Optimizing Laparoscopically Extracorporeal Knot Tying Using a Novel Pusher Device

Fung-Chao Tu, MD, Hsu-Dong Sun, MD,* Wan-Hua Ting, MD,**
Wen-Yih Wu, MD, Ho-Hsiung Lin, MD, PhD,*† and Sheng-Mou Hsiao, MD*†‡*

Abstract: The aim of this study was to evaluate the efficacy and feasibility of a novel pusher device for performing extracorporeal knot tying. Each of the 3 laparoscopists randomly performed 10 device-assisted double sheet bends (the device group), ten 4s modified Roeder sliding knots (the sliding group), and 10 laparoscopic traditional extracorporeal static surgeon's knots (the static group). All knots and 5 unknotted threads were measured for strength. The device group had higher knot strength, lower knotting failure rate, and shorter knotting time compared with the sliding group. The knot strengths of the successful knots in the device group were consistent with those obtained in the static group, and higher than the sliding group. Our laparoscopic novel pusher device should be an effective device in assisting knot tying with the advantages of steady and strong knot strength, lower failure rate, and shorter knotting time.

Key Words: gynecologic surgical procedures, minimally invasive surgical procedures, surgical procedures

(*Surg Laparosc Endosc Percutan Tech* 2017;27:e31–e35)

Conventional extracorporeal knotting methods, either static knots or sliding knots, have their advantages but exhibit some drawbacks.

On the basis of previous experiences in integrating intracorporeal suturing and knotting into a single procedure,[1,2] a novel pusher device was developed that may have many of the advantages of the current extracorporeal knotting methods such as the static knot and sliding knot. The present study aimed to evaluate the feasibility and efficacy of using this novel device to perform extracorporeal knotting.

MATERIALS AND METHODS

Our novel pusher device (patent pending) consisted of 2 components, including a working component and a pusher component (Fig. 1).

The working component included a small collar tubule (1.5 mm in diameter, 34 mm in length, Fig. 1A), which was inserted into a shorter outer sheath (2.6 mm in diameter, 23 mm in length, Fig. 1B). An excess of 2.5 mm of the small collar tubule was uncovered with the sheath.

The free end of a "0" coated silk thread with a needle was inserted into the small collar tubule (Fig. 1A), and the free end of the silk thread was hitched with a tiny metallic ring (Fig. 1C). We used the middle portion of the silk thread to construct a pretied 2-turn slip knot (Fig. 1D) at the uncovered portion of the small collar tubule and a small loop formation (Fig. 1E) at the rim of the tubule end.

The pusher component included a long sleeve (Fig. 1F), which functioned as an introducer with a grooved end and a holed round tip (Fig. 1G) for loading the working component and acting as a closed-end–type pusher. The other end of the pusher component included a large tube handle (Fig. 1H), which was equipped with a control button (Fig. 1I). The button can slide over the calibrated groove (Fig. 1J) to control the movement of the pretied slip knot (Fig. 1D) of the working component by a metallic wire (Fig. 1K) between the working and pusher components.

The steps for performing laparoscopic knotting using the novel device are described in the legend of Figure 2 and short video clips (Supplementary Video, Supplemental Digital Content 1, http://links.lww.com/SLE/A149).

We used a laparoscopic trainer (LiNA Laparo Trainer; Lina Medical, Glostrup, Denmark) as an experimental model. It consisted of an erect metallic rectangular plate ($75 \times 15 \times 2\,mm^3$) fixed on a board that was fastened to the bottom of the trainer. Two vinyl-coated screws (10 mm in diameter, 35 mm in length) were mounted on top and were 25 mm apart from the positions of the plate (Fig. 3A). Knots were tied around the 2 screws as shown in Figure 3A. The laparoscopic double sheet bends made using the novel

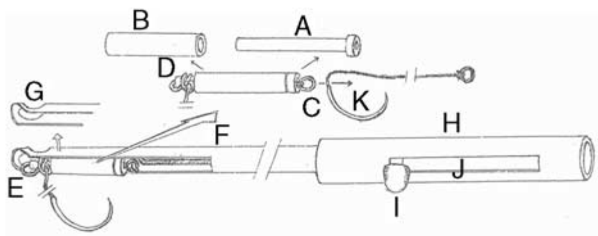

FIGURE 1. Components of the novel pusher device: collar tubule (A); outer sheath (B); tiny metallic ring (C); pretied 2-turn slip knot (D); loop formation (E); sleeve (F); hole in the round tip (G); handle (H); control button (I); groove for sliding button (J); metallic wire (K).

