INTRODUCTION

Gall stone disease (GSD) is a worldwide disease that remains to be one of the most common health problems leading to surgical intervention. Every year more than 700,000 cholecystectomies are performed in the United States of America (USA) [1]. The prevalence of GSD is about 10% in its adult population. [2]

The first cholecystectomy was performed by Carl langenbuch in Berlin, in 1882.[3] Eriche Muhe performed the first laparoscopic cholecystectomy in Germany in 1985 [4] and by 1992, 90% of cholecystectomies in the United States were being performed laparoscopically [5]

Compared with open cholecystectomy, the laparoscopic approach has dramatically reduced hospital stay, postoperative pain and convalescent time , that' s why the National Institutes of Health consensus elected Laparoscopic cholecystectomy as the gold standard for choleithesisis in 1992. [6]

The attractiveness of laparoscopic cholecystectomy has led to a new understanding of biliary anatomy especially of the Calot's triangle area in order to perform a successful surgery. [7]

Calot’s triangle is an important imaginary referent area for biliary surgery. The French surgeon Jean-François Calot, at 1891, first described a triangular anatomical space in the sub-hepatic area, hence it was called Calot`s triangle, bounded by cystic duct laterally, the cystic artery superiorly and the common hepatic duct medially , his original definition was not including the inferior surface of liver as a boundary [8], this space contains the cystic artery as it approaches the gall bladder, the cystic lymph node , lymphatics from gallbladder, one or two small cystic veins, the autonomic nerves running to the gallbladder and some loose adipose tissue. [9] (Fig 1)

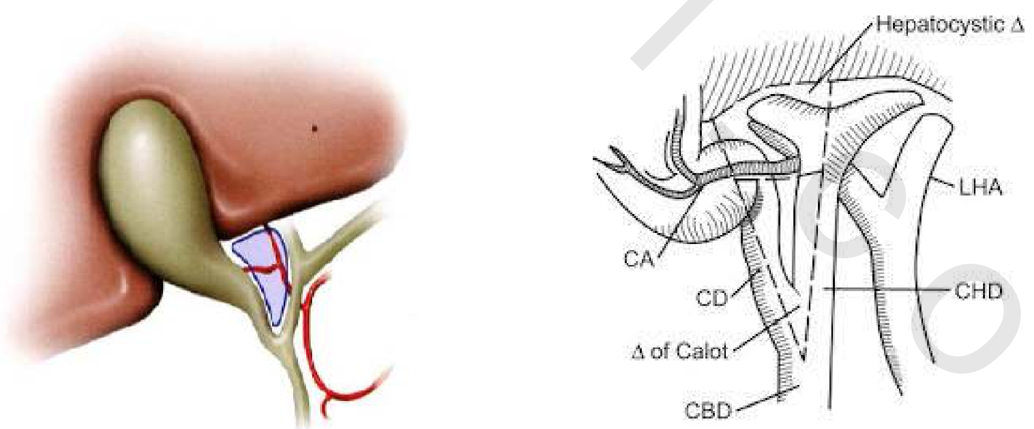

Fig (1): Boundaries of Calot's triangle (LHA-left hepatic artery,CHD-common hepatic duct, A-cystic artery,CD-cystic duct,CBD-common bile duct) [10]

Hugh, in 1992, suggested that Calot's triangle should be renamed the hepatobiliary triangle or cystohepatic triangle, being defined as an area of the cystic pedicle bordered by the common hepatic duct medially, the cystic duct inferiorly and the liver superiorly with the cystic artery within the triangle [11].

The triangle described by Calot is inconstant due to the frequent variations in the course of cystic artery whereas the hepatobiliary triangle suggested by Hugh is more constant and thus more useful in defining the important area of dissection in cholecystectomy.

Calot's triangle is considered to be an important landmark for identifying origin of cystic artery which has many possible origins(RT hepatic,LT hepatic, hepatic trunk,Celiac trunk, Superior mesenteric artery ,Superior pancreaticodudenal ,gastrodudenal) with the right hepatic artery being the most common.[12] (Table I)

Table I. Orgin of the cystic artery [13]

Origin of cystic artery	percent
RT hepatic artery	75 %
LT hepatic artery	8 %
Hepatic trunk	6 %
Superior pancreaticodudenal	2%
Celiac trunk	3 %
Superior mesenteric artery	2 %
Gastrodudenal artery	0.5 %

Cystic artery commonly arises from the geniculat flexure of the right hepatic artery in the upper portion of the "Calot`s" triangle, it usually passes posterior to the common hepatic duct and anterior to the cystic duct , but a site of origin from a more proximal or distal portion of the right hepatic artery is also considered relatively normal[14].Then it runs superiorly to become adjacent to the cystic duct, here it produces 2 to 4 minor branches the "Calot's arteries" which supply part of the cystic duct and cervix of the gallbladder then divides into major superficial and deep branches at the superior aspect of the gall bladder neck. The superficial branch (anterior branch) passes sub-serously over the left aspect of the gallbladder whereas the deep branch (posterior branch) runs between the gallbladder and gallbladder fossa. [15]

Cystic artery diameter ranges from 2-4 mm [16] (Fig 2) .Although anatomical variations are well described in literature , the information about arterial diameter is scanty.Tejaswi [17] papered on origin, course and branching pattern of cystic artery in human cadavers and he stated that cystic artery diameter ranges from 1.2 to 3.2 with mean diameter = 2.2mm.

Katri et al [18] divided cystic artery according to its external diameter into three groups: small (< 2mm), medium (2-3 mm) and large (> 3mm).

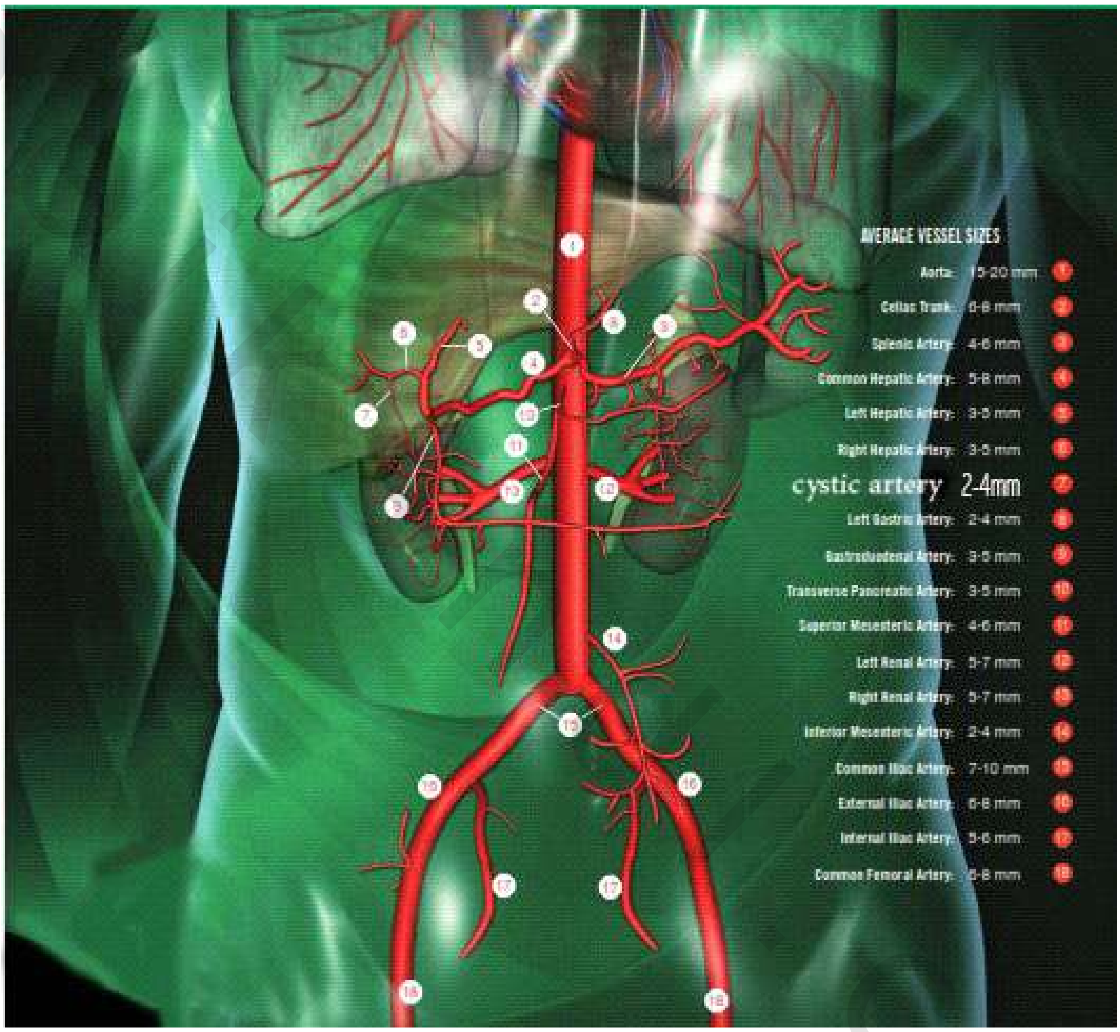

Fig (2): Cystic arterial diameter [16]

Cystic artery is known to exhibit variations in its origin and branching pattern which could be explained by the developmental pattern of the biliary system.

