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Camera Holding Robotic Devices in Urology

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1. Introduction

The efficacy of an operating surgeon in Laparoscopic Urological Surgery (LUS) is dependent on a two dimensional view seen on a monitor or projection device. The role of the camera driver is central to the procedure and the operating surgeon has usually had to constantly indicate exactly where he wants his assistant to focus to help optimise tissue exposure and handling during the procedure. The realization that the camera holder need not necessarily be a human and that a given task could be completed by devices under the direct or indirect control of the operating surgeon has led to the objective and subjective evaluation of several devices. Ideally, the surgeon should have full control of all instruments required that are directly required for conducting a given procedure. This includes surgical operative instruments and control of the operative field. The purpose of non-human camera holders is to return camera-control to the surgeon and to stabilize the visual field during minimally invasive procedures. As such, active and passive camera holders have been developed in a bid to offer the surgeon an alternative and better tool for control of the operating surgeon's direct visual field. Herein we describe the current Camera Holding Robots in surgery focusing on voice activated i.e. AESOP® (automated endoscopic system for optimal positioning) (Unger et al., 1994) and motion controlled robots i.e. EndoAssist® Camera Holding Robot (Kommu et al., 2007). We also look at camera holding elements of other robotic surgical systems including the da Vinci® and ZEUS® Surgical Systems.

2. Types of Camera Holding Robots

There are predominantly two type of robots, namely motion controlled and voice activated. Motion controlled camera holders currently in use are the EndoAssist® Camera Holding Robot, The camera arm of the da Vinci® Robotic System and Zeus® Surgical System. The Voice activated device currently in use is the AESOP® device.

2.1 Motion controlled camera holding robots – The EndoAssist® Camera Holding Robot

Ideally, the surgeon should have optimal control of all instrumentation that is directly required for conducting a given procedure including surgical operative instruments and control of the operative field. The purpose of non-human camera holders is to return camera-control to the surgeon and to stabilize the visual field. As a result of this, active and passive camera holders have been developed in a bid to offer the surgeon an alternative and potentially better tool for control of the operating surgeon's direct visual field. The

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published advantages include: [1] elimination of fatigue of the assistant who holds the camera, [2] elimination of fine motor tremor and small inaccurate movements and [3] delivery of a steady and tremor-free image (Allaf et al., 1998 & Nebot et al., 2003).

The EndoAssist® is a novel and unique robotic camera holder (EndoAssist®; Armstrong Healthcare, High Wycombe, Bucks, UK) (Fig. 1). that is controlled by simple head movement by the surgeon and enables complete autonomy over camera movement. Movement is executed by a head-mounted infrared emitter; the sensor is placed above the monitor and picks up any operator executed head movements (Fig. 2). The foot clutch ensures there is no unnecessary travel when movement is not required.



Figure 1. The *arrow* shows the camera driver of the EndoAssist®. [Copyright © JORS 2007]

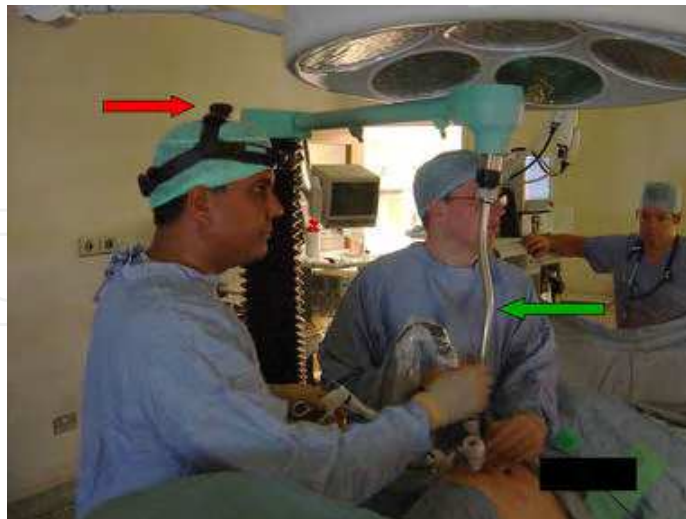


Figure 2. Head-mounted infra-red emitter (*red arrow*) and the camera driver being positioned (*green arrow*). [Copyright © JORS 2007]

