

## FUNDAMENTALS OF PHYSICS IN SURGERY- REVIEW

Dr. Puneet Kumar Agarwal<sup>1</sup>, Dr. Vikram Vasuniya<sup>2</sup>

<sup>1</sup>MS (General Surgery), FMAS, FICRS, Associate Professor, Dept of Surgery, AIIMS Bhopal

<sup>2</sup>MS (General Surgery), Senior Resident, Dept of Surgery, AIIMS Bhopal

**Article Info:** Received 18 June 2020; Accepted 11 July 2020

**DOI:** <https://doi.org/10.32553/ijmbs.v4i7.1290>

**Corresponding author:** Dr. Vikram Vasuniya

**Conflict of interest:** No conflict of interest.

### Abstract

Physics is everywhere in our daily life. It helps in understanding concepts of surgery easily. Application of physics in surgical field is very helpful especially for a surgeon. In this article we have summarized some common laws of physics, many of them we see in our operation theatre like Poiseuille's Law, Pascal's Law, Laplace's Law, Bernoulli Equation or Theorem, Ohm's Law, Floating Ball Valve Mechanism, Newton's Law of Cooling, Laws of Vector and Air-Water Seal System. The application and understanding of these laws would make a surgeon think more like a scientist. Doppler Effect is used in ultrasonography to evaluate the direction and velocity of blood flow. Reynolds number (NR) is used to predict whether the flow of blood will be laminar or turbulent.

The laws of Thermodynamics, Mechanics, and Vectors as they apply to soft and bony tissues. These include the Laplace's Law as applied to colonic perforation and esophageal varices etc. In Electrocautery, alternating current is passed through a resistant metallic wire electrode and generates heat. The heated electrode is used to achieve hemostasis and dissection. The Pascal's Law finds use in hernia repair

**Keywords:** Physics, Surgery, Fundamentals.

### Introduction

Physics is the most fundamental physical science and it has contributed in almost all scientific streams. Health science benefited very much from its concepts. In this age of multidisciplinary collaboration, many physics professionals working with healthcare experts to face the ever growing challenges of the modern Health Science. This article discusses some of the basic laws of physics, which help in the understanding of the various pathophysiological mechanisms in surgical field.

### Principles and its application in surgical field

#### Bernoulli's principle

Bernoulli's principle [1] formulated by Daniel Bernoulli (1700–1782) states that as the speed of a moving fluid (liquid or gas) increases, the pressure within the fluid decreases and vice versa. This is an application of the law of 'conservation of mechanical energy' (which in turn is made up of potential energy and kinetic energy) to the flow of an ideal fluid. The equation is:

$$\frac{1}{2} \rho v^2 + \rho gh + p = \text{Constant}$$

Where:  $\rho$  = density of fluid,  $v$  = velocity of the fluid,  $g$  = gravitational acceleration,  $h$  = elevation and  $p$  = pressure gradient across the conduit.

1. Enterocutaneous fistula [2]

Generally, Fistulas do not close if there is an obstruction distally. Fluid tends to find the easiest pathway, and relieving the distal obstruction according to Bernoulli's principle will increase the forward flow, causing a negative pressure at the junction of the fistulous tract and thus promotes its closure.

2. Sleeve gastrectomy

In case of a leaking sleeve gastrectomy, the leak usually occurs from the higher staples, close to the esophagogastric junction. This is caused by higher intragastric pressure, as the pyloric muscle is patent and tough, and acts as a barrier to pressures. Long transgastric stent decreases intragastric pressure is a definite remedy for this problem, as it decreases the flow into the leaked staples.

3. Pseudocysto-gastrostomy

In pseudocysto-gastrostomy, it was remained a mystery for several decades that why food from the stomach did not enter into the pseudocyst. The actual reason is explainable with the help of Bernoulli's principle. Food and liquid flows in the stomach from the esophagus towards the antrum causing a high forward flow. Pressure gradient develops between the pseudocyst cavity and the gastric cavity. Due to this high forward flow and pressure gradient, content flows only from the pseudocyst to the stomach cavity.

