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A multidisciplinary evidence-based guideline for minimally invasive surgery: part 2—laparoscopic port instruments, trocar site closure, and electrosurgical techniques

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Abstract Minimally invasive surgery (MIS) is practiced by different surgical disciplines applying similar basic techniques. In 2007, the Dutch Health Care inspectorate indicated the need for a guideline including multidisciplinary agreements for MIS aiming towards better patient care and safety. A multidisciplinary guideline development group was founded consisting of general surgeons, gynecologists, an anesthesiologist, and an urologist. All members were authorized by their scientific professional associations. Clinically important aspects were identified and discussed. The best available evidence on these aspects was gathered by systematic review. Recommendations for clinical practice were formulated based on the evidence and a consensus of expert opinion. The guideline was externally reviewed by members of the participating scientific associations and their feedback was integrated. Identified important topics were: laparoscopic entry techniques, intra-abdominal pressure, laparoscopic port instruments, electrosurgical techniques, prevention of trocar site herniation, patient positioning, anesthesiology, perioperative care, patient information, multidisciplinary user consultation, and complication registration. The text of each topic contains an introduction with an explanation of the problem and a summary of the current literature. The current available evidence on safety aspects in minimally invasive surgery is limited. Few conclusions could be deduced from evidence-based data. This underscores the need for larger studies with adequate design and methodology to define conclusions of importance. Above all, the development of this multidisciplinary guideline facilitated a rich discussion, which resulted in a very complete and implementable guideline. This is the second of three papers on the multidisciplinary guideline for minimally invasive surgery, in which we present our literature reviews, conclusions, and practical recommendations for the use of specific port instruments, port site closure, and electrosurgical and ultrasonic techniques.

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Introduction and methods

Since the early 1990s, minimally invasive surgery (MIS) or laparoscopic surgery has been used extensively to diagnose and treat a variety of conditions. The advancing technology and methods of laparoscopic surgery offer increasing surgical possibilities. Laparoscopic surgery is practiced in different surgical disciplines, general surgery, gynecology, and urology, using relatively similar basic techniques. Despite these similarities, there is little cooperation between the different disciplines to assure and improve the quality of minimally invasive surgery. A number of monodisciplinary gynecological guidelines on laparoscopic entry techniques do exist, a well-known

one is the guideline from the Royal College of Obstetricians and Gynaecologists [1]. Though, transcending the boundaries of monodisciplinary knowledge and skills and criticizing the differences between disciplines should result in multidisciplinary agreements to optimize patient safety. The Dutch Health Care Inspectorate encouraged the national scientific associations representing laparoscopically oriented surgeons to work together and develop a multidisciplinary guideline on MIS.

In our previous paper, we described the Evidence-Based Guideline Development (EBGD) methodology [2]. In short, the EBGD process includes the following steps: (1) problem analysis; (2) explicit formulation of the questions that the guideline is addressing (key questions); (3) defining eligibility criteria for evidence to be considered; (4) conducting a comprehensive search for evidence (search strategies are appended, see Appendix); (5) evaluating study quality; (6) summarizing the evidence and drawing scientific conclusions; (7) balancing the benefits and downsides of the alternative management strategies, discussing values and preferences (other considerations); (8) formulating recommendations based on evidence and consensus clinical opinion; (9) discussion about the draft guideline within working group; (10) setting up a final draft guideline; (11) external review by members of the participating scientific associations; (12) revision and finalization of the guideline; and finally, (13) authorization and (14) dissemination of the multidisciplinary guideline by the participating scientific professional associations.

In our first paper, we focused on primary entry techniques and the application of a pneumoperitoneum in laparoscopic surgery. The first technical step in laparoscopy is the primary entry: the introduction of a primary instrument (Veress needle or primary trocar) in the abdominal cavity, followed by the insufflation of carbon dioxide to create a pneumoperitoneum.

When the pneumoperitoneum is achieved, specific laparoscopic port instruments are introduced through the abdominal wall. Port instruments consist of several components: a central trocar, a corresponding peripheral cannula, a valve section, and a CO_2 stopcock. After insertion of this instrument, the central trocar is removed and the remaining cannula functions as an access port for laparoscopic instruments. The primary port, generally created in or near the umbilicus, is used for the introduction of the laparoscope. The creation of the primary laparoscopic port is called "primary entry." Secondary or ancillary ports are intended for the introduction of other laparoscopic instruments. The creation of secondary ports is called "secondary entry." The method of port creation, the port instruments' design, and the port location influence the risk of port-related complications.

Laparoscopic port instruments include a myriad of device designs, including over 100 brands from more than 20 manufacturers [3, 4]. Differences in diameter, shape, and material can result in an increased risk of laparoscopic port-related complications. An important postoperative port-related complication is port site herniation (PSH), a protrusion of intestine or omentum through a remaining defect at the laparoscopic port site. It is questionable whether closing the defect by suturing can prevent these herniations. In the initial problem analysis for this guideline, differences in the use of port instruments and port site closure were identified as important topics within laparoscopic surgery as well as electrosurgical and ultrasonic modalities. These modalities are very useful for coagulation and hemostasis in laparoscopic surgery but have been associated with serious complications. In this second paper on the multidisciplinary guideline on MIS, we discuss the evidence and consensus clinical opinion for the use of specific port instruments, port site closure, and electrosurgical and ultrasonic techniques.

