ORIGINAL ARTICLE

Evaluation of Various Port Positions for Minimal Access Cardiovascular and Thoracic Procedures

Anwarul Islam[1], Rajneesh K Mishra[2]

Abstract

Background: Video-assisted thoracoscopic surgery (VATS) is used to diagnose or treat diseases of the chest. Most of those procedures traditionally performed with open thoracotomy can be done using smaller incisions with video assistance. Robot-assisted thoracic surgery (RATS) is a technologically upgraded system that uses computers to help surgeons for precise tremor-less instrument control in a confined space with utmost accuracy. For access to the chest minimally, two principles are followed: the baseball diamond principle (BDP) and the triangle target principle (TTP) of port position. Both can be used for minimal access cardiovascular and thoracic surgery. Different manipulation angles (30°, 60°, and 90°) are used to perform the task and find out time, errors, and surgeon's discomfort during the surgery.

Objectives: To evaluate and compare task performance at different port positions during minimal access cardiovascular and thoracic procedures in a swine.

Materials and methods: A prospective experimental animal study was granted and conducted at the World Laparoscopy Hospital, Gurugram, Delhi, India. Three thoracic and two cardiac procedures were selected for this study conducted on 30 swines over 11 months from January 15, 2018, to November 15, 2018. At the end, euthanasia was conducted humanly and carcasses disposed appropriately as per the regulation under the provisions of the Prevention of Cruelty to Animals Act, 1960, and the Acts of 1998 and 2001.

Results: A total of 30 procedures were conducted in this study using TTP of port placement. The procedures are lung resection-6, thymectomy-6, closure of atrial septal defect (ASD)-6, internal mammary artery (IMA) harvesting for totally endoscopic coronary artery grafting (TECABG)-6, and esophagectomy-6. It is to evaluate the execution time (sum of the ports access time and the actual procedure time), error rates, and the surgeon's discomfort for each of the three angles of manipulation. Average timing of all tasks was shorter with 60° manipulation and all were reproducible. All the tasks were difficult at 30° and 90° angle. Closer manipulation of angle to 90° and above takes longer operative time. It may be due to fatigue from shoulder overstretching for increased elevation angle. It was demonstrated that the surgeon's discomfort level was least at the 60° port position.

Conclusion: There is no fixed position for port placement in the cardiovascular and thoracic procedures. The average timing of all tasks was shorter, there were less errors, and surgeon's discomfort was less operating at 60° manipulation angle.

Keywords: Internal mammary artery, Minimal access cardiovascular, Robotic-assisted thoracic surgery.

World Journal of Laparoscopic Surgery (2019): 10.5005/jp-journals-10033-1387

Introduction

Most major procedures traditionally performed with open thoracotomy can be done using smaller incisions with video-assisted thoracoscopic surgery (VATS) or robot-assisted thoracic surgery (RATS). In minimal access surgery, the access of entering the body can be minimal but inside the invasiveness does not remain minimal at all. Things we do, like opening the chest, can be done with limited access. The basic principles used in open surgery like exposure, dissection, traction, countertraction, and apposition are followed here too but hand of a surgeon remains outside of body or, in robotic surgery, at a separate console to manipulate the instruments.[1–3] The concept of VATS that greatly reduces the trauma of chest was initiated over two decades ago and has undergone a series of modifications and improvement. A Swedish Hans Christian Jacobeus (1879–1937) is considered as the father of thoracoscopy since he explored and established the practice of thoracoscopy in 1910. Lewis et al. reported 100 consecutive thoracoscopic surgeries in 1992.[4] Since then, VATS has shown significant advancements and currently entered into the era of robotic surgery.[5,6]

In VATS, surgeons hold the instruments while operating, but during RATS, surgeons control the instruments from a dedicated console using a computer for instrumental movement with utmost precision.[1,2] In an appropriately selected patient, the minimal access technique provides safe, effective, and successful surgery with equivalent or improved outcomes having less perioperative morbidity and equivalent oncologic results compared with open surgery. Outcomes may be better in frail and older patients.[3,5] Minimal access thoracic surgeries remove the need for thoracotomy that involves spreading of the ribs or long sternotomy incision, large scar mark, and prolonged postoperative analgesia. Usually, operative costs for minimal access procedures are higher because of costly equipments, although overall costs may be lower due to the shorter length of hospital stay and faster recovery.[7]

[1]Department of Cardiac Surgery, Bangabandhu Sheikh Mujib Medical University, Dhaka, Bangladesh

[2]Department of Minimal Access Surgery, World Laparoscopy Hospital, Gurugram, Delhi, India

Corresponding Author: Anwarul Islam, Department of Cardiac Surgery, Bangabandhu Sheikh Mujib Medical University, Dhaka, Bangladesh, Phone: +8801716529337, e-mail: sagarsurgery@gmail.com

How to cite this article: Islam A, Mishra RK. Evaluation of Various Port Positions for Minimal Access Cardiovascular and Thoracic Procedures. World J Lap Surg 2019;12(3):101–115.

Source of support: Nil

Conflict of interest: None

A thoracoscope attached to a video camera passed through ports into the chest cavity via 5–10 mm skin incisions where rod lens transmits the signal to see inside the chest on the monitor (Fig. 1). There are two ergonomic principles [baseball diamond principle (BDP) and triangle target principle (TTP)] for the position and placement of access ports, which helps in task performance and surgeons' comfort.[8,9] Three angles are used to perform the task in each principle. These manipulation angles are to be evaluated to find the ideal position. Besides laparoscopic surgery, the BDP is also applied for VATS as a conventional principle.[1,2] Here the camera port and the target are placed at the opposing vertical angles of the diamond and the other two working instruments are placed perpendicular to that plane at the horizontal angles (Fig. 2).[4,9]

The TTP is relatively a new principle. Here three ports are placed in a triangle keeping the target lesion at the apex. One side of the base becomes the site of the first port for the camera, and the another side becomes the site for the second port for the forceps or the endoscopic stapler. The third port is for the forceps to the target lesion (Fig. 3).[8,10] To explore a prospective experimental animal study was carried out to find out a suitable manipulation angle for the port position in TTP using 30°, 60°, and 90° angles regarding task performance time, error, and comfort of surgeons.

Aims and Objectives

To evaluate and compare task performance at different port positions during lung resection, thymectomy, IMA harvesting for totally endoscopic coronary artery bypass grafting (TECABG), ASD closure, and esophagectomy through minimal access using the TTP and find out which position for port is better and facilitates task performance.

Ergonomic Principle for Minimal Access Surgery

Ergonomics is "the scientific study of individual at work, in terms of equipment design, workplace layout, operating environment, productivity, safety and training." The ergonomic principle governs the position of ports in minimal access surgery to facilitate higher task performance and comfort to the surgeon. It includes the following:

- Port placement to be adjusted according to the specific chest anatomy. Most importantly, the skin incision to be placed directly in the middle of the corresponding intercostal space to avoid unnecessary pressure on the rib by the instrument during manipulation.
- The optical port is placed at the center so that telescope remains in between the operating instruments, which will act as a type I lever with equal length within and outside the thorax.
- The manipulation angle between the two operating instruments would optimally be 60° (elevation angle is 30° and the azimuth angle is 15°–45°)
- The operating instruments would not face or work against the telescope as this results in production of the mirror image and tough task execution with increased error rate.
- Height of the operating table ought to be adjusted between 64 cm and 77 cm higher than the floor level because discomfort and operative difficulty are lowest when working instruments are positioned at the level of the elbow.[9]
- Ergonomically, the monitor image within 25 optimal degrees below the horizontal plane of the eye offers least neck strain.[11]
- To facilitate easy instrument manipulation and proper visualization, the port to be placed in a triangular fashion. Troubles related to depth perception, vision, and loss of peripheral visual fields may be reduced by using 10–15× magnification.[12]
- The target organ ought to be 15–20 cm from the optical port. Generally, the two remaining ports are placed in the same 15–20 cm arc at 5–7 cm on either aspect of the optical port. It makes the instruments to work at a 60–90° angle.[13] If required, additional retracting ports may be placed in the same arc but more laterally to avoid clashing of instruments. If angle between target and instrument is too wide or obtuse, manipulation of the instrument is so tough. That's why surgeons used to customize the port position.
- The most effective task efficiency and performance quality are obtained with a perfect manipulation angle between 45° and 60°, which can be achieved by correct placement of ports. The 90° manipulation angle creates the greatest muscle workload by the deltoid and the trapezius. Manipulation angle starting from

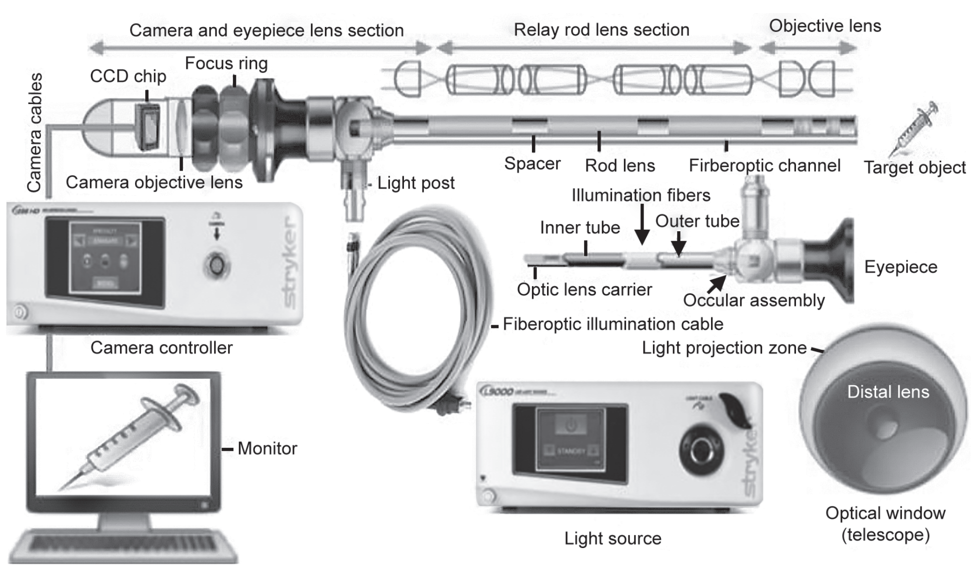

Fig. 1: Basic visual equipment used for minimal access surgery

Fig. 2: Different angles required for minimal access surgery (MAS)