We conducted a study using the EndoAssist® device in a total of 51 urological procedures (25 using the EndoAssist® device and 26 using a conventional human camera driver). The

procedures studied were conducted by three experienced surgeons. Cases included nephrectomy (simple and radical), pyeloplasty, radical prostatectomy, and radical cystoprostatectomy. We used two separate groups, the Endoassist arm [E-Arm] and the conventional arm [C-Arm], which involves a human camera holder or driver. For the EndoAssist® arm, data were prospectively collected for 25 procedures. For the conventional arm, data for 26 cases were retrospectively collected from our database. The surgeon noted six parameters:

- 1 THE EXTENT OF BODY COMFORT AND MUSCLE FATIGUE IN EACH CASE, BY USING A MODIFIED BODY PART DISCOMFORT SCORE (BPDS), A SCORE OF 0 IMPLYING NO DISCOMFORT DURING THE PROCEDURE AND 10 BEING SUFFICIENT DISCOMFORT TO STOP THE TASK BEFORE RECOMMENCING
- 2 EASE OF SCOPE MOVEMENT OR USABILITY
- 3 NEED TO CLEAN THE TELESCOPE
- 4 TIME OF SET-UP AND EFFECT ON OVERALL OPERATIVE TIME
- 5 SURGICAL PERFORMANCE
- 6 WHETHER IT WAS NECESSARY TO CHANGE THE POSITION OF THE ARM DURING SURGERY

Ease of scope movement was graded on basis of the International Organization for Standardization (ISO) which defines usability as the extent to which goals are achieved with effectiveness, efficiency, and satisfaction. Each of these was graded on a linear scale of 1-5, from lowest to highest. The number of times the scope had to be cleaned was also recorded for each case in both the E-Arm and C-Arm. The time to set up the device was also tabulated as mean time in minutes \pm standard deviation. The E-Arm data were collected prospectively whereas the C-Arm data was collected from database pool of retrospective data. For the renal surgery, a thirty-degree laparoscope was used. For the pelvic surgery, a 0° scope was used. The Harmonic® scalpel (Ethicon Endosurgery, Bracknell, UK), the Olympus SonoSurg (Keymed, Southend, UK), or the Lotus® (SRA Developments Ashburton, UK) were used to aid circumferential specimen mobilisation. Hem-o-lok® (Weck, High Wycombe, Bucks, UK) clips were used as appropriate for securing pedicles. Where statistical analysis was performed in this study, we used a Wilcoxon matched pairs signed-rank test and a result was deemed statistically significant if $P < 0.05$. All data were analysed by use of a preformed computer generated template of the variables of interest. Exclusion criteria were cases with major intraoperative complications including major bleeding or other factors which would have demanded additional haemostatic or reconstructive steps.

Findings with body comfort and muscle fatigue- all three surgeons felt comfortable with the E-Arm for each of the procedures studied, with no loss of autonomy. The surgeons were uncomfortable with use of the C-Arm for laparoscopic radical prostatectomy, and prompting for motion adjustment was required repeatedly for the cases studied. There was no reported difference between muscle fatigue for the two modes. The overall Modified BPDS (body part discomfort score) was 2.1 for the E-Arm and 2.2 for the C-Arm ($P = 0.2$) indicating no statistically significant difference between the two.

Findings with ease of scope movement and the need to clean the telescope-on average, the large arc generated whilst performing a nephrectomy led to more episodes of lens cleaning for the E-Arm group than for the C-Arm group. For laparoscopic nephrectomy, the EndoAssist port had to be relocated on several occasions whereas the C-Arm group did not require camera port relocation. Fewer problems were encountered while performing pelvic surgery or pyeloplasty. The grading for ease of scope movement was, on average, 3 for radical prostatectomy, 2 for pyeloplasty, and 1 for laparoscopic nephrectomy. There was a statistically significant difference between ease of scope movement, i.e. "usability", in favour of radical prostatectomy compared with simple or radical laparoscopic nephrectomy. For laparoscopic pyeloplasty the difference was statistically insignificant.

Findings of the time of set up (Tab. 1).- Set up time was greatest for laparoscopic radical cystectomy ([E-Arm] 6.8 ± 2.3 ; [C-Arm] 7.1 ± 1.9 min) and least for pyeloplasty ([E-Arm] 5.1 ± 1.8 ; [C-Arm] 5.3 ± 1.7 min) and there was no statistically significant difference between set up times for the E-Arm and C-Arm groups. The set-up time was < 8 mins in 100% of cases. Utility of EndoAssist had no effect on set up time compared with the conventional approach.