Laparoscopic port instruments

Background

Laparoscopic port instruments are the most common device named in malpractice injury claims associated with laparoscopic procedures, representing one third of all claims [5]. The incidence is estimated to be 4.24 per 1,000 procedures [3]. Typical port-related complications are intra-abdominal vascular injury, visceral injury, port site bleeding, port site herniation, port site infection, and pain. In the last few decades, there has been continuous innovation of the instrument design aimed at reducing these complications.

Distinguishing primary from secondary port entry and different entry techniques

A distinction between primary and secondary entry needs to be made. Within the primary entry technique, it has to be taken into account whether the open/Hasson-, closed/Veress needle-, or non-insufflated/direct entry technique has been used. Less frequently used instruments for the primary entry are visual port systems and single port techniques. These different conditions may result in different outcomes. The type of primary port instrument depends on the applied primary entry technique where the type of secondary port instrument generally does not. In the Veress needle entry technique or the direct insertion technique, the insertion of the primary port instrument is a blind procedure while secondary port instruments are mandatorily inserted under direct laparoscopic vision.

Laparoscopic port instruments

A distinction can be made between reusable and disposable port instruments. Reusable instruments are composed of metal. The perforator tip can be completely blunt (cone shaped) or

sharp with a conical, pyramidal, triflanged, or eccentric tip. Disposable instruments are usually made of plastic with bladed or bladeless tips. Shielded disposable port instruments are equipped with a retractable covering over the tip and were developed to protect against intra-abdominal vascular and visceral injury. These formerly called "safety trocars" are however also associated with major port-related complications [6]. The FDA does not allow anymore that the shielded port instruments are called safety trocars.

Radially expanding access (REA) systems represent yet another alternative in design. These port instruments are equipped with a radially expanding sleeve that can be dilated from 5 to 12 mm in diameter. The REA instrument is developed to minimize tissue trauma and, in theory, its use could result in fewer vascular injuries. The optical-access instruments are designed to decrease the risk of injury to the intra-abdominal structures by allowing the surgeon to visualize abdominal wall layers during placement [7]. A visual system that should be distinguished is the threaded visual cannula (TVC). The TVC enables body cavity access by applying a blunt cannula where a pointed or sharp central trocar is not required, linear penetration force is realigned to radial, and the cannula houses the laparoscope without an intervening pointed crystal that distorts visual layer enunciation [8]. The diameters of port instruments vary from 2 to 12 mm, depending upon the largest instrument needed for a particular port. For exceptional indications (for example extirpation of large cysts), larger or modified trocars are available [4].

Despite continuous innovation in the design of port instruments to enhance patient safety, port-related complications do still occur. The guideline development group indicated a need for advices on the use of specific laparoscopic port instruments to ensure patient safety.

Key question

1. What specific port instrument can be recommended to minimize the risks of port-related complications?

Summary of the literature

Major port-related complications

Major complications are mortality, visceral injury (such as perforation of the intestines or stomach, or injury of the bladder or liver), vascular injury (such as perforation of the aorta, vena cava, iliac artery, or iliac vein), and other injuries that required intensive care (IC) or intensive care unit (ICU) management or a subsequent surgical, endoscopic, or radiological intervention. In the recently updated Cochrane review from Ahmad et al., different laparoscopic port instruments were studied [9]. Eight RCTs were included comparing different port instrument designs. In four, REA instruments were compared with standard port instruments for primary port entry [10–13]. Two RCTs compared cutting and blunt port instruments for primary and secondary port entry [14, 15], and in two RCTs, the REA instrument was compared to a conventional instrument with cutting tip for secondary port entry [16, 17]. Trials that analyzed major complications with low incidences had too small sample sizes to identify any differences [10, 12, 15–17]. Meta-analyses demonstrated no significant differences for major complications (Table 1). Comparative prospective and retrospective studies on different laparoscopic port instruments did not evaluate major complications [18] or were underpowered [19].

Minor port-related complications

Minor port-related complications are port site herniation, port site bleeding or postoperative wound hematoma, port site infection, extraperitoneal insufflation and other injuries that did not require IC or ICU management or a subsequent surgical, and endoscopic or radiological intervention under general anesthesiology. In the meta-analyses of the Cochrane review, some differences were found for minor port-related complications. REA instruments compared to standard port instruments for primary entry were associated with a reduction of port site bleeding [OR 0.31 (95 % CI 0.15–0.62), three studies, 421 participants]. Comparing instruments with a cutting versus a blunt tip for primary port entry, no difference in port site bleeding [OR 0.33 (95 % CI 0.09–1.23), two studies, 195 participants] or wound infection [OR 7.76 (95 % CI 0.15–386.69), one study, 165 participants] was found. For secondary entry, radially expanding instruments were associated with lower rates of port site bleeding compared to conventional instruments with a cutting tip [OR 0.12 (95 %CI 0.02–0.92) one study, 68 participants]. No difference was found for port site infections after the use of REA instruments versus conventional instruments for secondary entry [OR 0.14 (95 % CI 0.01–2.21), one study, 61 participants].

