# Visual exposure using single-handed magnet-driven intra-abdominal wireless camera in minimal access surgery

## Is better than 30° endoscope

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**Abstract**

*Background* The operative field of view in minimal access surgery is constrained by the location of the optical port, the direction of view of the endoscope, and the limited degrees of freedom of movement of rigid endoscopes through the access port. The aim of this study was to examine the feasibility of employing a special magnetic setup with a single external handle to fixate, drive, and orientate intra-abdominal wireless camera, and compare its visual exposure with that of a 30° endoscope.

*Methods* A wireless magnet-driven camera setup was developed comprising a mini wireless camera with integrated white light-emitting diodes, a specially constructed base unit for orientation control and smooth sliding motion, and an external magnetic handle to fixate and drive the camera from the outer surface of the abdominal wall. In a laboratory-based experiment, ten subjects with no laparoscopic surgical experience were asked to identify 160 randomly distributed labels in a trainer box using both a 30° endoscope and the wireless camera magnetic setup in a random order. Data were analyzed using Student's *t*-test.

*Results* The mean (standard deviation) of the number of identified labels was higher using the wireless camera magnetic setup 74.8 (16.96) compared with 30° endoscope 54.7 (12.18); $p < 0.001$. However, the mean execution time was longer with the camera magnetic system 34.9 (4.4) min compared with the 30° endoscope 24.1 (2.8) min; $p < 0.001$.

*Conclusion* The use of the magnetic wireless camera setup with a single external handle is feasible and has demonstrated a wider visual exposure than the 30° endoscope.

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The standard video endoscopic system in minimal access surgery consists of a rigid endoscope coupled with an extracorporeal video-camera. The movement of the rigid endoscope through the access port has four degrees of freedom of movement. This restricted movement results in a limited field of endoscopic view. The direction of view of rigid endoscopes (angle between the optical axis and physical axis) determines the ability to inspect areas at different angles. Rotation of angled endoscopes provides a different perspective of the operative field and hence 30° or 45° endoscopes are preferred in advanced minimal access surgery.

Intracorporeal mini-cameras have been introduced in order to overcome the kinematic restrictions of access ports and to improve the visualization of the operative field. Several approaches have been adopted to drive intracorporeal cameras. The first approach is the chip-on-stick technology, where the camera is mounted on a flexible tip of the rigid endoscope to provide two additional degrees of freedom of movement [1]. However this technology has proved no better than the standard 30° rigid endoscope [2]. Another approach utilized miniature camera robots. A pan-and-tilt camera robot provided visual assistance in conjunction with standard endoscopes [3]. Also, a wheeled mobile adjustable-focus camera has been used to provide the sole visual feedback. Two motors independently control each wheel providing the robot with forward, reverse, and turning capabilities to swivel over abdominal organs [4–6]. A successful laparoscopic peg cholecystectomy was performed with this robotic camera system. The third approach employed the power of external magnets to drive

a wired camera that slides on the internal surface of abdominal wall. The assistant surgeon manipulates a pair of external magnets to orientate the camera horizontally, and by either pushing the external magnets apart or together, the surgeon would be able to actively point the camera lens upward or downward. A successful peg nephrectomy was carried out using this system [7]. Nevertheless, there have been no reports on the evaluation of the second and third approaches against the standard rigid endoscopes.

In this study we developed a magnet-driven, intra-abdominal wireless camera unit with an integrated light source and one external magnetic handle. The multidirectional visual recognition feedback of the system was compared against standard 30° rigid endoscope in a laboratory-based experiment.

## Materials and methods

### Magnet-driven camera unit

The setup is composed of a wireless camera system, a camera base, and an external magnetic handle (Fig. 1).

