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ORIGINAL ARTICLE

Experimental evaluation of the fineness of needle forceps: advantages other than minimal access

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Abstract

Purpose Needle forceps are used to limit damage to the abdominal wall in endoscopic surgery; however, few experimental studies have evaluated the fineness and performance of needle forceps. We conducted this study to identify the advantages of needle forceps over conventional 5 mm forceps, focusing on fine grasping and needle control.

Methods Twenty physicians executed tasks using 5 mm forceps and 2.1 mm small diameter forceps in a laparoscopic experimental setting. First, we timed the execution and recorded the number of drops in a task of grasping and moving grains of rice and red beans. Next, we measured the execution time, looseness of the knot, and the deviation from the stitching point in a suture and ligation task using suture needles with a diameter of 17 or 26 mm.

Results The needle forceps required a significantly shorter execution time to move the rice grains (37.7 s vs. 45.8 s; $p=0.01$) and a significantly higher completion rate (90% vs 20%; $p<0.01$). The deviation of the stitching point using the 17 mm needle with needle forceps was significantly smaller than with the 5 mm forceps (0.5 mm vs. 1.0 mm; $p<0.01$).

Conclusion Needle forceps are better for procedures requiring fine grasping and enable more accurate small diameter needle control than 5 mm forceps.

Keywords Ergonomics · Laparoscopy · Needlescopic surgery · Reduced port surgery · Task performance

Introduction

Laparoscopic surgery is performed widely and has become a standard treatment option for malignancies based on the feasible oncologic outcomes of multicenter prospective studies [1, 2]. Recently, robotic-assisted surgery has been implemented in the surgical field even for more advanced procedures, such as pancreatectomy [3] and esophagectomy [4]. In this passage from laparoscopic surgery to robotic surgery, surgeons have attempted to reduce the number and size of ports used to limit destruction of the abdominal wall and obtain excellent cosmetic outcome, which has led to the development of reduced port laparoscopic surgery (RPS) and reduced port robotic surgery (RPRS). Since needle forceps emerged to limit damage to the abdominal wall and obtain excellent cosmetic outcomes in the late 1990s [5, 6], they have played an important role in RPS as minimal access devices [7]. Some randomized controlled trials have shown the clinical advantages of needle forceps [8, 9]. These studies reported that downsizing the trocar in laparoscopic cholecystectomy from 10 mm to needle instruments resulted in less postoperative pain. Although smaller instruments demonstrate better knot-tying and reduce the surgeon's workload in a restricted workspace simulating an infant body in an experimental setting [10], few experimental studies have evaluated the fineness and performance of needle forceps according to object size. Theoretically, smaller forceps should make handling smaller objects easier; hence, we conducted a series of experiments to compare needle forceps with conventional 5 mm forceps.

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Methods

Doctors were recruited as subjects from the Departments of Surgery, Urology, and Gynecology at Ishikawa Prefectural Central Hospital and Yokohama Sakae Kyosai Hospital. We could not identify the effect size needed to calculate the sample size based on the prior information about the parameters of interest because of the limited published data on this. Thus, the number of participants included in the study determined the study size. Each subject was asked about his or her postgraduate year and board certification status, including certification from the endoscopic surgical skill qualification system by the Japan Society for Endoscopic Surgery (JSES). The need for ethical approval for this study was waived by the Ethics Committee of the Ishikawa Prefectural Central Hospital and Yokohama Sakae Kyosai Hospital.

Subjects were given the following two tasks (Fig. 1) in a laparoscopic experimental setting (Fig. 2).

Task 1: Grasping and moving red beans and grains of rice (Fig. 3). Repeated twice.

Task 2: Suture and ligation using thread and needles with a 26 mm radius and a 17 mm radius (Fig. 4). Repeated twice.

