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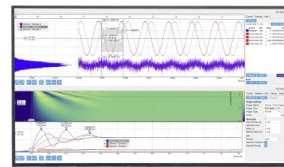
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Advances in Laparoscopic Surgeries and CFD Perspective of Suction-Irrigation Devices

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Abstract. The need for suction-irrigation devices in almost every surgery i.e., from an open incision to Laparoscopic, is well recognized by all different kinds of surgeons. This paper significantly highlights several problems of pneumoperitoneum, blocking, and other inefficiencies like misplacement of sponges, etc., while using suction and irrigation devices during surgeries. An irrigation device is studied for cleaning wounds or blood inside a human body. The citation has been counted as one of the most imperative factors in comprehending the quality of Laparoscopic instruments and their use during surgery. It helps to solve inefficiencies caused by separate suction and irrigation systems in surgeries such as suctioning the wound while irrigating and then simultaneously cauterizing to seal the tissue. Computational Fluid Dynamics or CFD evaluation is one of the key analysis strategies used to forecast fluid flow, heat transfer, and chemical reactions occurring among various materials which consists of fluid. Computational analysis is performed in the present study using ANSYS FLUENT as a commercial package. After evaluation of the modeled layout, the acquired outcomes for pressure, mass flow rate, and velocity at the inlet and outlet of the tube are cautiously studied, and essential optimizations are made in the design to prevent any undesired outcomes. The pressure drop in the instrument and the pipe is determined, and flow rates are compared subsequently. The objective of this paper is to determine the mass flow rate across an instrument for different pressures and to suggest improvements in the Suction-Irrigation device by enhancing additional features to make it as multi-functional instrument that can be used for minimally invasive surgeries.

Keywords: CFD, Suction, Irrigation, Laparoscopy, Instruments, Patients, surgery.

INTRODUCTION

Background

In 1812, when the New England journal of medicine and surgery first started to publish, medical knowledge in the U.S. and in other parts of the world was limited. At that point of time, life loss due to infections caused post surgeries was very high. Surgeries were performed in those days under relatively less hygienic conditions and without anaesthesia. Before the introduction of ether based anaesthesia, surgeries were brutal and gruesome. In 1846, William Morton, a Boston dentist persuaded Dr. John Collins Warren to use ether based anaesthesia to relieve pain during surgeries. In 1860s Luis Pastore developed the theory which suggested that, infections may be due to micro-organisms. Two centuries later, people have longer span of life due to the development of various healthcare measures and developments in various surgical procedures.

During the 19th Century, people realized the hygiene benefits. Before and after surgery, doctors as well make themselves sure to sterilize the equipment and wash their hands. Such a minor transformation brought about a drop in mortality rates. Different approaches were being made by the doctors to overcome the patient's death by a careful and persistent approach towards disinfection. This, together with the commencement of the Industrial Revolution,

got in various essential standards in the surgical field. Standard devices in the surgeries were introduced like, scalpel, palpation tube. The surgeons brought about a change in this medical arena and were given the status of Gods.

Surgeons were able to cut open the 'patient's body and exchange or dissect unhealthy organs as per the requirement. The length of the incision made during this period was about 100mm to 150mm. But still, the patient was not satisfied as the operation time is more, the time of recovery is in years, and there is a chance of infection. The patient's life can be saved, but the quality of life was miserable due to post-operative pain and wound complications.

Later, at the end of the 19th Century, the field of minimally invasive surgery brought about a drastic change and eliminated laparotomy (open-cut surgeries) procedures. This surgery requires a laparoscope, a camera-enabled instrument to view the abdomen cavity by inflating CO₂ gas into it. The other instruments for dissection, grasping has to be introduced due to its smaller size of 10-15mm to insert and perform surgical operations. This gave a wide range of scope for the development of instruments used in minimally invasive procedures. The below section briefly highlights the advancements made in laparoscopic surgeries and their instruments. However, an S-I instrument is taken for analysis and suitable flow rates are mentioned with respect to five different pressure drop.

