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Laparoscopic Insertion of Various Shaped Trocars in a Porcine Model

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ABSTRACT

Background and Objective: The number of laparoscopic procedures increases annually with an estimated 3% of complications, one third of them linked to Verres' needle or trocar insertion. The safety and efficacy of ports insertion during laparoscopic surgery may be related the technique but also to trocar design. This study aims to compare physical parameters of abdominal wall penetration for 5 different trocars.

Methods: Eleven pigs were studied. Five different commercially available trocars were randomically inserted at the midline. Real-time video recording of the insertions was achieved to measure the excursion of the abdominal wall and the time and distance the cutting surface of the bladed trocars was exposed inside the abdominal cavity. An especially designed hand sensor was developed and placed between the trocar and the hand of the surgeon to record force required for abdominal wall perforation.

Results: Greater deformations and forces occurred in nonbladed as compared to bladed trocars, and in conical trocars as compared to pyramidal pointed ones, except for peritoneum perforation. Greater distance and time of blade exposure occurred in pyramidal laminae as compared to conical.

Conclusion: The bladed trocars have lower forces and deformations in their introduction, and should be those that cause less injury and are more suitable for first entry. Conical and pyramidal trocars with the same blade size showed similar force, deformation, time, and distance of exposed blade.

Key Words: Laparoscopy; Trocar; Safety; Animal model.

INTRODUCTION

Laparoscopic surgery became a preferred access route for several surgical procedures.[1] However, the enthusiasm with new technology often omits a clear evaluation of their possible complications.[2] It is estimated that the rate of complications attributed to the laparoscopic access ranges from 3% to 16% and include puncture injuries (Veress' needle or trocar insertion), insufflation, tissue dissection, and ineffective hemostasis.[3,4]

One third of all laparoscopic complications are related to abdominal access.[3,5] Although trocar placement under direct vision into the peritoneal cavity is considered safer by several authors,[6] others use the "blind" technique in which the Veress needle is used to inflate the abdomen with subsequent introduction of the trocars,[7] one of the main moments for possible occurrence of complications.[8] Guidelines to prevent these adverse events are available but the ideal technique for cavity access is yet debatable.[9,10]

Technological evolution created several types and brands of trocars in order to increase the safety of the wall perforation.[11] However, comparative studies of different trocars with objective and reproducible parameters are still few in the literature.

This study aims to compare physical parameters of abdominal wall penetration for 5 different trocars in an in vivo animal model, which may help develop a safer method of insertion.

MATERIALS AND METHODS

Ethics

The study protocol was approved by the local Ethics Committee (#036/11).

The work has been reported in accordance with the Animals in Research: Reporting In Vivo Experiments (ARRIVE) guide-

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Informed consent: Dr. Passerotti declares that written informed consent was obtained from the patient for publication of this study/report and any accompanying images.

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lines. All procedures performed in studies involving animals were in accordance with the ethical standards of the institution or practice at which the studies were conducted. All applicable international, national, and/or institutional guidelines for the care and use of animals were followed. This article does not contain any studies with human participants performed by any of the authors.

Informed consent does not apply to this type of study.

There is no funding.

Experimental Model and Experiment Setting

Eleven female pigs weighting 20 to 22 kg were studied. Animals came from outsourced specialized facilities external to the laboratory where the experiments were conducted. Experiments were performed immediately upon the animal's arrival that were not housed in the local. Animals were anesthetized with a combination of telazol (5 mg/kg, intramuscular), xylazine (1.5 mg/kg), and atropin (0.04 mg/kg) for orotracheal intubation followed by isoflurane (2%). Animals were euthanized at the end of the procedure with a lethal dose of KCl (2 mEq/kg).

Full-thickness abdominal-wall incisions were performed bilaterally 4 cm lateral to the median line from the ribs (superiorly) to the inferior iliac crest (inferiorly). A metal frame was created from welded copper pipes to support the wall strip and allow trocar penetration visualization (**Figure 1**). A constant and uniform tension was achieved due to standardization of the support height and incision size.

