Received: 27 November 2018 | Revised: 12 September 2019 | Accepted: 11 October 2019
DOI: 10.1002/rcs.2050

ORIGINAL ARTICLE

The International Journal of Medical Robotics and Computer Assisted Surgery
WILEY

A novel hybrid 3D endoscope zooming and repositioning system: Design and feasibility study

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Abstract

Background: Manipulation of the endoscope during minimally invasive surgery is a major source of inconvenience and discomfort. This report elucidates the architecture of a novel one-hand controlled endoscope positioning device and presents a practicability evaluation.

Methods and materials: Setup time and total surgery time, number and duration of the manipulations, side effects of three-dimensional (3D) imaging, and ergonomic complaints were assessed by three surgeons during cadaveric and in vivo porcine trials.

Results: Setup was accomplished in an average (SD) of 230 (120) seconds. The manipulation time was 3.87 (1.77) seconds for angular movements and 0.83 (0.24) seconds for zooming, with an average (SD) of 30.5 (16.3) manipulations per procedure. No side effects of 3D imaging or ergonomic complaints were reported.

Conclusions: The integration of an active zoom into a passive endoscope holder delivers a convenient synergy between a human and a machine-controlled holding device. It is shown to be safe, simple, and intuitive to use and allows unrestrained autonomic control of the endoscope by the surgeon.

KEYWORDS
endoscope positioner, minimally invasive surgery, solo surgery, surgical assistant

1 | INTRODUCTION

The first laparoscopic cholecystectomy in 1985 heralded the arrival of minimally invasive surgery (MIS).[1] The ability to perform surgical procedures, compared with traditional open surgery, through only small incisions offers considerable benefits. Nowadays, MIS gains an increasingly important role in most surgical disciplines, and new applications are reported periodically.[2] Technological advancements such as articulated endoscopic instruments, ultra-high-definition endoscopes, and advanced three-dimensional (3D) videoscopy have further improved MIS techniques over the last years, enhancing the dexterity and precision of the surgeon.[3-6] Meanwhile, manipulation of the endoscope during conventional MIS has known little advancements since its introduction and is still encountered by surgeons as a major obstacle during surgery.[7,8] The surgeon is hereby limited to the control of two instruments and has to entrust the manipulation of the endoscope and other instruments to assistants, which has several drawbacks. The indirect control over the endoscope through communication with the assistant is unintuitive and discursive, may lead to frustrations and conflicts, and impairs the surgeon's depth perception

This study was not presented at any meeting nor supported by an agency.

and eye-hand coordination, which affects efficiency and quality of the procedure.[9,10] Not only is holding the endoscope a semi-static and fatiguing task resulting in involuntary movements of the endoscope over time, but it is also substantially time-consuming and can be associated with higher personnel costs.[11-13] Furthermore, especially during 3D endoscopy, rapid and unstable movements of the endoscope may induce more side effects, such as nausea and fatigue.[14] The use of an endoscope holding device has the potential to reduce these side effects and improve ergonomics of the primary surgeon and assistants, allowing them to perform more complex and lengthy procedures with ease. Finally, the need for manual assistance in a confined space may restrict the surgeon's freedom of movement. In this article, we propose a new, compact and single-hand controlled endoscope holder to overcome some of the former described difficulties. Two highly advantageous features were integrated into a single architecture: A passive endoscope positioning system was combined with an active zoom function. A preliminary porcine and cadaveric study using 3D endoscopy was performed. The aim of this report is to elucidate the architecture of an advanced prototype endoscope positioning device and to assess its feasibility, functionality, and ergonomics in clinical circumstances.

2 | MATERIALS AND METHODS

The evaluation of the new endoscope holder was carried out in a series of simulations. To assess feasibility, a team of experienced MIS surgeons performed different laparoscopic procedures (n = 3): a rectopexy (a) and abdominal wall hernia repair (b) during an in vivo porcine trial and another rectopexy (c) during a cadaveric trial. Each procedure was performed by another skilled surgeon. A full HD Image 1S 3D endoscopic system (Karl Storz, Tuttlingen, Germany) was used during all the interventions. Prior to the evaluation, the functionality of the endoscope holder was explained and demonstrated using phantom models. All procedures were recorded using a MediCap USB200 Medical Video Recorder (MediCapture Inc, Philadelphia, USA). Setup time, total surgery time, and the number and duration of the endoscopic manipulations were measured. Endoscopic manipulations were defined as any angular or longitudinal movement of the endoscope or the combination of both. Revisions of the endoscopic ports needed during the procedures were also registered. Afterwards, all surgeons (n = 3) were asked to evaluate their experiences with the endoscope holding system by means of a questionnaire: ease of manipulation of the assembly (easy, acceptable, demanding, and unsuitable); the perception of nausea, dizziness, and fatigue as side effects of 3D imaging (none, somewhat, considerably, and intolerable); and ergonomic complaints due to the use of the positioning device (none, somewhat, considerably, and intolerable).