### Wireless camera system

The wireless miniature camera system consisted of a small wireless color pinhole camera (MC; KGB Cameras, UK), a microwave tuner, a high-functionality thin-film transistor (TFT), and a color 15" liquid-crystal display (LCD)
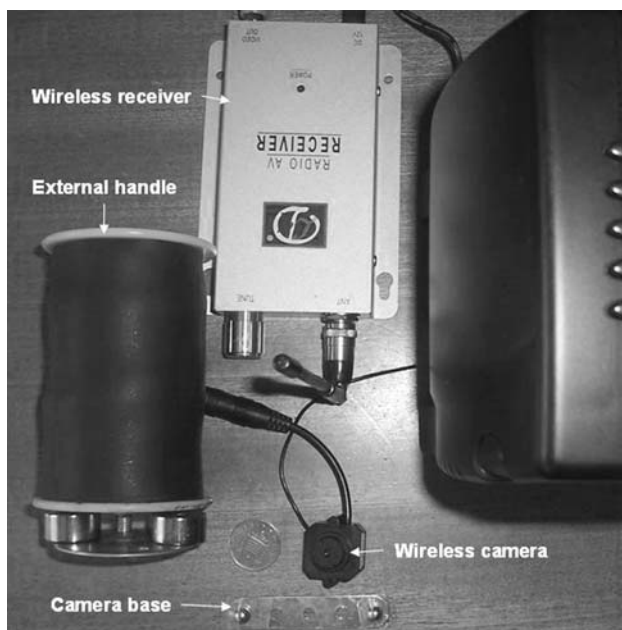


**Fig. 1** Wireless camera setup showing the external handle with two magnets at the bottom, the camera base with two small magnets attached, the wireless camera, wireless receiver, and the super VGA box

monitor (Dell, Dell Inc, Bracknell, UK). The wireless camera is 19 × 19 × 14 mm in size, weighing 22 g. It has a phase alternating line (PAL) 628 × 582 video output, high resolution 380 lines, 1 LUX, adjustable focal lens, and can be operated with battery or mains power (9 V). The microwave frequency used is 1.2 GHz and has minimal influence on medical electronic equipment. The built-in transmitter has a range of approximately 100 m, which is powerful enough to ensure that image quality is not reduced throughout. The camera was incorporated with white light-emitting diode (LED) as a light source. The output of the wireless receiver had a composite-video output which does not match the S-video input of the monitor and therefore a Super VGA Box 2 was connected to the composite-video output to give an S-video output.

### Camera base

The objective of constructing the camera base was to minimize friction when sliding on the internal surface of the artificial abdominal wall, and to facilitate orientation control by external magnets. The base consisted of a longitudinal plate of 62 mm length, 12 mm width, and 1 mm thickness. Two spherical neodymium magnets 6 mm in diameter (Shop4-Tools, Sheffield, UK) were attached to the upper surface of the plate, near to its ends. One magnet was placed exposing its north pole, and the other exposing its south pole. These alternate poles would couple with the two corresponding alternate pole magnets of the external handle. In a pilot study it was found that using alternate poles improved the movement and orientation control of the camera because both the repellant and attracting forces of the external magnets contribute to moving the base. This approach also minimized the jumps that might happen if both internal magnets expose the same pole and are attracted to both external ones (Fig. 2). A layer of adhesive tape was used to surround the flat plate and fasten the two spherical magnets in their alternate poles. This also further smoothes the sliding movement.
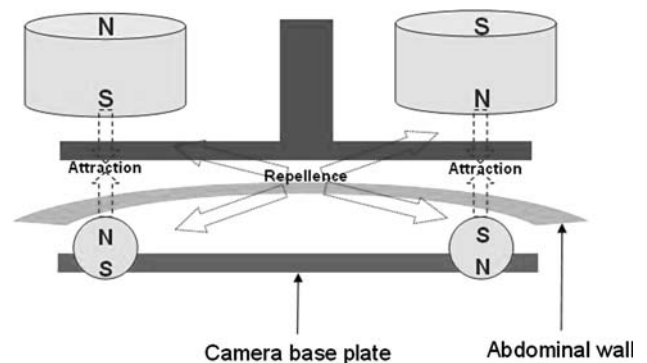