Embryologically, the simple branching pattern of the gastroduodenal and hepatobiliary vasculature is profoundly altered by the growth of the liver and pancreas and by the assumption of a curved form in the stomach and duodenum. These factors operate to complicate the branching of the celiac axis and proximal segment of the superior mesenteric artery. (19) Considering that the liver is derived from a portion of the primitive duct supplied primordially by the celiac and mesenteric arteries, it may receive rami from both of these sources. The same is true from the gallbladder. The liver and gallbladder develop from a foregut endodermal hepatic diverticulum, which usually carries a rich supply of vessels from the abdominal aorta and its initial branches. Most of the vessels picked up from the abdominal aorta during development degenerate leaving in place the mature vascular system. Because the pattern of degeneration is highly variable, the origin and branching pattern of the vessels to these organs also vary considerably .Considering the complexity of this developmental scheme, it is easy to understand the large degree of arterial variation within this vascular system (20)

Another explanation for cystic artery anatomical variation is methodological differences as well as ethnic variation as shown in the following table (Table II) (21)

Table II. Origin of cystic artery in different ethnic groups (21)

origin	Africans (%)	Caucasians (%)	Asians (%)	Kenyans (%)	Chinese (%)
RHA	78	72	96	92.2	76.6
LHA	2	6	4	0	4
CHA	17	3	o	o	2.8
GDA	3	1	0	0	1.4
CT	-	-	-	0	1.4
Others	0	17	0	0	9.8

RHA-right hepatic artery, LHA-left hepatic artery, CHA-common hepatic artery, GDA-gastrodudenal artery, CT-celiac trunk.

Variations in cystic artery anatomy (Fig 3), based on its origin, position and number were well described in literature as its sound knowledge can reduce the likehood of uncontrolled intraoperative bleeding, an important cause of iatrogenic extra hepatic biliary injury and conversion to open cholecystectomy .

That's why in 1923, exhaustive details of the variations of biliary anatomy were given by Flint (22) who stated that : "So frequent are the variations in the region of the liver and gall bladder ,it is impossible to regard any one type as normal". In 200 dissections of liver and gall bladder regions, the cystic artery was seen arising from the right hepatic artery in 196 cases, in 3 cases from the common hepatic artery and in 1 case from the gastroduodenal artery.Also, Gray's and Whit sell's (23) papered on the anatomical variations of cystic artery in 100 consecutive cases of cholecystectomy.

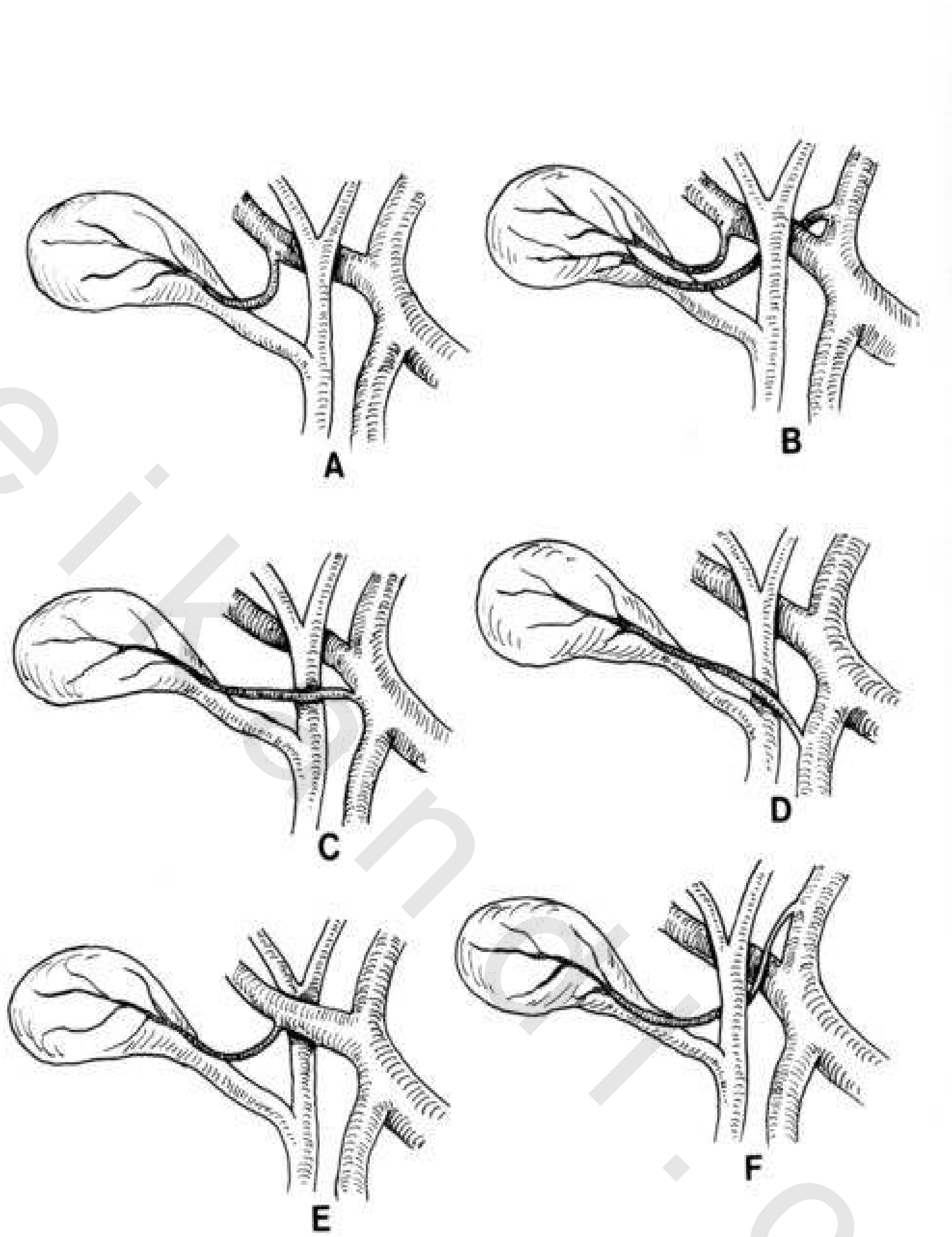

Fig (3): Anatomic variations of the blood supply for the gallbladder. The cystic artery usually arises from the right hepatic artery (A). Variations to this unusual anatomy include dual cystic arteries, one arising from each of the hepatic arteries (B), cystic artery arising from the common hepatic artery (C), cystic artery arising from the gastroduodenal artery (D),cystic artery arising from an anterior right hepatic artery (E), a single cystic artery arising from the left hepatic artery (F). [24]

In 1951,Michels NA [25] studied the arterial supply of supramesocolic organs in 200 cadavers ,he estimated that the origin of cystic artery may arise from common hepatic or gastroduodenal or LT hepatic and In 1976,Gammon K,Jacob M [26] conducted a pilot study on south Indian cadavers which showed variation in number as well as origin of cystic artery.In 1976,Benson EA and Page RE[27] made observations on 205 dissections of extra hepatic biliary anatomy and referred to three important vascular anomalies including :accessory cystic artery, caterpillar hump of RT hepatic artery and anterior transposition of cystic artery.

In 1981, Rocko [28] drew attention to possible variations in the region of Calot's triangle and in 1988 Bergmann[29] wrote in his " compendium of anatomical variation " regarding the cystic artery and its anatomical variations that the gall bladder was supplied by single artery in 88 %, two arteries in 12 %and three arteries in 1.8 % of cases. In 1992, Cimmino et al [30] stated that variation in cystic artery based on its origin, position and number are quite common being found in 25-50% of cases.

All these previously mentioned papers in the literature describing anomalies of the cystic artery have been solely based on specimens obtained at autopsy, with no description published about them in laparoscopic operative cases.

Laparoscopic visualization of cystic artery anatomy differs from the open technique due to the following causes:

1- Under laparoscopy, as the gallbladder fundus is pulled, the liver is moved upward, thereby opening the subhepatic space.

2- By pulling Hartman's pouch downward, the anterior aspect of Calot's triangle is presented. On the contrary, by pulling Hartman's pouch upward, the posterior aspect of Calot's triangle is clearly exposed.

3- Better transparency and visualization.

That's why a new term "laparoscopic anatomy" was introduced [31] and even found a place in anatomy texts, also it draw the attention of researchers to classify cystic artery anatomical variation from laparoscopic point of view. Classifications were proposed depending on different vascular patterns of gallbladder blood supply as well as different origins of the cystic artery as shown in the following scheme. (Fig 4)