Five different trocars were randomly inserted at the midline, one at a time, at distances of 1 cm between them, starting 1 cm from the umbilicus. Skin was incised before each insertion to avoid any additional resistance. Thirty-six insertions per trocar were performed (total, 180 insertions). A single experienced surgeon performed all tests.

Measuring Devices

Real-time video recording of the insertions was achieved with the aid of a high-resolution color camera (250 frames per second), placed on a tripod, parallel to the abdominal wall, at a fixed distance from the middle line. An especially designed hand sensor was developed from piezoelectric cells (strain gage) and placed between the trocar and the hand of the surgeon to record force required for abdominal wall perforation (**Figure 2**). Computerized analysis of the pressure applied in the sensor depicted characteristically curves corresponding to a double hump representing the force peak required for fascia (aponeurosis) perforation (F1) and a second force peak necessary for perforation of the peritoneum (F2) (**Figure 3**).

Figure 1. Experiment setup. The metal frame supporting the abdominal wall is in place with a camera positioned on a tripod. Punctures were performed every 1 cm with a hand sensor between the trocar and the surgeon's hand.

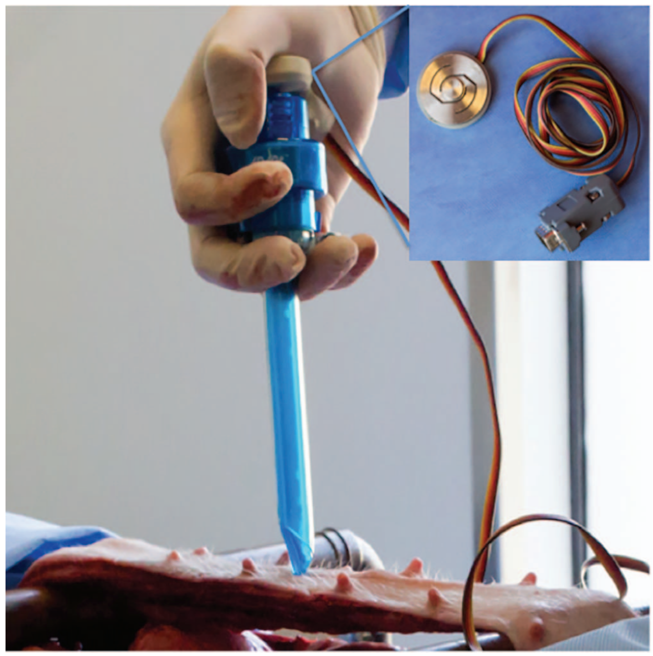

Figure 2. Hand sensor for force detection.

Parameters Evaluated

Penetration forces (F1 and F2) were recorded by the hand device.

Video recording allowed the measurement of the deformation distance (Dd) as defined by the excursion of the

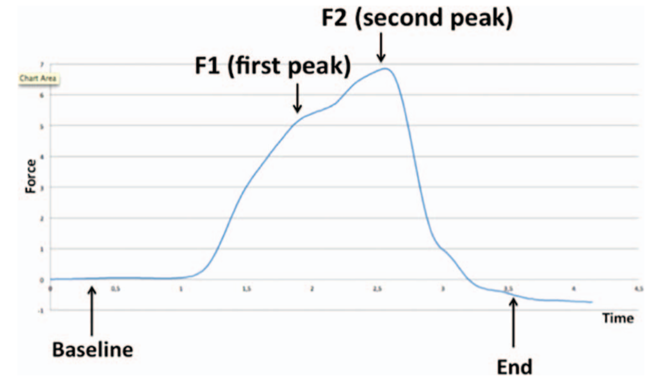

Figure 3. Two force peaks required for fascia (aponeurosis) (F1) and peritoneum (F2) perforation as detected by the hand sensor.