**Fig. 2** Illustration of the magnetic forces involved in driving the camera

*External magnetic handle*

Two powerful neodymium magnets (Shop4Tools, Sheffield, UK) with identical size [20-mm-diameter face × 10 mm magnetic length (axis), and 5.2 mm countersunk hole] but different polarity were placed on a flat metallic plate and oriented so that one had its north pole and the other its south pole facing down. The flat plate holding the two magnets together was fitted into a lightweight cylindrical piece for ease of handling.

### Subjects

Ten novice surgeons with no laparoscopic surgical experience (house officers and senior house officers) were invited to participate in the study. This level of skill ensured that there is no bias towards one method compared to the other.

### Task

One hundred and sixty numbered labels were randomly placed on all sides and directions of a maze that was constructed using Lego. The model maze was positioned inside a specially designed trainer box with a top surface that simulates the curvature of the inflated adult abdomen (Fig. 3). The model was taped down to maintain the same position for each participant. Each participant was asked to identify as many labels as possible.

### Procedure

Verbal and written instructions were given to all participants. Each subject had 5 min training with the 30° endoscope and another 5 min to use the magnet-driven camera across the participant's hand and across the neoprene cover of the trainer box. Each participant performed the task with both methods (Fig. 4). The order of method allocation was in a random sequence. Subjects were asked
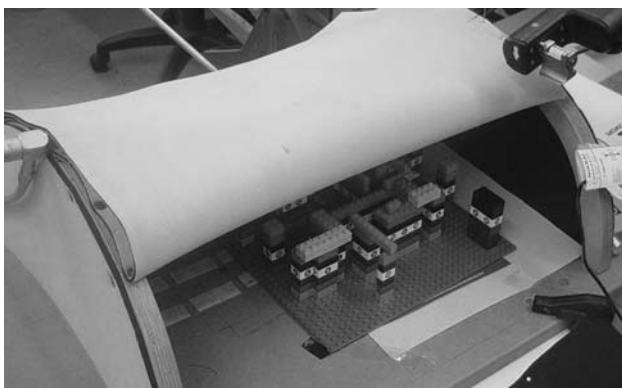


**Fig. 3** Construction with random numbers in a special trainer box

to call out the numbers of the labels as they identify them. The numbers were recorded by an observer. During the procedure they were permitted to move slightly on either side of the trainer box but they were not permitted to step around it. For each method a maximum time limit of 40 min was imposed.

### Video-endoscopic equipment and control measures

A video-endoscopic training stack was used consisted of an 18" flat surgical display (National display systems, CA, USA) with an adjustable-arm, arc-lamp source (Xenon nova, model 20131520, Karl Storz, Germany) and digital camera system (Image 1, model 22200020, Karl Storz). The intensity of the light source was fixed for all participants.

## Results

All tasks were completed within the 40 min time limit. All participants identified more labels using the magnetic camera setup than using the 30° endoscope (Fig. 5). Twenty-five labels were not identified by any of the two methods while 15 labels were only identified by the magnet-driven camera and six labels by the endoscope. The mean (standard deviation) of labels identified using the magnetic camera setup was 74.8 (16.96) compared to 54.7 (12.18) using the 30° endoscope ($p < 0.001$, paired $t$-test). The execution time was longer with the magnet-driven setup compared to with the 30° endoscope with a mean (standard deviation) of 34.9 (4.4) min versus 24.1 (2.8) min, respectively ($p < 0.001$, paired $t$-test). On average, the magnetic coupling with the camera failed twice during each task and the observer had to recouple it for the participant. Time spent during recoupling was included in the total task time.

## Discussion

In this study, a wireless magnet-driven camera system has been developed, consisting of a mini wireless camera with integrated white light-emitting diodes, a specially constructed base unit for orientation control and smooth sliding motion, and an external magnetic handle to fixate and drive the camera from the outer surface of the abdominal wall. In a laboratory-based experiment, this system was found to have a wider visual exposure than the 30° endoscope.