Laparoscopic surgeries and instrument

Laparoscopy is a minimally invasive surgery of size 5 – 10mm compared to laparotomy, which has cut 15 – 20cm. It uses a Laparoscope of biocompatible material and sealed off to avoid contact between the body fluids and internal mechanism. The surgeon introduces small incisions on the patient's belly to operate surgery on the infected organs, as shown in Fig. 1 (a) and (b). Initially, the trocar of varying sizes of 5, 10, and 15mm is inserted from the patient's belly through which CO₂ gas is passed. By the passage of CO₂ gas, the abdomen is inflated to view different organs. This reduces the chance of infection for the surgeon and patient as there is no physical contact with tissue inside the body.

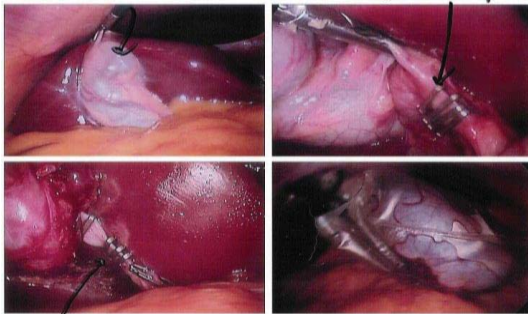


FIGURE 1. (a): Cholecystectomy from laparoscopy



FIGURE 1 (b): Surgeons perform laparoscopy

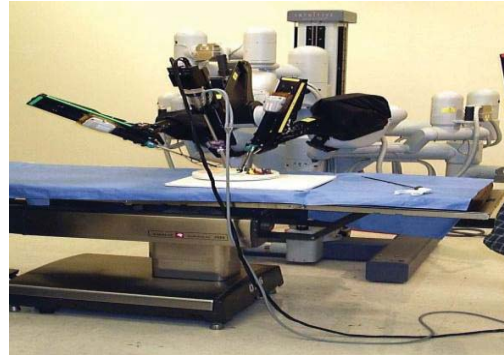
Many doctors require making a larger incision for the removal of unhealthy tissue from laparoscopic bag [2]. Moreover, they might as properly use this incision to visualize on a monitor and perform operations like a retractor, dissector, etc., as they would in open surgery. This technique is mentioned as hand-assist laparoscopy. The fact that CO₂ is required to be maintained inside the patient's stomach by hand access port. Due to the repetitive exchange of instruments, Surgeons experience post-operative pain in their shoulders and wrist. Conceptually, the laparoscopic technique is proposed due to lesser post-operative pain, shorter duration in hospital or cost, and less trauma for the patients [3].

Some devices in a laparoscopic surgeries include diathermy machine, camera-enabled laparoscope, insufflator, veress needle, cannulae and trocars, instrument holder, grasping forceps, dissectors, scissors, suction device, irrigation device, needle holder, sutures, ligatures, tacking clips, laparoscopic bag, etc.,

FUTURE PROSPECTS



(a)



(b)

FIGURE 2. (a) and (b): Single Incision Laparoscopic Surgery

Due to the advancements made in Laparoscopic surgeries, there is a consistent requirement for instruments concerning ergonomics, versatile, lighter, reusable, and cheap. The future enhancement to laparoscopic surgeries can be Non-robotic hand-guided assistance surgery and Robotic laparoscopic surgery

Non-robotic hand-guided assistance surgery

This can be categorized as Laparoscopic single-incision surgery and Single Incision Single Port Multi-Instrument Laparoscopy. They assist surgeons and their team provided; the instruments must be multi-functional, versatile to save time and money. For such surgeries, surgeons suggested a necessity of instrument development and enhancement to the existing device and mechanisms.

Robotic laparoscopic surgery

This uses a Da Vinci Robotic-arm laparoscopic system, as shown in Fig. 1. The machine here will perform surgery as per the instruction or signals given by the surgeon. In this, multiple incisions are made on the patient. So, the instrument should be robust, versatile, and easy to use.