PROCEDURE	TOTAL NUMBER OF CASES USING ENDOASSIST [E]	TOTAL NUMBER OF CASES CONVENTIONAL [C]	MEAN SETTING UP TIME (MINS)	STATISTICALLY SIGNIFICANT [Y/N]
Nephrectomy	16	17	[E] 5.9 ± 1.2 Vs [C] 5.6 ± 1.3	N
Pyeloplasty	4	4	[E] 5.1 ± 1.8 Vs [C] 5.3 ± 1.7	N
Prostatectomy	3	3	[E] 5.8 ± 2.8 Vs [C] 5.6 ± 2.9	N
Cyctectomy	2	2	[E] 6.8 ± 2.3 Vs [C] 7.1 ± 1.9	N

Table. 1. Setting up times for EndoAssist® and for the conventional human driver template (mean time in minute \pm standard deviation). [[Copyright © JORS 2007]

Findings of surgical approach - All three surgeons reported that the EndoAssist® device did not compromise surgical performance. They found that EndoAssist was a viable option and comparable with use of a human camera driver. There were no significant differences between complication rates or total operative time for procedures conducted with the EndoAssist® device or with a conventional human assistant.

Findings with need to clean scope - The need to clean the scope during the individual case depends on several factors, e.g. patient anatomy, the body mass index, the assistant's level of experience and inherent skill in driving the camera, and the exact type of surgery performed. We found this was not a useful tool for measuring the performance of the two arms because of the multiple confounding factors.

We have made several interesting observations. There are a number of advantages that are immediately apparent, primarily the intuitive positioning of the camera by the surgeon to optimise his operating field and, secondly, the potential reduction in cost without an assistant. There is a short learning curve but proficiency in the execution of the robotic movements is easily acquired over a few minutes. There was no neck or shoulder discomfort since the head mounted sensor weighs less than 10 grams and can easily be mounted onto a headband should the surgeon so decide. The BPDS showed no increased discomfort of one procedure over the other. The EndoAssist® allowed the surgeon to intuitively control his field of laparoscopic vision while co-ordinating movements of his instrumentation. Overall we found the EndoAssist® to be an effective and easy to use device for robotic camera

driving. This could potentially reduce the constraint of having to have an experienced camera driver.

2.2 Motion controlled camera holding robotic elements – da Vinci® Robotic System

The advent and indeed propulsion of minimally invasive surgery over the last two decades has seen marked improvements in instrumentation. One of the main drawbacks of minimally invasive surgery is the use of a 2 Dimensional picture of the operative field fed to a monitor. The resulting elimination of natural depth of field significantly reduces the surgeon's initial ability to perform the task optimally in terms of speed and accuracy when compared to an open or 3 Dimensional view. This makes the learning curve for a given procedure suboptimal. The da Vinci® Robotic System represents a paradigm shift in our approach to minimally invasive surgery.

The Camera port is position and optic feedback is controlled by the surgeon with a default mechanism that is entirely under the operating surgeon's control. This can be classed as a form of camera holding robot [Fig 3]. The coupling of this control with the world's first robotic surgical system with 3D HD vision makes this system a very desirable platform for many surgeons. However, the use of this robotic system is different from conventional laparoscopic surgery in terms of instrumentation and the cost of running such a unit is highly restrictive in most units with overall purchase and maintenance costs in excess of \$1,000,000 USD (2006).

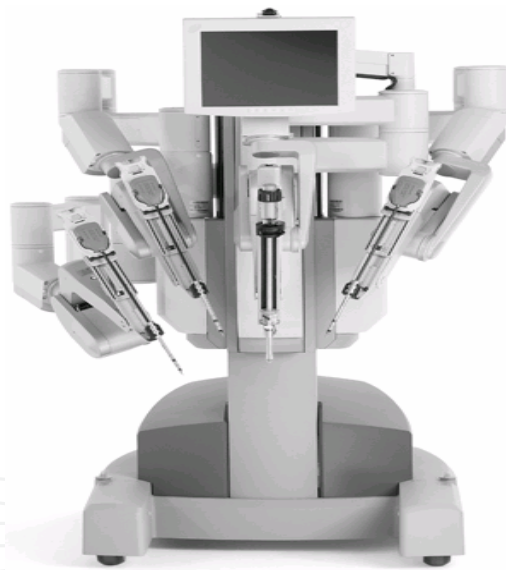


Figure 3. da Vinci® Robot. The Middle Arm represents the camera holder controlled by the operating surgeon

2.3 Motion controlled camera holding robotic elements – ZEUS® Surgical System

The ZEUS® Surgical System (Computer Motion and Medtronic) is a more recent addition to robotic surgery [Fig 4]. It is made up of an ergonomic surgeon control console and three table-mounted robotic arms. Two of these arms perform the surgical procedure. The third arm represents the endoscope with its camera providing either 2D or 3D visualization. The camera driver utilises an AESOP® Endoscope Positioner technology providing the surgeon with magnified, tremor free visualization of the internal operative field. The camera device

can be operated either by voice activation or by non verbal command. One of the drawbacks of ZEUS® is its cost which has been estimated at \$1,000,000 USD (2007 Cost).