A prospective cohort study comparing REA instruments to conventional sharp-shielded pyramidal instruments for secondary entry was probably underpowered to identify a difference in port site bleeding [OR 0.18 (95 % CI 0.01–4.00), 19 participants; 19]. A retrospective cohort study compared reusable steel cone-shaped non-cutting instruments to a historical group where disposable sharp cutting shielded instruments were used ($n=600$) for secondary entry [18]. A reduced risk was found for port site herniation [OR 0.09 (95 % CI 0.01–0.69)] and for port site bleeding [OR 0.27 (95 % CI 0.07–0.97)] when non-cutting instruments were used.

Port-related pain

No systematic reviews on pain related to laparoscopic port instruments were found. A total of seven RCTs evaluated

Table 1 Results from meta-analyses in Ahmad et al. for major port-related complications comparing different port instruments [9]

OR odds ratio, 95 % CI 95 % confidence interval

Radially expanding instruments versus standard instruments for primary port entry	
Vascular injury	OR 0.24 (95 % CI 0.05–1.21)
Visceral injury	OR 0.13 (95 % CI 0.00–6.37)
Solid organ injury	OR 1.05 (95 % CI 0.07–16.91)
Cutting instruments and blunt instruments for primary and secondary port entry	
Visceral injury	OR 7.67 (95 % CI 0.15–386.69)

postoperative pain after the use of REA instruments to standard port instruments for primary and/or secondary port entry. For primary and secondary ports, two RCTs found no differences ($n=77$ and $n=56$) [11, 15] and one was in favor of REA instruments ($n=87$) [12]. For primary ports specifically, one RCT found no difference ($n=244$) [10] whereas another RCT indicated less postoperative pain up to 12 h postoperative in patients where REA instruments were used ($n=100$) [13]. For secondary ports specifically, two RCTs reported less postoperative pain when REA instruments versus conventional instruments were used ($n=68$ and $n=54$) [16, 17]. Two RCTs found no differences for postoperative pain when blunt or cutting instruments were used [15, 20]. A prospective cohort study from Turner et al. ($n=19$) found less pain at secondary ports where REA instruments were used compared to conventionally cutting instruments [19].

There is substantial clinical and statistical heterogeneity between these trials. Within the studies, factors that could have influenced the results in these studies are fascial closure, manipulation at the port site, and postoperative analgesics. In most of the studies on pain regarding the use of different laparoscopic port instruments, no intention was made to identify any confounders neither to correct for confounders in the analysis.

Conclusions

Level 1	There is no evidence to suggest that any type of laparoscopic port instrument is more or less safe in terms of reducing severe complications either during primary or secondary entry.
	Evidence level A1 [9]
Level 1	The use of radially expanding access instruments compared to standard (cutting) port instruments for primary and secondary port entry leads to fewer port site bleedings.
	Evidence level A1 [9]
Level 3	The use of blunt port instruments compared to cutting port instruments for secondary port entry possibly leads to fewer port site bleedings and port site herniations.
	Evidence level C [18]
Level 1	REA instruments compared to conventional port instruments result in a decrease in postoperative pain. This reduction was not consistently found for primary entry.
	Evidence level A1 [10–13, 16, 17, 19]
Level 2	It remains unclear whether the use of cutting or blunt port instruments has different postoperative pain scores.
	Evidence level A2 [15, 20]

Considerations

In the preceding text, we described the best available data on different laparoscopic port instruments and specific port-related risks. The studies available to analyze are of very small numbers and basically no definite conclusions of importance can be deduced from their data. The expert's opinion in gynecology is that laparoscopic surgeons may continue to use their chosen technique for port creation [21].

Noticeably, the majority of trials compared REA instruments to conventionally cutting port instruments, even though they are not widely used in practice. A simple explanation could be encouragement by the pharmaceutical industry, though only two studies report that the REA instruments were supplied free of charge by the industry [15, 16]. REA instruments appear to have advantages in terms of less port site bleedings and postoperative pain. Reasons for their rare application probably are the higher cost price and a more complicated insertion technique of REA instruments compared to conventional instruments [15]. No appropriate cost–benefit analysis for REA instruments is available; therefore, one should be careful with the wide implementation of these systems.

Laparoscopic port instruments are either intended for single use (disposable instruments) or multiple uses (reusable instruments). Environmental concerns and spiraling health care costs generally encourage reusable instruments [22]. A disadvantage of reusable instrument is that their adequate function could diminish through repetitive use and sterilization. For example, reusable sharp instruments lose their sharpness through repetitive insertion; consequently, a relatively high puncture force for penetration through the abdominal wall is required, which could result in an abrupt and uncontrolled introduction of the laparoscopic port instrument leading to serious visceral and vascular injury [23]. No clinical trials comparing disposable to reusable laparoscopic port instruments were found. Multiple use of disposable port instruments is not recommended [24].

Another practical consideration that should not be overlooked is the use of port instruments with a smaller diameter (e.g., with 5 mm diameter compared to 10 mm) resulting in less postoperative pain and shorter convalescence [25].