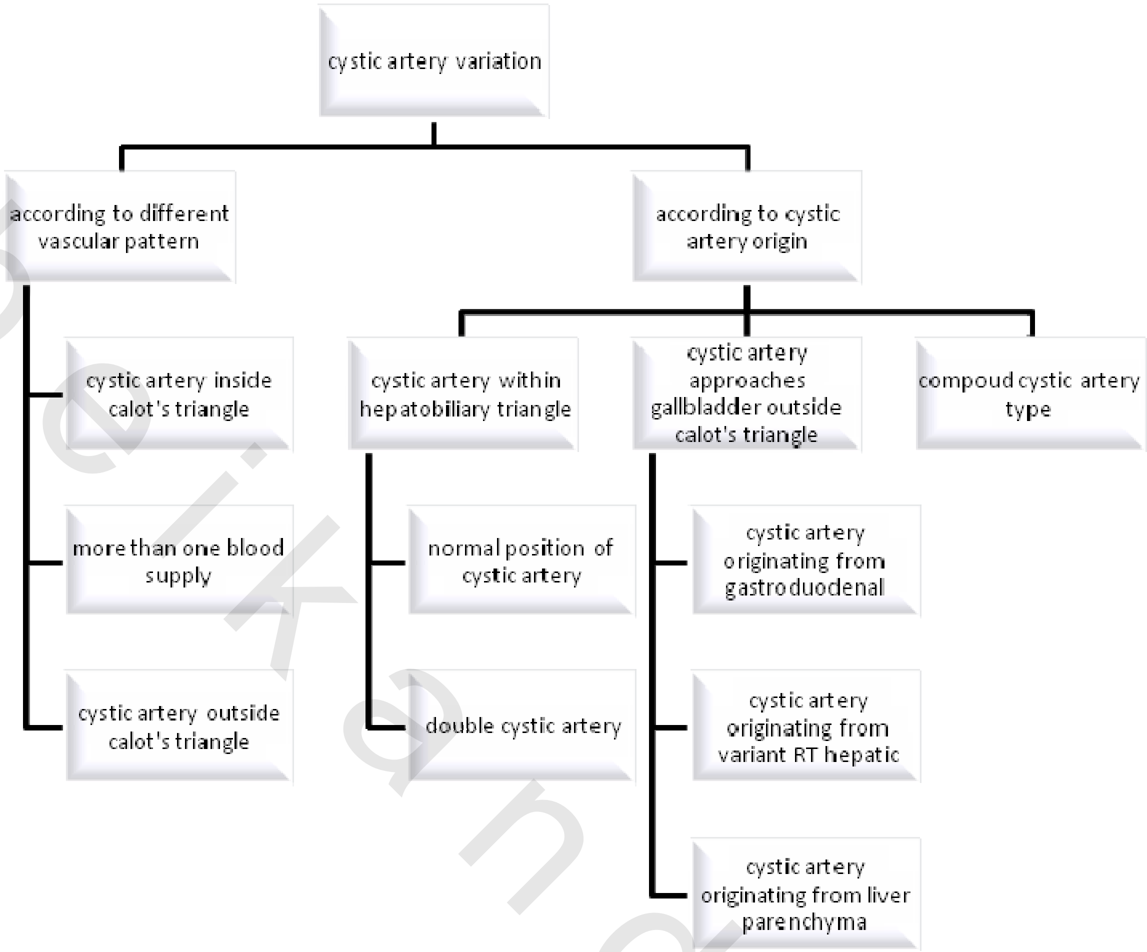

Fig (4): Scheme for cystic artery anatomical variations

First: Depending on different vascular patterns:

Suzuki [(32)] performed 200 cases of laparoscopic cholecystectomy and he divided the different vascular patterns of cystic artery into 3 groups:

Group 1: Cystic artery or arteries seen in Calot's triangle and no other source of supply is present. This group is further sub-divided into two groups:

1a Single artery is seen in Calot's triangle (normal anatomy).

1b Two vessels are identified in Calot's triangle. (Fig 5)

Cystic artery syndrome is described as a variation in group 1. This is a single cystic artery originating from the right hepatic and then hooking round the cystic duct from behind, reappearing at the peritoneal surface near the neck of the gallbladder. It was assumed that the main cause of stone formation was poor bile flow due to partial or complete obstruction by the cystic artery.

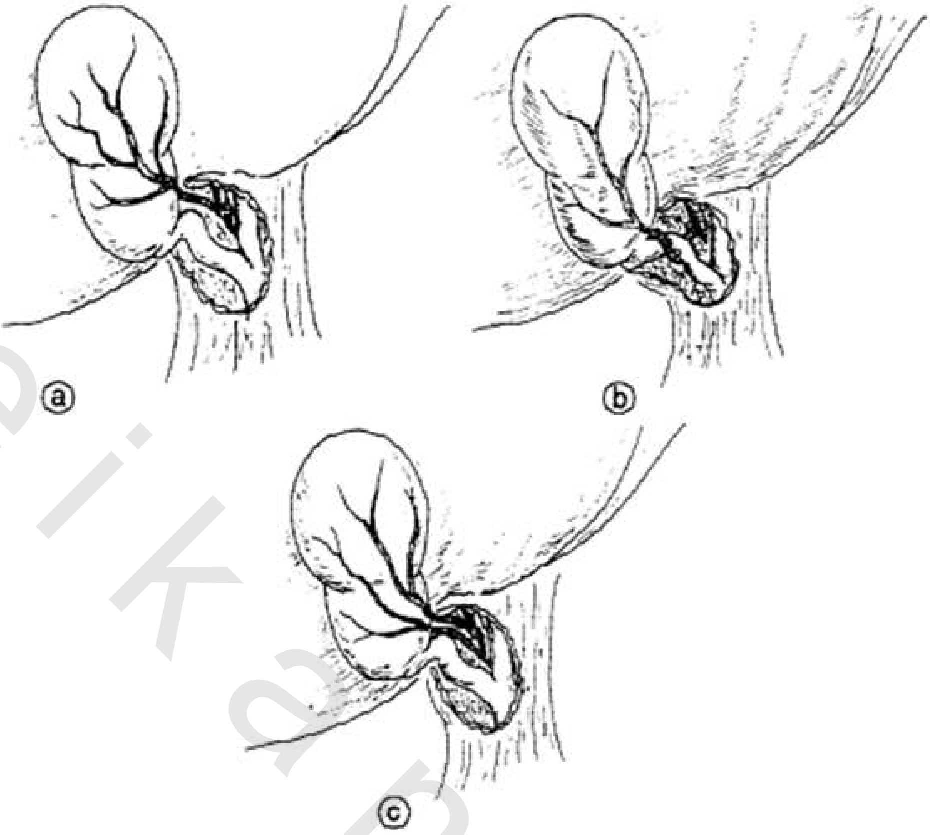

Fig (5):(a) A single typical cystic artery in Calot's triangle, (b) single cystic artery in Calot's triangle hooking around the cystic duct(cystic artery syndrome), (c) double cystic arteries in Calot's triangle.[32]

Group 2: There is more than one blood supply, one is observed in the normal position inside Calot's triangle and the other exists outside the triangle (Fig 6)

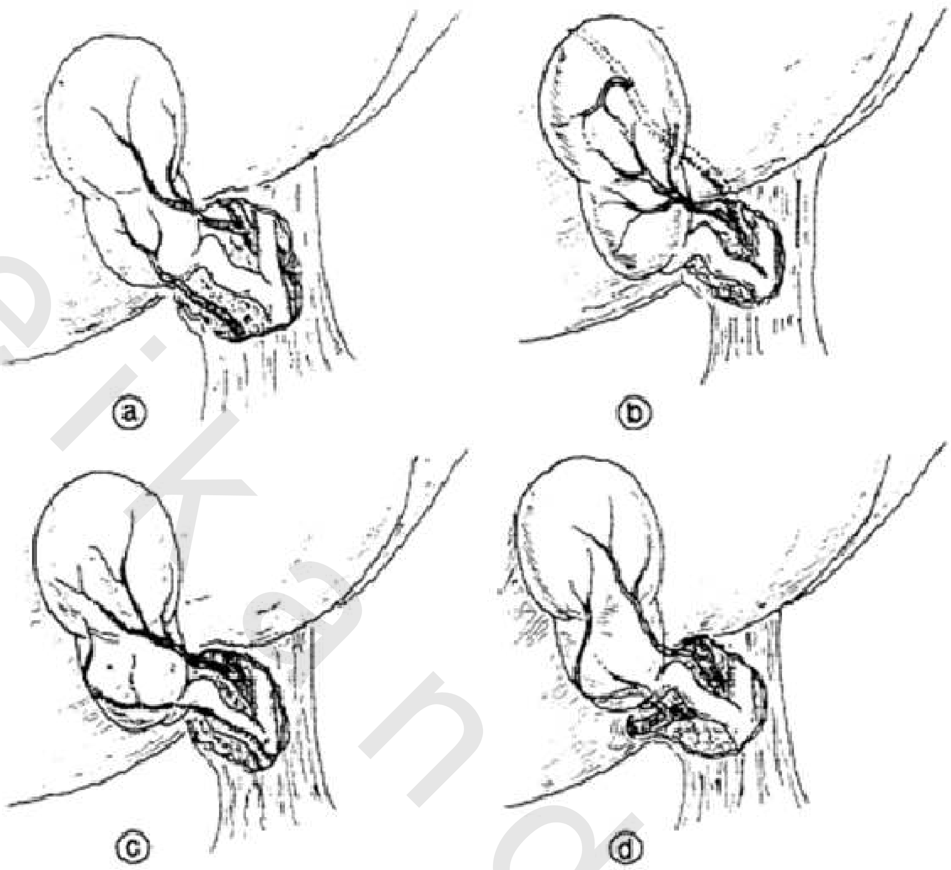

Fig (6): One artery is typically present in Calot's triangle but there are also accessory arteries from different origins (a) from below and lateral to the cystic duct, (b) piercing the gallbladder bed near the fundus, (c) along and posterior to the cystic duct, (d) just below Hartman's pouch [32]

Group3: Cystic arteries are observed outside Calot's triangle, this group is subdivided into (3a, 3b) based on the number of arterial supply to the gall bladder

3a: single artery is visualized outside the triangle

3b: more than one vessel is seen outside Calot's triangle.

