腹腔鏡下手術における，第１トロッカー配置用仮想訓練装置開発のための，実際の手術での

ブレードレス・トロッカー挿入動作の測定

渡邉卓哉，藤原道隆，小寺泰弘，坂口正道，日高広貴，藤本英雄，中尾昭公

Measurement of Inserting Motion of Bladeless Trocar at Real Surgery for Development of a Virtual Training System for Initial Trocar Placement in Laparoscopic Surgery

Takuya Watanabe[1], Michitaka Fujiwara[1], Yasuhiro Kodera[1], Masamichi Sakaguchi[2], Hiroki Hidaka[2], Hideo Fujimoto[2] and Akimasa Nakao[1]

[1]Department of Surgery II, Nagoya University Graduate School of Medicine, Nagoya, Japan

[2]Nagoya Institute of Technology, Nagoya, Japan

Corresponding Author: Takuya Watanabe, Department of Surgery II, Nagoya University Graduate School of Medicine, 65 Tsurumai-cho, Showa-ku, Nagoya, Aichi 466-8550, Japan

Tel.: +81527442250, Fax: +81527442245, E-mail: watanabetakuya@med.nagoya-u.ac.jp

KEY WORDS:
Optical view method; Trocar inserting motion; Training system; Virtual reality

ABBREVIATIONS:
U.S. Food and Drug Admin–istration (FDA); Laparoscopic Pylorus Preserv–ing Gastrectomy (LAPPG); Laparo–scopic Distal Gas–trectomy (LADG); Laparoscopic Total Colectomy (LATC); Laparoscopic Local Gastric Wedge Resection (LWR); Around the Navel (AN); Right Lower Quadrant of the Abdomen (RLQ); Left Side of the Abdomen (LS); Right Side of the Abdomen (RS); Left Lower Quadrant of the Abdomen (LLQ)

ABSTRACT

Background/Aims: The optical view method is an alternative to the open method as a laparoscopic entry technique, but it calls for a certain experience. Therefore we undertook the development of a training system for optical view method in initial trocar placement. For this purpose, kinetic data concerning insertion of a trocar were measured by means of non-invasive monitoring during actual surgery.
Methodology: We slotted force and motion sensors into an adapted trocar and measured the kinetic aspects of trocar insertion in terms of force and torque. The measurement was carried out at the time of the second and third trocar insertion by a single experienced surgeon.
Results: The measurement was carried out at 11 sites in 6 patients. We measured position, inserting force and inserting torque of the measuring trocar continuously. Mean maximum inserting force was 71.4N (range: 63.9-75.5N) at the perinavel port and 65.3N (range: 31.8-83.8N) at other sites. Mean maximum torque was 0.19Nm (range: 0.18-0.21Nm) at the perinavel port, and 0.23Nm (0.15-0.35Nm) at other sites. The number of rotations needed to penetrate the abdominal wall differed considerably among the patients.
Conclusion: In the measurement by an experienced operator, inserting force and torque data were consistent and generally did not depend on the patient characteristics or the site of puncture. Difficulty in penetration according to the physical characteristics of the patients was adjusted by differences in the number of rotations applied to the trocar.

INTRODUCTION

In recent years, laparoscopic surgery has been performed as a most popular version of minimally invasive surgery, and the number of cases of oncological surgery performed in Japan has increased exponentially. Laparoscopic surgery is considered to be beneficial to the patients, particularly regarding the short-term outcome, but can only be performed after the surgeons have received adequate education and training.

Initial trocar placement is the first challenging step in laparoscopic surgery that can lead to serious consequences, and is performed by various methods including Veress needle method (blind entrance), Hasson's open method and optical view method. In Japan, the open method has been most commonly performed since it does not need special training for those who have already established themselves as surgeons. However, skin incision tends to be longer than the diameter of the trocar, causing continuous leakage of carbon dioxide while the pneumoperitoneum is being maintained. This is often irritating for the surgeons and could prolong the operating time. In addition, the open method can be technically cumbersome, especially in obese patients.