Received for publication February 26, 2017; accepted March 12, 2017.
From the *Department of Obstetrics and Gynecology, Far Eastern Memorial Hospital, Banqiao, New Taipei; †Department of Obstetrics and Gynecology, National Taiwan University College of Medicine and National Taiwan University Hospital, Taipei; and ‡Graduate School of Biotechnology and Bioengineering, Yuan Ze University, Taoyuan, Taiwan.
The authors declare no conflicts of interest.
Reprints: Sheng-Mou Hsiao, MD, Department of Obstetrics and Gynecology, Far Eastern Memorial Hospital, No. 21, Sec. 2, Nanya South Road, Banqiao District, New Taipei City, 220, Taiwan (e-mail: smhsiao2@gmail.com).
Supplemental Digital Content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Website, www.surgical-laparoscopy.com.

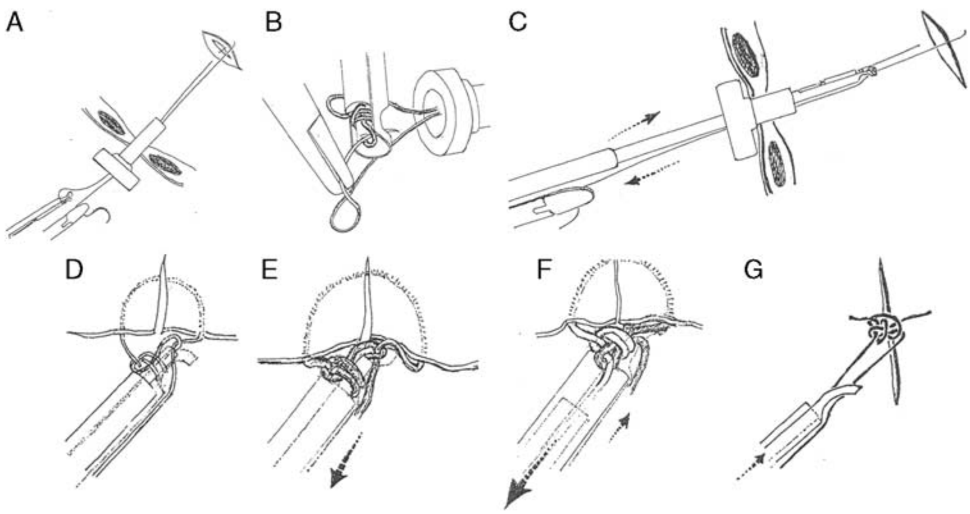

FIGURE 2. The serial steps for performing the laparoscopic knotting by the novel pusher device: the thread attached needle is pulled out by a needle holder (A); the needle is passed through the loop of a pretied 2-turn slip knot and the adjacent hole at the tip of the pusher device concomitantly (B); the pusher device is inserted into the trocar and down onto the wound, and the needle-attached thread is pulled out simultaneously (C); this diagram emphasizes the interwoven geometric structure of the 2-turn slip knot and the suture loop before tightening of the knot (D); the thread is pulled to tighten the suture loop to an appropriate tension and then keep it steady (E); the control button is forcefully pushed to withdraw the tubule and to release the tension applied on the thread simultaneously, and the pretied 2-turn slip knot is dislodged and automatically converted into a double sheet bend (F); the control button is pulled and the pusher device is withdrawn slightly (G). Thus, both short segments of the thread are exposed from the end of the pusher device, and this allows both segments of the thread to be cut using a laparoscopic scissor.