Cystic artery outside the Calot's triangle may be arising:

- Below and lateral to the cystic duct
- OR along and posterior to the cystic duct
- OR along and anterior to the cystic duct
- OR piercing the gallbladder bed near the fundus. (Fig 7, 8)

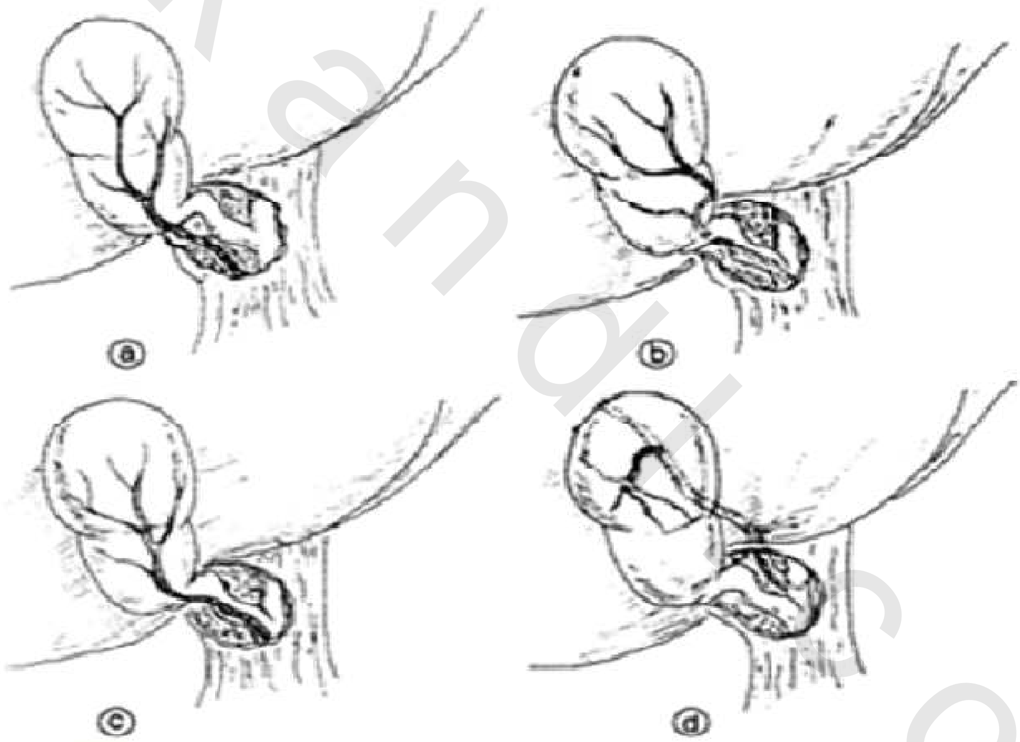

Fig (7): No cystic artery in calot's triangle,(a)a single artery from below and lateral to the cystic duct,(b) a single artery along and posterior to the cystic duct,(c) a single artery along and anterior to the cystic duct,(d)piercing the gallbladder bed near the fundus .[32]

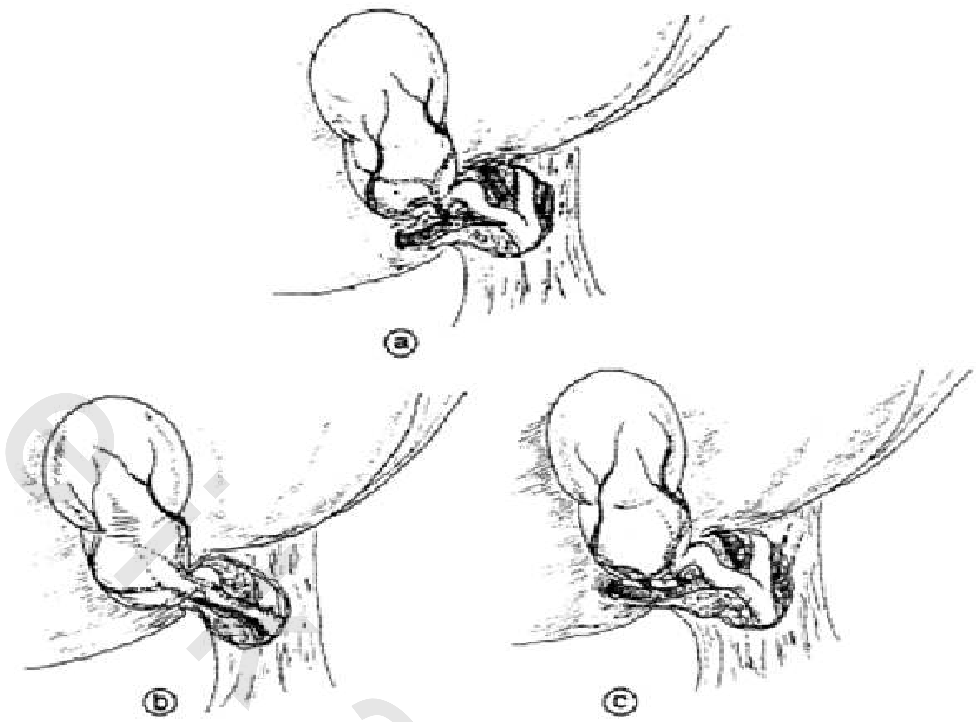

Fig (8): Single or double cystic arteries outside calot's triangle ,(a)a single artery supplying the gallbladder just below Hartman's pouch,(b) double arteries along and posterior to the cystic duct,(c) double arteries just below Hartman's pouch.[32]

Second: Based on different origins of cystic artery:

Ding et al [33] proposed classification for cystic artery anatomical variations as regard different origins, they divided them into 3 groups

Group I: Refers to a cystic artery found within the hepatobiliary triangle which is the most common pattern.

This group is further divided into several subtypes, as follows:

a- Normal position of cystic artery:

The cystic artery usually originates from the geniculate flexure of the right hepatic artery within the hepatobiliary triangle, and then when approaching the gallbladder, it divides into deep and superficial branches, when thus positioned, the artery is considered a normally lying cystic artery. It is found in 70-80% of cases [34]

B- Double cystic artery:

When the two branches, anterior and posterior, of the cystic artery are separated at their origin, Michels called them double cystic arteries .A double artery is found in 15% to 25% of patients. [35]

Group II: Cystic artery approaches the gallbladder outside Calot's triangle and cannot be observed within the triangle by laparoscopy during dissection

This group includes the following four subgroups

A- Cystic artery originating from gastrodudenal artery:

This type of cystic artery is also called low-lying cystic artery, which does not pass through Calot's triangle but approaches the gallbladder beyond it through the cholecystodudoneal ligament. In the literature its prevalence ranges from 2% to 30% [36]

B- Cystic artery originating from the variant right hepatic artery:

Anatomic variation of the right hepatic artery usually originates from the superior mesenteric artery or aorta[37], It enters Calot's triangle behind the portal vein and runs parallel to the cystic duct on its passage through the triangle occasionally forming a prominence in the area (caterpillar hump artery), then it passes between the gallbladder and liver parenchyma.

C- Cystic artery originating directly from liver parenchyma:

This cystic artery pierces the hepatic parenchyma approaching the bladder from the gallbladder bed, No other arteries are found within Calot's triangle. This anatomic variation is not observed until bleeding occurs.

D- Cystic artery originating from left hepatic artery:

The cystic artery occasionally originates from the left hepatic artery, passing through a tunnel of the liver parenchyma and reaching the middle of the gallbladder body in the gallbladder fossa, bifurcating there into two branches: ascending and descending branches, it has a prevalence of 0.4%.[38]

Group III: This group has more than one blood supply, that's why it is called "Compound cystic artery type."

The cystic arteries exist not only in Calot's triangle, but also outside it. A normal single cystic artery exists in Calot's triangle associated with an artery extending along the cystic duct but posterior to it, and some small arteries that passed immediately from the liver parenchyma to the gallbladder, or another cystic artery superficial to the cystic duct in addition to the normal artery was found.

Or existence of multiple cystic arteries, including the double cystic artery in Calot's triangle, and one of the arteries crossed anterior to the common bile duct, while another was situated on the right side of the border of the gallbladder body and fundus .[39]

Methods of cystic artery control:

Cystic artery control is considered to be an important step for safe cholecystectomy as its poor control will lead to troublesome bleeding that may nessicate conversion to open procedure that was reported to occur in 2% of cases [40] or iatrogenic extra hepatic biliary injury.

Classically, simple titanium clips have been used for control of cystic artery as well as cystic duct. However, application of these clips is associated with some problems including cystic artery stump pseudoaneurysm [41], dislodgement of the clip or bile duct necrosis resulting in postoperative cystic duct leak [42, 43]. Another clip-related problem was reported at long term follow up, is late postcholecystectomy clip migration which was reported to result in biliary stone formation [44] or duodenal ulcer [45].

That's why biliary surgeons tried alternative methods for cystic duct and artery control including: sutures, self locking polymer clips, harmonic scalpel, ligasure sealing device and monopolar electrocautery.

The self locking polymer clip (laparo clip) can be used for cystic duct and artery control; it is made of two components: an inner component manufactured from polyglyconate polymer and an outer component made of polyglycoic acid polymer. The inner track piece closes around the vessel or duct and a rigid outer body then slides over the track piece to occlude the vessel or duct, the clip degrarades by hydrolysis within 6 months. These clips seem to have fewer tendencies to slip off, compared with titanium clips, and therefore may be regarded as safer, however they are expensive and not readialy available. [46]

The ultrasonically activated scalpel (harmonic scalpel) is another alternative that can be utilized, it was previously used for the cystic artery division as well as liver bed dissection [47] but now recent advances in harmonic scalpel technology provide safe division and closure of the cystic duct up to 6 mm in diameter. The resulting decrease in temperature, smoke, and lateral tissue damage placed the harmonic scalpel superior to the more traditional electrocautery. [48]

LigaSure system has been shown to be effective for blood vessel sealing in many studies comparing it with monopolar electrocoagulation, bipolar coagulation, or ultrasonic techniques [49,50], Nii et al [51] confirmed it as a safe method for closure of the major bile duct in pigs. S.Schuzle et al [52] conducted a study about cystic duct closure by sealing with bipolar electrocoagulation, his results with no leakage suggest that the use of 5-mm LigaSure is safe and may be used for division of a cystic duct in patients undergoing laparoscopic cholecystectomy. One potential advantage of the LigaSure is that it leaves no metallic objects in the body and that the risk of damage of the surrounding structures is minimal due to the bipolar cautery. However, the cost of the instrument is higher than the cost of the clip applier.

Another modified technique for cystic duct and artery control was proposed, cystic artery was divided using monopolar cautery and the cystic duct was ligated intracorporeally using nonabsorpable suture.