SUCTION-IRRIGATION (S-I) INSTRUMENTS

Abraham Frech et al. [4] designed a suction instrument that overcomes the problem of occlusion by introducing a sponge near the instrument tip. However, if sponges are misplaced or kept in the abdomen may result in severe challenge to the patient after post-operative pain. In some cases of appendectomy surgery, an irrigation instrument is compared and examined with suction instrument [3-4], while others have concentrated on the SI instrument for pressure recommendation [5]. Studies have also conducted on wound complications during negative suction pressure [2, 6]

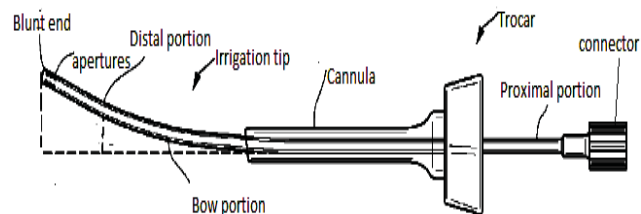


FIGURE 3. Bowed tip inserted into trocar during suction in Laparoscopic surgery.

The success of Laparoscopic procedures is subject to surgeon interacting in 2D vision with the tissues using surgical tools rather than open cut 3D vision. During surgeries, a standard S-I instrument most commonly used as either a 5mm or 10mm diameters extending up to a length of 330mm [8]. This S-I instrument has a problem of repeated insertion during the surgery whenever there is an obstruction in the field of view from the monitor [7]. The blockage can be basically due to blood clots or any charred particles during cutting, dissection, and fulgurating the tissue. It so happens, the abdomen is filled with CO₂ gas, and there is a chance of escape of gas when multiple instruments are re-inserted. It can be avoided by introducing a new instrument that can dissect, grasp, suck, or irrigate with the same instrument. Before, doing this, the preliminary results of the S-I device will facilitate the modified instrument to incorporate S-I device results and compare them effectively.

RESULTS AND DISCUSSION

The origins of CFD lie inside 'mankind's inquisitiveness in better understanding the energy of natural elements like wind, storms, floods, or sea waves, medical aspects, and other domains of interest. An S-I device having 5mm diameter and length 330mm is always used in most of the laparoscopic surgeries. Here, a standard suction-irrigation (S-I) device used in laparoscopic surgery is modeled and run on ANSYS Fluent to obtain a simulated picture that shows the physical properties of the affected model. The colored images depict the values of physical properties and predict the flow of the fluid through the instrument, the pressure, velocity, the flow rate of the liquid gradually varies throughout the length of the device. Mesh refinement studies have conducted at different elements that are 138276, 171051, and 947879. All elements have given errors at a mass flow rate of less than 3%. So, an intermediate mesh with 171051 is selected for all pressure variations across the instrument. The flow chart below shows the procedure of ANSYS Fluent set up.