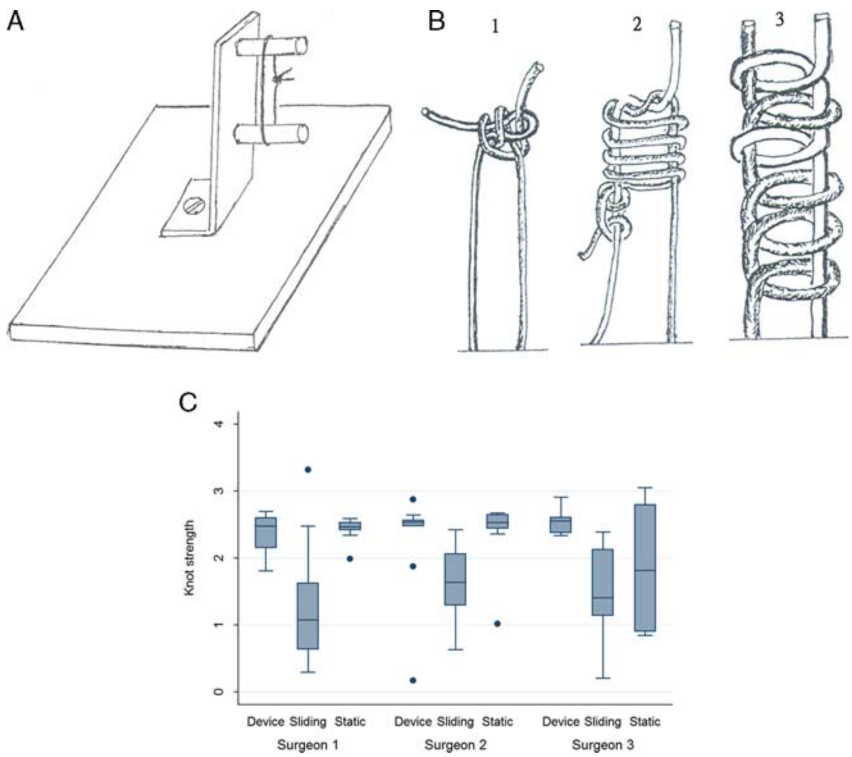

FIGURE 3. A, An erect metallic rectangular plate with 2 vinyl-coated screws. B, Double sheet bend (left) for the device group, 4s modified Roeder sliding knot (middle) for the sliding group, and static surgeon's knot (right) for the static group. C, Knot strengths among different surgeons and groups.

Copyright © 2017 Wolters Kluwer Health, Inc. All rights reserved.

TABLE 1. Comparisons of Suturing and Knot Tying Variables Between the Device and the Control Groups (the Sliding Knot and the Static Surgeon's Knot) for Each Surgeon

	Surgeon 1				Surgeon 2	
Variables	Device (a)	Sliding (b)	Static (c)	P*	Device (d)	Sliding (e)
KS (kg)	2.4 ± 0.3	1.3 ± 0.9	2.4 ± 0.2	< 0.001	2.3 ± 0.8	1.6 ± 0.5
KF (n)	0 (0)	5 (50)	0 (0)	0.005	1 (10)	1 (10)
SKT (s)	35 ± 9	105 ± 15	111 ± 13	< 0.001	27 ± 7	64 ± 10
KS of SK	2.4 ± 0.3	2.0 ± 0.9	2.4 ± 0.2	0.18	2.5 ± 0.3	1.7 ± 0.4
KE of SK	0.54 ± 0.07	0.45 ± 0.20	0.55 ± 0.04	0.18	0.57 ± 0.06	0.40 ± 0.10
CV (%) of SK	12.1	45.1	7.0		10.6	25.4

Values are expressed as mean ± SD, n (percentage), or percentage.
*ANOVA test with the Bonferroni correction or the Fisher exact test (only the device group's comparisons and significant results were shown).
KS: a versus b, $P = 0.001$; g versus h, $P = 0.003$.
KF: a versus b, $P = 0.03$.
SKT: a versus b or c; d versus e or f; and g versus h or i, all $P < 0.001$.
KS of SK: d versus e, $P < 0.001$; g versus h, $P = 0.001$.
ANOVA indicates analysis of variance; CV, coefficient of variation; KE, knot efficiency; KF, knot failure; KS, knot strength; SK, successful knots; SKT, suturing/knotting time.

device (the device group, Fig. 3B), the 4s modified Roeder knots (the sliding group, Fig. 3B), and the conventional extracorporeal static surgeon's knots (the static group, Fig. 3B) [using 1/2 circular 30-mm needles with wax-treated, braided, size 0 silk threads (Unik Surgical Sutures Mfg. Co., New Taipei, Taiwan)] were performed in a randomized order on the basis of computer-generated random numbers. Three surgeons tied the knots. The least experienced laparoscopist was surgeon 3, and the most experienced laparoscopist was surgeon 1. The knotting time was calculated from the beginning of the knot tying to the end of the knot tying.

The loops of the knotted threads were cut and removed from the training box after the completion of knot tying. Both the nonloop ends of the threads were trimmed to 3 mm in length, and the knot strength was measured using a tensiometer (Gotech Testing Machines Inc., Taichung, Taiwan). Gradual increasing force was applied to one loop end of the knotted thread or to one end of the unknotted threads after fixation of the other end.[3] The knot strength was determined as the force required for the knot to slip or break.[3–5] The thread strengths of the 5 unknotted threads were also measured. Knot failure was defined as a breach of the knot or slippage exceeding 3 mm.[3] Knot efficiency was defined as the knot strength divided by the mean thread strength of unknotted threads. The coefficient of variation (%) of the knots was defined as the SD of the knot strength divided by the mean strength of the knot.

