

Laparoendoscopic single-site simple nephrectomy using a magnetic anchoring system in a porcine model

Young Hyo Choi¹, Hye Won Lee¹, Seo Yeon Lee², Deok Hyun Han¹, Seong Il Seo¹, Seong Soo Jeon¹, Hyun Moo Lee¹, Han Yong Choi¹, Byong Chang Jeong¹

¹Department of Urology, Samsung Medical Center, Sungkyunkwan University School of Medicine, Seoul, ²Department of Urology, Myongji Hospital, Kwandong University College of Medicine, Goyang, Korea

Purpose: Magnetic anchoring devices may reduce the number of port sites needed in laparoscopic surgery. In this study, we prospectively assessed the feasibility of using a magnetic anchoring and guidance system (MAGS) in laparoendoscopic single-site (LESS) surgery performed by novices.

Materials and Methods: A total of 10 LESS simple nephrectomies were performed with or without MAGS in a nonsurvival porcine model by 6 operators with no previous LESS surgery experience. After installation of the homemade single port, an intra-abdominal magnet was fixed to the renal parenchyma with suturing and stabilized by an external magnet placed on the flank so that the position of the kidney could be easily changed by moving the external handheld magnet. The length of the procedure and any intraoperative complications were evaluated.

Results: Operative time (mean±standard deviation) was shorter in the group using the magnetic anchoring device (M-LESS-N) than in the group with conventional LESS nephrectomy (C-LESS-N) (63±20.8 minutes vs. 82±40.7 minutes, respectively). Although all nephrectomies were completed uneventfully in the M-LESS-N group, renal vein injury occurred during dissection of the renal hilum in two cases of C-LESS-N and was resolved by simultaneous transection of the renal artery and vein with an Endo-GIA stapler.

Conclusions: LESS-N using MAGS is a feasible technique for surgeons with no LESS surgery experience. Taking into account the 2 cases of renal vein injury in the C-LESS-N group, the application of MAGS may be beneficial for overcoming the learning curve of LESS surgery.

Keywords: Laparoscopy; Minimally invasive surgical procedures; Nephrectomy

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INTRODUCTION

Conventional laparoscopic surgery requires the placement of multiple ports through the abdominal wall, with the aims

of maintaining adequate internal spacing of instruments to reduce clashing and facilitating tissue manipulation for dissection [1]. These multiple transabdominal punctures are associated with morbidity and risks such as herniation,

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Corresponding Author: Byong Chang Jeong

Department of Urology, Samsung Medical Center, Sungkyunkwan University School of Medicine, 81 Irwon-ro, Gangnam-gu, Seoul 06351, Korea
TEL: +82-2-3410-3557, FAX: +82-2-3410-6992, E-mail: bc2.jung@samsung.com

bleeding, and damage to internal organs, as well as decreased cosmesis [1]. Laparoendoscopic single-site (LESS) surgery has been developed to overcome the port-related complications of laparoscopic surgery, to minimize morbidity, and to maximize cosmetic outcome. LESS surgery is performed through a single keyhole incision, typically at the umbilicus, allowing the completion of several urologic procedures with the use of familiar laparoscopic instruments and skills [2-9]. Since Raman et al. [5] first reported LESS nephrectomy (LESS-N) in 2007, subsequent studies have demonstrated that LESS-N is safe and feasible with outcomes equivalent to those of conventional laparoscopic nephrectomy for both benign and malignant kidney diseases [6-8]. The skill of surgeons at high-volume surgery centers has now reached a sufficient level such that LESS partial nephrectomy of small selected renal masses yields results comparable to those of conventional partial nephrectomy [9].

However, the passage of all of the instruments through a single access point promotes instrument clashing and maneuverability problems, loss of triangulation, and unfamiliar working angles, even for surgeons skilled at LESS surgeries, and these limitations have prevented these procedures from entering mainstream clinical practice [1]. Furthermore, when the need for bleeding control, increased traction, or a suture arises, it can become necessary to apply an additional port or convert to conventional laparoscopy. These limitations are encountered not only by novices but also by experienced surgeons during complicated or difficult cases. To facilitate LESS techniques and overcome the learning curve for novices, magnetic anchoring and guidance systems (MAGSs) have been explored. These devices harness magnetic forces to steer and operate completely insertable intracorporeal instruments via externally controlled magnets [1]. The devices are typically inserted through an already established entry site into the peritoneal cavity and are then coupled via magnetic attraction across the body wall to a handheld external component. By moving the external component around on the patient's abdominal wall, the internal device can be steered to the location appropriate for surgery [10-12]. The aim of this study was to investigate the feasibility and safety of MAGS for surgeons performing LESS-N for the first time in a porcine model.