A study revealed that blunt-tipped conical port instruments have a significantly greater fixity to the abdominal wall compared to cutting port instruments, resulting in significantly

lower numbers of spontaneous port dislodgement during surgery [14]. Accordingly, the use of blunt-tipped instruments could reduce antecedent gas leak and loss of pneumoperitoneum and the need for port replacement with its associated increase in risk of trauma to the abdominal wall. On the other side, it appeared from animal studies that the entry force needed to perforate the abdominal wall is higher for conical blunt-tipped than pyramidal sharp port instruments [26]. The higher entry force could increase the risk of injuries to the intra- or retroperitoneal organs during insertion. The use of optical-access port instruments does not avoid serious injury despite having the ability to visualize tissue layers during insertion [7]. The TVC is a different system of which some experts consider it could be a less damaging approach [8]. We found insufficient evidence to formulate clear recommendations for safe and cost-effective use of laparoscopic port instruments. Larger comparative studies, with good methodological quality, are needed to clarify the important safety issues. The guideline development group supposes that the selection of a port instrument should, above all, be based on weighing the advantages against disadvantages of its characteristics and the experience of the surgeon with a safe application.

Recommendations

- The selection of a laparoscopic port instrument should be based on the benefits of its characteristics to the individual patient and the experience of the surgeon in a safe application of the particular instrument.
- The use of blunt-tipped instruments is preferred for laparoscopic ports with a 10–12 mm diameter.
- Whenever possible, it is recommended to use port instruments with small diameters.

Port site closure

Background

The introduction of a port instrument through the abdominal wall creates a fascial defect. The estimated prevalence of PSH is 0.5 % [27]. Closure of the fascial defect could reduce the risk of port site herniation. In clinical practice, there is a wide variety of suturing methods. No consensus exists regarding the closure of the fascial defect according to the port instrument diameter. Also, risk factors for PSH should be defined. Below, the available evidence on fascial closure of port sites is discussed.

Key questions

1. Does fascial closure of port sites prevent or reduce the risk of port site herniation?

2. What is the minimal port site diameter whereby fascial closure should be advised?
3. What fascial closure technique can be recommended?

Summary of the literature

No RCTs or prospective observational studies were found that investigated fascial closure as a measure to prevent PSH. In two retrospective cohort studies, the PSH prevalence among patients with or without fascial closure was compared [28, 29]. Mayol et al. observed that PSH in 10 mm umbilical ports occurred among patients with (3.3 %, $n=151$) or without (1.9 %, $n=52$) fascial closure [OR 1·8 (95 % CI 0·2 to 15)]. Kadar et al. neither identified a difference in prevalence of PSH in 12 mm extraumbilical ports when the fascia was closed or left open [8.0 %, $n=25$ versus 2.2 % $n=136$, OR 3.9 (95 % CI 0·6 to 24)]. The study does show that PSH could not completely be prevented by fascial closure: three hernias were found in 136 patients. Both studies were underpowered to detect statistically significant differences.

We then performed a search to identify the port site diameter from which the risk of herniation becomes significant. The majority of reported cases on PSH occurred at ≥10 mm ports [30, 31]; however, these studies did not compare this with the prevalence of PSH in ports with different diameters. Only one retrospective cohort study shows a relationship between port instrument size and PSH [28]. The prevalence of PSH was higher when instruments with a diameter of 12 mm compared to 10 mm were used [OR 13.7 (95 % CI 1.6–118.3)]. For 5 mm instruments compared to 10 mm trocars, no differences were found.

Closure technique

The standard closure technique for the fascia at the port site is a hand-sutured figure-of-eight. A variety of other methods have been described [32]. We found two comparative studies wherein different port closure techniques were compared with the standard technique [33, 34]. No PSHs were observed as the studies were underpowered to analyze for differences in prevalence of PSH.

More recently, cases of intrafascial incisional hernia were found in patients where 12 mm bladeless radially dilating instruments (without fascial closure) had been used [35]. In this type of hernia, also called partial wall hernia, bowel herniates through a defect in the transversal and internal oblique fasciae, but the external oblique fascia is intact. These patients present with symptoms of bowel obstruction but lack the typical signs of herniation during physical examination. This could be an argument for full-thickness closure of the port site, including all abdominal layers [27].

Conclusions

Level 3	It is unclear whether fascial closure of port sites reduces the risk of PSH.
	Evidence level B [28, 29]
Level 3	The prevalence of PSH is significantly increased in port sites where instruments with a diameter of 12 mm are used compared to sites where instruments with a diameter of 10 mm are used.
	Evidence level B [28, 29]
Level 4	It is unclear which fascial closure technique results in the least PSHs.
	Evidence level D (opinion of guideline development group)
Level 4	Full-thickness closure of port sites could reduce the risk of intrafascial herniation.
	Evidence level D (opinion of the guideline development group)

Considerations

From data obtained from current literature, it is generally recommended to close fascial defects ≥10 mm to reduce the risk of PSH [28, 31]. However, current information is inadequate and no evidence confirms that fascial closure reduces PSH. On the other hand, the risk of nerve injury, superficial vascular injury, and inadvertent injury of the bowel should be taken into account. Some suggested that risk factors for PSH are preexisting umbilical hernia [36] or a history of port site hernia, history of postoperative wound infection, poor wound healing (e.g., diabetes mellitus, wound infection, chemotherapy, steroid use, or poor nutrition), ascites, obesity, cachexia, asthma, connective tissue disorders, and manipulation of the port (e.g., to retrieve specimens) [31]. The extent in which these factors may pose a risk has been insufficiently researched.