Figure 4. The ZEUS® Surgical System. The camera holder and driver is actually an AESOP derivative which uses AESOP® Endoscope Positioner technology

3. Voice activated camera holding devices

3.1 AESOP (Automated Endoscopic System for Optimal Positioning)

Since voice activation was recognised as a useful mode of direct communication with a mechanical tool to perform a preprogrammed task on verbal command, several devices have been developed mainly for commercial purposes. Surgical assist devices were among those developed at a later stage. The world's first surgical robot certified by the FDA in the USA was The AESOP® 1000 system (Intuitive Surgical, Inc., Sunnyvale, CA, USA) and was released in 1994. AESOP® stands for Automated Endoscopic System for Optimal Positioning. Later Computer Motion followed with AESOP® 2000 in 1996. The coupling of voice recognition technology with camera holding devices in surgery has seen the development of the AESOP® 3000 (in 1998) to control a robotic arm with seven degrees of freedom giving further flexibility in desired positioning of the endoscope [Fig 4].

Some of the shortcomings noted with master-slave design robots (e.g. Intuitive Surgical's da Vinci® Surgical System), such as excessive bulk or dimensions and high cost are were not similarly restrictive with AESOP®. This realisation led to the propulsion of several trials involving the use of AESOP® in minimally invasive surgery. The operating surgeon trains the device in simple commands for driving the camera holding tasks. The unique voice signature is then stored in a card which the surgeon can use at the time of surgery [Fig 5].



Figure 4. AESOP®. [Copyright JORS 2007]



Figure 5. (A) The AESOP® with its camera holding arm (B) The signature voice card. [Copyright © 2006 by Thieme Medical Publishers, Inc., 333 Seventh Avenue, New York, NY 10001, USA.]

AESOP can potentially eliminate the need for an assistant i.e. a member of the surgical team whose duty would conventionally be to physically manipulate the endoscope. Today in the USA approximately a third of all minimally invasive procedures incorporate AESOP. In Europe the uptake has been slower but is gradually increasing. The cost of AESOP is approximately \$65,000 to \$70,000 USD (in 2006).

Recently, a device called ViKy (endocontrol - medical, La Tronche, France) has been demonstrated, with both voice as well as foot pedal control. Publications regarding its efficacy and ease of use are awaited.

4. Discussion

In 1995, Kavoussi et al. (Kavoussi et al., 1995) reported their findings on their experience with the accuracy and use of a robotic surgical arm compared with a human assistant during LUS. They found that the positioning of the camera was significantly steadier with fewer unwanted or aberrant movements when under robotic control when compared with the human counterpart. There was no significant difference, however, in the total operative times using the robot or human assistant. In a later study, by the same team looked at the use of surgeon-controlled robotic arms as a substitute for human assistants and found that simultaneous use of remote-controlled robotic arms as surgical assistants was feasible in minimally invasive surgery (Partin et al., 1995). They found that when the robotic arms were deployed, there was little increase in the total operating time. Furthermore, there was no difference in set up and breakdown times.

The quest for replacements to human assistants was not just confined to urologists alone. Several non urological surgeons explored the potential of alternative camera drivers. One team (Benin et al., 1995), explored the motions of the human camera operator and expressed them mathematically by use of a spherical displacement model. This led to the development of a revolving robotic arm with six degrees of freedom in close association with a camera. This was tested in animal models for cholecystectomy and other procedures. Another team (Geis et al., 1996) explored robotic arm enhancement and its effect on efficiency and resource optimisation in complex minimally invasive surgical procedures. They found that robotic arm enhancement reduced costs and minimized risk for patients. In their study of the actual general surgical cases, they found that versatility, safety and reduction in burden of resources had an overall beneficial advantage.

With health economics in mind, Turner (Turner et al., 1996) compared the cost-effectiveness of using a robotic versus a human assistant in a series of laparoscopic bladder neck suspension cases. His conclusion was that the overall cost of deploying and using the robotic arm was less than that of using a human assistant and that the former was a cost-effective mode for performing the procedures. In an analysis of several studies to determine whether the robotic arm can effectively provide the surgeon with complete control of the surgical field, and the impact of this device on overall cost, it was found that a robotic arm not only outperformed human camera assistants but also improved efficiency and cost savings (Dunlap & Wanzer 1998). The current price of the EndoAssist® and AESOP® devices are under \$100,000 US. From a health economics point of view, these costs when balanced against use of man power and cost per hour of employing a human camera assistant, points in favour of the non-human-controlled camera devices.