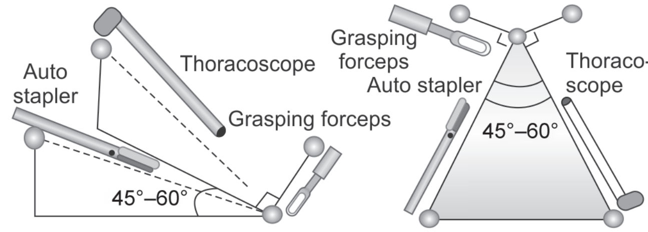

Fig. 3: Port placement using triangle target principle

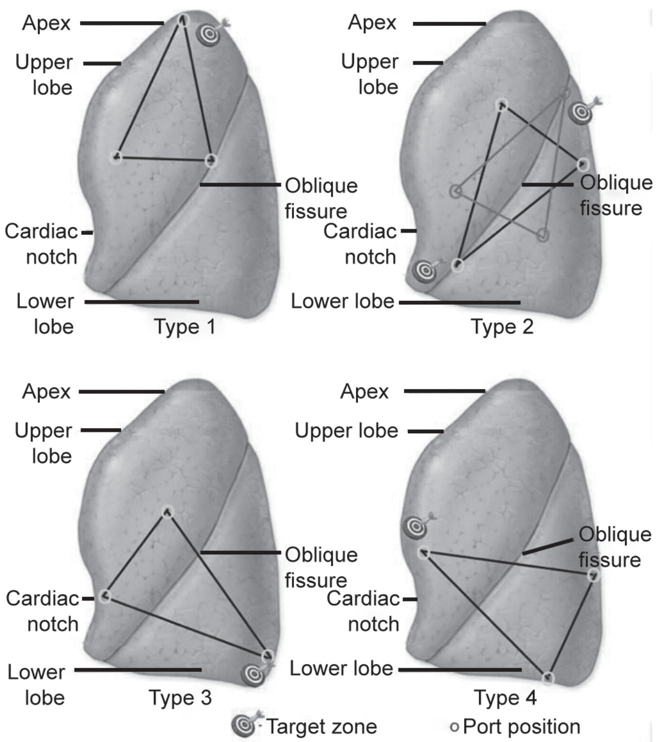

Fig. 4: Triangle target principle based on lesion location

45° to 75° with equal azimuth angles is suggested. Manipulation angles below 45° or higher than 75° are accompanied by increased difficulty and degraded performance.[14]

- It is reported that task efficiency is better with equal azimuth angles than with unequal azimuth angles. Achieving equal azimuth angles might be difficult in practical situations, but as a principle, azimuth inequality ought to be avoided because it degrades task efficiency.[15]
- There may be direct correlation between the manipulation and the elevation angles. A manipulation angle of 60° with optimal elevation angle offers the shortest execution time and optimal quality performance. Wide manipulation angles require wide elevation angles for better performance and higher task efficiency.[15]
- When a 30° manipulation angle is imposed on a patient, the elevation angle ought be also 30° because it carries the shortest execution time. The most effective ergonomic layout for endoscopic surgery consists of a manipulation angle stating from 45° to 75° with equal azimuth angles.[15,16]
- The recommended position of the arm is slightly abduction, retroversion, and rotation inward at the shoulder level. The elbow should be bent at about 90°–120°. The surgeon should primarily be moving and loosening up his hands intermittently to stop buildup of lactic acid and keep off fatigue.[17]

Ports Using in TTP

The experience that BDP could create difficulties in some VATS procedures led an exploration for an alternative principle to ensure higher task performance. Sasaki et al.[18] pointed to the problem they experienced in treating thoracic lesions, particularly peripheral lung lesions, using BDP. So they developed and introduced the TTP to resolve the problem. The TTP involves inserting three ports to create an equilateral triangle between the optical port, the operating instrument, and the target. A third port is usually used for grasping forceps, which is placed close to the target. Application of TTP for ports placement might be used to treat all thoracic lesions.[18]

For lung tumors, the TTP is indicated in peripheral tumors that are not attached to the lateral chest wall and are less than 3 cm in diameter. Because of different positions of the lesion, TTP is modified into four types.

Type I: for lesions of the upper lobe—anterior segments, apex, superior mediastinum.

Type II: for lesions of the upper lobe—posterior segments; middle lobe—right lateral segment; lower lobe—6, 8 segments, lingula, and upper posterior mediastinum.

Type III: for lesions of the lower lobe —9, 10 segments, lower posterior mediastinum, and diaphragm

Type IV: for lesions of the middle lobe—medial segment, anterior mediastinum, pericardium (Fig. 4).

Advantages of TTP

Advantages of TTP in relation to lung lesion include the following:[18]

The possibility of grasping tissue near the lesion via the target port.

Grasping forceps and stapler meeting at right angle, which is the required angle for stapling.

Possibility of palpating a peripheral tumor via the target port and ease in taking a needle biopsy.

Drawbacks of TTP

These are found mostly with type III TTP and are the following:

Difficulty in determining the site of trocar placement because of the proximity of the first operating port and the target port to the lesion leading to crowding and swording of instruments.

Produce mirror imaging too.

Complications of VATS

The complications of VATS include nerve injuries due to pressure from wrong positioning and anesthetic complications, trocar injury to intercostal vessels or internal mammary arteries (IMAs), instrument malfunction or breaking within the thoracic cavity, intercostal nerve dysfunction due to tight leverage on the chest wall and large vessels injury, hemothorax, perforation of thoracic organs, prolonged air leak, atelectasis, pneumonia, chylothorax, atrial fibrillation, etc.

Anesthesia and Positioning of Patient and Surgeon

In most VATS procedures, general anesthesia with a double-lumen endotracheal tube is employed to confirm collapse of the ipsilateral lung that offers more space inside the thorax.

In majority of the cases, patients are placed in the lateral decubitus position. To make the intercostal spaces wider, the OT table is flexed. This decreases leverage of the instruments on the ribs with reduction in frequency of intercostal nerve compressions and postoperative pain.[6] It also allows better maneuverability of the instruments. Some VATS procedures such as thymectomy can be done in the prone position or the supine position with slight elevation of the ipsilateral shoulder.[9] Alternatively, the supine position with a roll under patient's back to push him up allows access to the thorax from the anterior approach. The positions of the surgeon and the assistant rely on the location of pathology. The surgeon and the camera-holding assistant stand facing the site of pathology. The surgeon, the site of pathology, and the monitor are aligned to permit the surgeon to look straight ahead while operating (Figs 5 and 6).

Lung Resection

As a standard treatment of early-stage lung cancer, minimally invasive lung resection has replaced thoracotomy. Minimally invasive lung resection allows patients a much faster recovery with equivalent oncologic effectiveness and offers more accurate staging that potentially improved survival. About 98% of patients are usually operated successfully using TTP without major complications. Takao et al.[19] reported using TTP. For right VATS, the camera port is inserted at fourth intercostal space along the anterior axillary line (AL), first operating port at sixth intercostal space along the mid-AL, and second operating port inserted at sixth intercostal space along the posterior AL. For left VATS, the camera port is inserted at sixth intercostal space along the posterior AL, the first operating instrument at the sixth intercostal space along the mid-AL, and second operating port at fourth intercostal space along the anterior AL. Depending on the lesion, ports can be shifted one intercostal space below or above (Fig. 3).

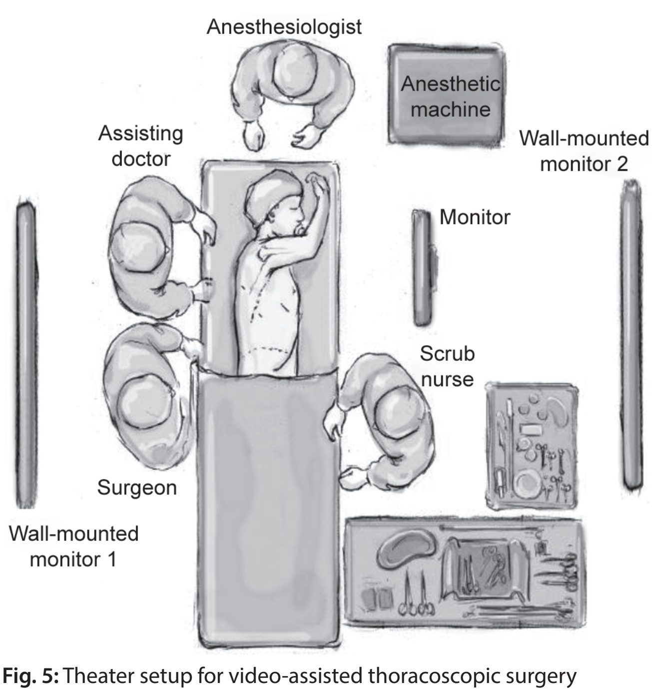

Fig. 5: Theater setup for video-assisted thoracoscopic surgery

Key Technical Points (Applicable To All VATS)

- Insert the instruments into the chest cavity without injuring the chest wall or lung. Division of the posterior pleural reflection greatly improves the ability to perform safe dissection of desired arterial branches.
- There should be no traction on pulmonary artery (PA) and tissue dissected away from PA and its branches. Complications can be prevented by avoiding excessive tension on PA during retraction and dissection. The pulmonary vein and bronchus can tolerate some degree of tension, therefore developing tissue planes between these structures. During dissection around PA, it should be stationary, moving the other structures away from PA.
- Lymph nodes to be cleaned away to facilitate dissection of relevant structures. Endobags to be used for retrieval of the excise tissue to prevent spillage of tumor cells within the thorax.

Thymectomy

Thymectomy is typically indicated for myasthenia gravis (MG), thymoma, and anterior mediastinal tumors.[20] Primary epithelial tumors of the thymus are found in approximately 50% of all anterior mediastinal masses, of which thymoma is foremost common.[21] Thymectomy is an appropriate therapy in the great care of MG and in the undetermined anterior mediastinal lesion.[22] Minimal access thymectomy can be performed in all patients of thymic neoplasm who will tolerate single lung ventilation. Minimally invasive methods include transcervical, thoracoscopic, and robotic thymectomy. They decrease postoperative morbidity and mortality particularly in patients with MG.[23,24]

Port Placement in VATS Thymectomy

Three ports are needed. The first port is made with a 5-mm skin incision along the upper edge of sixth ICS in the mid-AL to create

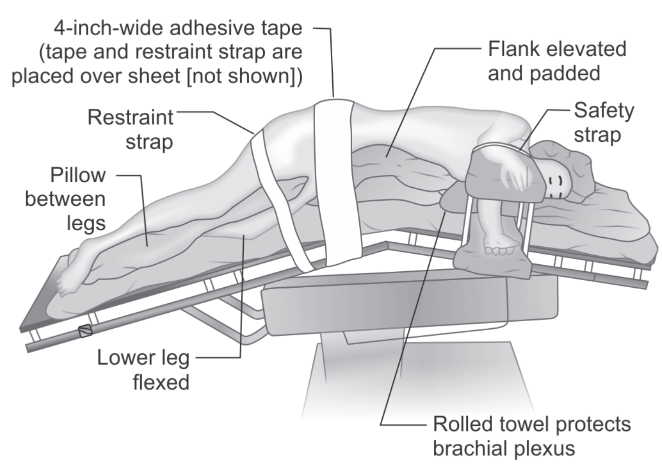

Fig. 6: Standard patient position for video-assisted thoracoscopic surgery

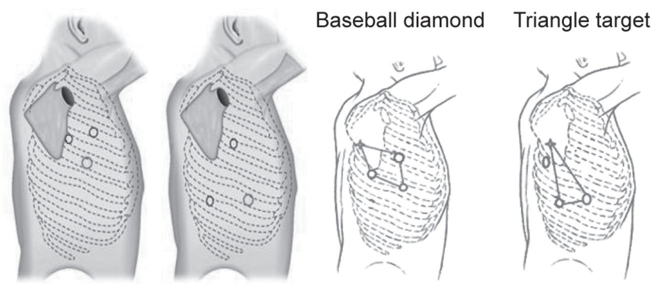

Fig. 7: Ports placement in video-assisted thoracoscopic surgery thymectomy

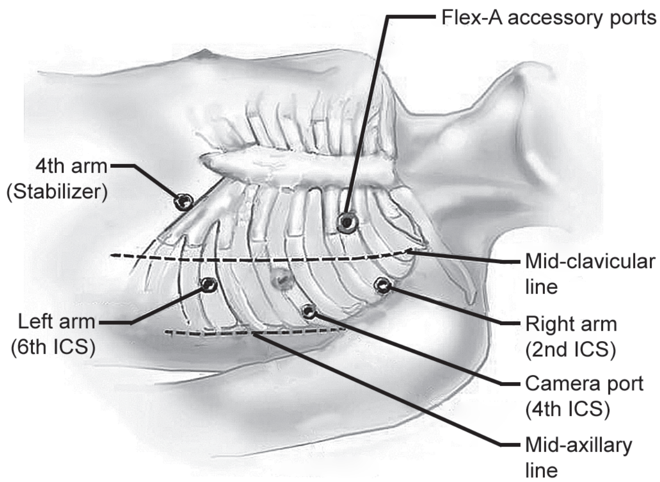

Fig. 9: Port position for endoscopic or robotic CABG

a pneumothorax. A 5-mm port is inserted and 30° thoracoscope is used for inspection of potential adhesions and pathology. CO_2 insufflation to be done using a pressure limit of 6–8 mm Hg. Under vision, a second 5-mm port is inserted in the third intercostal space along the anterior AL and a third 5-mm port is inserted into sixth or seventh intercostal space along the mid-clavicular line (Fig. 7).