Tera and Aberg[4] used a sample size of 5, with a power of 0.8 and a significance level of 0.05, to detect an ∼0.8 kg difference in mean strength. Thus, we tied at least 5 knots in each group to determine the differences in knot strength between the groups.

The STATA software program (Version 11.0; Stata Corp., College Station, TX) was used for the statistical analyses. The Wilcoxon rank-sum test or the Fisher exact test was used, as appropriate. A $P < 0.05$ was considered statistically significant.

RESULTS

Three surgeons tied 10 knots in the device group, 10 knots in the sliding group, and 10 knots in the static group. All knots and 5 unknotted threads were measured for strength (Table 1). The mean unknotted thread strength was 4.41 ± 0.49 kgw.

The knot strength of the device group was higher compared with the sliding group for surgeons 1 and 3 (Fig. 3C); the knot failure rate of the device group was

TABLE 2. Comparisons of Suturing and Knot Tying Variables Between the Device and Control Groups

Variables	Device (a)	Sliding (b)	Static (c)	P*	Post Hoc Test*
KS (kg)	2.4 ± 0.5	1.5 ± 0.7	2.2 ± 0.6	< 0.001	a vs. b, $P < 0.001$
KF (n)	1	8	4	0.04	a vs. b, $P = 0.03$
SKT (s)	27 ± 9	74 ± 27	81 ± 24	< 0.001	a vs. b, $P < 0.001$ a vs. c, $P < 0.001$
KS of SK	2.5 ± 0.3	1.8 ± 0.6	2.4 ± 0.4	< 0.001	a vs. b, $P < 0.001$
KE of SK	0.56 ± 0.06	0.40 ± 0.13	0.55 ± 0.09	< 0.001	a vs. b, $P < 0.001$ b vs. c, $P < 0.001$
CV (%) of SK	10.1	31.9	16.0		

Values are expressed as mean ± SD, n (percentage), or percentage.
*ANOVA test with the Bonferroni correction or the Fisher exact test (only the device group's comparisons and significant results are shown).
ANOVA indicates analysis of variance; CV, coefficient of variation; KE, knot efficiency; KF, knot failure; KS, knot strength; SK, successful knots; SKT, suturing/knotting time.

Copyright © 2017 Wolters Kluwer Health, Inc. All rights reserved.

TABLE 1. (*continued*)

Surgeon 2		Surgeon 3			
Static (f)	***P****	**Device (g)**	**Sliding (h)**	**Static (i)**	***P****
2.4 ± 0.5	0.02	2.5 ± 0.2	1.5 ± 0.7	1.9 ± 0.9	0.003
1 (10)	1.00	0 (0)	2 (20)	3 (30)	0.32
63 ± 7	< 0.001	22 ± 2	52 ± 14	69 ± 8	< 0.001
2.5 ± 0.1	< 0.001	2.5 ± 0.2	1.7 ± 0.5	2.3 ± 0.7	0.004
0.58 ± 0.02	< 0.001	0.58 ± 0.04	0.38 ± 0.11	0.52 ± 0.16	0.004
4.3		7.0	29.0	31.7	

lower for surgeon 1, and the knotting time of the device group was lower for all 3 surgeons.

For successful knots, the knot strength and knot efficiency of the device group did not differ from that in the static group for all 3 surgeons, but it was higher than that in the sliding group for surgeons 2 and 3 (Table 1). The coefficient of variation of successful knots in the device group was lower than that in the sliding group for surgeons 1, 2, and 3 (Table 1).

Taken together, the device group had higher knot strength, lower knotting failure rate, and shorter knotting time, compared with the sliding group (Table 2). The knot strengths of the successful knots in the device group were consistent with those obtained in the static group and higher than those in the sliding group (Table 2).

DISCUSSION

In our study, a double sheet bend was produced with the help of a novel pusher device. The knot strength of the device group was comparable with the static group, but exhibited a shorter knotting time. A static surgeon's extracorporeal knot is considered to be the best knot with a good balance between loop security and knot security.[1,3] However, it requires multiple passages of the knot pusher through a trocar sleeve and may cause leakage of the pneumoperitoneum, loosening of the loop before the second half hitch is seated on it, twisting of the threads, or premature release of the pusher from the thread.