In daily laparoscopic practice, some variety exists in the cutoff point of the port site diameter which should be closed; however, the fascia at port sites >10 mm are generally closed in all laparoscopic disciplines. In the literature, it appears that the risk of PSH is significantly increased in port site diameters ≥12 mm and it is supposed that fascial closure reduces the risk. The working group aligned their recommendation with current practice and recommends to close the fascia of port sites >10 mm diameter. The closure of smaller port site diameters should be considered, specifically when assumed risk factors are present.

As previously noted, the use of blunt trocars compared to cutting trocars for secondary port entry possibly leads to fewer TSHs. This is explained through the stretching and separating of tissues by blunt trocars rather than cutting through tissue layers by cutting trocars. This could be a reason for not closing a fascial defect with a diameter ≤12 mm, where a blunt trocar has been used.

It should be noted that single port surgery and robot-assisted surgery are not included in this guideline. It should be anticipated that in those techniques, a different port creation method is applied, probably increasing the occurrence of port site herniation and other port-related complications.

Recommendations

- Fascial closure is recommended for port sites with a diameter >10 mm. It could also be considered to close fascial defects of smaller ports, especially when assumed risk factors are present.
- When blunt port instruments of ≤12 mm diameter are applied, it is an option not to close the fascial defect.
- There are no recommendations for a specific fascial closure technique. Full-thickness closure of the port site could be considered, since it possibly reduces the risk of PSH.

Electrosurgical and ultrasonic energy techniques

Background

Electrosurgical and ultrasonic energy techniques have become indispensable in minimally invasive procedures. These techniques are used for coagulation, cutting, and hemostasis. The traditional modalities are monopolar and bipolar electrosurgery. Bipolar vessel sealing systems and ultrasonic technologies further improved the efficiency of operations and facilitated the surgical abilities to perform certain procedures. However, each of these energy sources can be associated with distressing complications. Compared to open surgery, a hazard in laparoscopic procedures is the visual field: the electrical current may damage adjacent structures outside the view of the laparoscope. Laparoscopic surgery presents additional hazards for electrosurgery, the primary ones being direct application, insulation failure, and direct- and capacitive coupling. Both electrosurgical instruments and ultrasonic instruments generate heat with the risk of thermal injury. It is important for users to have knowledge of the principles, applications, and safety aspects of the energy sources used in laparoscopy. We reviewed the literature concerning hazards of electrosurgical and ultrasonic energy sources in laparoscopy. Here we describe the specific complications and offer guidance to minimize the risks.

Monopolar electrosurgery

Monopolar electrosurgery is used for cutting, coagulation, and hemostasis. With monopolar electrosurgery, the active

electrode is located at the surgical site while the return electrode (a dispersive pad) is attached elsewhere to the patient's body. The current flows from the active electrode, into the target tissue, through the patient, the dispersive pad, and subsequently returns to the generator. With the dispersive pad properly placed, the electrosurgical effects occur at the active electrode.

General surgeons rely more on monopolar than on bipolar electrosurgery because of its ease of use [37]. Monopolar electrosurgery provides a better penetration of the current density, which can be advantageous for hemostasis in certain tissues. A "blended cut" (blend of surgical effects) can be applied with a combined modus of cutting and coagulation. Additional capabilities are enhanced cutting, rapid dissection, and non-contact fulguration. With fulguration, a high-voltage electric current is used to destroy tissue; this may be useful to control diffuse bleedings.

Bipolar electrosurgery

With bipolar electrosurgery, both active and return electrodes are located close together within the tip of the surgical instrument. The current flows from one tip to the other; only the tissue between the two electrodes is exposed to the electric current. Tissue thermal energy can be localized more precisely and is effective at a lower voltage and power. This enables electrosurgical safety. Bipolar instruments cannot be used effectively for pure cutting, and for coagulating, the tissue should be gripped between the two electrodes. Because of lower power settings, bipolar coagulation of large areas and dense tissues requires more time. In addition, spray coagulation (fulguration) is not possible.

Vessel sealing

Vessel sealing technology is a type of bipolar electrosurgery developed to coagulate blood vessels from a diameter of 2–3 mm and with minimized collateral tissue damage. An electrothermal bipolar vessel sealer (EBVS) combines an advanced electrical current with mechanical pressure, in order to fuse the vessel walls and create a seal. The EBVS allows the secure sealing of vessels with a diameter of up to 7 mm [38, 39]. The seals obtained with EBVS have proven to be stronger compared to those obtained with traditional bipolar and ultrasonic technology [40, 41]. The available instruments have a diameter of either 5 or 10 mm [40]. EBVS rely on a computer-controlled tissue feedback system that senses tissue impedance or resistance and adjusts the current and output voltage: a consistent electrosurgical effect is obtained through all tissue types.

Ultrasonic technology

With ultrasonic technology, electrical energy is converted into vibration and heat. The combination of a vibrating blade together with the produced heat forms the mechanism by which the instrument cuts and coagulates tissue. The heat generated by ultrasonic instruments is typically less compared to mono- and bipolar electrosurgery, resulting in less thermal injury to surrounding tissues. This optimizes the histopathology assessment of surgical margins. An ultrasonic instrument ensues less smoke emission and probably less toxin production since tissue destruction is by vaporization and avoid charring [42]. As no electrical current is applied, there is no risk of direct coupling or capacitive coupling injuries. There are some disadvantages of ultrasonic technology: the formation of steam from tissues being treated can interfere with visualization through a laparoscope. After prolonged use, the vibrating blade may remain hot for a long period and create a risk of inadvertent thermal injury.