ASD Closure

Atrial septal defect is one of the most common congenital heart defects. Currently, many ASDs can be closed with septal occluder devices through cardiac catheterization.[25] But large ASDs may not be appropriate for device closure and require surgical correction.[26] Minimal access surgical approaches are applied to repair ASD to minimize operating trauma and early recovery with better cosmetic results.[27]

Port Placement for ASD Closure

Four trocars to be placed. One 10-mm trocar at fifth intercostal space in the anterior AL for needle holder or knife, one 5-m trocar at third intercostal space in the mid-AL for tissue forceps, one 5-mm trocar at the fifth intercostal space in the mid-AL for camera, and one 5-mm trocar at sixth intercostal space in the mid-AL for sucker (Fig. 8).

IMA Harvesting

Internal mammary artery is the conduit of choice for myocardial revascularization as a result of its higher long-term patency rate and lower occurrence of myocardial infarction and reoperation

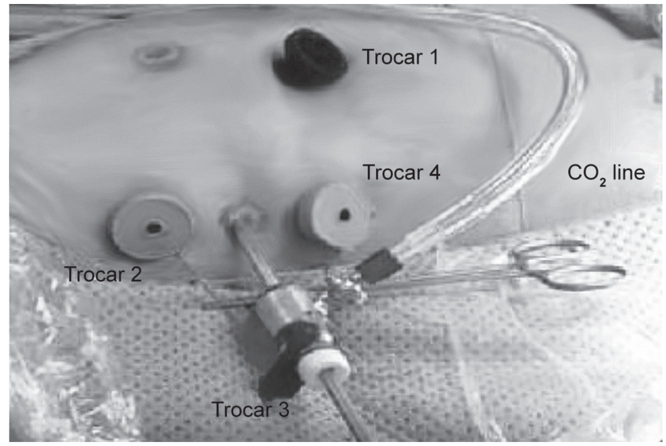

Fig. 8: Trocars position

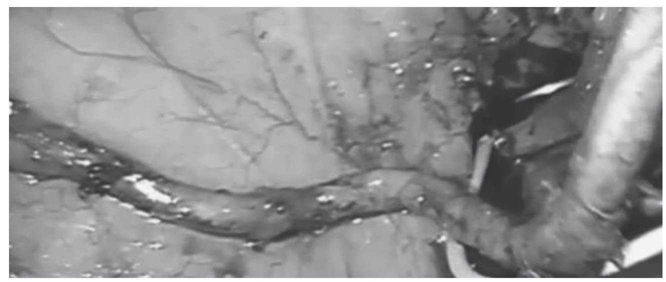

Fig. 10: Thoracoscopically harvested LIMA

compared with vein grafts.[28] Currently, closed chest coronary artery bypass grafting has become reality in several centers worldwide and considered as a safe, secure, less traumatic, and effective alternative to standard open surgery with or without robotic assistance.[29]

Dissection is almost similar to the open technique. In a closed chest environment, instead of a diathermy the harmonic scalpel (HS) is preferable to prevent production of excessive smoke that obscures telescopic vision during dissection.[30] The HS is an ultrasonically activated shaft that vibrates harmonically at 55,500 Hz over a distance of 80 µm.[31] It couples with tissues and mechanically denatures protein by destroying hydrogen bonds among the protein structure.[32] The newly formed disorganized protein creates a sticky coagulum that coapts the vessel walls.

Port Placement (Thoracoscopic Approach)

A 5-mm port at the level of fourth intercostal space for grasper. One 5-mm port at sixth intercostal space on the medial posterior AL for HS. One 10-mm port for the telescope to be placed sixth intercostal space at the level of the anterior AL (Figs 9 and 10).

For Robotic LIMA Harvesting

Robotic assistance greatly enhances the entire harvesting process. The patient has to be placed in the supine position with the left chest slightly elevated and the both arms to be tucked to the chest (Fig. 11).

The daVinci patient cart approaches to the patient from the right side. Deflating the left lung, the camera port is inserted within the fifth intercostal space along the anterior AL. Carbon dioxide is insufflated with a pressure limit between 6 and 8 mm of Hg. The 8-mm right arm port is inserted into the third intercostal space 3 cm anterior to the camera port to avoid conflict of the robotic

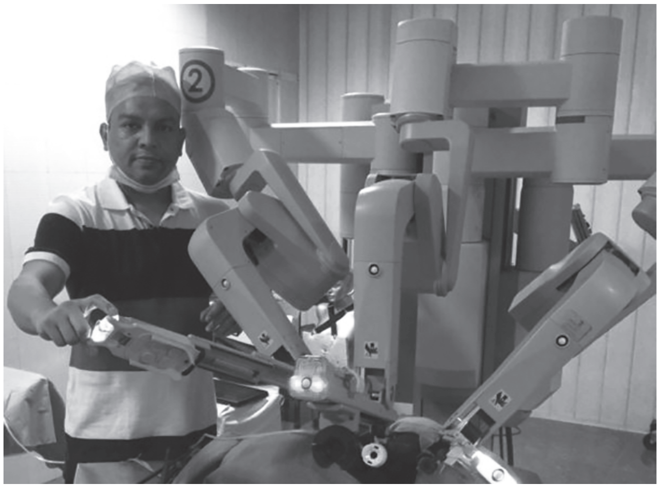

Fig. 11: Positioning daVinci robotic patient cart

arm with the patient's left shoulder. Another 8-mm left arm port is inserted into the seventh intercostal space 3 cm proximal to the camera port. This arrangement provides the triangle principle that is vital for minimal access procedure.

Graft Anastomosis

Time taken to perform the anastomosis is usually 35–45 minutes using the daVinci robot. The number of graft for endoscopic coronary revascularization has to be performed depending on number of lesion, patient clinical status, and comorbidities. The patency of robotic totally endoscopic left internal mammary artery to left anterior descending artery (LIMA-LAD) anastomosis is similar to traditional open procedures.[33–35] Several studies have found the long-term patency is between 92%[34] and 98%.[35] The use of an automated coronary connector like the "Flex-A" stapling device surely reduces endoscopic anastomosis construction time during closed chest off-pump robotic coronary artery bypass grafting (CABG) (Fig. 12).

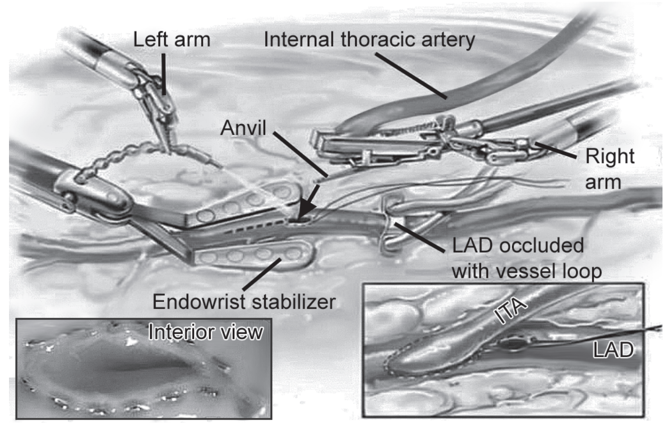

Fig. 12: Technique of anastomosis using a Flex-A device

Esophagectomy

Esophageal cancer is currently the eighth commonest cancer worldwide and also the sixth common reason behind death from cancer.[36] Global incidence of esophageal cancer has increased by 50% within the past two decades.[37] Squamous cell carcinoma is the foremost common esophageal malignancy worldwide; however, the incidence of adenocarcinoma has been increasing rapidly in the Western world.[38] Esophagectomy is the foremost invasive surgery that includes two- or three-compartment dissection, radical lymph adenectomy, and upper gastrointestinal tract reconstruction. As a result, conventional open esophagectomy is related to considerable morbidity and mortality, with complication rates starting from 26 to 41% and perioperative mortality rate is about 4–10%.[39] To overcome these, minimal access techniques came in practice.

Three-stage Mie

The combined thoracolaparoscopic esophagectomy along with cervical anastomosis is a standardized surgical technique to treat esophageal carcinoma through minimal access surgery for better outcome.

The First Stage: Thoracic Phase

VATS Esophageal Mobilization and Lymph Nodes Dissection: The patient is placed in the left lateral prone position leaning forward to 30° with the collapsed right lung. Four trocars to be inserted. A 30° telescope to be introduced through a 10-mm port into seventh/eighth intercostal space along the mid-AL; two 5-mm working ports to be placed in third/fourth and fifth/sixth intercostal space along the anterior AL. One 10-mm working port to be placed in sixth/seventh intercostal space on the subscapular angle line (Fig. 13).

The Second Stage: Abdominal Phase

Laparoscopic Gastric Mobilization and Lymph Nodes Dissection: During the laparoscopic phase, patient to be placed in the supine position. Five ports to be inserted. A 10-mm camera port to be placed below the umbilicus. Pneumoperitoneum established with CO_2 insufflation pressure set at 10–12 cm of H_2O. One 10-mm laparoscope to be used for intra-abdominal inspection. Another 10-mm operating port to be placed at 4 cm above the umbilicus beside the right border of the rectus muscle. A 5-mm operating port to be inserted 2 cm below the right costal margin along the mid-clavicular line. A 10-mm working port to be placed 2 cm above the umbilicus along the left mid-clavicular line. Last, a 5-mm working port to be inserted at the left costal margin along the anterior AL.

The Third Stage: Cervical Anastomosis

Gastric Conduit Formation and Anastomosis: A 3–5 cm incision to be given on the left neck in front of the left sternocleidomastoid and cervical esophagus to be isolated and divided. The dissected tissue then expelled from the thorax outside of the abdomen through subxiphoid incision. A 28–40 cm gastric conduit with 3–4 cm diameter is created using multiple applications of a linear stapler along the lesser curvature starting from right gastric vessels to the stomach fundus. Pulling up the gastric conduit through the posterior mediastinum anastomosis to be done by joining a 24-mm anvil with the end-to-end anastomosis stapler (Figs 14 and 15).

Materials and Methods

This study is a prospective experimental animal study and was conducted at the World Laparoscopy Hospital (WLH) at Gurugram, India

Sample Size Determination

The sample size was calculated using the formula, $n = Z^2pq/d^2$.