Analysis of Suction-Irrigation device

Contours of pressure

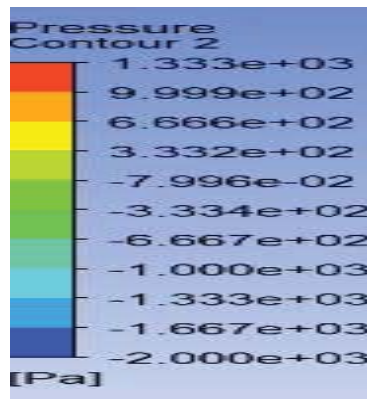


FIGURE 4. Suction-Irrigation device showing Suction pressure at -5 mm hg



FIGURE 5. Suction-Irrigation device showing Suction pressure at -10mm Hg



FIGURE 6. Suction-Irrigation device showing Suction pressure at -15mm Hg

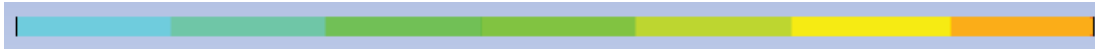


FIGURE 7. Suction-Irrigation device showing Suction pressure at -20mm Hg



FIGURE 8. Suction-Irrigation device showing Suction pressure at -25mm Hg

Contours of velocity

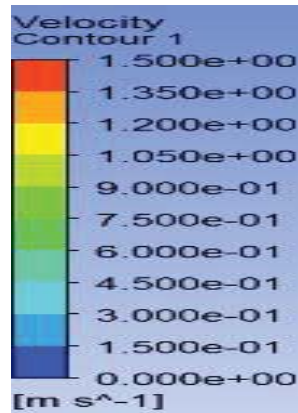


FIGURE 9. Suction-Irrigation device showing Suction velocity at -5 mm hg

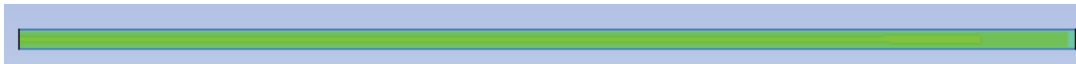


FIGURE 10. Suction-Irrigation device showing Suction velocity at -10mm Hg



FIGURE 11. Suction-Irrigation device showing Suction velocity at -15mm Hg



FIGURE 12. Suction-Irrigation device showing Suction velocity at -20mm Hg



FIGURE 13. Suction-Irrigation device showing Suction velocity at -25mm Hg

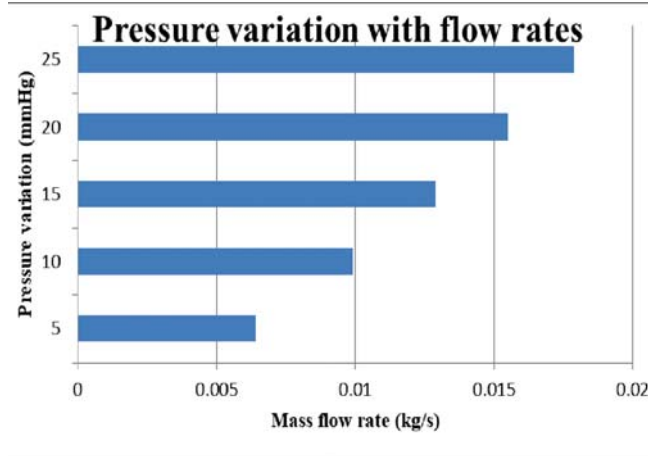


FIGURE 14. Pressure variation with flow rates

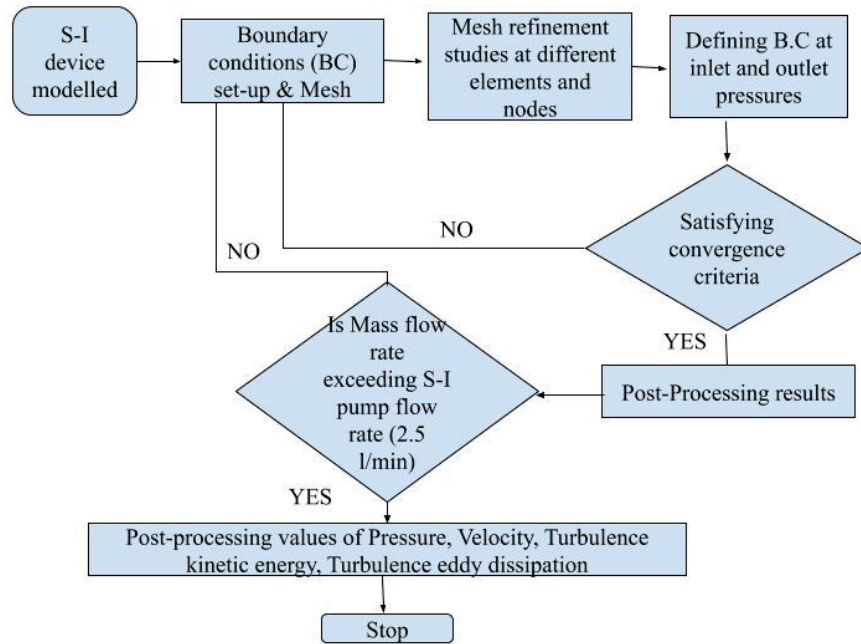


FIGURE 15. Flow chart

TABLE 1. Mass Flow rate at different pressure variations across the device.