Subjects executed these tasks in two different conditions (Fig. 5): One, using conventional 5 mm forceps [ENDOPATH™ 5DCD Maryland dissector (double action jaw, shaft length: 30 cm) and an ENDOPATH™ needle holder (shaft length: 30 cm), Ethicon Inc., New Jersey, United states]; and the other, using 2.1 mm small diameter forceps [BJ needle R™ forceps (single action jaw, shaft length: 31.5 cm) and a BJ pico™ needle holder (shaft length: 30 cm), NITI-ON Co., Ltd., Chiba, Japan]. The order of forceps tested was counterbalanced among the subjects to minimize order effects, such as fatigue and practice. Subjects stood in front of the laparoscopic trainer box and adjusted the angle of the scope to maximize comfort. Subjects used their nondominant arm for stability, but not to help them perform the test. The subjects were given 3 min of practice time before each condition and allowed to rest for short (30–60 s) periods between runs.

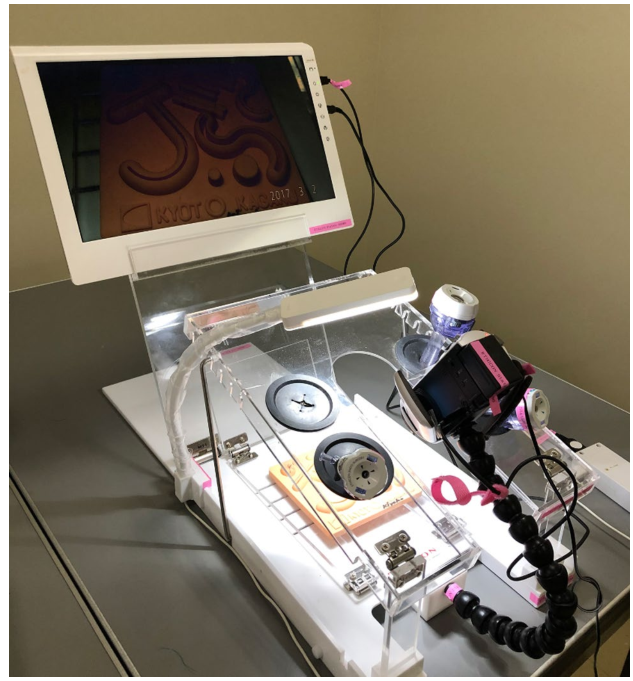

Fig. 2 Laparoscopic experimental setting. Subjects stood in front of the laparoscopic trainer box. The angle of the scope was adjusted by the subjects to maximize comfort

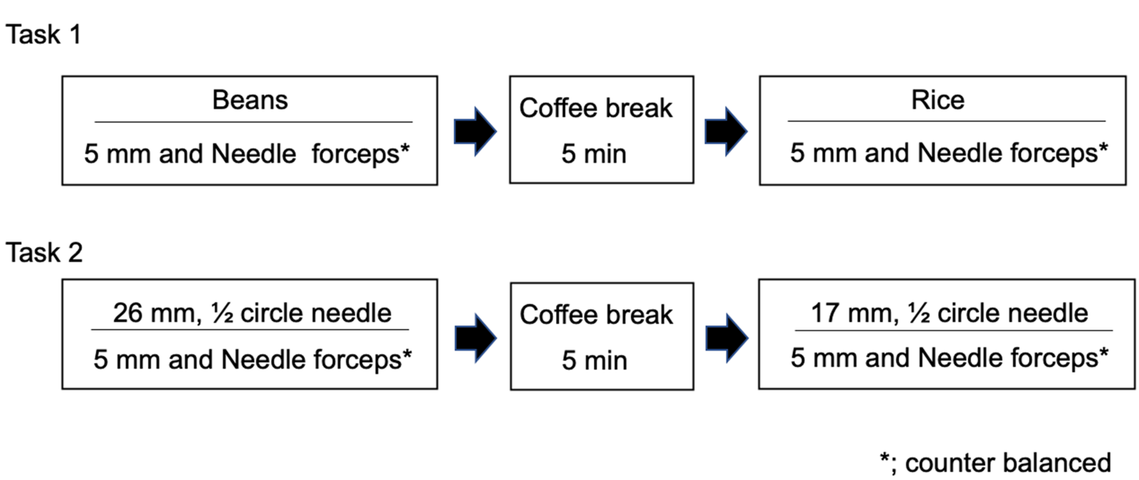

Fig. 1 Flow chart of experimental evaluation of the forceps. The order of forceps testing was counterbalanced among the subjects to minimize order effects