4. Post-stenotic dilatation [3]

Sudden widening at the end of the stenosis is due to conversion of high kinetic energy into high potential energy, dissipated in the form of increased lateral pressure and turbulence. This increased lateral pressure can deform the vessel wall and increases its diameter. Further increase in the diameter of vessel causes weakness of its wall.

### Pascal's Law

Given by Blaise Pascal in 1652 states [4] that "pressure applied to a confined fluid at any point is transmitted undiminished throughout the fluid in all directions and acts upon every part of the confining vessel at right angles to its interior surfaces and equally upon equal areas"

#### 1. Hernia repair

With the help of Pascal's law one can easily understand biomechanics of mesh placement in abdominal hernia surgery. We can understand this like, whenever if leak in the bath tub or in hot air balloon, it is repaired best from inside by sealing. Repair from inside pushes seal outwards and further pressure pushes the stopper in place and keeps it fixed there. The more the water pressure in bathtub, the more firmly does the stopper gets applied. If sealed from outside, the pressure of the air or water will push outwards and it is likely to fail. Now imagine this scenario while placing a prosthetic mesh on the hernial defect.

#### 2. Abdominal compartment syndrome (ACS)

Any increase in intra-abdominal pressure would reflect equal pressure on all sides equally towards abdominal wall and diaphragm. The renal, cardiovascular, and respiratory systems are also involved by virtue of compressing the inferior vena cava and pushing the diaphragm up. It usually not recognized easily as the affected patients who are ill and admitted in the ICU. This condition may develop due to penetrating trauma, intraperitoneal hemorrhage, pancreatitis, postoperative state, large volume resuscitation, intra-abdominal sepsis, and various other conditions. Measurement of the intravesical pressure through a Foley's catheter is a simple way to monitor the patient clinically and enables early detection of the onset of ACS. If the intravesical pressure increases beyond 15 mmHg, it means ACS is impending, and steps are to be taken immediately to reduce the pressure.

#### 3. The Heimlich maneuver

In the Heimlich maneuver chest wall circumferentially compressed with a sudden and abrupt pressure over xiphisternum, which lift up your diaphragm and expel out air from your lungs. This results in dislodgement of the foreign object from your airway.

### Laplace's Law

The law of Laplace [5] is applied in the physiology of blood flow and states that tension in the wall of a closed container is product of the pressure and the radius.

That is, for spherical vessel

$$2T=P \times R$$

For cylindrical vessel

$$T=PR$$

where,

T=tension on the wall,

P=pressure within the chamber,

R=radius of the container.

#### 1. Closed loop intestinal obstruction

In case of complete large bowel obstruction with a competent ileo-cecal valve, Laplace's law plays an important role. The entire colon segment from the ileo-cecal valve to the constricting growth acts as a container with equal pressures all around (Pascal's law). The cecum has the highest radius which increases chance of cecal blowout or perforation.

#### 2. Esophageal varices

Esophageal varices of grade III and IV has a much higher chance of rupture compared to grade I & II. Grade III and grade IV varices have the same intravariceal pressure as the grade I and II, but due to increased diameter tension is higher. This means larger the diameter, more prone for spontaneous rupture.

#### 3. Compression Therapy of edematous limb [6]

Compression bandage application on an edematous leg is an effective way to reduce the swelling. According to the Laplace's Law, the compressive pressure that will be generated on the bandaged limb will be transmitted to the veins which get compressed. This increases the venous return and lymphatic flow of the limb.

#### 4. Artificial Rupture of Membranes [7]

After releasing a significant volume of amniotic fluid from sac permits enough reduction in the radius of the gravid uterus so as to generate enough tension to begin parturition and expedite labor.

### Poiseuille's Law

It relates to the rate (Q) of blood flow through a blood vessel with the difference in blood pressure at the two ends ( $\Delta P=P_1-P_2$ ), the radius (r) and the length (L) of the artery, and the viscosity ( $\eta$ ) of the blood [8].

$$\text{Volume flow rate} = \frac{\pi (\text{pressure difference}) (\text{radius})^4}{8 (\text{viscosity}) (\text{length})}$$

This law can be expressed as:

$$Q = \pi r^4 \Delta P / 8L\eta$$

An increase in the diameter of a vessel from 1 to 2 mm will increase the flow rate by 16 times (for  $r=2$ ,  $r^4=16$ ), if other factors of equation remain constant [9].