Magnets have been used in dentistry for many years, most commonly to aid the retention of dentures and overdentures [8, 9]. In orthodontics they have been used in both research and clinical practice, particularly in the treatment
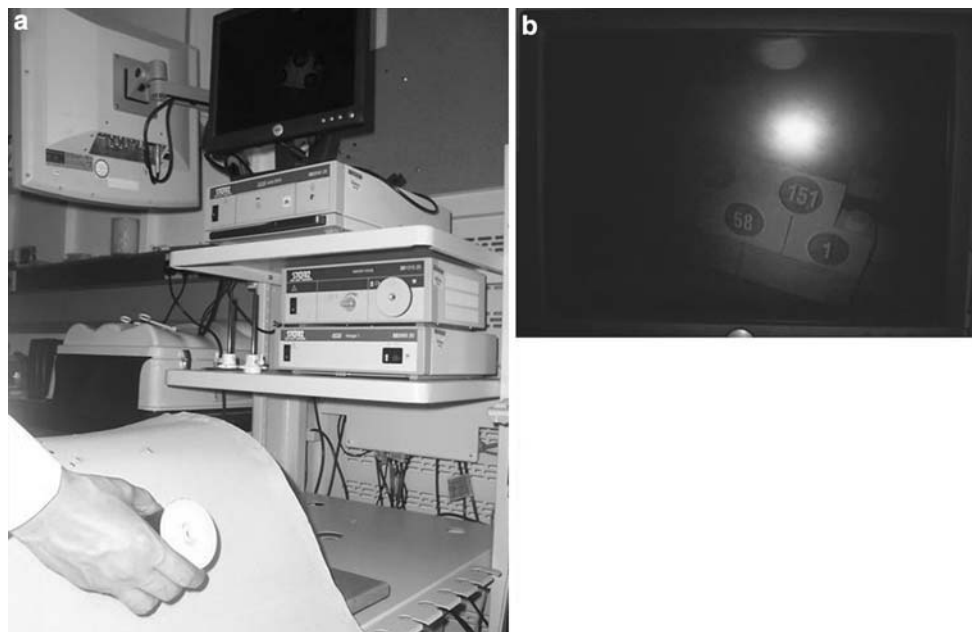
**Fig. 4** (**a**) The magnet-driven camera in action. (**b**) A close screenshot of the LCD screen, the light source is two small LEDs
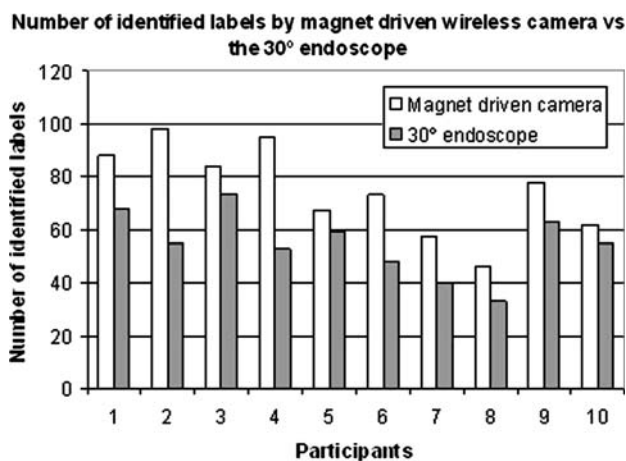


**Fig. 5** The number of labels identified by the participants

of unerupted teeth [10], for tooth movement along arch-wires [11], and expansion [12]. Recently, magnets have been introduced into clinical surgery to move catheters in brain surgery in order to control their placement in previously unreachable areas. Chin et al. reported the use of magnets to retrieve a foreign metallic body from the neck [13]. In laparoscopic surgery, magnet positioning systems for laparoscopic instruments have been proposed to allow unrestricted movement in the abdomen [7]. Magnets have several advantages over human manual manipulation. They are able to produce a measured force continuously over long periods of time. The force can be directed and exerted through mucosa and bone without direct contact. Also, they can be made to attract or repel, and therefore to push or pull.