To overcome these shortcomings, many surgeons prefer the laparoscopic sliding knot because it can be tied extracorporeally, and it only requires a single pass of the knot pusher through the trocar sleeve while working. The 4s modified Roeder knot is a sliding knot with a knot strength that is comparable with the 4-throw laparoscopic square knot.[4] Nevertheless, sliding knots are inherently weaker than static surgeon's knots. Our study also showed that the 4s modified Roeder sliding knot (ie, the sliding group) demonstrated moderate knot strength and was weaker than that in both the static group and the device group (Table 1).

The knotting time in the device group was shorter than that in the sliding and the static groups. The basic knotting mechanism and working process of our pusher device-assisted knot tying are different from that of current laparoscopic extracorporeal knotting techniques, for either the static or sliding knots. The shorter knotting time in the device group may be due to the waive time that is required to perform multiple steps in conventional knot tying.

Our device-assisted knotting is an easy procedure. The key procedure in our device-assisted knotting is to only pass the needle through the loop of the pretied 2-turn slip knot and the adjacent hole of the device.

In this study, the double sheet bend (ie, the device group) has strong and steady knot strength (Table 2). The basic mechanism for our novel device is to produce an in situ knot transformation. Traction force in the device results in the conversion of a pretied 2-turn slip knot into a steady double sheet bend.[5–7] Thus, the strong and steady knot strength of our double sheet bend should be related to its device-generated nature.

In addition, we can form variable diameters of a secure loop using our novel device. A secure loop without tension is important for some surgical procedures such as laparoscopic Burch colposuspension,[8] ovarian suspension,[9] liver retraction,[10,11] gastric banding[12,] or single-incision laparoscopic surgery.[12,13] Thus, this novel device may have potential clinical implications in the above surgical procedures.

The limitation of this study is that the knots were performed in the laparoscopic training box. Further in vivo studies may be performed to confirm its advantages.

In conclusion, the novel laparoscopic pusher device has the advantages of steady and strong knot strength, low failure rate, and short knotting time.

REFERENCES

1. Tu FC, Wu WY, Lin HH, et al. Laparoscopic intracorporeal knot tying using a novel device. *Surg Endosc*. 2012;26:872–876.
2. Tu FC, Sun HD, Chuang YC, et al. Integrating laparoscopic intracorporeal suturing and knot tying into a single procedure using a novel knotting device. *J Am Coll Surg*. 2015;220:e1–e5.
3. Trimbos JB. Security of various knots commonly used in surgical practice. *Obstet Gynecol*. 1984;64:274–280.
4. Tera H, Aberg C. Strength of knots in surgery in relation to type of knot, type of suture material and dimension of suture thread. *Acta Chir Scand*. 1977;143:75–83.

Copyright © 2017 Wolters Kluwer Health, Inc. All rights reserved.

5. Tera H, Aberg C. Tensile strengths of twelve types of knot employed in surgery, using different suture materials. *Acta Chir Scand*. 1976;142:1–7.
6. Mackenzie MW. Laparoscopic intracorporeal cinch knots: changing the square knot paradigm. *J Minim Invasive Gynecol*. 2012;19:225–235.
7. Dorsey JH, Sharp HT, Chovan JD, et al. Laparoscopic knot strength: a comparison with conventional knots. *Obstet Gynecol*. 1995;86:536–540.
8. Kent A, Jan H, Shakir F. Technical video: modified laparoscopic colposuspension. *J Minim Invasive Gynecol*. 2014;21:980.
9. Paradisi R, Fabbri R, Magnani V, et al. A new simple technique of laparoscopic temporary ovarian suspension in addition to ovarian cryopreservation for women prior to posterior pelvic radiation. *Gynecol Oncol*. 2010;117:385–386.
10. Woo Y, Hyung WJ, Kim HI, et al. Minimizing hepatic trauma with a novel liver retraction method: a simple liver suspension using gauze suture. *Surg Endosc*. 2011;25: 3939–3945.
11. Zachariah SK, Tai CM, Chang PC, et al. The "T-suspension tape" for liver and gallbladder retraction in bariatric surgery: feasibility, technique, and initial experience. *J Laparoendosc Adv Surg Tech A*. 2013;23:311–315.
12. Huang CK, Lin YH, Huang HP, et al. Single-incision transumbilical laparoscopic adjustable gastric banding: a novel minimally invasive surgical technique. *Surg Laparosc Endosc Percutan Tech*. 2010;20:e99–e102.
13. Chung do Y. The intracorporeal knot tying using rigid instruments in single-incision laparoscopic surgery. *Surg Laparosc Endosc Percutan Tech*. 2013;23:e90–e92.

Copyright © 2017 Wolters Kluwer Health, Inc. All rights reserved.