Many advantages to the simple ligation of the cystic duct was found, It is feasible and practical since the only required advanced skill is the ability to make intra- corporeal knotting. Additionally, this technique avoids the intrinsic disadvantages of the use of clips.[53]

Although there is a belief about monopolar electrocautery to be unsafe if used in closed abdominal cavity and some authors have recommended that electrocautery in certain anatomic regions should be replaced by other techniques, such as use of electrocauyery in Calot's triangle (*Jurka,* 1993) [54], yet Katri et al [18] safely used monopolar cautery for cystic artery control in 77% of cases admitted for laparoscopic cholecystectomy. Monopolar electrocautery has many advantages including: wide availability in any operating theatre, easy to use, it provides greater penetration of current density which can actually be an advantage for hemostasis in certain areas besides it produces an area of coagulation twice that of bipolar current. However, concern about the use of monopolar cautery regarding safety and effectiveness still exists.

Fundamentals of electro surgery:

The conception of electro surgery began in the early 19th century when French physicist, Becquerel, first used electrocautery rather than using boiled oil to achieve hemostasis, he passed direct current (D.C.) through a wire thereby heating it and effectively cauterizing tissue upon contact.

Modern electrosurgery began at the turn of the century (1881) when French physicist Alex d'Arsonval pioneered the use of alternating electrical current demonstrating that radio-frequency currents below 10,000 HZ could heat living tissue without muscle or nerve stimulation. [55] It was not until the 1920s; however, that Harvard biophysicist William Bovie produced a commercially available electrosurgical unit (ESU) capable of cutting and coagulating human tissue [56]. To this day, the terms "Bovie" and "electrosurgical unit" remain synonymous terms.

A basic understanding of electricity is needed to safely apply electrosurgical technology to patient care in the operating room.

Electrosurgery has been described as high-frequency electrical current passed through tissue to create a desired clinical effect. As the current is delivered, it passes through and heats the tissues. This differs from electrocautery, in which electrical current heats an instrument and a clinical effect is realized when the heated tool is applied to the tissues. Central to the understanding of electrosurgery is an understanding of electrical circuits and Ohm's Law. Circuit is an uninterrupted pathway of flowing electrons and Ohm's Law describes the actions of a given Circuit:

Voltage = Current x Resistance

A current is measured as the flow of electrons during a given period of time. Voltage is the force driving a current against the resistance of the circuit.

In electrosurgery, voltage is provided by the generator, and current is delivered to the tissues through the electrode tip of the instrument. The voltage produced by an electrosurgical generator provides the electromotive force that pushes electrons through the circuit. [57]

Resistance to current is inherent within all human tissues. The higher the inherent resistance, the greater the voltage needed for the current to pass. Also, as more superficial tissues are cauterized, they become less electrically conductive, increasing their resistance and requiring higher amounts of voltage for current to penetrate to the tissues beneath.

There are two consistent natural properties of electricity that can impact patient care in the operating room:

1- It always follows the path of least resistance

2- It always seeks to return to an electron reservoir, such as the ground.

Electrosurgery requires the presence of a circuit for current to flow. In the absence of a complete circuit, the current will seek the ground. Before 1970, electrosurgical generators were “ground referenced,” i.e. the flow of energy was in relation to earth ground. In this situation, anytime the patient came in contact with a potential path to ground, the current would choose the path of least resistance; this could potentially result in current flow through an electrocardiogram pad or through intravenous pole in contact with the patient.

If the current density was high enough at the point of contact then there is a possibility for a patient burn. This potential hazard was eliminated with the introduction of generators that were isolated from ground, confining the current flow to the circuit between the electrode and the patient return electrode, which offers a low-resistance pathway for current to return to the generator from the patient. D’Arsonval discovered that electricity can cause body temperature to rise. The temperature change was noted to be a function of the current density. The transformation of electrical energy into heat occurs in accordance with Joules Law and can be expressed by the following formula:

Energy= (current/cross-sectional area) 2 x resistance X time

Heat given off is a function of current density (current per cross-sectional area), time, and resistance. It is apparent from this formula that the heat produced is inversely proportional to the surface area of the electrode, i.e., the smaller the surface area, the more localized heating energy is produced. In the same way, larger electrodes require longer periods of current application to achieve the same heat production.

The heating effects produced are central to the desired function of the electrosurgical instrument; the rate at which tissues are heated plays a crucial role in determining clinical effect. When an oscillating current is applied to tissue, the rapid movement of electrons through the cytoplasm of cells causes the intracellular temperature to rise. The amount of thermal energy delivered and the time rate of delivery will dictate the observed tissue effects.

In general, below 45°C, thermal damage to tissue is reversible. As tissue temperatures exceed 45°C, the proteins in the tissue become denatured, losing their structural integrity. (This is called coagulation). Above 90°C, the liquid in the tissue evaporates, resulting in desiccation if the tissue is heated slowly or vaporization if the heat is delivered rapidly. Once the tissue temperatures reach 200°C, the remaining solid components of the tissue are reduced to carbon. (Fig 9, 10) [58]

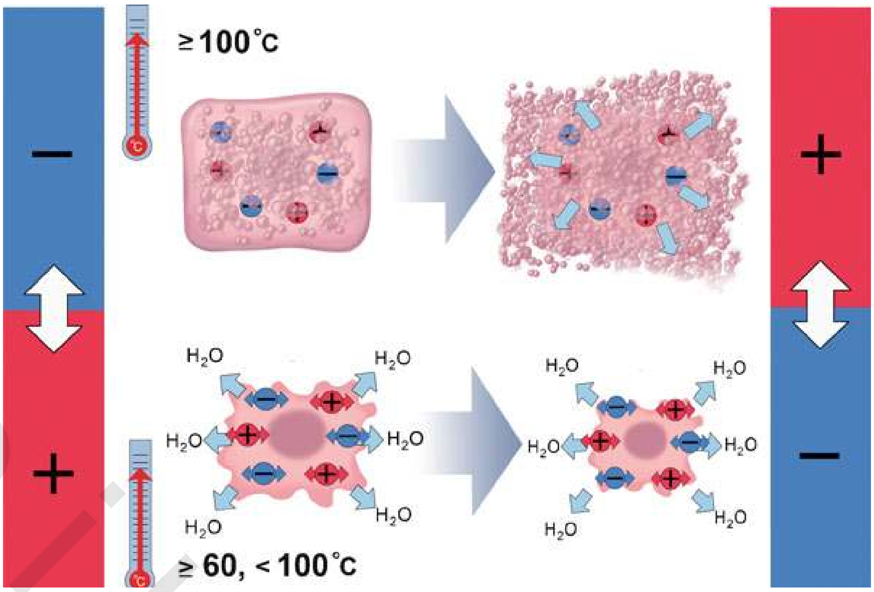

Fig (9): Impact of elevated temperature on cells. If temperature is at least 60°C, but below 100°C, there is loss of cellular water (desiccation) through the damaged cell wall (bottom). If the temperature meets or exceeds 100°C (top), the intracellular water turns to steam, there is massive expansion of the intracellular volume (vaporization).[59]

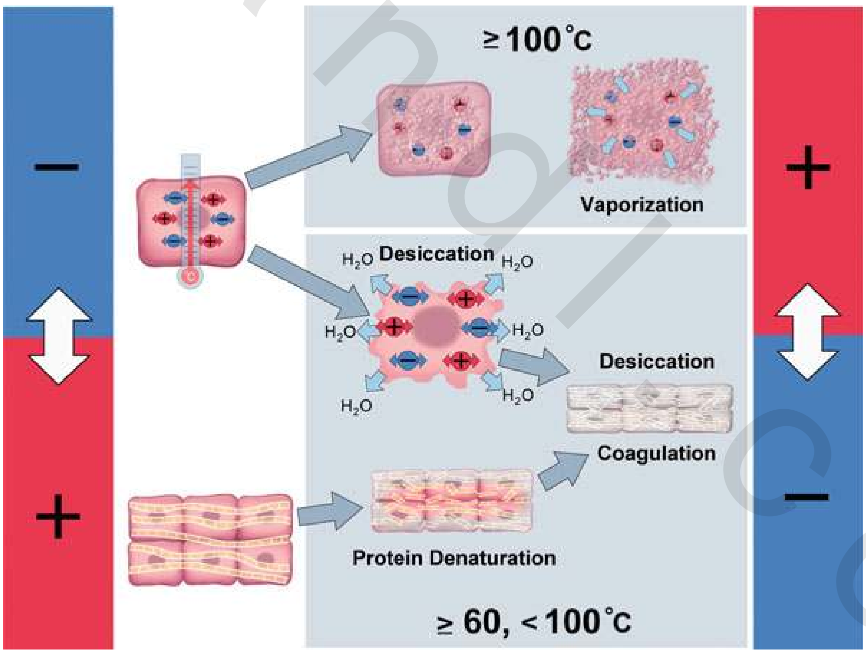

Fig (10): The formation of an electrosurgically-induced vessel seal occur when tissue temperature is at least 60°C, but below 100°C. First tissue desiccation (cellular dehydration and volumetric shrinkage). Second is the rupture of hydrothermal bonds or crosslink and reformation of these in a random fashion that includes bridging the gap between two opposing tissue surfaces. The result will be a strong seal, as if the vessel walls were compressed and welded together. [59]

The determinant of how tissue responds to electrosurgery is current type. Electrosurgical generators produce three different waveforms - cut, blend, and coagulation. Variation in waveform mediates corresponding changes in tissue effects.

A cut waveform consists of continuous radiofrequency waves which incorporate higher current but lower voltage than coagulation waveforms at the same power setting. This high current, low voltage waveform produces a local and intense heating effect that vaporizes tissue with the least effect on coagulation (homeostasis). A cutting current power setting must be between 50 and 80W to be effective.

A blend waveform is a modification of the cutting waveform and is used when homeostasis is needed while cutting. [60]

A coagulation waveform is composed of intermittent bursts of radiofrequency waves which have higher voltage and lower current than a cut waveform of the same power setting. Typically, the coagulation current is effective with the power setting in the range of 30 to 50 W. [61]

Electrosurgery modalities:

This refers to how the electrical circuit is completed. This could be achieved through 2 main methods:

1- Monopolar

2- Bipolar

First: Monopolar electrocautery:

Monopolar is the most frequently used method of delivering electrosurgery as it delivers a greater range of tissue effects. In monopolar electrosurgery, the generator produces the current, which travels through an active electrode and into target tissue and then it passes through the patient’s body to a patient return electrode where it is collected and carried safely back to the generator. This is the intended pathway for the current.