MATERIALS AND METHODS

In this prospective study we compared the perioperative outcomes of simple LESS-N with or without the use of a magnetic anchoring device. A total of 10 LESS-N procedures were performed on five 23-month-old female pigs weighing

Table 1. Comparison of perioperative outcomes between conventional LESS surgery and LESS surgery using a magnetic anchoring device

Operator	No magnetic anchoring			Magnetic anchoring					
	Laparoscopic surgery experience	Main operative time (min)	Complication	Operator	Laparoscopic surgery experience	Main operative time (min)	Time for internal magnetic device placement (min)	Total operative time (min)	Complication
A	Novice	114	-	A	Novice	58	15	73	-
B	Novice	NA (53)	Renal vein injury ^a	B	Novice	95	20	115	-
C	Novice	95	-	C	Novice	45	7	52	-
D	Expert	36	-	D	Expert	46	10	56	-
E	Novice	NA (65)	Renal vein injury ^a	E	Novice	71	18	89	-
Operative time (min), mean (SD)		82 (40.7) ^b				63 (20.8)	14 (5.4)	77 (25.8)	

^a:The procedure could not be continued owing to uncontrollable bleeding. The renal artery and vein were transected simultaneously with an Endo-GIA stapler (Medtronic, Minneapolis, MN, USA).

^b:Analyzed after excluding cases B and E.

LESS, laparoendoscopic single-site; NA, not applicable.

approximately 50 kg. All animal experiments were approved by the Institutional Review Board of Samsung Medical Center (Seoul, Korea) and were conducted in accordance with the National Institutes of Health Guide for the Care and Use of Laboratory Animals. The surgeons were 6 urologists working in the Samsung Medical Center as fellowship trainees, including five participants with no prior experience with conventional laparoscopic and LESS surgery and one experienced laparoscopic surgeon with no prior LESS surgery experience (Table 1). Four of the surgeons performed simple LESS-N with and without the magnetic anchoring devices in the nonsurvival porcine model with procedures occurring at least 2 weeks apart.

The pig was placed under general anesthesia and positioned obliquely on the table (semilateral position). A homemade single-port device was inserted transperitoneally (Fig. 1). The Alex wound retractor was inserted through the 2- to 2.5-cm incision site made at the midline. The homemade single-port device was constructed by first cutting the tips off the 1st, 3rd, and 5th fingers of a size 6½ surgical glove. Two 10-mm trocars were placed in the 3rd and 5th finger openings, respectively, and one 5-mm trocar was placed in the 1st finger opening. The trocars were secured with 1-0 silk or a rubber band tie. The glove was then fixed to the outer ring of the wound retractor. After establishing pneumoperitoneum (controlled at less than 14 mmHg), long, rigid 5-mm laparoscopes were used to obtain a view of the operative field through the 3rd finger 10-mm trocar of the homemade port. Six pieces of a cylindrical shaped neodymium internal magnet with a central hole (outer diameter, 5 mm; thickness, 5 mm; weight, 0.69 g; diameter of central hole, 1 mm) were then fixed to the renal parenchyma with a 1-0 Vicryl suture (Ethicon, Somerville, NJ, USA) (Fig. 2B). A cube-shaped external handheld magnet (width, 74 mm; length, 74 mm; height, 38 mm; weight, 1,543 g) was applied to the flank of the pig (Fig. 2A). The kidney was dragged to

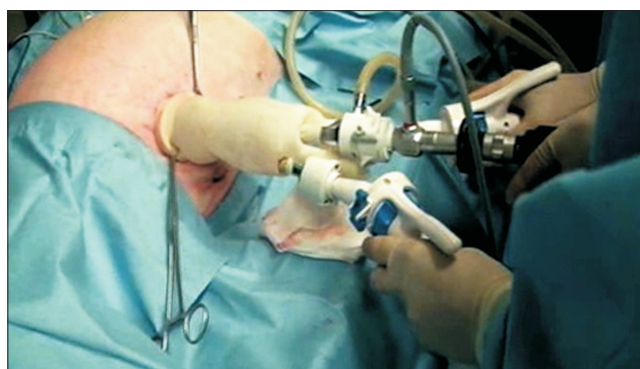


Fig. 1. Homemade single port device.