Fig. 3 Experimental setting of Task 1. Grasping and moving red beans and grains of rice

Fig. 4 Experimental setting of Task 2. Suture and ligation using 26 mm and 17 mm suture needles

Task 1 required the subjects to pick up 10 red beans or 10 grains of rice from a small paper dish and place them into another dish one by one. Grains dropped outside the dish were not allowed to be picked up again. In Task 2, subjects had to suture between two dots marked on different edges of a laparoscopic suturing practice pad (STPP06™, 3-Dmed Inc., Ohio, United States) and make one surgical square knot using the 26 mm and 17 mm suture needles. The distance between the dots was dependent on the size of the suture needles, with a 5 mm gap for the 26 mm suture needle and a 3 mm gap for the 17 mm suture needle.

Measurement and analysis items

For Task 1, we recorded the execution time and the number of drops. If the subject performed the task twice without any drops, this was evaluated as a completion. For Task 2, we recorded the execution time and deviation of the stitching point from the marked dots. The execution time started when the subject picked up the suture needle and ended when they finished tying the knot. The sum of the gaps between the tied thread and marked dots were calculated after finishing each run. If both edges of the suturing pad were adhered, the tightness of the knot was evaluated as secure.

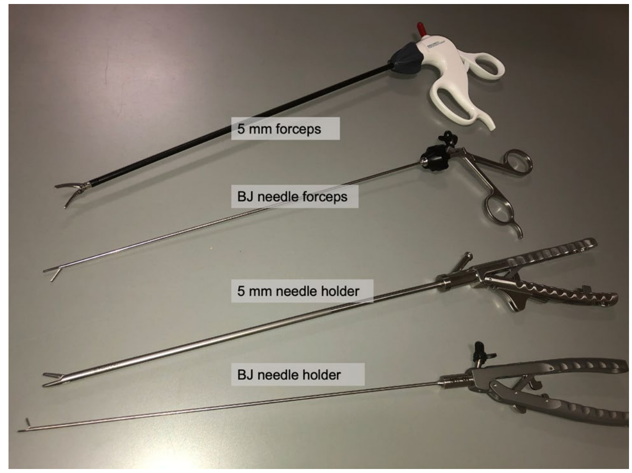

Fig. 5 Subjects executed Tasks 1 and 2 with 5 mm instruments and needle instruments

Statistical analysis

The Shapiro–Wilk test was used to verify whether the qualitative variables followed a normal distribution. Variables with a normal distribution are described as the mean and standard deviation (SD), and those with a non-normal distribution are described as the median and interquartile range (IQR). Student *t* tests or Mann–Whitney *U* tests were used to check independent means when the application conditions (normality and homoscedasticity) were not fulfilled. The paired Student's *t* test was used when the means were paired, and the Wilcoxon test was used when the conditions of applicability were not fulfilled. McNemar's test was performed to analyze the proportions of the paired data. $p < 0.05$ was considered statistically significant. All statistical analyses were performed with EZR (Saitama Medical Center, Jichi Medical University, Saitama, Japan) [11], which is a graphical user interface for R (The R Foundation for Statistical Computing, Vienna, Austria). More precisely, EZR is a modified version of the R commander designed to add statistical functions frequently used in biostatics.

Results

Twenty physicians were recruited as subjects and their number seemed to be acceptable for the experimental evaluation [12]. The study group included 15 surgeons, 4 gynecologists, and 1 urologist. The subjects consisted of 7 endoscopic surgical skill qualified physicians, 7 board certified physicians, and 6 residents in training. The mean duration since medical licensing was 9 (4.75–14) years. The study group comprised 19 men and 1 woman. Two of the seven endoscopic surgical skill qualified physicians had prior experience of using needle forceps in surgery. No subgroup comparisons were performed. All subjects executed both Task 1 and Task 2.