The preliminary findings that robotic camera holders were economically and technically feasible led several groups to compare the actual devices in terms of different parameters of

functional efficacy. A team from Johns Hopkins (Allaf et al., 1998) evaluated the standard foot pedal for the AESOP® robot compared with a voice control interface and found that voice control was more accurate and had the advantage of not requiring the surgeon to look away from the operative field. However, voice control was slower and required more attention as an interface. The first direct comparison of EndoAssist® and AESOP® (Wagner et al., 2006) using the index procedure of laparoscopic radical prostatectomy, found that the EndoAssist was as efficient as AESOP® with regard to surgical performance. The advantages of the EndoAssist® included its accurate response and its ability to provide the surgeon with complete control of the desired operative view. The disadvantages of the EndoAssist were found to be its large size, the inability to mount it on the table, and its pedal activation dependence.

A review of published literature revealed that the advantage of the EndoAssist over AESOP is its seeming short response time. Furthermore, EndoAssist obviated the need for multiple surgeons to be trained in the use of the same robot and the need to generate different sound cards for each user. The disadvantages of the EndoAssist appear to be its reasonably large footprint (it cannot be mounted on the operating table). Additionally, EndoAssist's foot-operated clutch requires the surgeon to focus away from the operative field to search for the foot pedal from time to time. Further comparative studies using larger cohorts of procedures are currently under way.

Nguan et al. (Nguan et al., 2007) recently published a clinical comparison between three robotic surgical systems (Aesop, Zeus and da Vinci) in assisting laparoscopic pyeloplasty procedures, a technically challenging minimally invasive surgical procedure. They found that the da Vinci robot required significantly more time to set up initially than the AESOP platform but the time was similar to that for the Zeus robot. However, despite the startup time disadvantage, laparoscopic robotic pyeloplasties performed using the da Vinci robot was significantly faster than that for AESOP and Zeus. They concluded that procedures performed using the da Vinci robotic system resulted in decreased anastomotic and operating times. The exact role of the camera holding element in each of these procedures is difficult to quantify. Intuitively, a 3 D camera holding robot under complete autonomous control of the surgeon would be optimal. This could be one of the reasons, apart from differences in other instrumentations, why the camera holding and driving element of the da Vinci System is optimal.

5. Conclusion

The coherent blend between man and machine is now well established and has been taken to the next level. This is exemplified by the seeming symbiotic relationship between some surgeons and their robot assist devices during surgical procedures in ensuring optimal performance. The replacement of a camera holding human surgical assistant by camera holding mechanical robot devices is a testament to the advances in one area of surgical robotics made over the last two decades. The current role played by each camera holding device is likely to evolve in the near future; precision camera holding devices will become a matter of preference by individual surgeons in many instances with each individual device having its pros and cons. We are currently working on several concepts including the next generation of the EndoAssist that could help achieve the very exciting prospect of a near ideal camera holding device.

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The first generation of surgical robots are already being installed in a number of operating rooms around the world. Robotics is being introduced to medicine because it allows for unprecedented control and precision of surgical instruments in minimally invasive procedures. So far, robots have been used to position an endoscope, perform gallbladder surgery and correct gastroesophageal reflux and heartburn. The ultimate goal of the robotic surgery field is to design a robot that can be used to perform closed-chest, beating-heart surgery. The use of robotics in surgery will expand over the next decades without any doubt. Minimally Invasive Surgery (MIS) is a revolutionary approach in surgery. In MIS, the operation is performed with instruments and viewing equipment inserted into the body through small incisions created by the surgeon, in contrast to open surgery with large incisions. This minimizes surgical trauma and damage to healthy tissue, resulting in shorter patient recovery time. The aim of this book is to provide an overview of the state-of-art, to present new ideas, original results and practical experiences in this expanding area. Nevertheless, many chapters in the book concern advanced research on this growing area. The book provides critical analysis of clinical trials, assessment of the benefits and risks of the application of these technologies. This book is certainly a small sample of the research activity on Medical Robotics going on around the globe as you read it, but it surely covers a good deal of what has been done in the field recently, and as such it works as a valuable source for researchers interested in the involved subjects, whether they are currently “medical roboticists” or not.

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