### Tubes and Drains

1. During the decompression of the stomach, a wide nasogastric tube connected to a short and wide tubing (e.g., urobag), this will increase the flow by virtue of increased radius ( $r$ ) and short length ( $L$ ).
2. Using drains of a large diameter 16 or 18 F connected to short and wide tubing can increase the flow rate. Additionally, by applying vacuum, the ( $\Delta P=P_1-P_2$ ) is kept high.[9]
3. The downside of excessive negative pressure suction is continued effluent from the drainage tube. This can be avoided by decreasing the negative pressure and hence the  $\Delta P$ . In 2005, **Chintamani et al.**[10] showed in a randomized controlled study that a half vacuum suction drain after modified radical mastectomy for breast cancer significantly reduced the hospital stay as compared to those on full suction vacuum drain without added morbidity. A good guide to the timing of decreasing the vacuum would be when the RBC settles on the tube with clear serum above. This indicates that the bleeding has stopped, and it is the serum that is draining [10].

### Serial transverse enteroplasty (STEP)

In patients with Crohn's disease with multiple strictures, Serial transverse enteroplasty (STEP) is a alternative to bowel resection and short bowel syndrome. By making multiple cuts in the intestine and creating a zigzag pattern, surgeons lengthen the amount of bowel available to absorb nutrients. This transverse enteroplasty is repeated at all the stricture to increase the diameter of bowel.

### Fluid Resuscitation

In case of hypovolemia due to hemorrhage, rapid fluid replacement is the key to resuscitation. Short and bigger gauge cannula to be used to achieve faster transfusion. Additionally using crystalloid (low viscosity) and applying pressure cuff around the infusion bottle also helps to achieve high flow rate.

### Carcinoma colon

Right sided tumours typically present at a more advanced stage with symptoms of weight loss and anaemia. Obstruction is a late phenomenon in right colonic cancer. It is due to nature of tumour, exophytic rather than constricting and also because of liquid content compared to left side. Left sided tumours often present early with rectal bleeding, change in bowel habit, and tenesmus.

### Ohm's Law

Ohm's Law is the very basic law in electricity. It correlates voltage, current and resistance.

$$V = I \times R,$$

Where  $I$  is the intensity of the current,  $V$  is the Voltage (force driving the current against the resistance) and  $R$  is the resistance of the circuit. It is measured in volt, ampere and ohm respectively. Every surgeon understands the basics of Ohms law because there is almost no surgery without some form of electrocautery. Here, radiofrequency alternating current is used to raise the temperature of cells to cause desiccation and coagulation of proteins, with a net result of either cutting or coagulation (used for hemostasis of tissues) [2]. The inappropriate placement of diathermy pad may cause a diathermy burn.

### Floating Ball Valve Mechanism

A mass tethered to the wall or lumen of hollow viscera by a stalk causes partial or complete obstruction to the free flow of a gas or fluid [014]. This is classically seen in case of partial intestinal obstruction, specially at a stricture/narrowing when a food bolus gets stuck there, it causes complete obstruction. If we manage such patient non-operatively by giving rest to the gut, the pressure gradient proximal to the obstruction decreases and the food bolus may get dislodged. Thus, most of the times obstruction gets relieved.[11]

### Air-Water Seal System

Chest tube drain insertion allows drainage of air, blood or fluid from the pleural space, resulting in expansion of the lungs and restoration of negative pressure in the thoracic cavity. This air-water seal system acts as one-way valve to air. It allows air to escape from chest cavity to the draining bag or bottle. But there is no movement of air in reverse direction. [11]

### Newton's Law of Cooling

The Newton's law of cooling [12] is given by the following formula:

$$\frac{dQ}{dt} = h \times A \times (T_{env} - T)$$

Where,

Q Thermal energy

h Heat transfer coefficient

A Surface area across which the heat is being transferred

T Temperature of the object's surface

T (env) Temperature of the environment

Wound healing is influenced by many factors like ambient Temperature around the wound, oxygenation, infection etc. The closer the wound temperature to the core body

temperature the better is the healing process. The concept behind this is that during the early stages of wound healing the higher temperature helps macrophages in their phagocytic actions and is also inhibitory to the growth of the microbes. Dressing and keeping the wound moist also promotes healing by preventing loss of heat.[9]

### Reynolds number (NR)

Reynolds number (NR) is used to predict whether blood flow will be laminar or turbulent.