In the optical view method, a bladeless trocar with a handle and blunt tip made of transparent plastic material is used. The laparocope is inserted into the trocar which a surgeon holds by the handle and inserts directly into the peritoneal cavity by applying a constant axial penetration force accompanied with rotations. The insertion is performed after making a small skin incision and while the abdominal wall is lifted upwards by the surgeons. During insertion, the blunt tip will progress by pushing the blood vessels aside rather than cutting into them, resulting in minimal hemorrhage from the abdominal wall. Since the tip is transparent, surgeons will be able to identify the abdominal wall layers as the laparoscope-containing trocar progresses through the wall. The penetrated structures such as rectal sheath are visualized as multi-layers of a ring that starts from the tip center and becomes enlarged before disap-

Hepato-Gastroenterology 2011; 58:854-858

pearing outside of the trocar. When the last ring known as the white ring enlarges and disappears, that ring represents the peritoneum and the surgeon will notice that the insertion is complete. When the surgeon becomes accustomed to the procedure and the direct visual identification of the abdominal wall layers, this method could be considered as a safe and time-sparing method for initial trocar placement (1). On the other hand, according to the database of the U.S. Food and Drug Administration (FDA), fatalities occur even when laparoscopists used optical trocars. Although designed to help avoid injury, these designs are not a substitute for adequate training or for the use of proper technique (2). A teaching leaflet has been created to facilitate surgeons in identifying the layers as the laparoscope-containing trocar penetrates through the abdominal wall. Currently, however, the only method to train a surgeon to insert the trocar with adequate force remains to be the hands-on training.

This situation prompted us to create a virtual reality simulator for trocar insertion using the optical view method. The training using virtual reality technology is different from training using animals or dummy models and has many advantages such as allowance for repeated usage and failed attempts (3-5). For this purpose, some basic data regarding the number of rotations and axial force needed to drive the bladeless trocar was necessary. However, little data measuring the entry force of trocar in animals or dummy models is available (6-9). In the current study, original data needed for development of the virtual abdominal wall model were accumulated using non-invasive monitoring of trocar insertion during actual laparoscopic surgery.

METHODOLOGY

System for measurement of kinetic data for trocar insertion

At first, we developed a non-invasive measuring system for trocar insertion at Nagoya Institute of Technology (**Figure 1**). We modified a 12mm disposable Optiview trocar (Ethicon Endo-surgery Cincinnati, OH, USA), and constructed a measuring trocar of 340mm length, containing the 6DOF force sensor (NANO sensor 5/4, BL Autotech, Ltd.) and receiver of the three dimensional motion tracking system (FASTRAK, Polhemus) (**Figure 2**). Through insertion of this trocar, the position of the trocar tip can be continuously tracked and recorded by the FASTRAK and kinetic data (force and torque) can be measured by the NANO sensor 5/4. Because the FASTRAK uses a magnetic field, the transmitter was placed as far from the surgical bed as possible.

Acquisition of kinetic data for trocar insertion during actual laparoscopic surgery

Since the measuring trocar cannot accommodate the laparoscope, insertion of a camera port was needed before insertion of the measuring trocar to ensure its safe placement under the laparoscopy. The measuring trocar was accordingly inserted as a second or third trocar. One experienced laparoscopic surgeon (M.F.) with experience of optical view method in more than 1,000 patients inserted the measuring trocar for all cases. This was because data had to be compared between patients with different body contour and between different sites of trocar insertion, and difference owing to the technique of the surgeon had to be minimized. This study was approved by the ethics committee of Nagoya University and written informed consent was obtained from all patients.