Where n = sample size, z = constant at 95% confidence interval = 1.96, p = prevalence = 0.019,[14] $q = 1 - p$ complementary

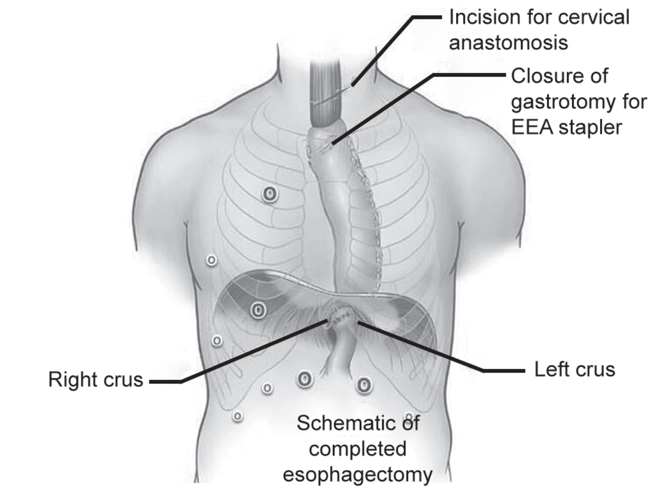

Fig. 13: O-10 and O-5 mm port position and completed task

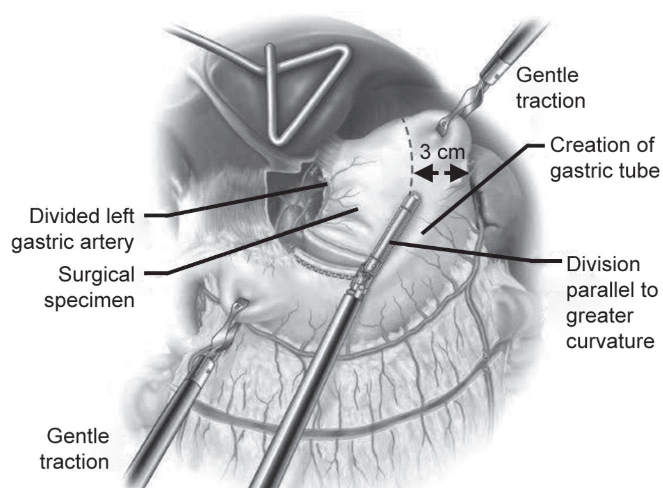

Fig. 14: Preparing gastric conduit

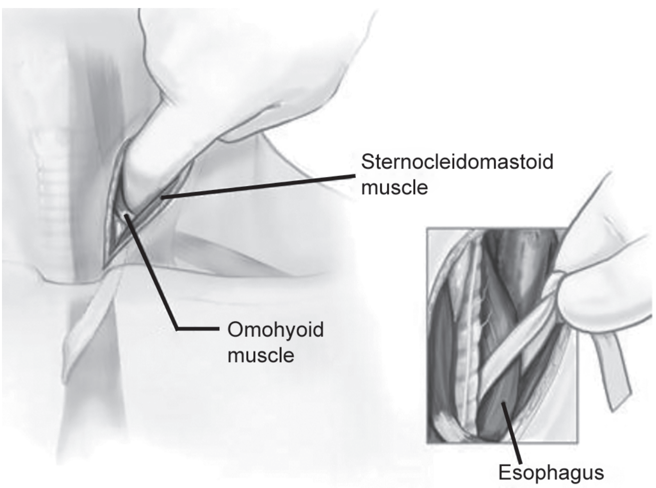

Fig. 15: Cervical incision for anastomosis

probability = 0.991, $d = 0.05$ precision. Thus $n = 1.96^2 \times 0.019 \times 0.991/0.05^2 = 28.93$.

Hence, 30 VATS procedures were done as the sample size.

Data Collection

A total of 30 VATS procedures were conducted on swine at the institute of minimal access surgery, World Laparoscopy Hospital, NCR Delhi, India, over 11 months from January 15, 2018, to November 15, 2018.

Three thoracic and two cardiac surgeries were included. The details of the procedures are: lung resection: 6 (20% of total case), thymectomy: 6 (20% of total case), closure of ASD: 6 (20% of total case), IMA harvesting for TECABG: 6 (20% of total case), and esophagectomy: 6 (20% of total case) on 30 animals through minimal access techniques. Each procedure was done using TTP.

The outcome measures are: the execution time in seconds (port access time plus actual procedure time), error rate (lung perforation, myocardial injury, injury to the great vessels, injury to the phrenic nerve, esophageal perforation, subdiaphragmatic primary trocar entry for esophagectomy and intercostal vessels bleeding for port placement during LIMA harvesting), and the surgeons' discomfort level as analyzed by the visual analogue system (VAS) starting from 110 in increasing the discomfort pattern. These outcome measures recorded for each procedure were entered into a proforma.

The procedures were done after the swine were given general anesthesia. The ports were made using a surgical scalpel and CO_2 insufflation was done to collapse the ipsilateral lung. The camera port was inserted blindly and operating ports were introduced under direct vision. Video-assisted thoracoscopic surgery ASD closure either direct closure or pericardial or PTFE patch using grasper, scissors, retractor, arterial and venous cannula, hook dissector, cardiopulmonary bypass circuit and Heart-Lung machine. The VATS esophagectomy was performed with alternating use of grasper, scissors, and hook dissector. Diathermy and harmonic device were used to perform thymectomy.

Methods of Data Collection and Analysis

The data were recorded in a preconstructed data collection sheet, cleaned and entered into a computer using SPSS version 16 for Windows. The analysis was done using statistical methods such as mean and Chi-square. Results are presented in figures.

Ethical Considerations

The research was an animal study that strictly regulated in India underneath the provisions of Section 15 of the Prevention of Cruelty to Animals Act, 1960, and the principle beneath the Act of 1998 and 2001. It was governed by the Committee for the Purpose of Control and Supervision of Experiments on Animals (CPCSEA).[40] For this analysis, the operational guidelines for Observance of good Practices by the CPCSEA were strictly followed. Permission and approval for procurement of the swine and conduct of the research was obtained from CPCSEA-registered animal breeding houses. At the end of the experiments, euthanasia was conducted and therefore the animals' carcasses were properly disposed according to the guidelines.

Result and Observations

A total of 30 procedures were conducted in this study. The TTP of port placement was applied. Three thoracic and two cardiac procedures were included. The procedures are lung resection, thymectomy, closure of ASD, LIMA harvesting, and esophagectomy. It is to evaluate the execution time (sum of the ports access time and

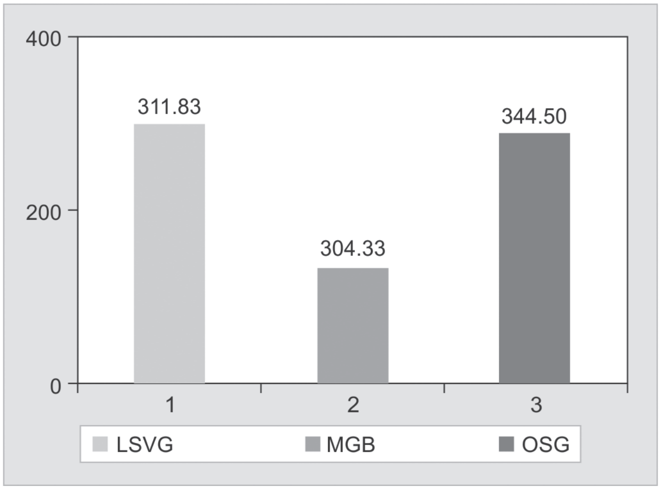

Fig. 16: Average timing in seconds for suturing and tying surgeon's knot in lung resection at 30°, 60°, and 90° port position angles

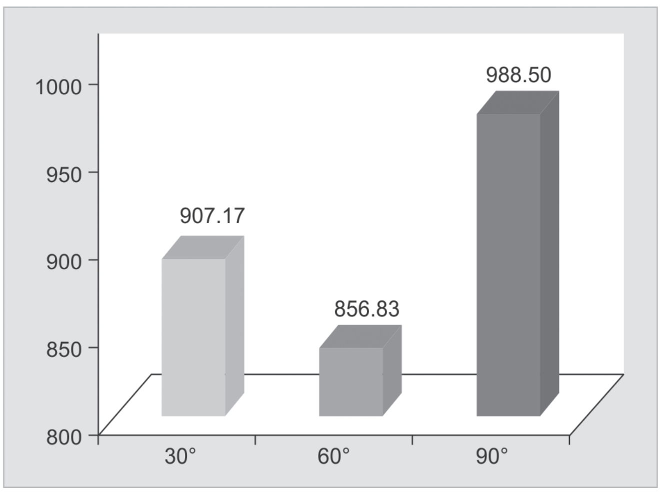

Fig. 18: Average timing for applying an endolinear stapler in lung resection with different manipulation angles

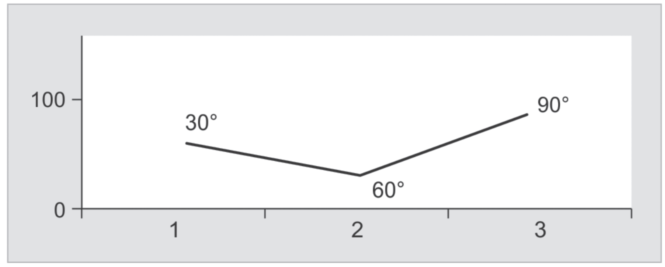

Fig. 17: Surgeon's discomfort level for suturing and tying surgeon's knot in lung resection at 30°, 60°, and 90° port position angles

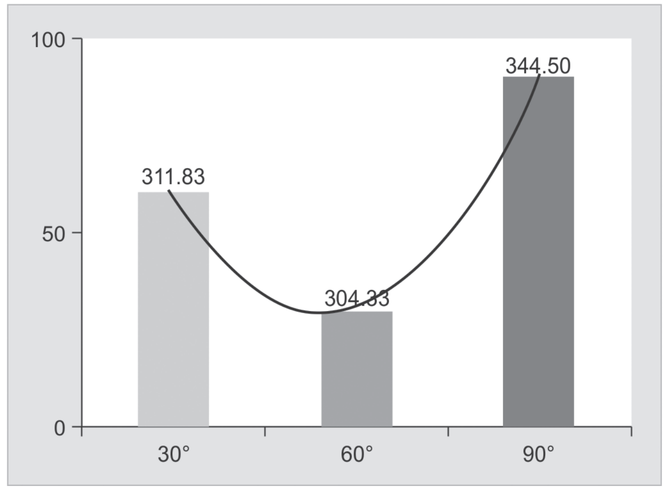

Fig. 19: Surgeon's discomfort level for applying endolinear stapler in lung resection with different manipulation angles

the actual procedure time), error rates. and the surgeon's discomfort for each of the three angles of manipulation.

Lung Resection

Timing for Suturing and Tying Surgeon's Knot in Lung Resection

Average timings (mean time) in seconds for suturing and tying the surgeon's knot in lung resection at 30°, 60°, and 90° angle are 311.83, 304.33, and 344.50, respectively. χ^2 values at those angles are 6.55, 2.73, and 10.84. The lowest time required is at 60° angle manipulation (Figs 16 and 17).

All the readings were reproducible at a *p* value of 30.144 at 5% level of significance. It has been demonstrated that the 60° angle has shorter operative time followed by 30° and then 90°.

Timing for Applying Endolinear Stapler in Lung Resection

Average timings (mean time) in seconds for applying an endolinear stapler in lung resection at 30°, 60°, and 90° angle are 907.17, 856.83, and 988.50, respectively. χ^2 values at those angles are 0.69, 3.94, and 0.74. The lowest time required is at 60° angle manipulation (Figs 18 and 19).