S.No.	Pressure Variation (mm of Hg)	Suction and irrigation modes in S-I device (kg/s)
1	5	0.0064
2	10	0.0099
3	15	0.0129
4	20	0.0155
5	25	0.0179

Since very few computational analysis is carried out in medical instrument, the novelty of work lies in determination of mass flow rates with the help of ANSYS Fluent from the medical perspective. From table 1, it is clear that with an increase in pressure difference, the mass flow rate also increases. The suction irrigation pump used

in the laparoscopic surgeries has a maximum flow rate of 1.8 lit/min [8] in both suction and irrigation process. The ideal pressure to be sent to the abdomen is 1333 Pa. So, the inlet pressure is set at this pressure, as shown from Figure 3 to 7, but the outlet pressure in case of suction is decreased in steps of 5mm Hg (666 Pa) so as get the flow rates. The flow rate in the abdomen is varied from patient to patient depending upon the obesity. However, negative pressure can suck the tissue from the abdomen. Hence, 10 mm Hg (1333 Pa) is considered as the maximum safe limit within which the fluid can be irrigated or sucked from the abdomen cavity. The mass flow rate of 0.0179 kg/sec is equal to 1.07 lit/min, which is well below the S-I pump limit and can be irrigated or sucked for effective tissue rinsing. From the analysis, at maximum pressure difference at -2000 Pa, corresponding velocity, turbulence eddy dissipation, and turbulence kinetic energy is found to be 1.354 m/s, 1294 m²/s³, and 0.08247 m²/s² respectively. With these S-I device results, the work shall be further proceeded to incorporate dissection and grasping features to make an instrument more useful in the field of modern laparoscopic surgeries.

MATERIAL, METHOD, AND IMPROVEMENTS

Previously, the suction device and irrigation device were used as a separate unit. But, as technology advances, the S-I device became a single unit in almost all surgeries. The S-I device is typically made of either disposable or non-disposable. The non-disposable materials should be resistant to corrosive material like alloys of stainless steel. During the laparoscopic surgery, there is a consistent requirement of the S-I device either to suck the fluid from the abdomen or to irrigate the fluid to clear the vision for seeing in the monitor. It is basically due to Electro cauterization surgery that the blood oozes out from the abdomen and needs to clean by water through an irrigation device. As the fluid gets accumulated inside the abdomen, it gets sucked out by the Suction device. It is mandatory to view the organs on monitor clearly to operate and complete required surgery. Any unhealthy tissue, blood, or water obstructs the vision of a surgeon. This adds a considerable amount of time to the operation theatre room risking the patient's life. Thus, there is a requirement of an instrument that can suffice both cauterization and S-I device so that there can be considerable time reduction for both surgeon and patient. A multi-functional instrument is strongly recommended, which can facilitate a simultaneous operation without re-insertion of an instrument without a reduction in mass flow rate as per the surgeon requirement. Thus there is a broader scope in the developments of surgical devices.

CONCLUSION

This paper aims to highlight the requirement and to develop instruments in the field of minimally invasive surgery. An S-I device is analyzed, and results have been taken between pressure drop and corresponding mass flow rates. It suggests the desired flow rate clean and remove fluid from the abdomen. Also, these are the preliminary results to achieve better flow rates from this existing design. During the past decade, there is a significant change in surgeries from an open incision to single-incision surgeries. However, there is not much versatility in instruments. Incorporation of S-I devices with dissectors with the same mass flow rate can bring about the advancement in laparoscopic surgeries. S-I instrument is used in almost all surgeries like appendectomy, splenectomy, diagnostic laparoscopy, hysterectomy, and many more, which in combination with dissectors can benefit the versatility of the instrument. With this improvement, there is a reduction in time due to the exchange of instruments resulting in a considerable reduction in time of operation theatre room and also patient safety for instrument mishandling due to continuous re-insertion.

FUTURE SCOPE

Medical devices and procedures elucidate the problem confronted during surgeries and are favorable to the patient and surgeon with respect to safety and time reduction. There are a wider scope and good opportunity in the medical field due to the advancement in the health care systems, changing lifestyle pattern, and new technology inventions. Hence, instruments with multi-functional features are highly desirable and can be efficient to eliminate the problems faced in the latest surgical developments.

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