the body wall where the external magnet was located. The position of the kidney could then be changed depending on the position of the external magnet (Fig. 3; Supplementary video clip). Specialized articulating instruments (Laparo Angle; Cambridge Endo, Framingham, MA, USA) were used for most of the dissection and traction maneuvers. Standard laparoscopic instruments such as a hook cautery, straight dissector, and straight scissors were also used. The surgical procedure was similar to that of a simple conventional laparoscopic transperitoneal nephrectomy in humans. After division of the renal artery and vein, the artery was clipped with a Hem-o-Lok clip (Teleflex Medical, Wayne, PA, USA) and then transected. The renal vein was subsequently transected with a vascular Endo-GIA stapler (Medtronic, Minneapolis, MN, USA). The ureter was also clipped with a Hem-o-Lok clip and divided.

Procedure duration was regarded as the intracorporeal time, not including the time required for port placement, magnetic anchoring device placement, specimen retrieval, and wound closure. Conversion to laparoscopy or any additional port placement was not permitted. All operations were observed by a urologist who recorded the procedure duration and any intraoperative complications.

RESULTS

The mean time to complete the operation (\pm standard deviation) with the magnetic anchoring device (the M-LESS-N group) was 63 ± 20.8 minutes (range, 45–95 minutes), which was shorter than that for surgery without the magnetic device (the C-LESS-N group; mean, 82 ± 40.7 minutes; range, 36–114 minutes) (Table 1). Among four surgeons who performed two simple LESS-N procedures with and without the aid of MAGS, 3 surgeons who had no prior laparoscopic experience first performed the surgery without MAGS and then used MAGS in subsequent procedures (Table 1). The other operator, who was an

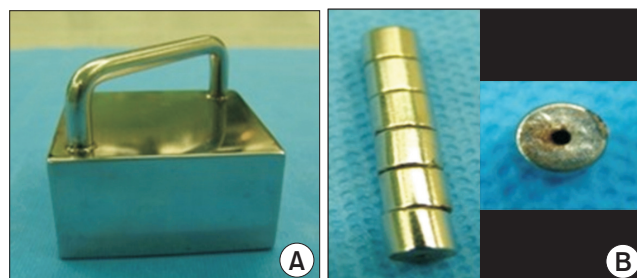


Fig. 2. Magnetic anchoring and guidance system. (A) External handheld magnet. (B) Internal magnet with central hole.