3 | RESULTS

The holding device consists of four main components: a connector (Figure 1 (1)), enabling the attachment of the endoscope to a positioning device such as a mechanical articulated arm; a ball-and-socket joint assembly (Figure 1 (2)), allowing directional movement of the endoscope; and a friction-based locking mechanism, applying friction to the joint ball and thus fixating the joint assembly and a motorized slidable clamp (Figure 1 (4)), allowing movement of the endoscope along a longitudinal axis of the device (zooming in or out). The device comprises a ball-and-socket joint assembly and establishes a center-of-motion corresponding with the center of the joint ball. By placing the ball joint near the entrance point of the trocar (Figure 1 (7)), a fixed rotation point is established, and tangential forces applied to the abdominal wall are minimized. A locking mechanism enables fixation of the endoscope in a certain position. It comprises a lever (Figure 1 (3)) that, when actuated, releases the ball-and-socket joint, which allows frictionless repositioning of the endoscope (Figure 1 (9)). The lever can be actuated by placing the thumb on its distal end while still firmly supporting the positioning system, as illustrated in

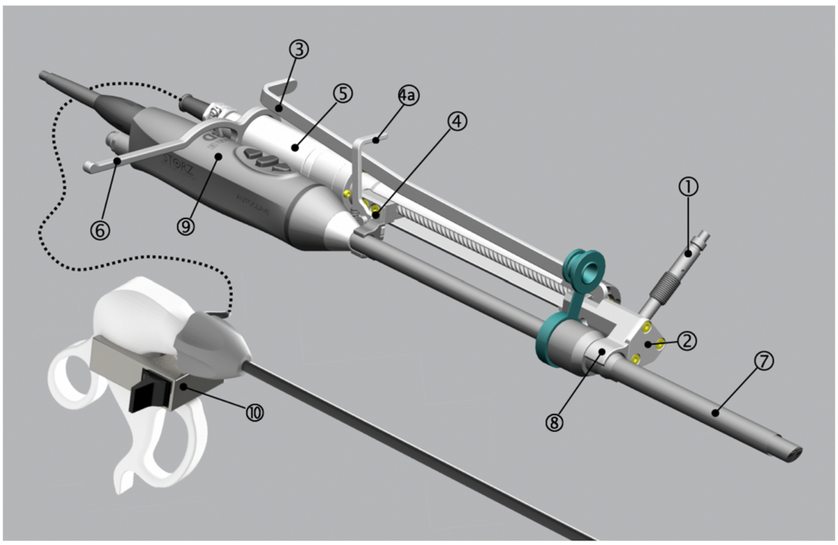

FIGURE 1 An overview of the endoscope positioning system, which comprises a connector (1) for an articulated arm, a lockable ball-and-socket joint (2) controlled by a lever (3), a slideable clamp (4), an electromotor (5), and an instrument support (6). The positioning system is connected to the trocar (7) by means of a docking system (8). A slideable clamp (4), which can be actuated by a separate lever (4a), fixates the endoscope (9). The zoom function is controlled by a toggle switch (10), attached to a laparoscopic instrument

Figure 2C. Situating the proximal end of the lever near the proximal end of the holding device (Figure 1 (5)) not only amplifies actuation forces of the lever but also enables the surgeon to manipulate the lever and reposition the endoscope single handedly. An additional instrument support (Figure 1 (6)) permits the surgeon to release one of his or her instruments during repositioning of the endoscope without needing an assistant. After the trocar is inserted through the abdominal wall, it is connected to the positioning system by means of an intuitive docking system (Figure 1 (8)). This provides a reversible but firm connection. Fixating the trocar directly to the positioning system results in a second fixation point for the positioning system, without the endoscope itself being part of this connection. This "bridge" between the patient and the endoscope positioning system is maintained during the whole procedure, enhancing the stability of the system, even when the endoscope is removed to clean the lens, for example. The endoscope is then fixed in a slideable clamp, which permits intuitive longitudinal shift (zooming) by an electronic toggle switch (Figure 1 (10)). The switch can be connected to the handle of any laparoscopic instrument (eg, a laparoscopic grasper). A notably unique advantage of this attribute is that it allows the surgeon to not only zoom in or out using only one finger without the need to release one of his instruments but also perform angular movements simultaneously.