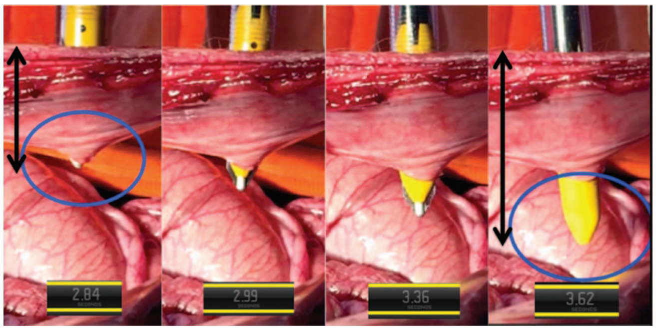

Figure 4. Time (Tbl) and distance (Dbl) the cutting surface of the bladed trocars was exposed inside the abdominal cavity.

abdominal wall in centimeters between the resting position and the last recorded frame before the exposure of the trocars tip; and the time (Tbl) and distance (Dbl) the cutting surface of the bladed trocars was exposed inside the abdominal cavity (**Figure 4**).

Trocars

Five commercially available 12-mm trocars accessible in the country were studied:

B1—Bladed (1 cm) conical trocar (D12LT, Endopath Xcel, Ethicon Endo-Surgery, Guaynabo, Puerto Rico)

B2—Bladed (1 cm) pyramidal trocar (179096PF, Covidien Versaport Plus V2 Bladed, Auto Suture, Norwalk, Connectcut, USA)

B3—Bladed (1.2 cm) pyramidal trocar (FN 100-108, Femcare, Nikomed Shielded Trocar & Canula, Hampshire, UK)

NB4—Nonbladed pyramidal trocar (41051, Taut, Adapt, Geneva, Illinois, USA)

NB5—Conical nonbladed trocar (B12LT, Endopath Xcel bladeless, Ethicon Endo-Surgery, Guaynabo, Puerto Rico)

Statistical Analysis

Student *t*-test, Analysis of Variance (ANOVA), and Kruskal-Wallis test were used when appropriate. Variables are expressed as mean ± standard deviation (range).

Sample size calculation was based on a minimal difference of 1.0 cm for deformation distance with an estimated ideal sample of 36 penetrations per trocar.

RESULTS

Results for all trocars are depicted in **Table 1**.

Greater deformations (7.10 ± 1.04 cm versus 4.54 ± 1.0) and forces (8.7 ± 2.27 N versus 5.85 ± 1.44 for F1 and 10.32 ± 2.54 N versus 6.38 ± 1.89 for F2) occurred in nonbladed compared to bladed trocars ($P < .001$). Greater deformations (6.01 ± 1.18 versus 5.26 ± 1.78 cm, $P < .001$) and forces (F1, 7.47 ± 2.81 versus 6.67 ± 1.79 N, $P = .01$) occurred with conical trocars as compared to pyramidal pointed, except for peritoneum perforation (F2), which obtained greater absolute value but with $P = .1$ (**Table 2**).

Distance (B3, 2.34 ± 0.83; B1, 1.88 ± 0.49; and B2, 1.86 ± 0.91 cm) and time of blade exposure (B3, 0.75 ± 0.47; B1, 0.39 ± 0.30; and B2, 0.23 ± 0.17 s) was different for trocar B3 ($P < .001$ for all parameters) as compared to others (**Table 3**).

DISCUSSION

Trocar puncture accidents are rare but associated to high morbidity due to viscera lesion or even mortality in cases of vascular injury.[12–14] The technique is also of some importance for safe trocar insertion, in addition to the characteristics of the trocar itself. Some systematic review compared different laparoscopic entry techniques.[10,15,16] One of them evaluated 57 randomized controlled trials, including 25 techniques (as direct vision entry, open entry Evidence and Veress needle entry techniques) and concluded that there was insufficient evidence to support the use of one laparoscopic entry technique over another.[10] Another Japanese systematic review highlighted 17 studies and also did not reported any difference when comparing major complications (major vessel injury, gastrointestinal injury, and solid organ injury)[16]. Trocar design is also linked to the rate of complications.[13] Blunt trocars have been found in some studies to cause decreased