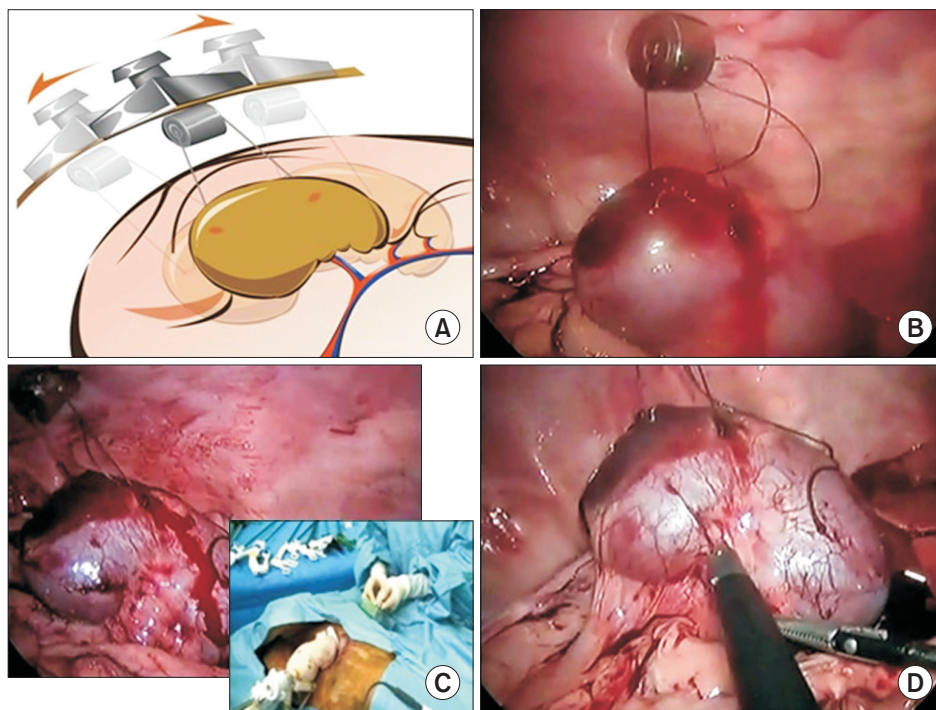


Fig. 3. Laparoendoscopic single-site-simple nephrectomy with magnetic anchoring and guidance system (MAGS) platform. (A) Schematic representation of MAGS platform. (B) Internal magnet with central hole was fixed to kidney with suturing. (C) Kidney being retracted by the paired magnetic intraluminal device and external magnet. (D) The renal hilum is dissected with the aid of MAGS. Scan this QR code to see the accompanying video, or visit www.icurology.org or <https://youtu.be/Pb46-HIINuE>.

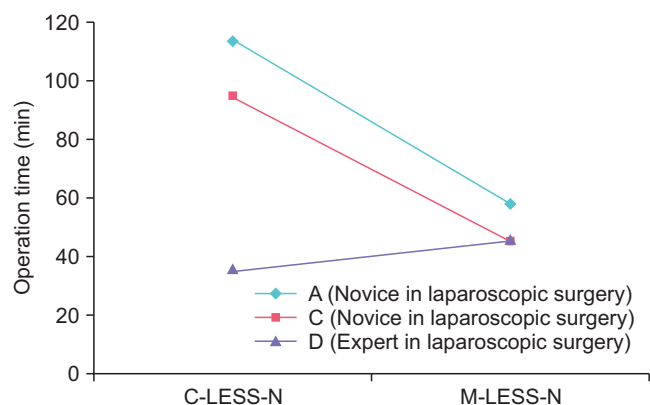


Fig. 4. Comparison of times for LESS-simple nephrectomy depending on MAGS platform performed by same surgeon. LESS, laparoendoscopic single-site; MAGS, magnetic anchoring and guidance system; C-LESS-N, LESS nephrectomy without MAGS; M-LESS-N, LESS nephrectomy with MAGS.

experienced laparoscopic surgeon but had no prior LESS surgery experience, initially used MAGS but did not use it in the subsequent surgery (Table 1). A remarkable decrease in the duration of the procedure was observed with the aid of MAGS for the 2 surgeons who were novices in laparoscopic surgeries, whereas there was no significant improvement in procedure duration for the surgeon who was an expert in laparoscopic surgeries (Fig. 4).

All M-LESS-N procedures were uneventful and were completed with no need to convert to open surgery and no need to add a second port. Intraoperative complications

were observed in the C-LESS-N group only, in which there were 2 cases of renal vein injury during dissection of the renal hilum. The surgeons were unable to control the bleeding because the blood loss was rapid and they lacked the required skills. In these cases it was so difficult for the operators to continue the procedure that they decided to transect the renal artery and renal vein together without dissection by using a vascular Endo-GIA stapler. Interestingly, 1 surgeon who experienced renal hilar injury during a C-LESS-N procedure completed the operation successfully using MAGS (Table 1).

DISCUSSION

Since the first laparoscopic nephrectomy was performed by Clayman et al. [13] in 1991, variations of this surgery have been performed with laparoscopic techniques. Recently, LESS surgery was devised as an alternative to conventional laparoscopy. High-volume surgery centers have reported on their experiences performing nephrectomies, adrenalectomies, pyeloplasties, and nephroureterectomies with the LESS technique [2,3,14-16]. Even though these surgeons had experience with laparoscopic surgery, some cases of LESS surgery needed an additional port. These additional ports can cause bleeding, internal organ damage, or postoperative pain and hernia, thereby diminishing the cosmetic benefit and minimizing the value of the LESS surgery. Therefore, an improved modality is required for

this surgical technique to be universally applied.