3.1 | Experimental evaluation

The setup time, total surgery time, adverse events, port revisions (ie, number of times that the trocar for the endoscope has to be reinserted), and side effects due to 3D vision for each procedure are presented in Table 1. During the procedures, an articulated arm (Unitrac arm, Aesculap, Germany) was used to attach the positioning

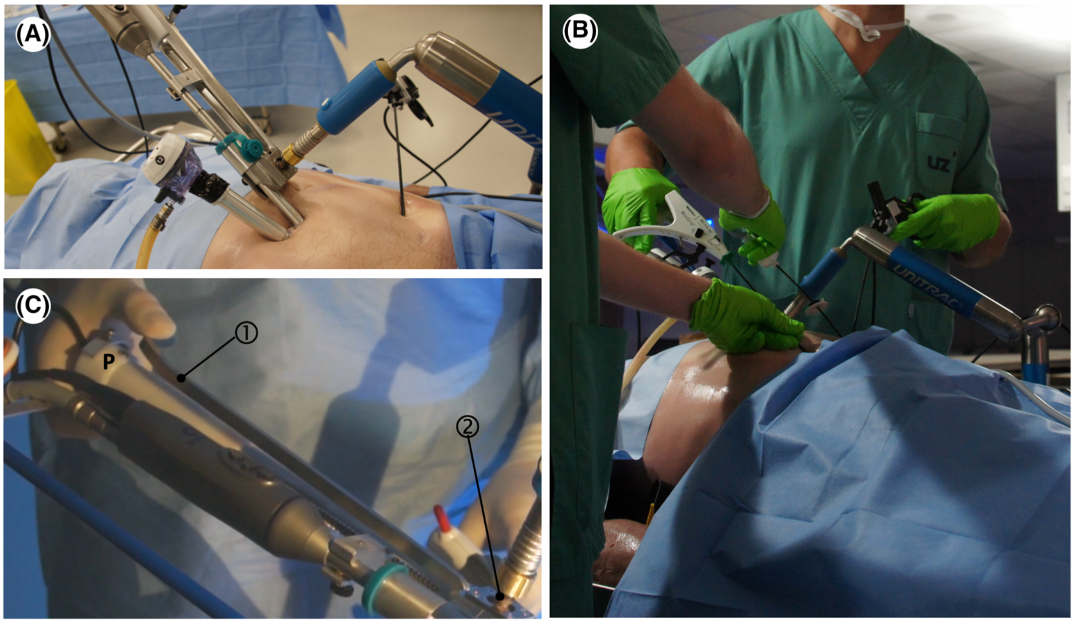

FIGURE 2 Single-port rectopexy during a cadaveric trial. A, Overview of the setup. B, Illustration of the compact design, optimizing the posture of all surgeons. C, Detail of the position of the hand during repositioning of the endoscope. The lever (1) is pressed using the thumb, which releases the ball-and-socket joint (2). The other fingers support the proximal end of the positioning system

TABLE 1 Overview of the trials

Procedure (n = 3)	Trial Type	Setup Time, min	Total Surgery Time, min	Adverse Events During the Operation	Number of Port Revisions	Side Effects Due to 3D Vision		
						N	D	H
Rectopexy	In vivo porcine trial	3.5	105	None	0	None	None	None
Rectopexy (single port)	Human cadaveric trial on a Thiel-embalmed specimen	6	132	None	1	None	None	None
Abdominal wall hernia repair	In vivo porcine trial	2	51	None	0	None	None	None

Abbreviations: D, dizziness; H, headache; N, nausea.