Table 1.
Global Results for All Trocars

Trocar	Deformation Distance (cm)	F1 (N)	F2 (N)
B1	5.03 ± 0.55 (3.88–6.04)	5.27 ± 0.77 (2.63–6.83)	5.22 ± 1.22 (1.84–7.49)
B2	4.26 ± 1.19 (2.29–7.36)	5.46 ± 1.11 (3.06–8.0)	5.84 ± 1.28 (3.62–8.82)
B3	4.33 ± 0.99 (1.74–6.06)	6.82 ± 1.74 (2.90–11.20)	8.07 ± 1.79 (4.61–11.9)
NB4	7.2 ± 1.27 (4.95–9.9)	7.73 ± 1.71 (4.78–11.30)	9.17 ± 1.84 (5.91–12.98)
NB5	7.0 ± 0.74 (5.23–8.68)	9.67 ± 2.36 (3.58–15.38)	11.46 ± 2.65 (7.22–19.18)

B1, bladed conical 1.0 laminae trocar; B2, bladed pyramidal 1.0-cm laminae trocar; B3, bladed pyramidal 1.2-cm laminae trocar; NB4, non-bladed pyramidal trocar; NB5, non-bladed conical trocar.

Table 2.
Results According to Trocar Design

Trocar	Deformation (cm)	*P*	F1 (N)	*P*	F2 (N)	*P*
Comparison to the presence of a blade						
Bladed (B1 + B2 + B3)	4.54 ± 1.0 (1.74–7.36)	<.001*	5.85 ± 1.44 (2.63–11.20)	<.001*	6.38 ± 1.89 (1.84–11.90)	<.001*
Non-bladed (NB4 + NB5)	7.10 ± 1.04 (4.95–9.9)		8.7 ± 2.27 (3.58–15.38)		10.32 ± 2.54 (5.91–19.18)	
Comparison according to tip shape						
Conical (B1 + NB5)	6.01 ± 1.18 (3.88–8.68)	<.001*	7.47 ± 2.81 (2.63–15.38)	.01*	8.34 ± 3.74 (1.84–19.18)	.1
Pyramidal (B2 + B3 + NB4)	5.26 ± 1.78 (1.74–9.9)		6.67 ± 1.79 (2.90–11.30)		7.69 ± 2.15 (3.62–12.98)	

*Statistically significant.

B1, bladed conical 1.0 laminae trocar; B2, bladed pyramidal 1.0-cm laminae trocar; B3, bladed pyramidal 1.2-cm laminae trocar; NB4, non-bladed pyramidal trocar; NB5, non-bladed conical trocar.

trauma and lead to a lesser chance to injury intra-abdominal organs[17] and less pain.[18] Other authors advocate conical trocars in opposition to pyramidal devices.[19] A consensus; however, is not found and conflicting results are seen in different series.

We proposed an experimental model to evaluate physical parameters of different designed trocars as an indicator for safety and striking differences were indeed found, which could be useful in the development of new trocars.

Methodology

We previously developed a model to measure trocars' penetration force in animals[1] using an apparatus constructed to insert trocars with a nonrotational, constant speed, single direction, and to measure the axial force applied to the trocar during insertion as a function of time. This setup; however, did not consider the rotational movement, ergonomics, and variable force applied by the surgeon's hand in real situations. The model used in the current study tried to fix these limitations.

The access through the porcine abdominal wall with the trocars was made in the midline; however, we are aware that most advanced laparoscopic surgeons access the abdomen in the left subcostal region (Palmer's point) in order to be able to visualize several layers of tissue rather than one single at the *linea alba*. The abdominal place for the first punction was highlighted in some studies. Some guidelines report indeed that the safest point is the left subcostal region, mainly in patients with peri-umbilical adhesions or umbilical hernia.[9] In our study, all punctions were done in the midline to optimize the number of punction per animal, allowing a greater homogeneous tissue area (equivalent in thickness and number of muscle layers). There may be differences in the abdominal wall according to gender. We dissected only female animals since the urethra of male pigs ascends in the midline close to the umbilicus, forbidding the use of almost half of the abdominal wall.