To this end, magnetic devices that can aid the surgery without requiring additional skin incisions were designed. Magnetically anchored technology is a way to minimize the number of incisions needed to operate while increasing the degree of triangulation compared to standard single-incision surgeries [1]. The Cadeddu group demonstrated the feasibility of MAGS for LESS-N in the porcine model [10,11]. In addition, they reported a redesigned MAGS camera that provides improved optics and easy maneuverability during LESS porcine nephrectomy [17]. The MAGS camera allows the use of standard rigid, straight laparoscopic instruments, rather than the articulating or curved ones commonly used during complex LESS operations. The initial results of human trials using a magnetically guided intra-abdominal camera in conjunction with LESS-N and LESS appendectomy were reported to be successful [18]. MAGS camera technology significantly decreases the surgeon workload and improves ergonomics, although suturing and knot-tying during LESS surgery remain challenging tasks that require training [12]. Additionally, the use of magnetic forceps resulted in no intraoperative complications in 40 reported cases of human LESS cholecystectomy [19]. In addition to the development of novel devices, MAGS is also being utilized in broader applications and in a greater number of surgical fields, including natural orifice transluminal endoscopic surgery [20,21].

Our study showed shorter procedure durations with use of the magnetic anchoring device compared with surgery without the device. Complications requiring early clipping of the pedicle without dissection occurred in the group without the magnetic anchoring device. With use of the magnetic anchoring device, the kidney could be dragged to the abdominal wall and the pedicle could be straightened for easy division. The shorter procedure duration and fewer hilar complications observed in the group using the magnetic anchoring device support adoption of this methodology for nephrectomies. These findings are consistent with findings from previous reports of the use of magnetic devices in LESS-N in which surgeries were completed successfully without any intraoperative complications, although the authors of one study noted that they experienced decoupling in one human case [11,18].

There are some differences between this study and previously reported studies. First, the surgeons in this study had no previous experience with performing LESS surgery. Second, the magnetic device used was different. In our study, we simply used the magnetic force between the internal and external magnets to pull the kidney, whereas

the device used in the previous porcine or human model procedures contained retractors, a magnetic camera, and a robotic cauterizer. Third, the surgical procedure differed. We dissected the pedicle and clipped the renal artery and vein separately, whereas in other studies the artery and vein were transected together with the vascular Endo-GIA stapler. Although hilar complications were observed in this study, they would not have happened without hilar dissection, which was unique to this study. Despite these differences, the results of our study are consistent with those of previous studies and indicate that use of magnetic devices in these types of operations is feasible with minimal complications. In our study, 2 surgeons who initially operated without the magnetic device exhibited a remarkable reduction in procedure duration for the second surgery using MAGS. These surgeons may have benefitted from the assistance of the magnetic anchoring device in the second surgery. Additionally, because they struggled harder and took a longer time to complete the first LESS-N, the long intraoperative time may have allowed them to practice and learn the skills required to shorten the second operation time. One surgeon exhibited the opposite trend: the duration of the second procedure was longer than that of the first. In this case, the pedicle was ligated early with the Endo-GIA stapler because of renal vein injury inflicted during the hilar dissection in the first operation. Therefore, the surgeon had a shorter time to practice and the initial operative time was underestimated. As a result, it took longer to complete the second surgery with the magnetic anchoring device. In contrast, a reduction in the time to perform LESS-N using MAGS was not observed in the procedures performed by the experienced laparoscopic surgeon.

There were some limitations to this study. Because it was a pilot study, the number of surgeries was too small to yield statistically reliable data. Second, postoperative complications were not evaluated because we sacrificed the porcine models after surgery. We did not evaluate postoperative complications because the primary focus of the experimental design was to compare the intraoperative variables of surgery aided by the magnetic devices versus the conventional LESS surgery. Third, 4 surgeons performed LESS-N both with and without the magnetic anchoring device. The purpose of this study was to compare LESS-N with our magnetic anchoring system versus the conventional procedure. However, surgical skills could be improved by any prior LESS surgery and might have influenced the duration of the second procedure. Therefore, comparisons between the group that used the magnetic anchoring device and the group that did not might not be reliable, even though

an interval of at least 2 weeks between the surgeries was implemented to minimize this factor.

CONCLUSIONS

In conclusion, LESS-N using a magnetic anchoring device is feasible and can be safely performed by surgeons with no previous LESS surgery experience. Judging from 2 cases of renal vein injury and the slightly longer procedure duration in the group without the magnetic anchoring device, it can be suggested that the device may help novices performing LESS surgery dissect the renal hilum more easily.

CONFLICTS OF INTEREST

The authors have nothing to disclose.

SUPPLEMENTARY MATERIALS

Accompanying videos can be found in the 'Urology in Motion' section of the journal homepage (www.icurology.org). The supplementary video clips can also be accessed by scanning a QR code located on the Fig. 3 of this article, or be available on YouTube (<https://youtu.be/Pb46-HIINuE>).

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