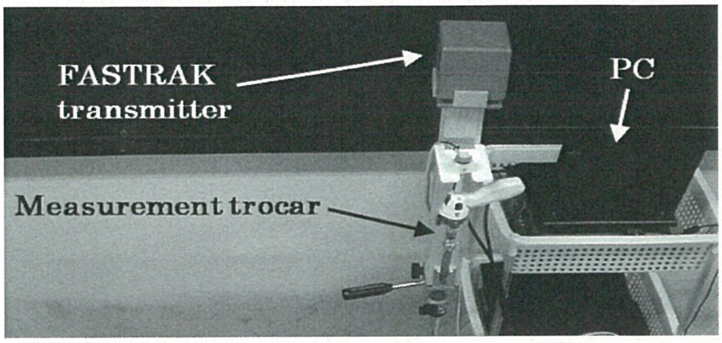

FIGURE 1 The inserting motion measurement system

RESULTS

Evaluation was performed at 11 sites in 6 patients. **Figure 3** shows an example of the pressure applied upon insertion of the trocar as monitored by NANO sensor 5/4. **Figure 4** shows an example of torque applied upon insertion as monitor by the same device. In this particular case, the maximum force was about 61N and maximum torque was about 0.26Nm. The time needed for insertion time was about 13 seconds.

Table 1 shows the summary of all cases. At the perinavel site, the mean maximum inserting force (N) was 71.4N (range: 63.9-75.5N) at the perinavel site and 65.3N (range: 31.8-83.8N) at the other port sites, with no significant difference between the two sites. No difference was observed between the individuals. The mean maximum torque (Nm) was 0.19Nm (range: 0.18-0.21Nm) at the perinavel site and 0.23Nm (range: 0.15-0.35Nm) at other sites, again, with no significant difference. Total number of rotations (twisting motion as the trocar penetrates through the abdominal wall) ranged from 11 to 33 and was variable among the individuals.

DISCUSSION

The authors have utilized optical view method for the laparoscopic entry in 1,300 cases of laparoscopic surgery since 1998. This method has its own training process and learning curve (10). Although this procedure is safe and practical, there are some pitfalls. One potential hazard is derived from inability to identify the position of the trocar tip through the simultaneously obtained endoscopic vision. In this case, the surgeon could keep driving the trocar when the tip is already in the abdominal cavity, causing visceral and vascular injuries. To avoid this serious problem, training to identify the abdominal wall layers, particularly the aforementioned white ring that represents the peritoneum, is mandatory. In addition, inadequate force to drive the trocar could lead either to an abrupt and unexpected penetration into the abdominal cavity and beyond, or to the inability to penetrate through either of the anatomical layers that constitute the abdominal wall. When the trocar is inappropriately guided, the trocar tip could slide on the surface of the fascia without penetrating through it. For these problems, training to exert adequate pressure to drive the trocar through each of the anatomical layers is necessary.

Abdominal wall dummy model does not imitate the layered structure of the abdominal wall with sufficient authenticity and is not suited for training optical view method where the inserting procedures should coordinate with the laparoscopic findings of the penetrating abdominal wall. Training using the animals is unsuitable due to the anatomical difference in which the swine, typically used for training, has smaller amount of subcutaneous fat and tough and thickened peritoneum that do not resemble the human abdominal wall. Thus, the authors opted for training by virtual reality simulators.