Task 1

Table 1 shows the results of Task 1. The mean execution time to move the rice grains with the needle forceps was 37.7 s (32.2–41.3 s), which was significantly shorter than that with the 5 mm forceps [45.8 s (40.7–51.2 s)] ($p=0.011$). The completion rate was also significantly higher with the needle forceps than with the 5 mm forceps, with 18 people (90.0%) vs. 4 people (20.0%), respectively, finished the task ($p=0.0005$). The mean execution time for moving the red beans with the needle forceps was 45.2 s (36.6–64.9 s). Although it took longer with the 5 mm forceps [40.3 s (34.7–47.0 s)], the difference was not significant ($p=0.057$).

Table 1 Task 1: grasping and moving red beans and rice grains

	5 mm forceps	Needle forceps	*p* value
Beans			
Completion rate, n (%)	5/20 (20%)	12/20 (60%)	0.046
Execution time, s	40.3 (34.7–47.0)	45.2 (36.6–64.9)	0.057
Rice grains			
Completion rate, n (%)	4/20 (20%)	18/20 (90%)	0.0005
Execution time, s	45.8 (40.7–51.2)	37.7 (32.2–41.3)	0.011

The completion rate of moving the red beans was higher with the needle forceps than with the 5 mm forceps ($p=0.046$).

Task 2

Table 2 shows the results of Task 2. The mean deviation of the stitching point with the needle forceps with a 17 mm needle was 0.5 (0–1) mm, which was significantly smaller than with the 5 mm forceps [1 (0.5–2) mm] ($p=0.009$). There was no difference in the execution time required for suture and ligation or the tightness of the knot. No significant differences were observed in the task when using the 26 mm needle for all evaluation items.

Discussion

Needle forceps with a diameter of 2.1 mm showed more accurate maneuverability for subtle tasks than 5 mm diameter forceps, without extending the operation time. To our knowledge, this is the first report of an experimental comparison of 2.1 mm diameter forceps and 5 mm forceps, although a previous study found that 3 mm instruments outperformed 5 mm instruments for a suture knot task with 5–0 polyglactin suture and other subtle tasks [13].

When designing this study, we assumed that 2.1 mm needle forceps would be better for smaller tasks whereas 5 mm forceps would be better for larger tasks. Thus, we prepared two different-sized objects per task to evaluate this. For the grasping task (Task 1), we chose beans as a suitable object for the 5 mm forceps, in accordance with the previous report [13], and rice grains as suitable object for the 2.1 mm forceps considering the size difference between the two forceps. For the suturing and knot-tying task (Task 2), a 26 mm suture needle was selected as the optimal size for the 5 mm forceps, because a 26 mm suture needle is commonly used for laparoscopic procedures like reconstruction after gastrectomy and peritoneal closure during hernia repair. A suitable suture needle for 2.1 mm forceps is considered to be a 17 mm suture needle, as used commonly in pediatric

Table 2 Task 2: suture and ligation using needle and thread

	5 mm forceps	Needle forceps	*p* value
26 mm suture needle			
Deviation of stitching point, mm	0.75 (0.5–1)	0.75 (0.38–1)	0.63
Tightness of knot, n (%)	9/20 (45%)	11/20 (55%)	0.72
Execution time, s	48.7 (39.7–58.5)	50 (37.5–64.9)	0.84
17 mm suture needle			
Deviation of stitching point, mm	1 (0.5–2)	0.5 (0–1)	0.009
Tightness of knot, n (%)	15/20 (75%)	13/20 (65%)	0.72
Execution time, s	51.8 (43.2–73)	55.8 (41.4–66)	0.43

surgery, bile duct reconstruction suturing, and other subtle procedures.