All the readings were reproducible at a *p* value of 30.141 at 5% level of significance. It was found that the 60° angle had shorter operative time followed by 30° and then 90°.

Thymectomy

Timing for Suturing and Tying Surgeon's Knot in Thymectomy

Average timings (mean time) in seconds for suturing and tying surgeon's knot in thymectomy at 30°, 60°, and 90° angle are 222.17, 133.17 and 282.83, respectively. χ^2 values at those angles are 8.39, 7.88, and 8.52. The lowest time required is at 60° angle manipulation (Figs 20 to 23).

Only readings at 30° and 60° were reproducible at a *p* value of 30.141 at 5% level of significance but the χ^2 of readings at 90° was less than the *p* value, indicating nonreproducibility. These suggest that the 60° angle has shorter operative time than 30° and 90° and above.

Timing for clipping in thymectomy.

ASD Closure

Timing For Suturing and Tying Surgeon's Knot in ASD Closure

The average timings in seconds for 30°, 60°, and 90° were 225.67, 128.67 and 293.33, respectively. It was demonstrated that the 60° angle had shorter operative time followed by 30° and then 90°, although all the readings were reproducible at a *p* value of 30.141 at 5% level of significance (Figs 24 and 25).

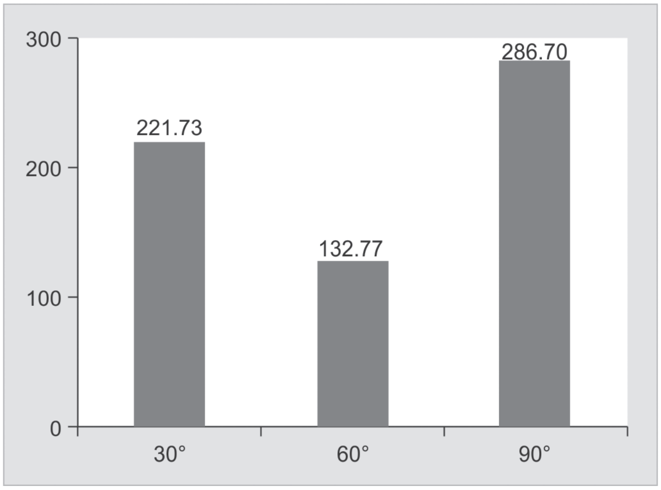

Fig. 20: Average timing for suturing and tying surgeon's knot in thymectomy with different manipulation angles

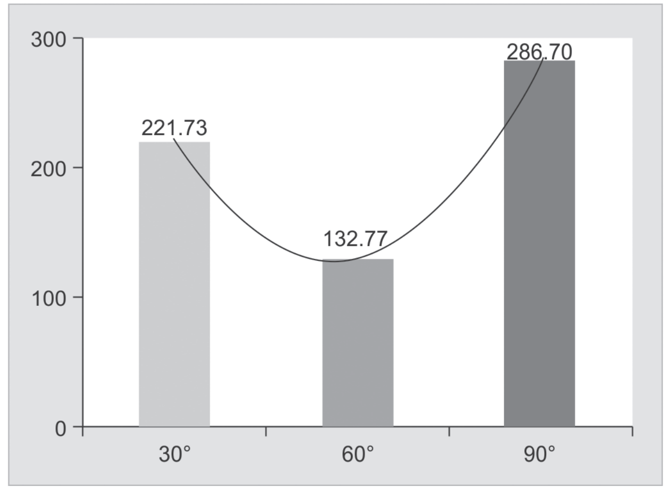

Fig. 21: Surgeon's discomfort level for suturing and tying surgeon's knot in thymectomy with different manipulation angles

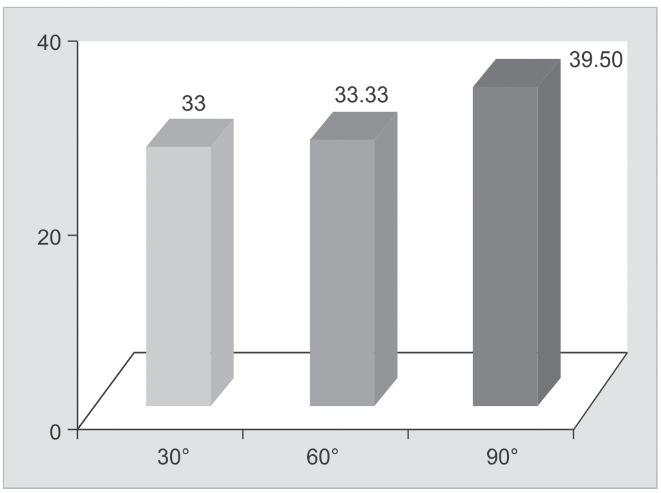

Fig. 22: Average timing for clipping in thymectomy with different manipulation angles

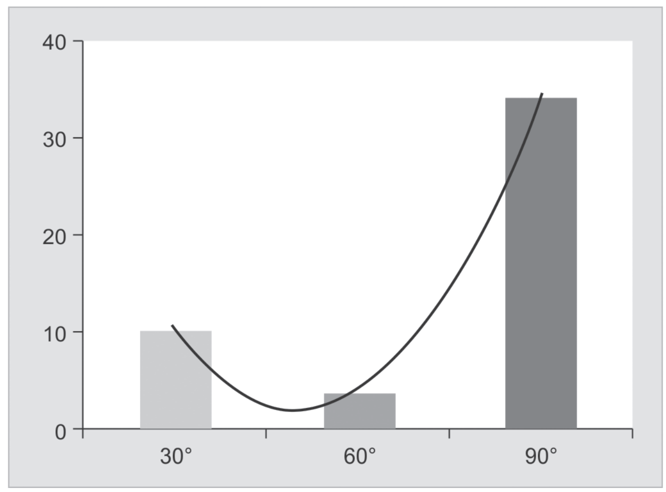

Fig. 23: Surgeon's discomfort level for clipping in thymectomy with different manipulation angles

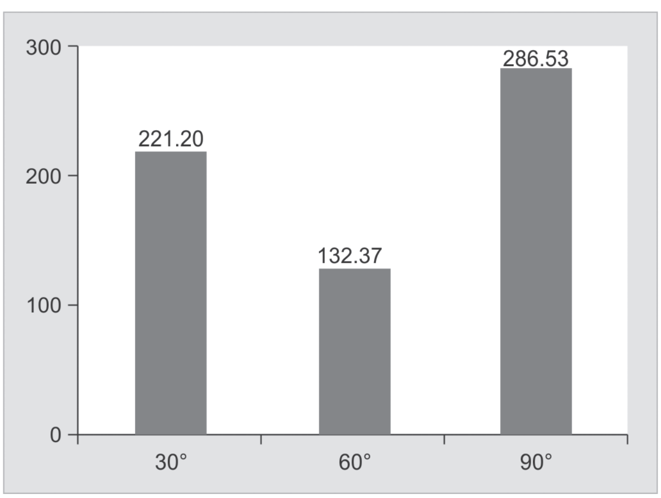

Fig. 24: Average timing for suturing and tying surgeon's knot in atrial septal defect closure with different manipulation angles

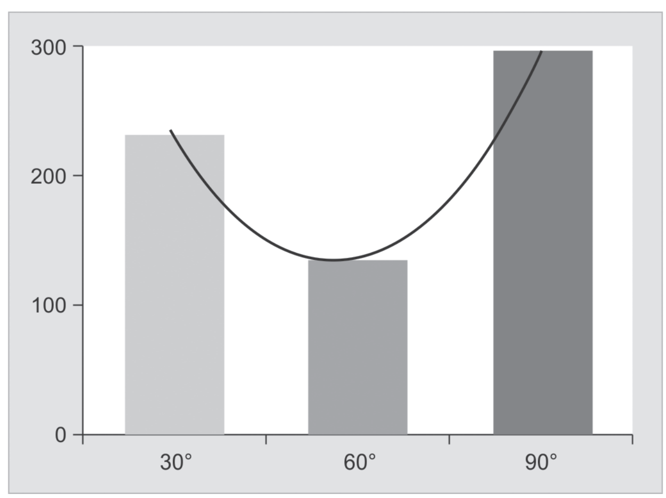

Fig. 25: Surgeon's discomfort level for suturing and tying surgeon's knot in atrial septal defect closure with different manipulation angles

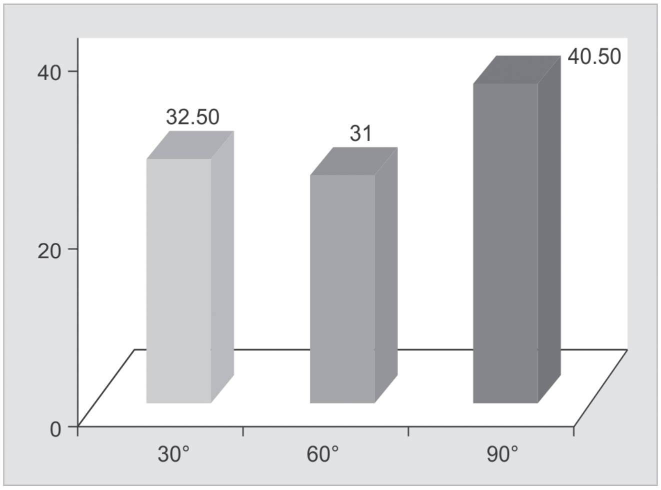

Fig. 26: Average timing for aorta cross-clamping in atrial septal defect closure with different manipulation angles

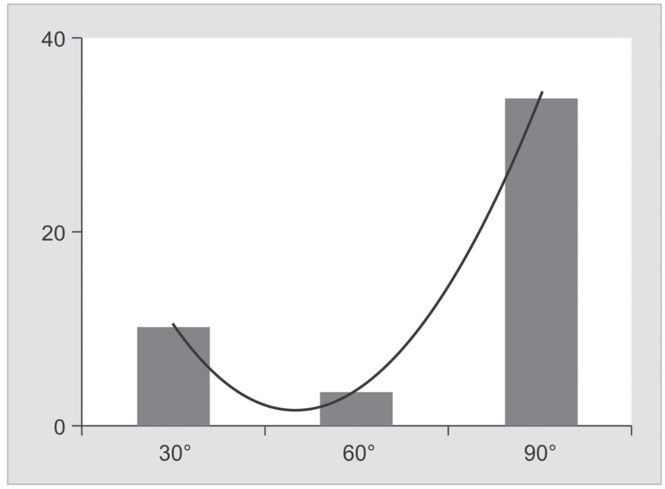

Fig. 27: Surgeon's discomfort level for aorta cross-clamping in atrial septal defect closure with different manipulation angles

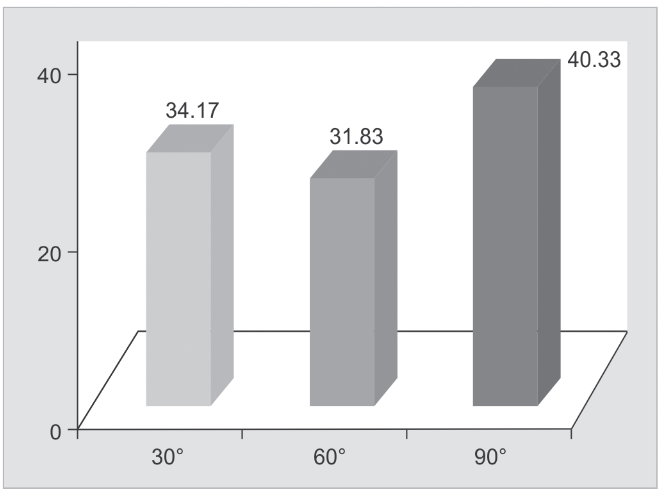

Fig. 28: Average timing for trimming of anastomotic end of LIMA for LAD grafting with different manipulation angles