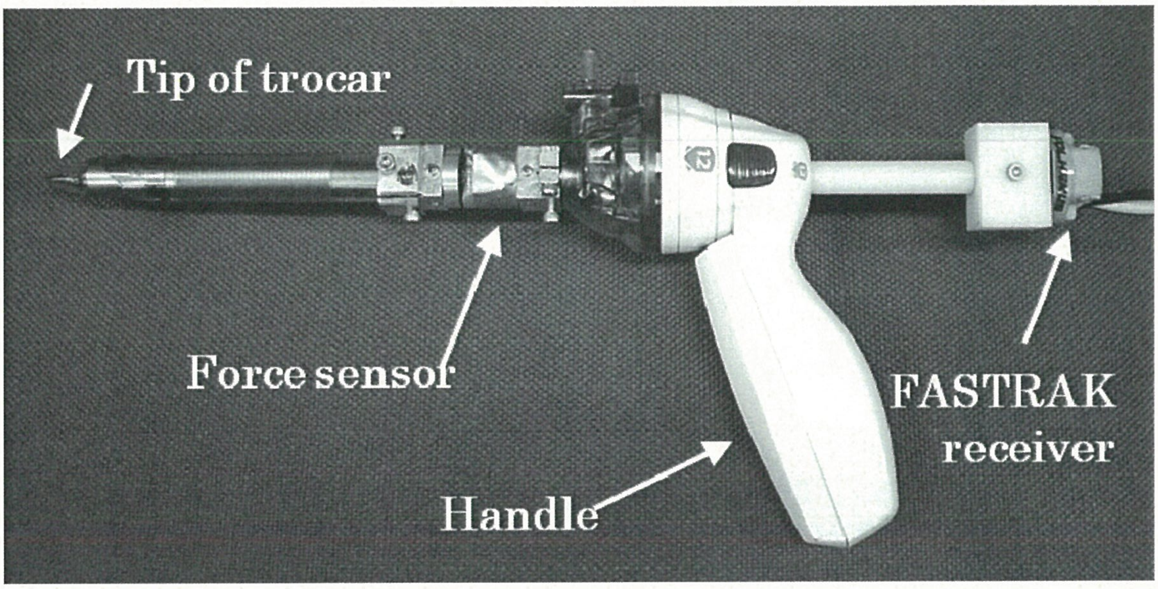

FIGURE 2 The reconstructed measuring trocar

TABLE 1 Summary of All Cases

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 5
age/gender	71M	63M	54M	67M	38F	69M
disease	Gastric cancer	Gastric cancer	Gastric cancer	Ulcertive colitis	Gastric GIST	Gastric cancer
operation	LAPPG	LADG	LAPPG	LATC	LWR	LADG
BMI	27.0	18.9	21.0	19.6	27.6	24.7
The first measurement site	AN	AN	AN	RLQ	AN	LS
Puncture time (S)	Record failure	13	10	10	20	13
maximum force (N)		75.54	72.54	83.02	73.59	61.27
maximum torque (Nm)		0.19	0.18	0.32	0.21	0.26
Total rotation		19	14	14	30	22
The second measurement site	RS	LS	LS	LLQ	LS	AN
Puncture time (S)	26	14	18	7	18	25
maximum force (N)	54.10	62.04	80.76	31.82	83.84	63.85
maximum torque (Nm)	0.15	0.15	0.35	0.09	0.30	0.18
Total rotation	26	23	24	11	31	33

LAPPG, Laparoscopic pylorus preserving gastrectomy; LADG, Laparoscopic distal gastrectomy; LATC, Laparoscopic total colectomy; LWR, Laparoscopic local gastric wedge resection; AN, Around the navel; RLQ, Right lower quadrant of the abdomen; LS, Left side of the abdomen; RS, Right side of the abdomen; LLQ, Left lower quadrant of the abdomen;

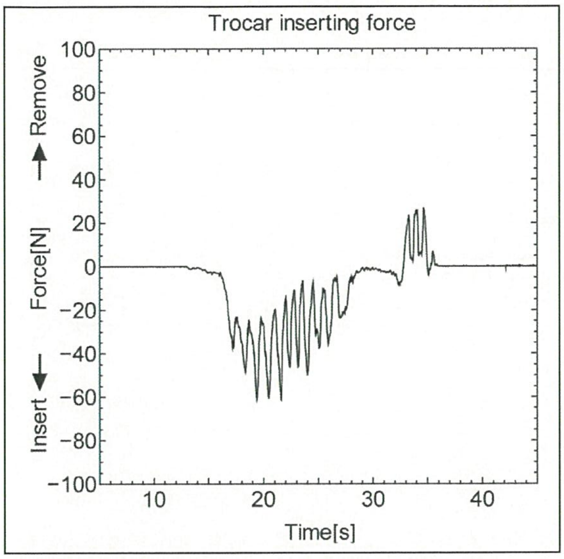

FIGURE 3 Inserting force data of trocar (Case 6)