The ultrasonic technology enables the coagulation and sealing of blood vessels from 2 to 5 mm in diameter [43]. It has been shown that this modality can be used safely and effectively in different laparoscopic procedures such as myomectomy, hysterectomy, cholecystectomy, and colorectal laparoscopic surgery [43–46].

Key questions

1. What are the potential complications related to electrosurgery and what is the incidence of recognized injuries?
2. What measures can be taken to reduce the risk of electrosurgery-related complications?

Summary of the literature

Electrosurgery-related complications

Although electrosurgery-related complications are widely described, no systematic reviews, prospective or retrospective cohort studies, or case–control studies were identified that collected data on the incidence of electrosurgery-related complications in laparoscopy. Several studies retrospectively analyzed data on laparoscopic electrosurgery-related complications limited to specific procedures [47–49]. Consequently, a reliable incidence rate of electrosurgery-related complications is missing. The estimated incidence is 2 to 5 per 1,000 procedures [50]. One of the most serious complications is bowel perforation caused by an electrosurgical burn, frequently unrecognized at the time of occurrence. Symptoms of peritonitis are usually seen 4 to 10 days later and often lead to long-term complications.

Several RCTs comparing different electrosurgical and ultrasonic techniques were identified [41, 43, 45, 51–53]. There is

considerable heterogeneity in the investigated surgical procedures between studies. In the majority of the trials, no difference in electrosurgery- and ultrasonic-related complications was found. However, the studies were generally underpowered to identify differences in complications. The use of distinct electrosurgical and ultrasonic instruments depends on the suitability of the instruments characteristics in the type of surgical procedure. Therefore, the following text is a delineated description of the electrosurgical mechanisms that may lead to complications and how to avoid potentially dangerous situations.

Hazards in monopolar electrosurgery

With monopolar electrosurgery, the patient forms a major part of the electrical circuit. This causes additional risks: stray currents, insulation failure, direct coupling, and capacitive coupling.

Stray currents through insulation failure

Insulation failure occurs when the insulation covering of the shaft of the active electrode is damaged. This allows the current to flow through alternative pathways and non-target-tissue. Breakdown of insulation can be caused by the use of high-voltage currents, repeated use, frequent re-sterilization, inappropriate use, or mechanical damage of instrumentation. The small and undetectable defects in the insulation are more dangerous, because this creates a higher current density.

Open circuit and detachment of the dispersive pad

hen the electrosurgical unit is activated without the active electrode in contact with the tissue (i.e., open circuit activation), a high-voltage level emerges at the active instrument. This may cause stray currents. Poor quality of contact between the dispersive pad and the patient's skin compromises a safe return of the current to the generator. The dispersive pad must be of low resistance with a large enough surface (>20 cm^2). When the dispersive pad is (partially) detached through bony prominences, adipose, excessive hair, scar tissue, presence of fluid or lotions, or dryness of the pad, the current exiting the body can have a high density. This may produce heat and unintended burns at the site of the dispersive pad. The use of a return electrode monitoring system averts these burns. This system inactivates the electrosurgical unit if the resistance between the patient's body and the dispersive pad is too high.

Direct coupling and capacitive coupling

Direct coupling occurs when the electrosurgical unit is accidentally activated while the active electrode is in close proximity to another secondary non-insulated instrument (e.g., a metal laparoscope). Electrical current flows from the active electrode to the secondary instrument and potentially damages adjacent structures.

Capacitive coupling occurs when current is transmitted from the active electrode through intact insulation and into adjacent materials without direct contact. Activation of the active electrode produces an alternating current inducing an electrostatic field between two "conductors" (conductive elements). When the net charge exceeds the insulator's capacity, the current is transferred from one conductor to the other. Hybrid cannulas are prone to induce capacitive coupling, since the plastic parts prevent the current dissipating from the metal part into the abdominal wall. This can result in electrical current passing through nearby structures. Longer instruments, thinner insulation, higher voltages, and narrow trocars increase the risk of injury [43, 50, 54].

Interference with (cardiac) implantable electronic device and prosthetics

Implantable devices that use electric current may be affected by the use of electrosurgery. In monopolar surgery, interaction of the current with a cardiac implantable electronic device (CIED) may have life-threatening consequences. Adverse effects include damage to the device, inability to deliver pacing or shocks, lead tissue interface damage, and electrical reset. The preoperative management of the CIED function should be guided by the cardiologist or anesthesiologist [42]. The risk of interference is low in procedures where the path between the active electrode and dispersive pad does not cross the CIED or its leads. There may be some diffusion of current and it is therefore safer to use bipolar electrosurgery or ultrasonic technology in patients with implantable electronic devices [55, 56]. Conductive prosthetics should as well be placed out of the direct path of the circuit since activation of the electrosurgical unit may cause heating of the prosthetic material.

Thermal injuries in electrosurgery and ultrasonic technology

Prolonged activation of both mono- and bipolar electrosurgical instruments as well ultrasonic instruments generate heat (up to 80–100 °C). The instrument can remain hot for some time after activation with the risk of thermal injury when it unintentionally touches surrounding tissue.