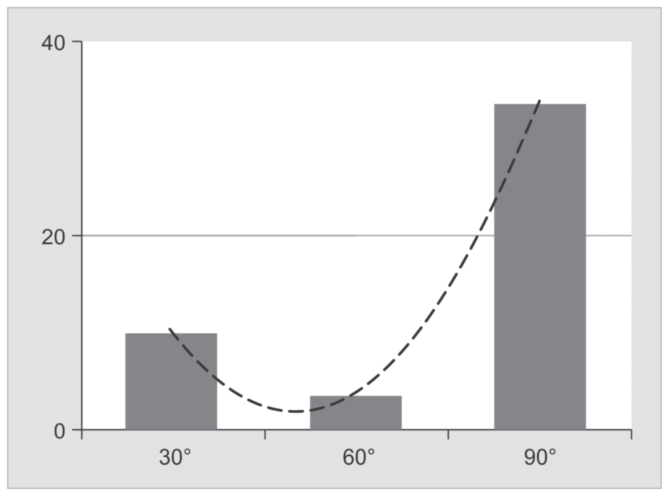

Fig. 29: Surgeon's discomfort level for trimming of anastomotic end of LIMA for LAD grafting with different manipulation angles

Timing for Aorta Cross-clamping in ASD Closure

Average timings (mean time) in seconds for aorta cross-clamping in ASD closure at 30°, 60°, and 90° angle are 32.50, 31.00, and 40.50, respectively. χ^2 values at those angles are 2.88, 1.48, and 1.52. The lowest time required is at 60° angle manipulation (Figs 26 and 27).

The average timings in seconds for 30°, 60°, and 90° were 32.50, 31.00, and 40.50 respectively. All the readings were reproducible at a *p* value of 30.141 at 5% level of significance. It was demonstrated that the 60° angle had shorter operative time followed by 30° and then 90°.

IMA Harvesting

Timing for Trimming of Anastomotic End of LIMA for LAD Grafting

Average timings (mean time) in seconds for trimming of the anastomotic end of LIMA for LAD grafting at 30°, 60°, and 90° angle are 34.17, 31.83, and 40.33, respectively. χ^2 values at those angles are 1.42, 1.28, and 1.52. The lowest time required is at 60° angle manipulation (Figs 28 and 29).

The average timings in seconds for 30°, 60°, and 90° were 34.17, 31.83, and 40.33 respectively. Here it is observed that only the readings at 60° manipulation angle were reproducible at a *p* value of 30.141 at 5% level of significance, which further support any port position that will provide working angle of 60° as the ideal.

Timing for Grafting of Harvested LIMA to LAD in TECABG

Average timings (mean time) in seconds for grafting harvested LIMA to LAD in TECABG at 30°, 60°, and 90° angle are 2110.83, 2097.33, and 2146.17, respectively. χ^2 values at those angles are 0.21, 0.11, and 0.14. The lowest time required is at 60° angle manipulation (Figs 30 and 31).

Esophagectomy

Timing for Suturing and Tying the Surgeon's Knot in esophagectomy

Average timings (mean time) in seconds for suturing and tying the surgeon's knot in esophagectomy at 30°, 60°, and 90° angle are 340.33, 304.50, and 359.33, respectively. χ^2 values at those angles

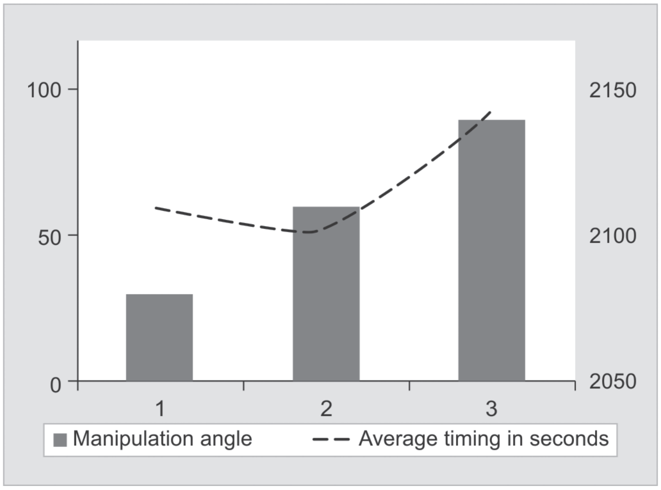

Fig. 30: Average timing for grafting of harvested LIMA to LAD in TECABG

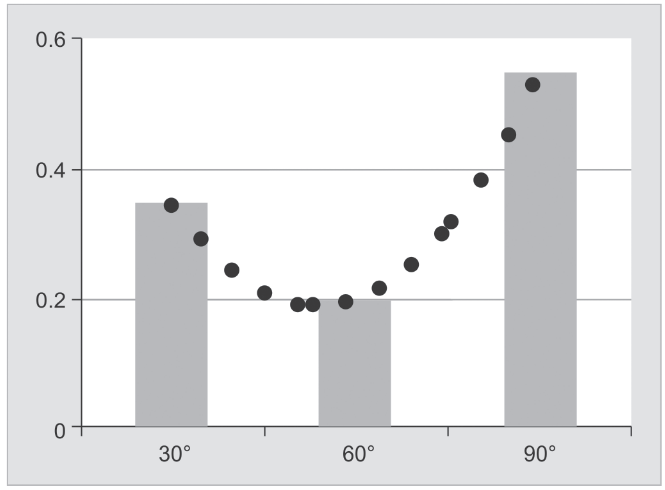

Fig. 31: Surgeon's discomfort level for grafting harvested LIMA to LAD in TECABG

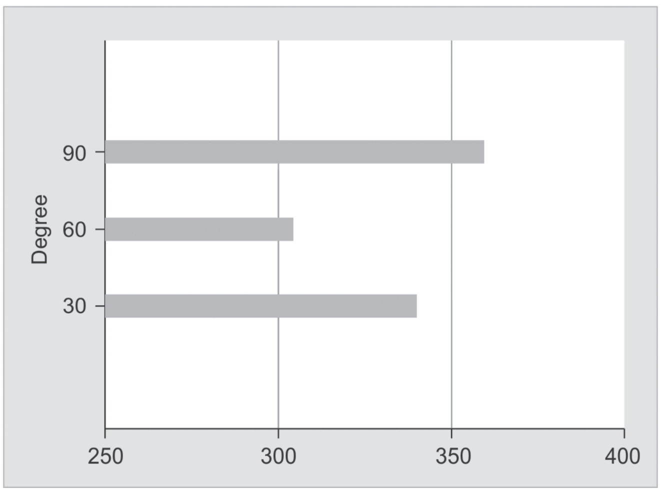

Fig. 32: Average timing in seconds for suturing and tying surgeon's knot in esophagectomy at 30°, 60°, and 90° port position angles

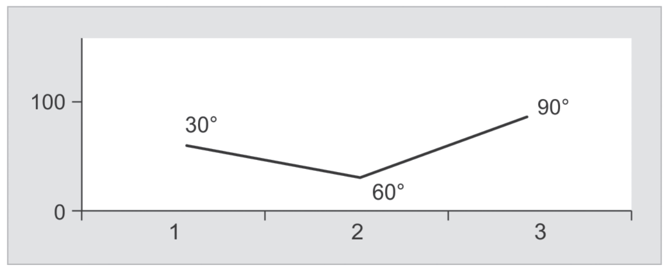

Fig. 33: Surgeon's discomfort level for suturing and tying surgeon's knot in esophagectomy at 30°, 60°, and 90° port position angles

are 1.09, 0.29, and 0.48. The lowest time required is at 60° angle manipulation (Figs 32 and 33).

The average timings in seconds for 30°, 60°, and 90° were 340.33, 304.50, and 359.33, respectively. The first two readings were reproducible at a p value of 30.141) at 5% level of significance. It was found that the 60° angle has shorter operative time than that of 30° and 90° angle. It shows increased difficulties and time consumption when ports are placed in such a manner that will give working angles of 90° and above.

Timing for Purse String Suture Placement for a Circular Stapler in Esophagectomy

Average timings (mean time) in seconds for purse string suture placement for a circular stapler in esophagectomy at 30°, 60°, and 90° angle are 635.50, 598.50, and 659.33, respectively. χ^2 values at those angles are 0.34, 0.18, and 0.26. The lowest time required is at 60° angle manipulation.

From above discussions, with 60° manipulation angle the average timings of all tasks were shorter and all were reproducible. All the tasks were difficult and time-consuming when they were followed by 30° and 90° angle. The closer the manipulation angle is to the 90° and above, the more likely it is to take longer operative time. It might be due to fatigue from increased elevation angle and overstretching of the shoulder (Figs 34 and 35).

From above figures and discussion, it is obvious that the surgeon's discomfort level is least at the 60° port position.

Discussion

A total of 30 procedures were done in this prospective experimental animal study. The TTP of port placement was used. Three thoracic and two cardiac procedures were included. The details of the procedures are as follows: lung resection—6 (20% of total case), thymectomy—6 (20% of total case), closure of ASD—6 (20% of total case), IMA harvesting for TECABG—6 (20% of total case), and esophagectomy—6 (20% of total case) on 30 animals through minimal access techniques.

Execution time (sum of the ports access time and the actual procedure time), error rates, and the surgeon's discomfort for each of the three angles of manipulation were evaluated.

Lung Resection

Timing for Suturing and Tying Surgeon's Knot in Lung Resection

In this study, it was found that average timings (mean time) in seconds for suturing and tying surgeon's knot in lung resection at 30°, 60°, and 90° angle are 311.83, 304.33, and 344.50, respectively. χ^2 values at those angles are 6.55, 2.73, and 10.84. The lowest time required is at 60° angle manipulation.

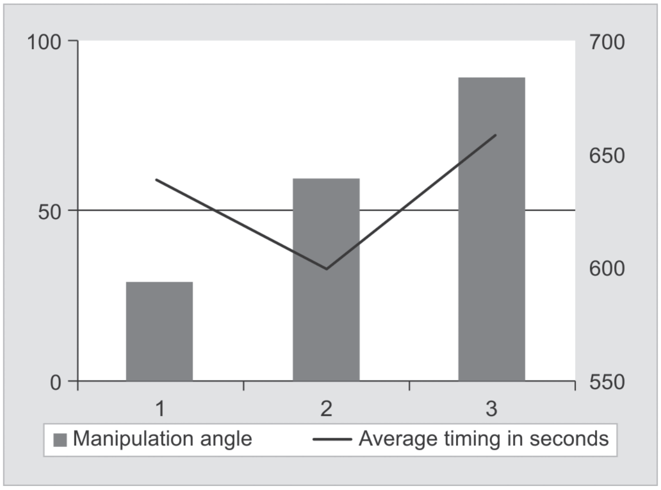

Fig. 34: Average timing for purse string suture placement for a circular stapler in esophagectomy with different manipulation angles

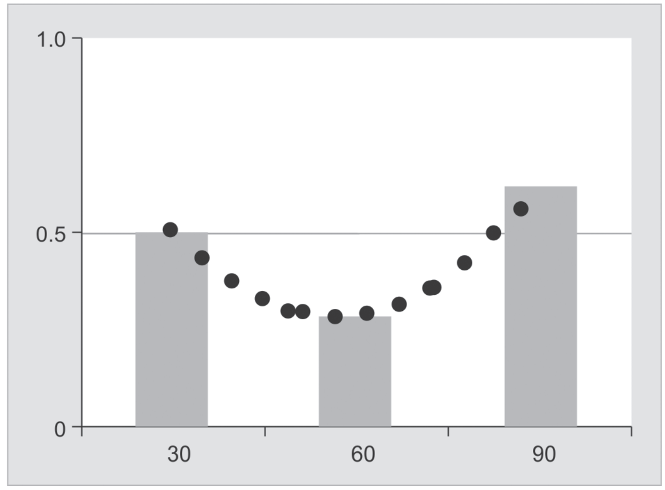

Fig. 35: Surgeon's discomfort level for purse string suture placement for a circular stapler in esophagectomy

Readings of timing obtained while taking a suturing and tying surgeon's knot in lung resection on swine at different manipulation angles (30°, 60°, 90°) were validated and average obtained by χ^2 tests. All the readings were reproducible at a *p* value of 30.144 at 5% level of significance. It was demonstrated that the 60° angle had shorter operative time followed by 30° and then 90°.