system to the operation table. A 0° and a 30° full HD Image 1S 3D endoscope was used in combination with the prototype endoscope positioning device (Figure 2A,B). After a demonstration of 3 minutes, all participants were able to fluently control and reposition the endoscope positioning system. The single-handed, directional control of the endoscope by actuating a lever was perceived easy and considered more intuitive than an assistant holding and controlling the endoscope. Setup was easy for all participants and only added an average (SD) of 3.8 (2) minutes to the operative time. The ability to zoom in and out without the need to release any instruments resulted in smooth working conditions: All procedures were accomplished within 51–132 minutes, without any complications. There were no mechanical or technical failures. Throughout the procedures, repositioning of the endoscope (angular movement and zooming) was performed 30.5 (16.3) times and took an average (SD) of 2.88 (2.04) seconds, permitting a continuous optimal working view without the need to release working instruments at any time and without the need for an assistant. Solitary angular movement of the endoscope took an average (SD) of 3.87 (1.77) seconds, while only zooming took an average (SD) of 0.83 (0.24) seconds. Rapid in and out movements facilitated the suturing work during the rectopexy and abdominal hernia repair. Once the surgical target was identified, the single-finger controlled zoom function was sufficient, without the need to remove or reposition any instruments. None of the surgeons reported dizziness, nausea, or headache due to 3D imaging nor ergonomic constraints.

4 | DISCUSSION

While many authors agree that the transition from human-assisted to mechanically assisted MIS is favorable, the choice for active or passive positioning systems to improve surgical (cost-)efficiency remains controversial. Drawbacks of either have impeded broad implementation of endoscope positioning systems in practice. Ideally, the surgeon should have full control over the endoscope during the whole procedure. Over the last decade, several prototypes of endoscope holders have been introduced to alleviate some of these difficulties by returning the control over the endoscope back to the surgeon.[15-20] Jaspers et al emphasized the difference between passive and active endoscope manipulators and described their advantages, disadvantages, and implications of their use during surgery.[21] They, as well as Breedveld et al,[22] concluded that passive endoscope holders seem to be more cost-efficient, intuitive, and user-friendly than are active manipulators and postulated that single-handed repositioning is essential to achieve efficient use of these devices. However, the surgeon still has to release at least one of his or her instruments to move the endoscope, which is a considerable drawback, particularly when compared with fully robotized endoscope manipulators.[11,13] Despite substantial investments made this last decade, no extensive implementation of these devices in MIS is seen, suggesting that today's available passive and active positioning systems do not entirely fulfill the needs and expectations of MIS surgeons. Most currently available systems enable the surgeon to obtain the required operator view without relying on the experience and skills of his or her assistant but often fail to generate an improved surgical efficiency for several reasons, such as a complex human-machine interface or the need for frequent release of one or both endoscopic instruments during repositioning of the endoscope or high production costs of the devices. Likewise, a voice controller of the camera arm has been proposed but was not widely implemented.[23]

The basic principle is very straightforward: An endoscope holding device must allow manipulation and fixation of the endoscope, providing an optimal and steady image. Furthermore, the manipulation of the endoscope must be very intuitive, provided by a single-handed control.[16] Pursuing a compact design, combined with a minimal setup time, not only will preserve the surgeon's workspace but also will respect the standard MIS procedures. Finally, attention should be paid to the affordability of the device to facilitate the transition towards solo, mechanically assisted surgery. The prospect to autonomously operate with both hands and simultaneously zoom in or out the endoscope without the need to release an instrument promises major advantages and was reported very satisfying according to all the involved surgeons. Endoscopic manipulations, such as placing a suture, require only a limited angular movement of the endoscope, especially when working in a confined space, which is often the case during MIS. Most of the time, the ability to zoom in or out is sufficient to perform these actions. Once the surgical target is centered, no further angular movements are needed to place a suture. Furthermore, based on the observation of the smooth operation by the surgeons with average manipulation times of 3.87 seconds for angular movements and 0.83 seconds for zooming in or out, the control of the device is arguably much more intuitive than are joystick-controlled devices, which do not permit simultaneous zooming and repositioning. While there is an immediate mechanical response of the electronic zoom upon pressing the control button, the speed of the automatic zooming device is restricted to 20 mm/s for safety and precision reasons. If, however, swift repositioning of the camera is required, the device also permits easy and intuitive manual repositioning without the need of detachment from the holder. Setup was perceived easy, and the average setup time of 3.8 (2) minutes is found to be comparable with that of other active camera holders. Kommu et al reported an average setup time for the Endoassist from 5.1 (1) to 6.8 (2) minutes depending on the type of the procedure.[19] The average setup time for the ViKY system[24,25] and SoloAssist II[26] was reported to be 3 to 7.9 and 34.2 (7.8) minutes, respectively. The average setup time is also comparable with that of other passive camera holders. Arezzo et al reported a setup time of 4 minutes for the Endofreeze system.[15] Bosma et al developed a passive endoscope positioner, based on a scissor and a deflectable ball principle. They reported a setup time of 10 to 20 minutes.[20] Using a regular toggle switch (Figure 1 (10)) to zoom in or out the endoscope enhances surgical efficiency since no instruments need to be released. Furthermore, the instant control over the angle of the endoscope by single-handedly actuating a lever reduces the complexity of the human-machine interface. The mean surgery time during the rectopexy was 118 (range 105–132) minutes, compared with an average (SD) surgery time of 115 (36), 119 (31), 153 (33), and 163 (39) minutes during conventional minimal invasive rectopexy as reported by several authors.[27-30] All procedures were performed using a 3D endoscopic system. Because maximal 3D-image stability is critical to avoid side effects such as headache, nausea, and dizziness,[12,31] the complete absence of these side effects also underlines an optimally stabilized 3D visualization by the prototype endoscope positioning system. Since frequent cleaning or defogging of an endoscopic camera is often required, a convenient system must permit easy and fast detachment and reliable reattachment during demanding procedures. Therefore, the connection system (Figure 1 (4) and (4a)) permits an intuitive release of the endoscope from the holder by actuating only one lever. It is worth mentioning that an additional advantage of such a repositioning system is the absence of involuntary movements, with less contamination of the lens, and therefore less need for cleaning.[32-34] Secondly, lens irrigation systems, such as the Endosplash,[35] are fully compatible with the endoscope repositioning system.

