The Ultrasonic Trocar Provides an Easy, Sharp, Bloodless, and Repeatable Approach to the Abdominal Cavity

Sumio Matsumoto, MD, Norihiko Kawabe, MD, Yoshihisa Mizuno, MD, Nozomu Shirasugi, MD, Hiroichiro Suzuki, MD, Shunji Umemoto, MD

ABSTRACT

Reusable trocars have the advantage of being more cost-effective than disposable trocars. However, the reusable trocar does lose its sharpness on insertion with repetitive insertion. Nonreusable trocars are expensive, but the sharpness of the knife facilitates insertion. Nonreusable trocars have a safety shield system designed to decrease abdominal organ injury, though the potential problem of bleeding from the abdominal wall port site has yet to be resolved. We therefore developed a novel ultrasonic vibrating trocar that does not lose its sharpness even with repetitive insertion. This trocar prevents bleeding by means of an ultrasonic cavitation effect. The ultrasonic vibrating trocar has the advantage of ease of insertion, and the force required for new reusable trocar insertion was only 34% of the force required for insertion of commercially available nonreusable trocars. The force required for multiply used conventional reusable ultrasonic vibrating trocar insertion, ie, 900 insertions, was maintained at less than 46% of the force required by the corresponding nonreusable trocars. Bleeding from the abdominal wall was prevented by an ultrasonic cavitation effect.

Key Words: Ultrasonic device, Trocar, Cavitation, Abdominal organ injury.

INTRODUCTION

Endoscopic surgery, either by laparoscopy or thoracoscopy, was achieved through a trocar that inserted into the cavity where the target organ was located. All surgeons were obliged to use trocars as long as they adopted the CO2 gas insufflation method. Because the first trocar was always inserted through the abdominal or chest wall, a risk has always been present of inadvertently injuring an abdominal or thoracic organ, as well as the possibility of bleeding. Two types of trocars, reusable and disposable, are available. We have often used the disposable trocar because of its sharpness on insertion. Reusable trocars have the potential advantage of costing less than disposable trocars, if they can be used many times without losing the sharpness of the knife. Dull reusable trocars might tear the abdominal wall much more than a sharp disposable trocar on insertion. Injury on insertion of the trocar has been among the possible major complications of laparoscopic surgery. The safety shield system in which the knife popped in and out across the tip of the trocar was later developed, and this improvement has decreased injuries. However, a problem that surgeons cannot ignore has remained in regard to the procedure for inserting the trocar: bleeding from abdominal wall muscles torn by the trocar knife. Drops of blood along the trocar conceal the target organ from laparoscopic view and create problems for surgeons. In a French survey, this accounted for 38% of all trocar accidents. We developed an ultrasonic (US) vibrating trocar, the sharpness of which was not diminished even with more than 900 repetitive insertions, overcomig the disadvantages of commercially available trocars, and also preventing bleeding from the tract at insertion. However, the friction due to movement of the obturator generated heat in the adjacent tissue along the insertion tract. This novel instrument raises the possibility of delaying wound-healing reactions. Therefore, we examined the degree of histological damage along the insertion tract and the recovery of abdominal wall tension by comparing port-site skin tensile strength with each trocar, in a porcine model.
METHODS

A generator and ultrasonic vibrating trocar (Olympus Optical Co., Tokyo, Japan) were used in this study. The frequency of the generator was set at 23.5 kHz, the vibration amplitude at 150 µm. The ultrasonic trocar is composed of an obturator, which conducts ultrasonic vibratory movements, and a trocar (Figure 1). The diameter of the obturator is 12.6 mm, and the diameter of the trocar is 14.8 mm.

Swine were purchased from Sumichiku Limited, and six 9- to 11-week-old female swine were raised on specific-pathogen-free food for young swine purchased from ShimizuKou Feed Company. Tap water was provided for drinking. General anesthesia was achieved with midazolam (Yamanouchi, Japan) 0.2 mg/kg and medetomidine hydrochloride (Meiji Seika, Japan) 40 µg/kg for presedation, ketamine hydrochloride (Sankyo, Tokyo, Japan) 10 to 15 mg/kg for induction, and Isoflurane (Dainihon Pharm. Co., Japan) 2% to 3%. Sodium sulbactam/sodium ampicillin (1.5g) was administered intravenously during the operation. Veterinary ampicillin was administered orally (2 g/day) for 5 days after the operation.