These findings were supported by some other studies. Yunusa et al. and Ismail and Mishra also mentioned that 60° angle has shorter operative time followed by 30° and then 90°.

Timing for Applying Endolinear Stapler in Lung Resection

Average timings (mean time) in seconds for applying an endolinear stapler in lung resection at 30, 60°, and 90° angle are 907.17, 835.00, and 988.50, respectively. χ^2 values at those angles are 0.69, 0.58 and 0.74. The lowest time required is at 60° angle manipulation.

Readings of timing obtained while applying an endolinear stapler in lung resection in swine at different manipulation angles (30°, 60°, 90°) were shown, which were validated and average obtained by χ^2 tests. The average timings in seconds for 30°, 60°, and 90° were 907.17, 835.00, and 988.50, respectively. All the readings were reproducible at a *p* value of 30.141 at 5% level of significance. It was demonstrated that the 60° angle had shorter operative time followed by 30° and then 90°.

Similar findings were demonstrated by some other researchers.[8,10]

Thymectomy

Timing for Suturing and Tying Surgeon's Knot in thymectomy

Average timing (mean time) in seconds for suturing and tying surgeon's knot in thymectomy at 30, 60 and 90° angle is 222.17, 133.17, and 282.83, respectively. χ^2 values at those angles are 8.39, 7.88, and 8.52. The lowest time required is at 60° angle manipulation.

Readings of timing taken for suturing and tying a surgeon's knot in thymectomy in swine at different manipulation angles, which were validated by the χ^2 test and average obtained. The average timings in seconds for 30°, 60° and 90° were 222.17, 133.17, and 282.83, respectively. Only readings at 30° and 60° were reproducible at a *p* value of 30.141 at 5% level of significance but the χ^2 of readings at 90 was less than the *p* value, indicating nonreproducibility. These suggest that the 60° angle has shorter operative time than the 30° and 90° and above.

These findings were consistent with some other researchers.[8,10]

Timing for Clipping in Thymectomy

Average timings (mean time) in seconds for clipping in thymectomy at 30°, 60°, and 90° angle are 33.00, 32.33, and 39.50, respectively. The χ^2 values at those angles are 3.03, 0.91, and 1.46. The lowest time required is at 60° angle manipulation.

Similar findings were found by some other researchers.[8,10]

ASD Closure

Timing for Suturing and Tying Surgeon's Knot in ASD Closure

Average timing (mean time) in seconds for suturing and tying surgeon's knot in ASD closure at 30°, 60°, and 90° angle are 225.67, 128.67, and 293.33 respectively. χ^2 values at those angles are 12.33, 10.21, and 11.15. The lowest time required is at 60° angle manipulation.

Readings of timing taken to suturing and tying surgeon's knot in ASD closure in swine at different manipulation angles are shown, which were validated by χ^2 test and means obtained. The average timing in seconds for 30°, 60°, and 90° were 225.67, 128.67, and 293.33, respectively. It was clearly demonstrated that the 60° angle had shorter operative time followed by 30° and then 90°, although all the readings were reproducible at a *p* value of 30.141 and 5% level of significance.

Different studies showed similarity with the present study.[8,10]

Timing for Aorta Cross-clamping in ASD Closure

Average timings (mean time) in seconds for aorta cross-clamping in ASD closure at 30°, 60°, and 90° angle are 32.50, 31.00, and 40.50, respectively. χ^2 values at those angles are 2.88, 1.48, and 1.52. The lowest time required is at 60° angle manipulation.

The average timings in seconds for 30°, 60°, and 90° are 32.50, 31.00, and 40.50, respectively. All the readings were reproducible at a *p* value of 30.141 at 5% level of significance. It was demonstrated that the 60° angle had shorter operative time followed by 30° and then 90°.

Similar findings were observed by some other researchers.[8,10]

IMA (LIMA) Harvesting

Timing for Trimming of Anastomotic End of LIMA for LAD Grafting

Average timings (mean time) in seconds for trimming of the anastomotic end of LIMA for LAD grafting at 30°, 60°, and 90° angle are 34.17, 31.83, and 40.33, respectively. χ^2 values at those angles are 2.42, 1.28, and 1.52. The lowest time required is at 60° angle manipulation.

Readings of timing taken for trimming of the anastomotic end of LIMA for LAD grafting of swine at different manipulation angles are shown, which were validated by the χ^2 test and average obtained. The average timings in seconds for 30°, 60°, and 90° were 34.17, 31.83, and 40.33, respectively. Here it is observed that only the readings at 60° manipulation angle were reproducible at a p value of 30.141 at 5% level of significance, which further support any port position that will provide working angle of 60° as the ideal.

Some other researchers found similar findings.[8,10]

Timing for Grafting of Harvested LIMA to LAD in TECABG

Average timings (mean time) in seconds grafting harvested LIMA to LAD in TECABG at 30°, 60°, and 90° angle are 2110.83, 2097.33, and 2146.17, respectively. X^2 values at those angles are 0.21, 0.11, and 0.14. The lowest time required is at 60° angle manipulation.

Similar findings were explored by some other researchers.[8,10]

Esophagectomy

Timing for Suturing and Tying Surgeon's Knot in Esophagectomy

Average timings (mean time) in seconds for suturing and tying surgeon's knot in esophagectomy at 30°, 60°, and 90° angle are 340.33, 304.50, and 359.33, respectively. χ^2 values at those angles are 1.09, 0.29, and 0.48. The lowest time required is at 60° angle manipulation.

Readings of timing of suturing and tying surgeon's knot in esophagectomy of swine at different manipulation angles are shown, which were validated by χ^2 tests and average obtained. The average timings in seconds for 30°, 60°, and 90° were 340.33, 304.50, and 359.33, respectively. Despite the facts that the first two readings were reproducible at a p value of 30.141 at 5% level of significance, it was demonstrated that the 60° angle had shorter operative time than that of 30° and 90° angle. It indicates increased difficulties and time consumption when ports are positioned in such a way that will give working angle of 90° and above.

Similarity of these findings were found by some other researchers.[8,10]

Timing of Purse String Suture Placement for Circular Stapler in Esophagectomy

Average timings (mean time) in seconds for purse string suture placement for a circular stapler in esophagectomy at 30°, 60°, and 90° angle are 635.50, 598.50, and 659.33, respectively. X^2 values at those angles are 0.34, 0.18, and 0.26. The lowest time required is at 60° angle manipulation.

Similar findings were found by some other researchers.[8,10]

From above discussions, the average timings of all tasks were shorter with 60° manipulation and all were reproducible. Irrespective of the difficulty of the tasks then, it was followed by 30° and 90° angle. The closer the manipulation angle is to the 90° and above, the more the likely to take longer operative time. It may be due to fatigue from increased elevation angle and shoulder overstretching.

From above figures and discussion, it is obvious that a surgeon's discomfort level is least at the 60° port position.

Fortunately, no errors during surgical procedures occurred. But in some other studies different errors occurred during surgical task performance.[8,10]

Regarding surgeon's discomfort, 30° and 90° angles were revealed as discomfortable port positions, whereas 60° angle of manipulation showed a more comfortable position. Though 60° angle showed some discomfort in a few cases, but it was not significant. In their article, Yunusa et al. mentioned that the BDP is the standard principle for deciding sites of port placement during VATS.[8,10] It is the conventional principle to which other principles are compared. The TTP was discovered as an alternative principle where BDP is associated with difficulties especially in lung procedures.

In a study of VATS pericardial window, Yunusa et al. found similar results. The result showed that using the TTP for ports placement led to a longer execution time with a mean distinction of 93 seconds. Error rates and surgeons' discomfort were almost similar.

They explained the prolonged execution time might be due to the mirror image production when TTP is employed. The scissors and grasping forceps were usually alternated between the operating port and the target port during the procedure to adapt the various orientations for resecting the pericardial segment. The mirror image distorts the visuals, so the orientation causes prolongation of execution time.

They also mentioned that with more experience this problem might be solved by maintaining the grasping forceps in the target port and incise the pericardium with a scissor through the operating port.

They discussed that TTP might have a role when dealing with pericardial lesions requiring digital palpation and stapling in case of pericardial cysts. The manipulation angle between the grasping forceps and the stapler (through the target and operating ports) is then 90° that is the proper angle for stapling. When BDP is employed in this scenario, an alternate access might be needed for the stapler to get this angle.

In that study, they explained that BDP is preferable for ports placement during the VATS pericardial procedure but TTP might have clear advantages when dealing with pericardial lesions requiring digital palpation and stapling.

In this present study, it was also found that the 60° angle of manipulation is advantageous for ASD closure and some other procedures.

In VATS esophagocardiomyotomy, Ismail and Mishra and Yunusa et al. found almost similar results. From the results, the execution time for VATS esophagocardiomyotomy using BDP for ports placement was more than when TTP was used. This is in contrast to the results of the errors rates and surgeons' discomfort that were more when TTP was used.

In the study of Yunusa et al., one episode of esophageal perforation was recorded when using the BDP while two major errors (esophageal perforation and descending aortic injury) were recorded when TTP was employed. This is vital as it translates to 33.3% error rate. But fortunately, no such error occurred in the present study.

They found that the surgeon's discomfort using TTP was worse with an average of 7 compared to 5.83 recorded for BDP, which was contrary with the present study.

They mentioned that the increased error rates and surgeon's discomfort can be explained by the mirror image produced when using TTP and the flimsy nature of the swine tissue giving rise to injury to the esophagus and the encircling structures even with minimal force.

The prolongation of the execution time when BDP was used which is in contrast to the trends of the error rates and the surgeon's discomfort might have been due to the increased error rates in TTP use. When these major errors are encountered, the procedure does not typically proceed and the execution time when using TTP is recorded as shortened. This calls for more data from larger sample size to revalidate this and provide more explanations.

The observed BDP seems to be better than the TTP of ports placement for VATS esophagocardiomyotomy in terms of the error rates and the surgeon's discomfort, although it took longer time to be executed.

They concluded that the TTP might have clear benefit over BDP when treating different esophageal diseases requiring stapling such as esophageal diverticulum or during esophagectomy because of the 90° manipulation angle between the grasping forceps and the stapler. It clearly supports the present study.

Yunusa et al. and Ismail performed study on VATS thoracic sympathectomy in 2014. They had almost similar results and observations, which were consistent with this study where thymectomy was done instead.