With the return electrode properly placed, the desired electrosurgical effect takes place only at the active electrode, not the dispersive electrode. The return or dispersive electrode (often referred to as the grounding pad) returns the current from the patient’s tissue to the electrosurgical unit (ESU). The large surface area of the dispersive electrode lowers the current density, preventing the current from heating and damaging tissues as it leaves the patient’s body.[62]

Most modern ESUs use a pad monitoring system to measure the quality of the contact between the patient’s skin and the dispersive electrode. If the pad becomes dislodged or high resistance exists between the pad and the patient’s skin, the unit will sound an alarm and become disabled.

High resistance may be caused by excessive hair at the placement site, air trapped between the pad and the skin or placement over poorly conductive tissue (e.g., scar tissue). Constrictive clothing or tourniquets may also produce a nadir effect and focus the energy away from the grounding pad, resulting in a remote burn.

Second: Bipolar electrosurgery

Bipolar electrosurgery has an active and a return electrode. The two arms of the circuit are part of a single surgical instrument, most often in the form of forceps. A grounding pad does not need to be applied to the patient as the current flows from one tip of the instrument to the other, only the tissue between the two electrodes is exposed to the electric current. Lower voltages are used to achieve the same tissue effect because the poles are close to each other. (63)

Localization of current between the poles offers distinct advantages. Thermal damage is generally limited to a discrete volume of tissue. The concentrated current and small distance between the poles also makes it possible to desiccate tissue that is immersed in fluid.

There are certain disadvantages to bipolar electrosurgery, such as increased time needed for coagulation and adherence to tissue with incidental tearing of adjacent blood vessels. The size of the forceps tips can be a disadvantage as well. If working near larger veins, this tip can create a hole in the vessel rather than causing an occlusion, and then, it is necessary to change to the bipolar forceps that have a broader rather than a pointed tip. Finally, bipolar coagulation cannot be used for cutting tissues. (64)

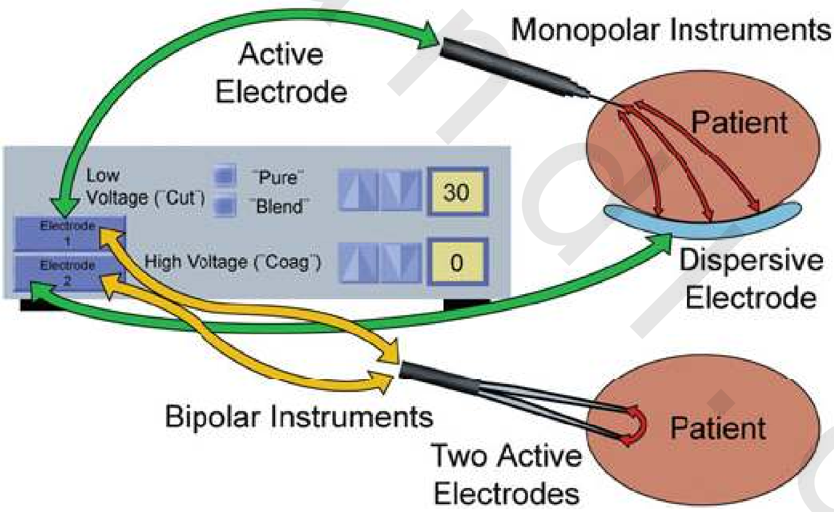

Fig (11): Electrosurgery modalities (65)

Other energy devices include:

Ligasure sealing device:

The Ligasure vessel sealing System (Valley lab) utilizes a new bipolar technology for vascular sealing with a higher current and lower voltage (180 V) than conventional electrosurgery. It uses a unique combination of pressure and energy to create vessel fusion. This fusion is accomplished by melting the collagen and elastin in the vessel wall and reforming it into a permanent, plastic-like sealer. A feedback-controlled response system automatically discontinues energy delivery when the seal cycle is complete thus minimizing thermal spread to approximately 3 mm, this unique energy output results in virtually no sticking or charring. (66)

Ultrasonic technology :(harmonic)

The basic working principle of ultrasonic surgical instruments is to use the low-frequency mechanical vibrations (ultrasonic energy in the range of 20–60 kHz) of the tool tips or the blades for tissue cutting and coagulation .The mechanical vibrations when transferred to the tissues on contact induce protein denaturation by breaking down the hydrogen bonds in tissues due to the internal cellular friction caused by the vibrations. The mechanical vibrations are produced by the piezoelectric transducers embedded in the tools that convert the applied electrical energy to mechanical vibrations, which are then transferred to the active blades for cutting or coagulation. The Harmonic scalpel operates at a frequency of 55.5 kHz. (67, 68)

The major advantage of using UAS is that it produces less heat compared with other energy devices (less than 80°C compared with 100°C for electro surgery), thereby reducing the risk of thermal injury .Due to lesser heat generation, charring and desiccation also is greatly reduced.

General disadvantages of ultrasonic devices include slower coagulation compared with electrosurgery. The active blade becomes very hot and remains so for several seconds after application thus the surgeon should not touch bowel or other vital structures, as it could induce a thermal injury and result in an immediate or possibly a delayed full thickness injury. Another limitation of the Harmonic Scalpel is that it should be reserved for vessels 5 mm or less in diameter (69). Table III shows comparison between different energy modalities. (70)

Table III: Comparison between different energy modalities.

	Monopolar	**Traditional bipolar**	**Advanced bipolar**	**Ultrasonic**
Tissue effect	Cutting,coagul-ation	coagulation	Coagulation, cutting	Cutting, coagulation
Power setting	50-80 w	30-50 w	Default generator setting	55. 5 HZ
Maximum temperature	> 100 °C	> 100 °C	Not well assessed	< 80 °C
Thermal spread	Not well assessed	2-6 mm	1-4 mm	1-4 mm
Vessel sealing ability	Not applicable	Not applicable	Seal vessel < 7 mm	Seal vessel <5mm

Complications of monopolar electro surgery:

Burn is one of the most common complications of monopolar electrosurgery.[71] Burns are the result of a concentrated current exiting the body, which can happen if the dispersive electrode is not in full contact with the body, if it has dried out, or if it becomes disconnected .

Excessive hair, adipose, scar tissue, and even the presence of fluid lotions can diminish the quality of contact between the return electrode and the patient's skin. In these situations, current will seek other routes such as: towel clips, electrocardiogram leads, intravenous stands and even the operating table. [72]

Although return electrode monitoring systems can usually detect if the dispersive electrode has lost full contact with the patient's skin, they will not prevent all burns. [73]

Fires are another problem associated with electrosurgical devices. These devices are the most common cause of fires and explosions in operating room, with 100 cases reported every year. Electrosurgical units can ignite nearby sources of fuel that include paper or cloth drapes, flammable liquids, or gaseous anesthetics when in proximity with an oxygen-rich environment. [74]

Electromagnetic interference is another inherent danger of monopolar electrosurgery. The electrical current in a monopolar device can interfere not only with electrocardiogram monitors but also with pacemakers, conductive prosthetic joints, and cochlear implants. In the case of the pacemaker, this interference can result in asystole, syncope, bradycardia, ventricular fibrillation, and reprogramming or even destruction of the pacemaker. As for cochlear implants, they can be damaged by the electrical interference or cause unintended cochlear stimulation and injury through the electrode array. [75]

These previously mentioned problems do occur with the use of monopolar electrosurgical devices in both open as well as endoscopic procedures.

As regard their use in minimally invasive surgeries it was found that laparoscopic monopolar electrosurgery is associated with both direct and indirect thermal injury. Direct thermal injury occurs when the surgeon misidentifies anatomic structures or accidentally applies the tip of the active electrode to non-targeted tissue (i.e., surgical "pilot error"). In contrast, indirect thermal injury can result when electrical current is conducted along unintended pathways and burns or vaporizes a non-targeted tissue. During a laparoscopic electrosurgical procedure, energy passes through the abdominal wall by way of a cannula. The surgeon's vision is confined to a diametric view of several centimeters inside the peritoneum.

The laparoscope shaft, electrode shaft, and cannula are not in the surgeon's view. Any unintended transfer of energy along the shaft of the laparoscope, electrode or cannula can result in visceral damage without the surgeon's knowing. Such indirect injuries occur during laparoscopic monopolar electrosurgery as a result of insulation failure, direct coupling, and capacitive coupling. The incidence of complications related to laparoscopic electro- surgery has been reported to be 2.3 per 1,000 electrosurgical procedures in the 1970s [76] and 2 to 5 per 1000 in 1990s. [77]

In order to understand how and where laparoscopic electrosurgical hazards occur it is better to divide the active electrode and cannula system into four zones

Zone 1 is the area at the tip of the active electrode in view of the surgeon.

Zone 2 encompasses the area just outside the view of the surgeon to the end of the cannula.

Zone 3 is the area of the active electrode covered by the cannula system. This is also outside the view of the surgeon.