The phantom was a block of swine muscle 200 mm x 300 mm x 35 mm. The ultrasonic trocar attached to a Digital Push-Pull gauge (Aiko Engineering Co., Tokyo, Japan, Model-9500) (Figure 2) was pushed into the muscle block, and the strength of the force was measured and recorded by a computer. Four trocars were compared: a new ultrasonic trocar (USN), a conventional trocar (USO) that had been inserted 900 times, a 12-mm Dilating Tip (DT) trocar (Ethicon Endosurgery, USA) and a 12-mm VERSAPORT (VE) trocar (US Surgical Co., Tokyo, Japan). The force required for insertion into the abdominal wall could be varied according to the means of insertion. Rapid and forceful insertion required much more force than gentle insertion. Therefore, we kept in mind the necessity of arranging the times for insertion so as to be the same length, and compared the levels of force among the trocars. It took an average of 6.5 seconds to completely insert the new and conventional US trocars; the average insertion time was 6.6 seconds for the DT trocar and 6.4 seconds for the VE trocar. Each trocar was inserted 10 times, and the insertion force was recorded. The average force was calculated and statistical significance was evaluated with the Student $t$ test.

Six animals were used in this experiment. An 18-mm incision was made in the skin of a pig, and the US trocar, Dilating Tip trocar, and VERSAPORT trocar were inserted into the abdominal cavity through the incision. Trocars were then removed, and the wound was closed with 2 skin staples. Bleeding from under the skin was equally controlled by monopolar electrocautery with all 3 types of trocars. In the actual procedure, 1 vertical full-thickness skin stitch up to the muscle fascia was placed 1 cm from the wound line, and the suture was retracted with a Digital Push-Pull gauge. The force at which the wound opened 5 mm was recorded as the break strength. Each of the trocars was tested at 4 sites in each animal.

The port site not used in the tensile strength evaluation was saved for pathological examination. The full thickness of the abdominal wall around the port was removed, fixed with formalin, and stained with hematoxylin-eosin (HE). The specimens were examined for degree of wound healing.

The temperature around the port site was measured and recorded with a Thermal Video System TVS 8000 (Nihon Avionics, Tokyo, Japan) to detect temperature elevations. The ultrasonic vibrations stopped when the trocar tip entered the cavity through the peritoneum. Statistical analysis was performed with the Student $t$ test, and $P < 0.05$ was considered significant.

RESULTS

We compared the force necessary to insert the trocar through swine muscle (Table 1). The new and conventional US trocar insertion forces were significantly less
than the forces of the other 2 trocars, but the insertion procedure was performed in almost the same time. The DT and VE trocars required the same level of force.

The respective break forces at 1 and 2 weeks were 2.4 ± 0.7 kg (n = 4) and 4.8 ± 0.3 kg (n = 4) for the US trocar, 1.3 ± 0.2 kg (n = 4) and 5.7 ± 0.6 kg (n = 3), for the DT trocar; and 2.9 ± 0.9 kg (n = 4) and 3.9 ± 0.4 kg (n = 4) for the VE trocar (Figure 3). The break forces for the US and VE trocars were higher than that of the DT trocar at 1 week, while that of the DT trocar was highest at 2 weeks.

The widths of the scars made by the trocars were compared. The US trocar scar was larger than the DT trocar scar. Degenerative changes caused by burning were

|       | USN (n = 10) | USO (n = 10) | DT (n = 10) | VE (n = 10) |
|-------|-------------|-------------|-------------|-------------|
| Force (kg) | 1.8 ± 0.2  | 2.2 ± 0.1  | 2.2 ± 0.1  | 4.8 ± 0.3  |

USN = new US trocar; USO = conventional US trocar; DT = Dilating tip trocar; VE = Versaport trocar.

Figure 2. The US trocar was inserted after attaching a CPU gauge.

Figure 3. Tensile strength of the port site. Tensile strength at the US trocar site was greater than at the sites where the other 2 trocars were used.

Figure 4. Histological appearance of the abdominal wall specimen. The width of the scar was greater at the US port site than that at the DT port site.
found in the muscle tissue when the US trocar was used. This change was thought to be due to heat generated by friction. No difference was found between the US and DT trocars in the epidermal layer (Figure 4).

We measured temperature changes produced by the US trocar because the other 2 trocars did not produce friction that generated heat. Skin temperature around the port site started to increase after the trocar was inserted, and rose to 78.8°C just before the peritoneum was broken. The temperature gradually decreased thereafter, and fell to 43.2°C in 30 seconds.