The needle forceps were better for subtle tasks, such as moving grains of rice and maneuvering small needles, but there was no or little difference when handling larger objects, such as moving beans and maneuvering large needles, which could be attributed to better visualization. In a limited working space, even a 5 mm shaft can obscure visualization and slow down the speed of detecting and grasping small objects (Fig. 6). For transanal endoscopic microsurgery (TEM), which requires surgeons to operate in a restricted working space, mini-instruments provided better visualization than 5 mm instruments [14]. Lee et al. reported that intracorporeal knot tying was faster in the neonatal simulator box using pediatric needle holders while maintaining knot quality [10]. They concluded small tips of the pediatric instruments occupy less space and allow better viewing. Better visualization within in a small space may have contributed to the superior results of the needle forceps with subtle objects. However, the needle forceps did not shorten the time for knot tying, unlike in the previous report [13]. This can be explained by the fact that accuracy was also evaluated in our study and subjects may have put emphasis not only on time but also on accurate maneuverability.

Restriction of the working angle and space are common problems in single-incision laparoscopic surgery (SILS) [15, 16]. Because needle forceps minimize surgical trauma and obtain excellent cosmetic outcomes, they are used not only for needlescopic surgery but also for SILS [17, 18] to improve the limited working angle. Although needle forceps are frequently used for RPS, including SILS and needlescopic surgery, they are not generally used in conventional laparoscopic surgery because of the drawbacks of the instruments, such as weak grasping power, small jaw size, and shaft rigidity. However, the new-generation needle forceps, including the BJ needle instruments™, have more reliable holding power and less bending of the shaft [19–21]. In the nonclinical setting of this study, the newly developed needle forceps maximized the performance of subtle tasks while being consistent with handling larger objects. In the clinical setting of uniportal video-assisted thoracoscopic surgery (VATS), the shaft of large forceps bends easily because of the ribs; however, the introduction of BJ needle™ forceps to assist facilitated the uniportal VATS to be performed efficiently and safely [22]. Now, we use these new generation needle instruments to perform laparoscopic surgery safely without compromising the advantage of less postoperative pain and early recovery. Procedures for which needle devices are appropriate include hernia repair [19, 23, 24], suturing of bile duct [25] and lymphadenectomy around nerve tissue that should be preserved [26, 27].

Needle instruments also help us to perform robotic surgery. Cundy et al. reported that in spatially constrained workspaces, 3-mm nonrobotic instruments are better suited for advanced bimanual operative tasks, such as suturing than 5- and 8-mm robotic instruments [28]. The da Vinci SP™ surgical system, a single-incision robotic surgery system, was invented to reduce destruction of the abdominal wall and enable intracorporeal triangulation through a single port at the umbilicus with three double-jointed instruments. Despite the excellent function of the arms, the working angle and space are still limited, and an additional assistant port could be inserted in difficult cases [29].

This study had some limitations. First, there was selection bias in the choice of devices. Although there are several small diameter forceps and 5 mm instruments, we chose the BJ needle instruments™ and Maryland forceps for the study. Every instrument has different jaw quality in its surface, size, and action. Unless we develop different size forceps with similar jaw quality for the experiment, we have to compare established products with different jaw quality. The 5 mm Maryland forceps we used in the study

Fig. 6 A 5 mm instrument (left) obscures visualization and slows down the detection and grasping of rice grains on a small dish compared with the 2.1 mm instrument (right)

had a double action jaw, whereas the 2.1 mm forceps we used in the experiments had a single action jaw. Since 5 mm Maryland forceps are frequently used for fine grasping in the clinical setting, we used it for the experiment. In theory, needlescopic instruments should have a double-action jaw in this comparison study, but there are no 2.1 mm instruments with a double-action jaw on the market. When we conduct our next experimental evaluation of these forceps, it would be favorable to use 5 mm forceps with a single-action mechanism to compare with 2.1 mm forceps, which all have a single-action jaw. The second limitation was related to the learning curve of using needle forceps. Except for two of the seven qualified physicians, the subjects had little experience using needle forceps in surgery. Because the task of moving grains and suturing task with 17 mm suture needles in a laparoscopic setting is unfamiliar work for physicians, we counterbalanced the order of the forceps used to minimize order effects. However, the several minutes allocated for practice were not enough to overcome the learning curve effect of needle forceps use. This might have led to an underestimation of the results of the needle forceps in this study. Surgeons of various skill level were included among the subjects and subgroup analysis was not designed in advance because the sample size of the study was too small, which was also a limitation of this study. All subjects performed the same task with 2.1 mm forceps and 5 mm forceps, but subject bias could not be avoided. If the participants were all experts or all novices such as medical students or interns, the forceps would have been evaluated more appropriately.