Zone 4 is the portion of the electrode and cannula that is outside the patient's body. (Fig 12)

The greatest concern is the unseen incidence of stray electrosurgery current in Zones 2 and 3 (Harrell, 1998). [78]

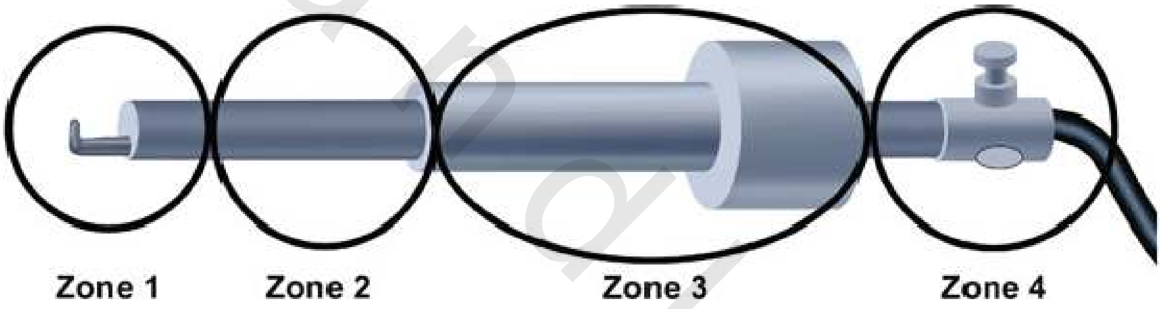

Fig (12): zones of injury [79]

Pitfalls of monopolar electrosurgery during minimally invasive surgery:

1- Direct application:

This may be due to unintended activation of the electrosurgical probe e.g., moving from the intended operating area to an iliac artery or vein on the pelvic sidewall or operating on a moving ovarian cyst. [80]

This hazard could be avoided by:

- Activate electrode when fully visible and in contact with the target tissue.
- avoid using other instruments as much as possible.

2- Direct Coupling

Direct coupling occurs when the electrosurgical unit is accidentally activated while the active electrode is in close proximity to another metal instrument. Current from the active electrode flows through the adjacent instrument through the pathway of least resistance, and potentially damages adjacent structures or organs not within the visual field that are in direct contact with the secondary instrument.[81] This can occur within zones 1, 2 or 3. If it occurs outside the field of vision and the current is sufficiently concentrated a patient injury can occur.

It can be prevented with visualization of the electrode in contact with the target tissue and avoiding contact with any other conductive instruments prior to activating the electrode .(Fig 13)

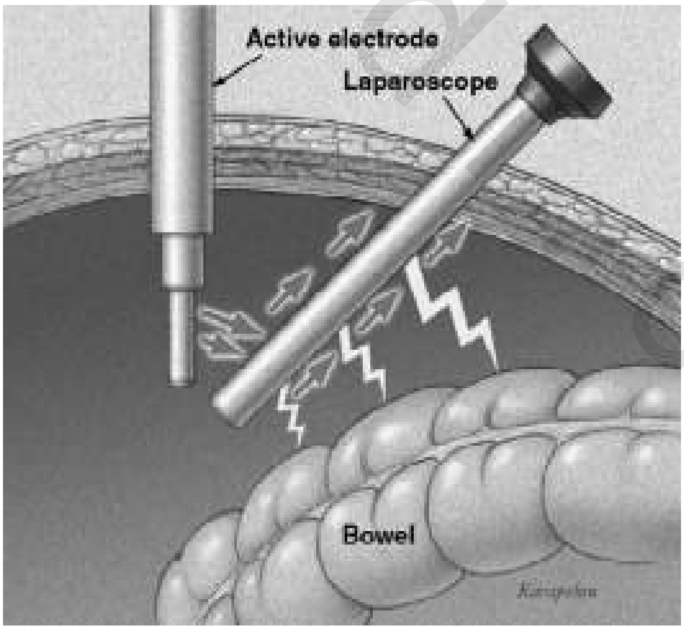

Fig (13): Direct coupling occurs when an active electrode makes an unintended contact with another electrode or conductive instrument. [82]

3- Insulation failure:

This is now thought to be a main cause of laparoscopic electrosurgical injuries. It is defined as a break or defect in the insulation that coats the instrument. Insulation failure is caused by excessive use of reusable instruments, particularly with repetitive passage through trocars and frequent mechanized sterilization.[83] By lowering the concentration of the current used, coagulation with cutting current and use of an active electrode monitoring system, the risk of accidental burns can be reduced.

Eighteen percent of insulation defects are located in the section of the instrument most likely to create a catastrophic electrosurgical injury. Originally described as ‘‘Zone 2 ” by Voyles and Tucker, the location along the instrument, which is outside the view of the monitor but distal to the protective cannula, carries the highest risk for creating an injury that even the most attentive surgeon is unable to detect. Disposable instruments have a lower incidence of insulation failure compared with reusable instruments. The distal third of laparoscopic instruments is the most common site of insulation failure. (Fig 14)

It could be prevented by:

- lowering the current concentration by coagulation with a cutting current
- Use of an active electrode monitoring system.

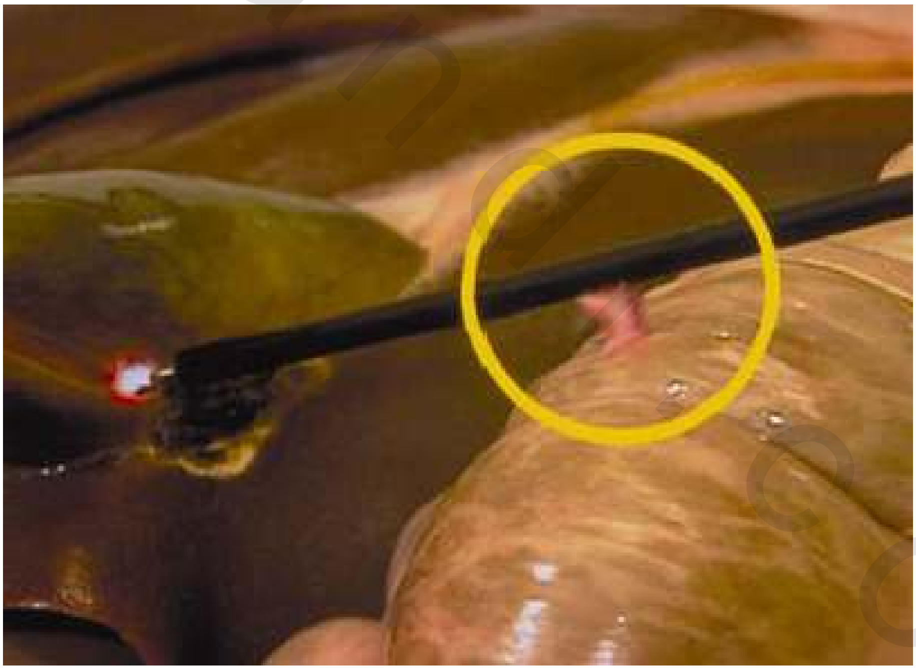

Fig (14): Insulation failure [84]

4- Capacitive coupling:

Capacitive coupling is electrical current that is established in tissue or in metal instruments running parallel to but not directly in contact with the active electrode. This occurs when electric current is transferred from one conductor (the active electrode) through intact insulation and into adjacent conductive materials (e.g., bowel) without direct contact. [85]

In monopolar mode, an alternate current flowing through an active monopolar electrode and back to the electrosurgical generator through the patient and the return pad induces an unintended current in any conductors in close proximity. The degree of current induced will depend on the proximity of the conductors, the voltage, and the insulation. Any conductor in the operating room is at risk of inheriting a stray current by becoming capacitively coupled to the current coming from the active electrode. (Fig 15)

If an injury is to occur it is often away from the surgeon's visual field and involves body structures. Ironically, the use of metal trocars can actually reduce this risk by allowing the stored energy from a capacitor to dissipate over the large surface area of the patient’s skin, thereby making the electrical energy less concentrated and less dangerous.

Capacitive coupling can be prevented by the following precautions:

- Activate the electrode only when it is in contact with the target tissues.
- Limit time on the coagulation setting.
- Use metal cannulas that allow stray current to be dispersed through the patient's abdominal wall not internal tissues.

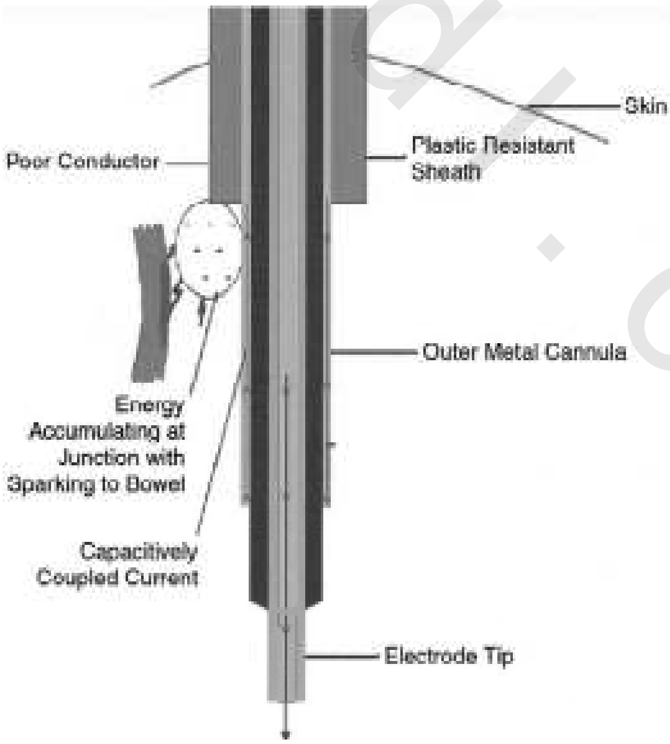

Fig (15): Capacitive coupling [86]

