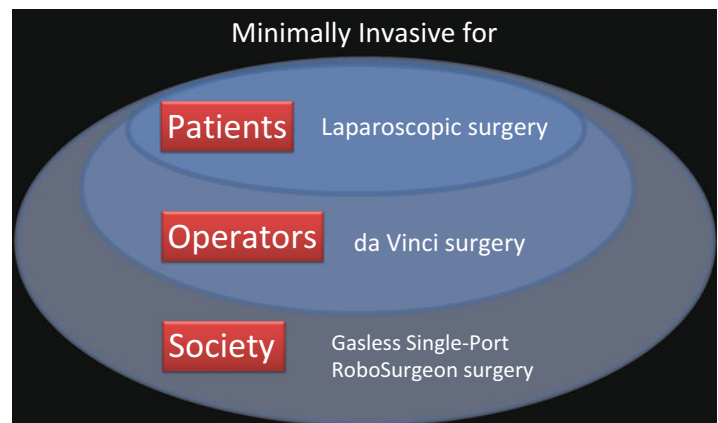


Fig. 1.48 Minimal invasiveness of gasless single-port RoboSurgeon surgery for patients, operators, and society



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