In conclusion, our study demonstrated that needle forceps are able to be used effectively for fine grasping operations and enabled more accurate small needle control than 5 mm forceps. This suggests that adding needle forceps to RPS is rational to maintain both surgical quality and minimal invasiveness.

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Data availability Raw data were generated at Ishikawa Prefectural Central Hospital and Yokohama Sakae Kyosai Hospital. Derived data supporting the findings of this study are available from the corresponding author (NI) on request.

Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

Informed consent Informed consent was obtained from all individual participants included in the study.

References

1. Bonjer HJ, Deijen CL, Abis GA, Cuesta MA, van der Pas MH, de Lange-de Klerk ES, et al. COLOR II study group. A randomized trial of laparoscopic versus open surgery for rectal cancer. N Engl J Med. 2015;372:1324–32.
2. Inaki N, Etoh T, Ohyama T, Uchiyama K, Katada N, Koeda K, et al. A multi-institutional, prospective, phase II feasibility study of laparoscopy-assisted distal gastrectomy with D2 lymph node dissection for locally advanced gastric cancer (JLSSG0901). World J Surg. 2015;39:2734–41.
3. Zureikat AH, Moser AJ, Boone BA, Bartlett DL, Zenati M, Zeh HJ 3rd. 250 robotic pancreatic resections: safety and feasibility. Ann Surg. 2013;258:554–9.
4. van der Sluis PC, Ruurda JP, Verhage RJ, van der Horst S, Haverkamp L, Siersema PD, et al. Oncologic long-term results of robot-assisted minimally invasive thoraco-laparoscopic esophagectomy with two-field lymphadenectomy for esophageal cancer. Ann Surg Oncol. 2015;22(3):S1350–6.
5. Watanabe Y, Sato M, Ueda S, Abe Y, Horiuchi A, Doi T, et al. Microlaparoscopic cholecystectomy—the first 20 cases: is it an alternative to conventional LC. Eur J Surg. 1998;164:623–5.
6. Gagner M, Garcia-Ruiz A. Technical aspects of minimally invasive abdominal surgery performed with needlescopic instruments. Surg Laparosc Endosc. 1998;8:171–9.
7. Inaki N. Reduced port laparoscopic gastrectomy: a review, techniques, and perspective. Asian J Endosc Surg. 2015;8:1–10.
8. Schmidt J, Sparenberg C, Fraunhofer S, Zirngibl H. Sympathetic nervous system activity during laparoscopic and needlescopic cholecystectomy. Surg Endosc. 2002;16:476–80.
9. Bisgaard T, Klarskov B, Trap R, Kehlet H, Rosenberg J. Microlaparoscopic vs conventional laparoscopic cholecystectomy: a prospective randomized double-blind trial. Surg Endosc. 2002;16:458–64.
10. Lee AC, Haddad MJ, Hanna GB. Influence of instrument size on endoscopic task performance in pediatric intracorporeal knot tying: smaller instruments are better in infants. Surg Endosc. 2007;21:2086–90.
11. Kanda Y. Investigation of the freely available easy-to-use software “EZR” (Easy R) for medical statistics. Bone Marrow Transplant. 2012;48:452–8.
12. Kondo A, Nishizawa Y, Horikiri Y, Amemori H, Tsukada Y, Sasaki T, et al. A novel device designed to improve the operability of energy devices with foot pedals in endoscopic surgery: the foot-site monitor. Surg Today. 2019;49:965–70.
13. Firme WA, Carvalho GL, Lima DL, Lopes VG, Montandon ID, Santos Filho F, et al. Low-friction minilaparoscopy outperforms regular 5-mm and 3-mm instruments for precise tasks. JSLS. 2015;19(e2015):00067.
14. Araujo SE, Mendes CR, Carvalho GL, Lyra M. Surgeons’ perceptions of transanal endoscopic microsurgery using minilaparoscopic instruments in a simulator: the thinner the better. Surg Endosc. 2015;29:2331–8.
15. Ishiyama Y, Inaki N, Bando H, Yamada T. Assessment of intracorporeal suturing in single-port surgery using an experimental suturing model. Indian J Surg. 2017;79:137–42.
16. Tang B, Hou S, Cuschieri SA. Ergonomics of and technologies for single-port laparoscopic surgery. Minim Invasive Ther Allied Technol. 2012;21:46–54.
17. Omori T, Oyama T, Akamatsu H, Tori M, Ueshima S, Nishida T. Transumbilical single-incision laparoscopic distal gastrectomy for early gastric cancer. Surg Endosc. 2011;25:2400–4.
18. Park DJ, Lee JH, Ahn SH, Eng AK, Kim HH. Single-port laparoscopic distal gastrectomy with D1+β lymph node dissection