Conclusions

Level 4	Bowel perforation, biliary- and urinary tract injuries are among the most serious electrosurgical injuries. *Evidence level D (opinion of guideline development group)*
Level 2	There is insufficient evidence to define the differences in electrosurgery-versus ultrasonic-related complications. *Evidence level A2 [41, 44, 45, 51–53]*

Level 4	Exact incidence rates of electrosurgery-related complications are unknown. The estimated incidence is 2 to 5 per 1,000 procedures.
	Evidence level D (opinion of guideline development group)
Level 3	Additional risks of monopolar electrosurgery, compared to bipolar electrosurgery and ultrasonic technology, include: stray currents, insulation failure, direct coupling, and capacitive coupling.
	Evidence level C [37, 43, 50, 54]
Level 4	Based on electrophysiology, the following factors increase the risk of electrosurgical injuries:
	- The use of high-power and high-voltage settings
	- Inadequate placement of the dispersive pad
	- Hybrid cannulas
	- The intermingling use of plastic and metal cannulas
	- Long instruments and narrow cannulas
	- Insulation failure
	- Char of coagulated tissue on the instrument
	- Prolonged activation of an electrosurgical instrument
	- Activation of an electrosurgical instrument in an open circuit
	Evidence level C [37, 42]
Level 4	When using electrosurgery, cardiac implantable electronic devices and conductive prosthetics are additional hazards.
	Evidence level D [55, 56]

Considerations

The current available evidence on electrosurgical and ultrasonic energy techniques is inadequate to formulate definite evidence-based conclusions. Therefore, larger scale studies are needed. With the current information available, a safe application of these techniques can be achieved by adequate education of the surgical team and supporting staff. The team should be aware of the physics and hazards associated to the use of different energy sources used in MIS. Another obstacle in safety is that biomechanical engineers involved in the purchase of minimally invasive instruments are not routinely involved in the maintenance. Reusable trocars and instruments are often used until defects appear; this might represent a danger to the patient. Participation of biomechanical engineers in maintaining and testing instruments in use could possibly prevent those dangers. Instead of reusable instruments, disposable instruments could be used to prevent insulation failure through wear and tear. However, disposable instruments are often more expensive and not immune from insulation failures.

Finally, postoperative vigilance is required when a patient does not easily recover. The surgeon, physicians, and nurses on duty should be highly alert to the early manifestations of peritonitis. The warning signs may be insidious with atypical or mild symptoms such as slight abdominal discomfort, slight temperature increase, and inability to void. Symptoms of bowel perforation following electrothermal injury are usually seen 4 to 10 days after surgery, leading to a delay in diagnosis and treatment, with sometimes fatal consequences [54]. Laboratory results are often normal with a slight leukocytosis. Expedient evaluation and early intervention is demanded when a patient's recovery is below what should be expected [50].

Recommendations

- When using electrosurgical or ultrasonic techniques, one must have knowledge of electrophysiological functioning and effects.
- To reduce the risk of electrosurgical complications, the following precautions are recommended:

  – When both mono- and bipolar instruments are used, pedals and connections should be checked for accuracy before activating the electrosurgical units.
  – Instrument electrodes should be kept smooth and clean from char, to avoid disruption of current transfer.
  – To prevent capacitive coupling, an isolated position of metal trocars from the abdominal wall should be avoided. Use all-metal or all-plastic cannula systems; the use of metal–plastic hybrids is discouraged.
  – An instrument should be activated only when its electrode is fully visible and in contact with the target tissue. Do not activate in an open circuit.
  – Preferably use brief intermittent activation versus prolonged activation.
  – Use the lowest possible power setting and low-voltage waveform for the desired effect.

- Prior to each MIS procedure, monopolar instruments should be tested for insulation failure with a porosity detector at the central sterilization department.
- With monopolar electrosurgery, the dispersive pad should be applied to well-perfused, dry skin over a large muscle away from bony prominences and conductive prostheses. When disinfecting the skin, be cautious that there are no fluid leaks under the dispersive pad.
- In patients with conductive prosthesis, it is strongly recommended to place the prosthesis out of the direct path of the electrical circuit.
- For procedures in patients with a CIED, the use of bipolar over monopolar electrosurgery is preferred.
- Alertness for electrothermal injury is needed when a patient presents with mild symptoms such as slight abdominal discomfort or slight temperature increase.