Table 3.
Blade Exposure in Bladed Trocars

Trocar	Deformation Distance (cm)	Statistical Comparison	F1 (N)	Statistical Comparison	F2 (N)	Statistical Comparison	Distance of Exposed Blade (cm)	Statistical Comparison	Time of Exposed Blade (s)	Statistical Comparison
B1	5.03 ± 0.55 (3.88–6.04)	B2 = B3 < B1	5.27 ± 0.77 (2.63–6.83)	B1 = B2 < B3	5.22 ± 1.22 (1.84–7.49)	B1 = B2 < B3	1.88 ± 0.49 (1.05–2.96)	B3 > B2 = B1	0.39 ± 0.30 (0.05–1.45)	B3 > B2 = B1
B2	4.26 ± 1.19 (2.29–7.36)		5.46 ± 1.11 (3.06–8.0)		5.84 ± 1.28 (3.62–8.82)		1.86 ± 0.91 (0.52–4.94)		0.23 ± 0.17 (0.06–0.58)	
B3	4.33 ± 0.99 (1.74–6.06)	**$P < .001$**	6.82 ± 1.74 (2.90–11.20)	**$P < .001$**	8.07 ± 1.79 (4.61–11.9)	**$P < .001$**	2.34 ± 0.83 (0.27–4.34)	**$P < .001$**	0.75 ± 0.47 (0.06–2.00)	**$P < .001$**

B1, bladed conical 1.0 laminae trocar; B2, bladed pyramidal 1.0-cm laminae trocar; B3, bladed pyramidal 1.2-cm laminae trocar. Statistical significant values are in bold.

Hand sensors were used previously to assess Verres needle insertion.[20] The device was, however, abandoned for technical reasons. Some authors used a pressure sensor attached to the trocars and a vertical continuous movement of the hand in order to be insensitive to torsion.[21–22] The insensitiveness to torsion would constitute an advantage according to some.[21] We, however, believe that torsion should be considered as the highest applied force is of interest. A new hand sensor was developed during our study in conjunction with an engineering school. It worked satisfactorily and it can be used in future studies in *anima nobili* and in simulators for teaching purposes.

High-resolution recording of the images during trocar insertion allowed a correct evaluation of the abdominal wall dynamics and the exposure of the cutting blade.

As a limitation of the developed technology, the effect of a pneumoperitoneum is not reproduced. Also, abdominal wall variability is critical in clinical cases; however, we planned the protocol in a controlled environment in animals for reproducibility.

Trocars Design

Previous experimental studies analyzed the force necessary to insert a trocar in animal models. All of them found lower forces for bladed trocars as compared to blunt brands.[1,22] Some clinical series also studied the safety of bladed compared to blunt trocars. Antoniou et al[11] compiled 720 procedures in a metanalysis to show a decreased relative risk of bleeding from the abdominal wall for nonbladed trocars (3% compared to 9%) but no difference with regard to visceral injury. Our study reproduced these previous results with lower forces for bladed trocars. We added to these results a lower deformation of the abdominal wall representing decreased chance of contact of the trocar with viscera. Although nonbladed trocars do not have a cutting surface, viscera may be injured by blunt trauma. Moreover, higher degrees of abdominal wall deformation denote more traumatic insertions and seem to be related to postoperative local pain.[18]

The shape of the tip of the trocars also influences the dynamics of insertion. Böhm et al[21] showed in a porcine model that conical tips needed a higher force than purely pyramidal tips. Hurd et al[23] studied in rabbits the risk of vascular injury inserting trocars aimed at the vena cava. Risk for injury was higher for pyramidal tipped trocars compared to conical. The blade size of pyramidal trocars also influenced results with higher risk for 10-mm blades compared to 5-mm blades. Our experiment also showed dissimilarity in results when 2 pyramidal-tipped bladed trocars with different blade sizes. Larger blades provoked higher forces, higher distance and time of exposed blade. Besides, conical (B1) and pyramidal (B2) trocars with the same blade size showed similar force, deformation, time and distance of exposed blade.

CONCLUSIONS

Our results showed that bladed trocars demanded lower forces for penetration leading to less abdominal wall deformation. Lower deformations and forces also occurred with pyramidal pointed as compared to conical trocars. Pyramidal trocars with smaller blades showed lesser time and smaller distance exposed. Pyramidal pointed trocars with smaller blades should be those that cause less injury and are more suitable for first puncture for clinical practice. Therefore, this study can guide young surgeons in choosing a more suitable trocar. Besides, trocar inserting technique should be more clearly understood and a protocol of training should be included during laparoscopy training.

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