for gastric cancers: report of 2 cases. Surg Laparosc Endosc Percutan Tech. 2012;22:e214–6.
19. Kanehira E, Tanida T, Kamei A, Nakagi M, Yoshida T, Touma S. Needlescopic intragastric surgery facilitated by newly developed 2 mm instruments. Minim Invasive Ther Allied Technol. 2016;25:210–4.
20. Kamei A, Kanehira E, Nakagi M, Tanida T. Development of scar-less laparoscopic hernia repair (TAPP-252) facilitated by new 2 mm instruments. Minim Invasive Ther Allied Technol. 2016;25:314–8.
21. Tagaya N, Kubota K. Reevaluation of needlescopic surgery. Surg Endosc. 2012;26:137–43.
22. Ko HJ, Chiang XH, Yang SM, Yang MC. Needlescopic-assisted thoracoscopic pulmonary anatomical lobectomy and segmentectomy for lung cancer: a bridge between multiportal and uniportal thoracoscopic surgery. Surg Today. 2019;49:49–55.
23. Wada H, Kimura T, Kawabe A, Sato M, Miyaki Y, Tochikubo J, et al. Laparoscopic transabdominal preperitoneal inguinal hernia repair using needlescopic instruments: a 15-year, single-center experience in 317 patients. Surg Endosc. 2012;26:1898–902.
24. Chan YW, Hollinsky C. Needlescopic surgery versus single-port laparoscopy for inguinal hernia. JSLS. 2015;19:e2015.00056.
25. Kim SJ, Kim KH, An CH, Kim JS. Innovative technique of needlescopic grasper-assisted single-incision laparoscopic common bile duct exploration: a comparative study. World J Gastroenterol. 2015;21:12857–64.
26. Ghezzi F, Cromi A, Uccella S, Bogani G, Sturla D, Serati M, et al. Nerve-sparing minilaparoscopic versus conventional laparoscopic radical hysterectomy plus systematic pelvic lymphadenectomy in cervical cancer patients. Surg Innov. 2013;20:493–501.
27. Tagaya N, Kubota K. Experience with endoscopic axillary lymphadenectomy using needlescopic instruments in patients with breast cancer: a preliminary report. Surg Endosc. 2002;16:307–9.
28. Cundy TP, Marcus HJ, Hughes-Hallett A, MacKinnon T, Najmaldin AS, Yang GZ, et al. Robotic versus non-robotic instruments in spatially constrained operating workspaces: a pre-clinical randomized crossover study. BJU Int. 2015;116:415–22.
29. Heo JE, Kang SK, Koh DH, Na JC, Lee YS, Han WK, et al. Pure single-site robot-assisted pyeloplasty with the da Vinci SP surgical system: initial experience. Investig Clin Urol. 2019;60:326–30.