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Appendix

Table 2 Literature searches

Subject	Data base	Search terms
Laparoscopic port instruments	Medline (OVID) 1950–March 2012	1. *Laparoscopy/
		2. (trocar* or troicar* or trocard*).ti.
		3. ((secondary adj trocar*) or (classical adj trocar*) or cannula or (disposable adj3 trocar*) or (radially adj expanding adj trocar*) or (STEP adj trocar*) or (visual adj entry) or systems or (conical adj trocar) or (pyramidal adj trocar*) or (reusable adj trocars*) or (disposable adj trocar*) or (single adj2 trocars) or optiview or endotip or visiport or (bladeless adj trocar*) or (sharp adj trocar*) or (trocar adj valve*)).ab,ti.
		4. 2 or 3
		5. *Surgical Instruments/
		6. "Equipment Design"/
		7. exp Gynecologic Surgical Procedures/is [Instrumentation]
		8. Laparoscopy/mt [Methods]
		9. or/5-9
		10. 1 and 4 and 9
		11. systematic reviews (filter)
		12. randomized controlled trials (filter)
		13. exp longitudinal studies/
	Embase (Elsevier) 1974–March 2012	14. 10 and 13 (trocar* OR troicar* OR trocard* OR 'secondary trocar' OR 'classical trocar' OR 'radially expanding trocar' OR 'step trocar' OR 'visual entry system' OR 'conical trocar' OR 'pyramidal trocar' OR 'reusable trocar' OR 'disposable trocar' OR 'single trocar' OR optiview OR endotip OR visiport OR 'bladeless trocar' OR 'sharp trocar' OR 'trocar valvë' OR 'secondary trocars' OR 'classical trocars' OR 'cannula'/exp OR 'radially expanding trocars' OR 'step trocars' OR 'visual entry systems' OR 'conical trocars' OR 'pyramidal trocars' OR 'reusable trocars' OR 'disposable trocars' OR 'single trocars' OR 'bladeless trocars' OR 'sharp trocars' OR 'trocar valves') AND 'surgical instrument'/exp/mj NOT [animals]/lim) AND ([dutch]/lim OR [english]/lim AND [embase]/lim
Port site closure	Medline (OVID) 1950–Nov 2009	1. exp *Laparoscopy/
		2. "laparascop*".m_titl.
		3. "minimal invasive*".m_titl.
		4. 1 or 2 or 3
		5. Surgical Wound Dehiscence/ Obesity/"obes*".m_titl./ Body Mass Index
		6. deep sheath closure*.mp. or Surgical Wound Infection/
		7. port closure*.mp.
		8. port site hernia*.mp.
		9. port infection*.mp.
		10. hernia/ or hernia, abdominal/
		11. herniation.mp.
		12. fascia defects.mp. or Hernia, Ventral/
		13. or/5-15
		14. exp *Sutures/
		15. exp *Suture Techniques/
		16. "suture*".m_titl.
		17. 17-19
		18. 4 and 16 and 20
		19. 9 or 10 or 11 or 12 or 14 or 15
		20. *Laparoscopy/ae [Adverse Effects]
		21. 22 and 23
		22. 21 or 24
		23. "ventral hernia repair*".m_titl.
		24. 25 not 26
		25. Roux-en-Y Gastric Bypass.m_titl.

Table 2 (continued)

Subject	Data base	Search terms
		26. (suture* or closure* or port*).m_titl.
		27. 27 and 29
		28. 30 not 28
	Embase (Elsevier) 1974–Nov 2009	(laparoscop*:ti OR 'laparoscopy'/exp/mj OR 'minimal invasive':ti AND ('deep sheath closure' OR 'port closure' OR 'port site hernia' OR 'port infection' OR 'herniation'/exp OR 'fascia defect' OR 'deep sheath closures' OR 'port closures' OR 'port site hernias' OR 'port infections' OR herniations OR 'fascia defects' OR 'wound dehiscence'/exp OR 'obesity'/exp OR 'body mass'/exp OR 'surgical infection'/exp OR 'abdominal wall hernia'/exp) AND ('suture'/exp/mj OR 'suture'/exp OR suture*:ti)) NOT ('roux en y' AND gastric AND bypass:ti)
		AND filter randomized controlled trials
Electrosurgical and ultrasonic techniques	Medline (OVID) 1950–Nov 2009	1. Laparoscopy/
		2. Laparoscopy.ti.
		3. 1 or 2
		4. Electrosurgery/
		5. Electrosurgery.ti.
		6. 4 or 5
		10. 3 and 6
		11. limit 10 to (dutch or english)
		12. limit 11 to (clinical trial, all or clinical trial or review or comparative study or consensus development conference or controlled clinical trial or evaluation studies or guideline or meta analysis or multicenter study or practice guideline or randomized controlled trial or research support, nih, extramural or research support, nih, intramural or research support, non us gov't or research support, us gov't, non phs or research support, us gov't, phs or technical report or validation studies)
		13. exp Epidemiologic Studies/
		14. 11 and 13
		15. systematic reviews (filter)
		43. randomized controlled trials (filter)
		68. 12 or 14
		69. 68 not (66 or 67)
	Embase (Elsevier) 1974–Nov 2009	'clinical study'/exp OR 'comparative study'/exp OR 'controlled study'/exp OR 'observational study'/exp AND ('electrosurgery'/exp/mj OR electrosurg*:ti) AND ('laparoscopy'/exp/mj OR laparoscop*:ti) NOT [animals]/lim) AND ([dutch]/lim OR [english]/lim AND [embase]/lim

Medline (OVID) and Embase were searched for relevant literature on the topics trocar use, trocar site closure and electrosurgical and ultrasonic techniques. The search was restricted to articles published in Dutch and English from 1966 to November 2009, with exception to the search for trocar use which we updated in March 2012. Additionally, the reference lists of all included studies and systematic reviews pertinent to this topic were screened. Methodological filters of the Scottish Intercollegiate Guidelines Network (http://www.sign.ac.uk/methodology/filters.html) were used to identify potential systematic reviews and randomized controlled trials

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