Cameras with wireless technology on the other hand are progressively advancing towards further miniaturization and higher image quality. This has been triggered by an expanding market for mobile phone technology and sophisticated surveillance devices. In medicine, Pillcam [14] was a novel technique using small, capsule-sized, wireless camera to detect esophageal pathologies. It showed the potential of using wireless video technology in medicine. Similarly a robot for intestinal inspection with a locomotion mechanism which is capable of feedback of temperature, pH, and pressure is under development [15]. Miniature cameras, transmitters, and receivers are now capable of transmitting high-quality images, although their effect on laparoscopic performance has not yet been studied.

In this laboratory-based experiment, all participants identified more labels using the magnet-driven camera system compared with 30° endoscope. The longer execution time when using the magnet system indicates the complexity in driving the magnet-controlled camera compared with the simple movement of rigid endoscopes. Nevertheless, the proposed wireless magnet-driven system has the advantage of easier orientation with the use of one external handle compared with the two-handle control system [7] where the participant has to use both hands in a careful and delicate manner. The integration of LEDs into the camera unit allowed the identification of labels in narrow areas where an external light would be less likely to reach. Also, the base of the camera allows easy movement of the camera over the abdominal wall. This design of the wireless camera unit can be improved by employing a high-quality camera designed for endoscopic surgery rather

than the commercial surveillance camera used in the experiments. In terms of zooming functionality, contemporary mini wireless cameras are produced with exceedingly higher resolution. This allows for the use of digital zooming rather than optical zooming and hence does not require a larger camera. However, digital zooming comes at the expense of image quality and therefore further work needs to be carried out to establish the optimum, safe minimum resolution required for clinical purposes. As technology progresses, no doubt optical zoom will eventually be available as is the case in the latest mobile phone cameras. The power supply can be provided by watch battery to create a totally wireless system. The selection of the wireless camera used in this experiment was constrained by a combination of size, weight, and cost, and was acceptable as long as it can be controlled by the external magnetic handle. Smaller, yet more expensive, cameras with an integrated LED light source are increasingly available for use in mobile phones and are expected to produce better results. Differences in thickness of the abdominal wall between different individuals and between different abdominal sections can be overcome by the use of adjustable electric magnets.

The clinical use of such proposed system requires a fail-safe design. There is a need to study the magnet forces used in driving the camera to ensure no tissue damage occurs when the wireless camera is accidentally moved to a narrow space. Also, another imaging source should be available to recouple the camera in case of magnet failure.

In principle, the inflated abdomen with its dome-shaped ceiling requires more innovative visual techniques than the use of long endoscopes designed to visualize luminal structures in gynecology, urology, and gastroenterology. Multiple miniature wireless cameras can be introduced through one port and attached to the dome-shaped ceiling of the abdominal cavity using external magnets to provide multiple angular views. Image mosaicking [16, 17] can then be used to construct a single panoramic view of the operative area which minimizes out-of-view manipulations. Multiple views can also be used to construct a three-dimensional image [18].

We would like to empathize that the current study was designed to demonstrate the ergonomic advantage of using a magnet-driven wireless camera unit over the standard angled endoscope. Therefore, the experimental design used novice subjects to laparoscopic surgery in order to eliminate the bias towards using the endoscope and hence did not demonstrate the benefit of the proposed system for experienced surgeons in clinical practice. Testing the proposed system in a clinical environment by experienced surgeons will be the subject for future research after further development of the system. Also, with a more advanced system, clinical experiments will be required to study the optimum camera base design which results in the most favorable sliding performance on the peritoneal surface of the abdomen.

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