They found that the execution time for VATS thoracic sympathectomy when using the TTP was less than when BDP was applied (mean difference of 194 seconds). However, the execution time data are not statistically significant and therefore not reproducible ($\chi^2 = 21.04$ at p value of 11.07). Thus, there might be need for a larger sample to reassess its reproducibility and then objectively compare it with the TTP. The BDP and the TTP are comparable in terms of the error rates and the surgeon's discomfort. I also recommend it.

They concluded that it can also be seen that TTP is comparable or more favorable to BDP when the instrument through the target port is employed for retraction only and not for other manipulations. When used for different purposes, the mirror image produced will lead to reduced task performance and increased surgeon's discomfort. It is also consistent with my observations.

Conclusion and Recommendations

Conclusion

The BDP is the standard principle used to decide sites of port placement during VATS. The TTP was introduced as an alternative principle when problem was observed during some procedures using the BDP particularly in lung procedures. The TTP could provide more benefit when the instruments through the target port are used only for retraction. It might also be preferred in VATS procedures where stapling could be required. The manipulation angle of 60° in TTP is found more favorable than 30° and 90° angles, but it requires further evaluation with a large data.

Recommendations

The TTP should be preferred when the instrument through the target port is employed only for retraction or stapling will be required and BDP should be preferred when stapling might not be required.

The duration for the study is also short. A long cohort should be conducted to have a more reproducible and validated result.

There should be caution when translating this data to humans as the swines have some peculiarities such as flimsy tissues and shortened thoracic space. Surgical simulation using animal models may be the high fidelity method and should be encouraged whenever feasible. Sheep can be an alternative to the swine as they have stronger tissues.

Limitations

The sample size is small. It may affect the extrapolation of the results. This is because the study on animal models is guided by stringent legislations and requirements, which limit the sources.

The swine are smaller and adult VATS instruments were used. So, some ergonomic difficulties are obvious. The appropriate location of the intercostal spaces and ports placement were more challenging. Translation of the data to humans may also be affected by some differences with the swine as the space between the anterior and posterior ALs and the intercostal spaces are narrower than those in human. There could be other confounding variables such as dysfunctional instruments that could have impacted on the measures of outcome.

References

1. Shields T. General Thoracic Surgery. Lippincott Williams & Wilkins; 2004. p. 524.
2. McKenna RJ,Jr, Houck W, Fuller CB. Video-assisted thoracic surgery lobectomy: experience with 1,100 cases. Ann Thorac Surg 2006;81(2):421–425. DOI: 10.1016/j.athoracsur.2005.07.078.
3. De Silva MC, Swanson SJ. Video-assisted thoracic surgery in ACS surgery: principles and practice. 4th ed., ch. 10, Canada: Decker Intellectual Properties; 2010.
4. Lewis RJ, Caccavale RJ, Silver GE, et al. One hundred consecutive patients undergoing video-assisted thoracic operations. Ann Thorac Surg 1992;54(3):421–426. DOI: 10.1016/0003-4975(92)90431-3.
5. Agasthian T. Revisiting the prone position in video-assisted thoracoscopic surgery. Asian Cardiov Thorac Ann 2010;18(4):364–367. DOI: 10.1177/0218492310375857.
6. Swanson SJ, Miller DL, McKenna RJ, Jr, et al. Comparing robot-assisted thoracic surgical lobectomy with conventional video-assisted thoracic surgical lobectomy and wedge resection: results from a multihospital database (Premier). J Thorac Cardiovasc Surg 2014;147(3):929–937. DOI: 10.1016/j.jtcvs.2013.09.046.
7. Bertolaccini L, Rocco G, Viti A, et al. Geometrical characteristics of uniportal VATS. J Thorac Dis 2013.
8. Ismail AJ, Mishra RK. Comparing task performance and comfort during nonpulmonary video-assisted thoracic surgery procedures between the application of the 'baseball diamond' and the 'triangle target' principles of port placement in swine models. World J Lap Surg 2014;7(2):1–6.
9. Manasnayakorn S, Cuschieri A, Hanna GB. Ergonomic assessment of optimum operating table height for hand-assisted laparoscopic surgery. Surg Endosc 2009;23(4):783–789. DOI: 10.1007/s00464-008-0068-9.
10. Yunusa B, Mishra RK, Chowhan JS. Is there an ideal port position for laparoscopic urological procedures? World J Lap Surg 2014;7(2):74–87. DOI: 10.5005/jp-journals-10007-1221.
11. Hansen HJ, Petersen RH, Christensen M. Video-assisted thoracoscopic surgery (VATS) lobectomy using a standardized anterior approach. Surg Endosc 2011;25(4):1263–1269. DOI: 10.1007/s00464-010-1355-9.
12. Menozzi M, von Buol A, Krueger H, et al. Direction of gaze and comfort: discovering the relation for the ergonomic optimization of visual tasks. Ophthalmic Physiol Opt 1994;14(4):393–399. DOI: 10.1111/j.1475-1313.1994.tb00131.x.
13. Hanna GB, Shimi SM, Cuschieri A. Task performance in endoscopic surgery is influenced by location of the image display. Ann Surg 1998;227(4):481–484. DOI: 10.1097/00000658-199804000-00005.

14. Trejo A, Jung MC, Oleynikov D, et al. Effect of handle design and target location on the insertion and aim with a laparoscopic surgical tool. Appl Ergon 2007;38(6):745–753. DOI: 10.1016/j.apergo.2006.12.004.
15. Manasnayakorn S, Cuschieri A, Hanna GB. Ideal manipulation angle and instrument length in hand-assisted laparoscopic surgery. Surg Endosc 2008;22(4):924–929. DOI: 10.1007/s00464-007-9520-5.
16. Ergonomics DeU. And laparoscopy. Indian J Surg 2005;67:164–166.
17. Mishra RK. Textbook of Practical Laparoscopic Surgery. 3rd ed., New Delhi, India: Jaypee Brothers Medical Publishers (P) Limited; 2013.
18. Sasaki M, Harai S, Kawabe M, et al. Triangle target principle for trocar placement during video-assisted thoracic surgery. Eur J Cardiothorac Surg 2005;27(2):307–312. DOI: 10.1016/j.ejcts.2004.10.042.
19. Takao M, Tarukawa T, Shimamoto A, et al. Principle of video-assisted thoracic surgery—letter to the editor. Eur J Cardiothorac Surg 2005;28(4):657–664. DOI: 10.1016/j.ejcts.2005.06.021.
20. Davenport E, Malthaner RA. The role of surgery in the management of thymoma: a systematic review. Ann Thorac Surg 2008;86(2):673–684. DOI: 10.1016/j.athoracsur.2008.03.055.
21. Jaretzki A, Steinglass KM, Sonett JR. Thymectomy in the management of myasthenia gravis. Semin Neurol 2004;24(01):49–62. DOI: 10.1055/s-2004-829596.
22. Keating CP, Kong YX, Tay V, et al. VATS thymectomy for nonthymomatous myasthenia gravis: standardized outcome assessment using the myasthenia gravis foundation of America clinical classification. Innovations (Phila) 2011;6(2):104–109. DOI: 10.1097/imi.0b013e3182165cdb.
23. Keijzers M, de Baets M, Hochstenbag M, et al. Robotic thymectomy in patients with myasthenia gravis: neurological and surgical outcomes. Eur J Cardiothorac Surg 2015;48(1):40–45. DOI: 10.1093/ejcts/ezu352.
24. Rea F, Marulli G, Bortolotti L, et al. Experience with the "da Vinci" robotic system for thymectomy in patients with myasthenia gravis: report of 33 cases. Ann Thorac Surg 2006;81(2):455–459. DOI: 10.1016/j.athoracsur.2005.08.030.
25. DiBardino DJ, McElhinney DB, Kaz AK, et al. Analysis of the US Food and Drug Administration Manufacturer and user facility device experience database for adverse events involving Amplatzer septal occluder devices and comparison with the Society of Thoracic Surgery congenital cardiac surgery database. J Thorac Cardiovasc Surg 2009;137(6):1334–1341. DOI: 10.1016/j.jtcvs.2009.02.032.
26. Doll N, Walther T, Falk V, et al. Secundum ASD closure using a right lateral minithoracotomy five-year experience in 122 patients. Ann Thorac Surg 2003;75(5):1527–1531. DOI: 10.1016/s0003-4975(02)04889-0.
27. Vistarini N, Aiello M, Mattiucci G, et al. Port-access minimally invasive surgery for atrial septal defects: a 10-year single-center experience in 166 patients. J Thorac Cardiovasc Surg 2010;139(1):139–145. DOI: 10.1016/j.jtcvs.2009.07.022.
28. Olearchyk AS, Magovern GJ. Internal mammary artery grafting. clinical results, patency rates and long-term survival in 833 patients. J Thorac Cardiovasc Surg 1983;92(6):1082–1087. DOI: 10.1016/S0022-5223(19)35824-6.
29. Vassiliades TAJr, Cosgriff N, et al. Superiority of using bipolar radiofrequency energy for internal mammary artery Harvesting. Ann Thorac Surg 2007;83(4):1508–1512. DOI: 10.1016/j.athoracsur.2006.08.014.
30. Jatene FB, Pêgo-Fernandes PM, Hayata ALS, et al. VATS for complete dissection of LIMA in minimally invasive coronary artery bypass grafting. Ann Thorac Surg 1997;63(6):S110–S113. DOI: 10.1016/S0003-4975(97)00427-X.
31. Ohtsuka T, Wolf RK, Hiratzka LF, et al. Thoracoscopic internal mammary artery harvest for MICABG using the harmonic scalpel. Ann Thorac Surg 1997;63(6 Suppl):S107–S109. DOI: 10.1016/s0003-4975(97)00292-0.
32. Amaral JF. The experimental development of an ultrasonically activated scalpel for laparoscopic use. Surg Laparosc Endosc 1994;4(2):92–99.
33. Bonaros N, Schachner T, Lehr E, et al. Five hundred cases of robotic totally endoscopic coronary artery bypass grafting: predictors of success and safety. Ann Thorac Surg 2013;95(3):803–812. DOI: 10.1016/j.athoracsur.2012.09.071.
34. Folliguet TA, Dibie A, Philippe F, et al. Robotically-assisted coronary artery bypass grafting. Cardiol Res Pract 2010;2010:175450. DOI: 10.4061/2010/175450.
35. Srivastava S, Gadasalli S, Agusala M, et al. Beating heart totally endoscopic coronary artery bypass. Ann Thorac Surg 2010;89(6):1873–1879. DOI: 10.1016/j.athoracsur.2010.03.014.
36. GLOBOCAN 2012. Online. Accessed at 10.31.2016. Available online address: http://globocan.iarc.fr/Pages/fact_sheets_cancer.aspx.
37. Jemal A, Bray F, Center MM, et al. Global cancer statistics. CA Cancer J Clin 2011;61(2):69–90. DOI: 10.3322/caac.20107.
38. Torre LA, Bray F, Siegel RL, et al. Global cancer statistics, 2012. CA Cancer J Clin 2015;65(2):87–108. DOI: 10.3322/caac.21262.
39. Enzinger PC, Mayer RJ. Esophageal cancer. N Engl J Med 2003;349(23):2241–2252. DOI: 10.1056/NEJMra035010.
40. Operational guidelines for observance of good practices in CPC-SEA. An Indian committee for the purpose of promotion and supervision of experiments on animals (CPCSEA) Document.