DISCUSSION

We developed an ultrasonic trocar that does not lose blade edge sharpness, and prevents the problem of bleeding. This instrument decreased bleeding. The insertion force of the new US trocar through the abdominal wall was 34% of the force required by commercially available DT trocars. We examined the force with the conventional US trocar, which had been used 900 times. The conventional US trocar insertion force decreased to only 22% less than that of the new US trocar, maintaining ease of insertion as compared with other trocars. The value of the insertion force for the conventional US trocar was only 42.3% of that of the DT trocar, and 45.8% of that of the VE trocar. The US trocar maintained its capacity even with 900 insertions, and this novel instrument had the added advantage that the heat generated by friction between the ultrasonic vibrating trocar and adjacent tissue induced protein denaturation and thereby decreased bleeding. The force of the US trocar insertion was less than that required by the DT and VE trocars. This meant that the US trocar was inserted through the abdominal wall more easily than either the DT or the VE trocar.

When we did not insert the trocar smoothly through the abdominal wall, we pushed the trocar more forcefully than usual. Champault reported 7 perioperative deaths due to vascular injuries. The insertion force through the abdominal wall by the US trocar was less than that required by either the DT or the VE trocar. The US trocar had the advantage of a lower probability of abdominal organ injury when not vibrated, even when an organ was touched, because the edge of the US trocar tip was made nontraumatic in order to decrease injuries. Therefore, we speculated that the US trocar might decrease the probability of injuring an abdominal organ, or vessels, or both, and thereby decrease potentially fatal complications. This observation indicated that we had developed a reusable trocar with the advantage of cost-effectiveness.

We have often experienced stress due to unexpected bleeding from the port site. Bleeding from the port requiring conversion to open surgery was reported in 10 out of 537 cholecystectomies in the Japan Society of Endoscopic Surgery 1998 Survey. We have used US trocars in clinical practice since 1998 and have performed 35 cholecystectomies, 5 gastrectomies, and 10 colonic resections. We have never encountered bleeding when inserting the US trocar. This advantage may be attributable to the nontraumatic tip of the US trocar, which decreased the likelihood of injuring vessels and may also be ascribed to the ultrasonic vibrating tip dividing tissues and thereby preventing vessels from being torn.

The US trocar produced friction that generated heat in adjacent tissues. Despite the wider scar generated by the US trocar, as compared to the DT trocar, in HE-stained specimens, the tensile strength of port site at 1 week was 2.4 kg, which was no less strong than those of the others. The strength at 2 weeks was 4.8 kg and was almost the same as the 5.7 kg achieved with the DT trocar and was stronger than the 3.9 kg achieved with the VE trocar. These findings confirmed the absence of clinical problems in regard to the tensile strength of the port site with the US trocar. However, this thermal scar might allow surgeons to add a stitch between the fascia split made by the US trocar.

The skin burn injury associated with temperature elevation has the potential to delay the healing process. Shortening the time of contact between the obturator and tissue could decrease the degree of the burn injury. This was accomplished by making the trocar surface smoother and thinner, which decreased resistance during insertion and allowed the trocar to be inserted quickly. The issue of the burning effect on the peritoneum remains to be resolved, but it is anticipated that resolution will be achieved with a smoother and thinner trocar.

CONCLUSION

We developed a reusable ultrasonic vibrating trocar that could be bloodlessly and smoothly inserted more than 900 times through the abdominal wall. This instrument is inexpensive and is anticipated to decrease organ injury and other complications.
References:

1. Cogliandolo A, Manganaro T, Saitta FP, Micali B. Blind versus open approach to laparoscopic cholecystectomy. A randomized study. Surg Laparosc Endosc. 1998;8:353-355.

2. Marret H, Harchaoui Y, Chapron C, Lansac J, Pierre F. Trocar injuries during laparoscopic gynaecological surgery. Report from the French Society of Gynaecological Laparoscopy. Gynaecol Endoscopy. 1998;7:235-241.

3. Nezhat FR, Silfen SL, Evans D, Nezhat C. Comparison of direct insertion of disposable and standard reusable laparoscopic trocars and previous pneumoperitoneum with Veress needle. Obstet Gynecol. 1991;78:148-150.

4. Deziel D, Millikan KW, Economou SG, Doolas A, Ko ST, Airan MC. Complications of laparoscopic cholecystectomy: a national survey of 4,292 hospitals and an analysis of 77,605 cases. Amer J Surg. 1993;165:9-14.

5. Champault G, Cazacu F, Taffinder N. Serious trocar accidents in laparoscopic surgery: a French survey of 103,852 operations. Surg Laparosc Endosc. 1996;6:367-370.

6. Japan Society of Endoscopic Surgery survey. JSES. 1998;3:510-580.