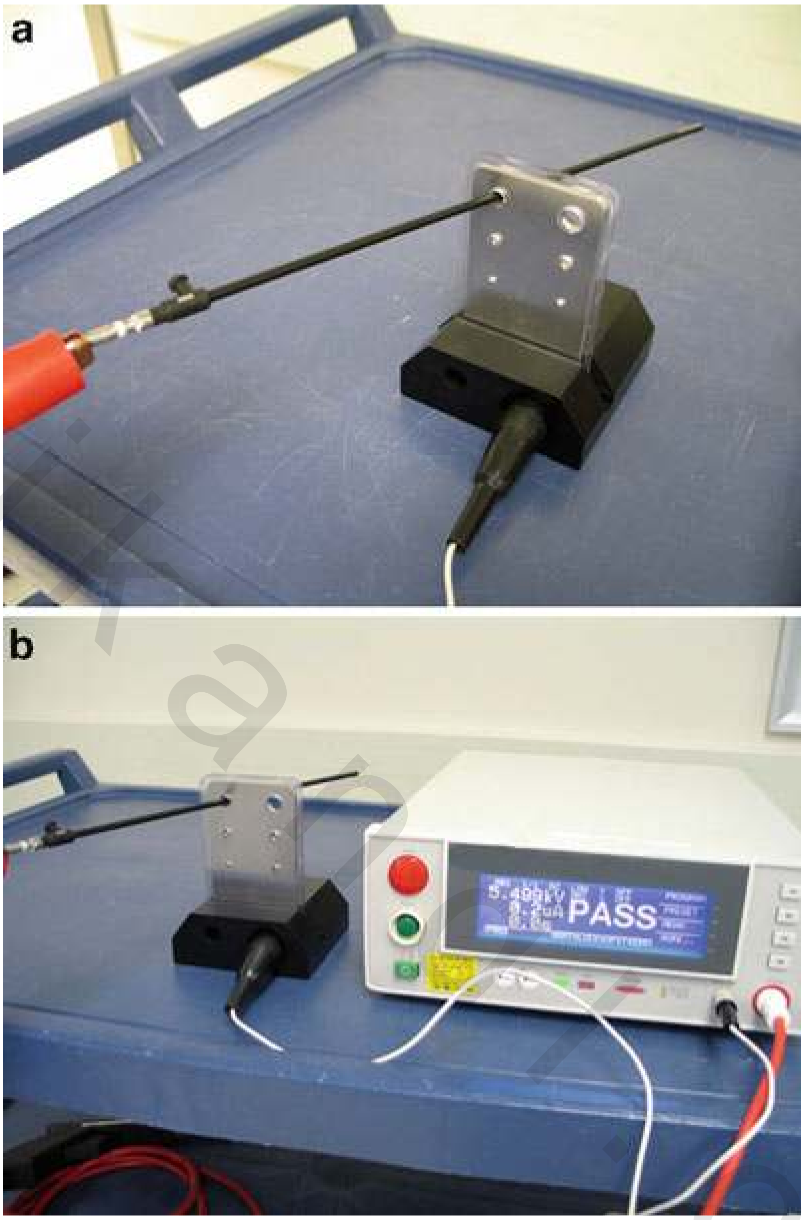

Figure (16): Example of one type of active electrode monitoring system used to detect insulation failure in laparoscopic instruments.

(a) The instrument is passed back and forth through a test plate while connected to the monitoring unit.

(b) The “PASS” readout on the monitoring unit indicates that no insulation breaks were detected. If a break was present, the readout would have been “FAIL”. [87]

Clinicopathological findings of electrosurgical injuries:

The use of monopolar electrosurgical devices during laparoscopic cholecystectomy might contribute to the following drawbacks:

1- Biliary tree injuries.

2- Bowel injuries

3- Duodenal perforation

4- Disseminated intraabdominal heat.

1-Biliary injuries:

Bile duct injury (BDI) is defined as an accidental injury (i.e. laceration, Transsection, resection, thermal injury or stricture) of any part of the major extra hepatic biliary tract, excluding biliary leakage from the cystic duct or the gallbladder fossa with an intact extra hepatic biliary system. These BDI are sometimes reported as "major BDI" in the literature with an incidence of 0.4%-o.7 % following laparoscopic cholecystectomy (88, 89).

Thermal injury related to the use of monopolar cautery near the portal hilum, during dissection of Calot's triangle or during attempt to stop hemorrhage is involved in LC induced BDI. Cautery-induced injuries are also more likely to occur in the presence of severe inflammation, because this condition may lead to the use of excessively high cautery settings to control hemorrhage. Higher settings may lead to arcing of current to the ducts, either cystic duct stump or the adjacent bile duct resulting in loss of ductal tissue due to thermal necrosis. Thermal injury could be responsible for bile duct necrosis resulting in pinhole perforation or late biliary stricture (90).

The two most frequent scenarios are bile leak and bile duct obstruction. Bile leak scenario is easily recognized during the first postoperative week. Constant bile effusion is documented through surgical drains, surgical wounds or laparoscopic ports. Patients usually complain of diffuse abdominal pain, nausea, fever and impaired intestinal motility. In addition, bile collections, peritonitis, leukocytosis and mixed hyperbilirubinemia may be part of the clinical setting .An obstructive pattern in liver function tests accompanied by jaundice is frequent in the biliary obstruction scenario.

On the long run BDIs result in biliary fistula, intra-abdominal abscess, biliary stricture, recurrent cholangitis and secondary biliary cirrhosis. (91)

2- Bowel injury:

Bowel injury due to a laparoscopic surgical procedure, though rare, is a devastating and potentially life-threatening complication. The reported incidences of bowel injury and bowel perforation are between 0.13% and 0.22%, respectively (92).

The mechanical damage of bowel may be perforating or non perforating, and may be recognized at the time of surgery or become apparent some time postoperatively. The other form of complication relates to the electro thermal burn.

Bowel cautery injuries, both contact and conductive, usually occur in proximity to the field of dissection. Contact burn injuries may be recognized at the time of surgery and treated appropriately. In contrast, conductive burns either are not recognized at all or are recognized remotely when perforation occurs 1 to 2 weeks after the initial procedure. [93]

The average time in cases of Bovie injury, from injury to diagnosis, was 10.4 days.[94]. Chapron et al reported that approximately 75% of bowel injuries were diagnosed within the first postoperative week and Perforations that were diagnosed late generally resulted from thermal injury and were generally longer for large bowel injury than for small bowel injury.[95] Saltzstein et al. [96] reported that the time delay from burn to perforation appears to be related to the severity of the coagulation necrosis.

At surgery for delayed bowel perforation, the gross appearances of traumatic and electro thermal injuries are the same; the perforation with a surrounding white area of necrosis. However, microscopic examination reveals completely different characteristics

The puncture injuries are characterized by:

(1) Limited, noncoagulative-type cell necrosis, more severe in the muscle coat than the mucosa.

(2) Rapid and abundant capillary ingrowths with rapid white cell infiltration.

(3) Rapid fibrin deposition at the injury site followed by fibroblastic proliferation.

(4) Significant reconstitution of the injured muscle coat by 96 hours.

Whereas sites of electrical injuries are distinguished by:

1- An area of coagulative necrosis.

2- Absence of capillary in-growth and absence of white cell infiltration, except in focal areas at the viable borders of injury. [97, 98]

Bovie injury to the bowel has a hidden depth, causing a slow transmural tissue necrosis, and it might also impair local healing and eventually lead to perforation. Therefore, presentation may be delayed, obviating simple primary closure as an option and increasing the chance of diffuse peritoneal soiling or abscess formation. [99]

Bishoff et al. [100] reported that a patient with bowel injury after laparoscopic surgery may have an unusual presentation and devastating sequelae. The initial presenting complaint of all patients with unrecognized bowel injury was persistent increased pain at a trocar site without significant erythema or purulent drainage. On examination, the painful trocar site was closest to the injured bowel segment. Symptoms then progressed to abdominal distension and diarrhea, whereas ileus, diffuse abdominal pain, nausea, and vomiting were uncommon findings.

3- Duodenal perforation:

Duodenal perforations after laparoscopic cholecystectomies are rarely reported. It is a fatal complication which may result from electric burns. These burns may occur without any contact between the active electrode and the duodenal wall, due to stray currents. [101]

During laparoscopic surgery, electric burns are likely to occur, because the electrosurgical instruments are partially out of the surgeon's visual field. The symptoms usually arise soon after surgery, except in case of duodenal burns, when they occur abruptly 1–3 weeks after cholecystectomy. [102]

The proximal portion for the duodenum is typically involved, commonly in its posterior aspect; thus the duodenal contents leak into the peritoneal cavity and the retroperitoneal space. The duodenal juices which escape into the abdomen and retroperitoneum contain bile and pancreatic enzymes which are immediately activated, Such cocktail, which typically is mixed with intestinal bacteria, is very toxic, it dissolves tissue plans, thus spreading rapidly and causing peritonitis and systemic sepsis.

A duodenal perforation should be suspected in cases of bile leakage, peritonitis, intra abdominal or retroperitoneal collections, high serum or drainage amylase concentration, absence of bile leakage from the biliary tree and the existence of a retroduodenal mass. [103]

It is important to mention that free perforations of the duodenal cap are easier to diagnose and usually have an early and successful primary repair by laparoscopy. On the other hand, perforations of the descending duodenum may be walled off, and have poor abdominal signs (pain, tenderness, muscle contraction, fluid collection at ultrasound, pneumoperitoneum at radiograph). They also may be complicated with a lumbar abscess and end up with a late diagnosis and long secondary healing processes.

4- Disseminated intra abdominal heat injury:

In the presence of electrical leak and high frequency monopolar electrocautery,irrigation solution (ex : normal saline) will act as a conductor of electricity, passage of electrical current through the irrigation solution and other intraabdominal fluids can lead to increase in temperature of the fluid. Then disseminated heat burn will be probable in the organs which are in contact with the hot fluid.

This was the explanation proposed by Jafari in his published case report [104]. He reported a case of a patient admitted for elective laparoscopic cholecystectomy, about 40 minutes after initiation of the laparoscopic surgery a progressive tachycardia and hypertension was noticed. Anesthetic machine, O2, inhalational anesthetics and appropriate position of tracheal tube were checked, the operation ceased and when laparoscope was withdrawn, it was unexpectedly hot and heat injury was supposed. The abdomen was opened immediately. Intraabdominal temperature was abnormally high and visceral organs were reddish and inflamed.