Obviating the camera assistant by virtue of an endoscope positioning system can be expected to alleviate some difficulties as mentioned before. However, it is worth noting that holding the endoscope is considered to be one of the initial tasks during laparoscopic training of young residents in university and teaching hospitals. Nevertheless, several studies emphasize the importance of simulated-based training to acquire technical skills for camera navigation. The use of nonliving biological tissues or a virtual reality-based platform may act as a safer and better-controlled environment to reacquire basic camera skills. Furthermore, the use of a camera holding device would advantageously permit to focus on other tasks during surgery such as retracting structures or to pay more attention to the surgical maneuvers of the first surgeon.

This study has some limitations. This study was performed to provide a first assessment of the benefits of this new technology and to evaluate possible manifestations of ergonomic inconveniences. However, the sample size should be considered insufficient to reliably compare outcomes with those of alternative technologies, particularly nausea and headache, as these symptoms are already rare events in short procedures with the available routine devices. Furthermore, there is only a limited comparison of the presented device with currently available robotic assisted cameras, owing to a paucity of available objective data on alternative systems. While the aim of this study was to provide a first assessment and demonstration of the principles of the new device, additional research is needed to quantify the different aspects in clinical practice in terms of manipulation, functionality, and magnification and to assess the benefits of this technology in clinical circumstances.

ACKNOWLEDGMENTS

The authors thank the ORSI Academy staff for the organization and support during the porcine trials and CETRAS Ghent (University of Ghent) for the organization and support during the cadaveric trials. They also thank Tine Wyckhuys, Simon Schiettecatte, Bart Haesaerts, and Christoph Diddens for their excellent technical support.

CONFLICT OF INTEREST

Dewaele, Kalmar, Maene, Blanckaert, and Mabilde report shares in Steerable Instruments; they are inventors on several related patents. The company received funds from the Flemish government. All other authors have no conflicts of interest or financial ties to disclose.

AUTHOR CONTRIBUTIONS

Study design/planning was carried out by De Pauw, Dewaele, Kalmar, Maene, Mabilde, and Blanckaert. The study was conducted by De Pauw, Dewaele, Mabilde, Bauwens, Blanckaert, and Van Nieuwenhove. Data analysis was performed by Lievens, Van Haver, Kalmar, and Van De Putte. De Pauw, Dewaele, Kalmar, Lievens, and Van De Putte wrote the paper. All authors revised the paper.

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How to cite this article: De Pauw T, Kalmar A, Van De Putte D, et al. A novel hybrid 3D endoscope zooming and repositioning system: Design and feasibility study. *Int J Med Robotics Comput Assist Surg*. 2019;e2050. https://doi.org/10.1002/rcs.2050