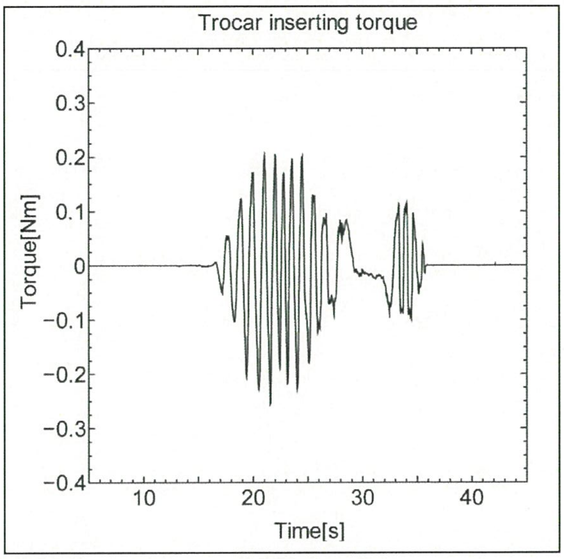

FIGURE 4 Inserting torque data of trocar (Case 6)

The most important data needed to create an original virtual training system were the kinetic profile of trocar insertion obtained from actual patients. Although similar data had been available, these originated from measurements using animals and dummy models. Data from humans have never been reported.

Through the current study, we have shown that the force needed to penetrate through the human abdominal wall is 60-70N. In addition, the force and torque needed for penetration did not in general differ significantly from patient to patient or according to the site of puncture. The only exception was a patient who had been under a high dose steroid therapy. The force needed for trocar insertion was outstandingly small at 31.8N. On the other hand, the number of twists needed depended more heavily on the patient and site of puncture. Thus, the amount of total workload needed for penetration of the abdominal wall, which should apparently be different according to the amount of subcutaneous fat, thickness of the muscles and durability of the fasciae that depend on the gender, age and condition of the patients, has been controlled not by force or torque but by the number of rotations a surgeon gives to the trocar.

This is the first data of the kinetic profile obtained from the human subjects and will be a valuable reference for creating a virtual training system. We are currently in the process of creating a new simulator which can be pre-adjusted to various patterns corresponding to patients with varying conditions. The current data also inform the surgeons that when they have difficulty inserting a trocar to a patient with particularly tough abdominal wall, they are adviced to penetrate through the abdominal wall not by putting extra strength, but by keeping the rotating motion of the trocar as long as needed with consistent appliance of their usual force.

There were two weaknesses in the current study. Firstly, the insertion procedure we evaluated was not for the initial trocar. Since the measuring trocar we had built for this study could not accommodate a laparoscope (**Figure 2**), we had to initially insert another trocar as a laparoscope port to observe while the measuring trocar was inserted. It was not ethical to attempt inserting the measuring trocar to a human subjects through blind access entry. The effect of the pneumoperitoneum that had been obtained at insertion of the measuring trocar is currently considered as negligible, since the actual first trocar insertion through the optical view method is performed by lifting the abdominal wall with a considerable strength. However, the first prototype of the simulator will have to be tested by several surgeons and receive their feedbacks for relevant adjustments before the simulator can be validated. Another weakness was that the information obtained through the laparoscope as the trocar penetrates through the abdominal wall was apparently not available to the surgeon who inserted the measuring trocar. Thus, the surgeon had to insert the measuring trocar without the real time knowledge as to which structure he is penetrating.

In conclusion, we obtained original data under the actual laparoscopic surgery for development of the virtual abdominal wall model. In the measurement by an experienced operator, inserting force and torque data were consistent and generally did not depend on the patient characteristics or the site of puncture. Difficulty in penetration according to the physical characteristics of the patients was adjusted by differences in the number of rotations applied to the trocar. Based on these data, we are planning to develop the training system which combines force feedback system with image display.

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