It is calculated [13] as:

$$Re = (v.d.\rho) / \eta$$

Where: mean velocity of flow = v, diameter of vessel = d, density of fluid =  $\rho$  and viscosity of fluid =  $\eta$  are known.

Murmurs occur in the heart when laminar flow is replaced by turbulence flow and this occurs when Reynolds number are above 2000. In large arterio-venous fistulas turbulence can also damage red blood cells causing haemolysis. One should be aware of these facts while choosing the right diameter of a tube delivering blood at a high speed e.g. in an Extracorporeal membrane oxygenator (ECMO).[3]

### Doppler Effect

Doppler Effect refers to the change in wave frequency during the relative motion between a wave source and its observer. It was discovered by Christian Johann Doppler in 1842. This principle is used in Doppler ultrasonography.

$$\Delta F = (F_o - F_e) = \frac{(2. F_o. V. \cos \theta)}{c}$$

where:  $\Delta F$  = Change in frequency also called Doppler shift,  $F_o$  = transmitted frequency,  $F_e$  = reflected frequency,  $V$  = relative velocity of the reflector,  $c$  = velocity of sound,  $\theta$  = Doppler angle/angle of the transducer with the direction of the blood flow

Doppler ultrasound detects moving blood cells or other moving structures and measure their direction and speed of movement. The Doppler Effect is used to evaluate movement by measuring changes in frequency of the echoes reflected from moving structures. It permits real-time evaluation of the major arteries & veins of the body, the heart, and in obstetrics for fetal monitoring. The test is most often used to evaluate blood flow in the limbs and helps to diagnose deep vein thrombosis (DVT), peripheral vascular diseases (PVD) and incompetent valve in varicose veins etc.

### Laws of Vector

All sutures produce vector forces that act in various directions as the suture is tightened. The vector forces extend in three different directions: perpendicular to the wound surface, parallel to the wound margin, and perpendicular to the tissue surface. If a suture is placed perpendicular to the wound surface, the force vectors cause compression in a line where the suture plane intersects with the wound surface. Each interrupted suture generates a zone of compression. The compressive effect is maximal in the plane between the point of suture entry and suture exit and falls off laterally. The action of the suture can be described in terms of force triangles extending laterally from the suture. The width of these compression zones depends on the length of the suture bites and the degree of suture tension after the suture is tightened. Adequate wound closure is achieved when the zones of compression of each interrupted suture overlap.[14]

### References

- Halliday D, Resnick R, Walker J (2001) Fundamentals of Physics. Singapore: John Wiley and Sons – 6<sup>th</sup> ed. Chapter 15: Fluids. pp 336–337
- Rajkumar JS, Chopra P, Chintamani. Basic Physics Revisited for a Surgeon. *Indian J Surg.* 2015;77(3):169-175. doi:10.1007/s12262-015-1308-6
- Srivastava, Anurag & Sood, Akshay & Joy, Parijat & Woodcock, John. (2009). Principles of physics in surgery: The laws of flow dynamics physics for surgeons - Part 1. The Indian journal of surgery. 71. 182-7. 10.1007/s12262-009-0064-x.
- Halliday D, Resnick R, Walker J (2001) Fundamentals of physics, 6th edn. Wiley, Singapore, pp 328–329
- Ganong William F (2005) Review of Medical Physiology 22<sup>nd</sup> International Ed. Chapter 30—Dynamics of blood & lymph flow. McGraw Hill, pp 586–587
- Stemmer R (1992) Theoretical and practical basis of compression. *J Mal Vasc* 17(4):329–32
- Stillwell GK (1973) The Law of Laplace: Some clinical applications. *Mayo Clin Proc* 48(12):863–9
- Anurag S, Akshay S, ParijatJoy S, John W (2009) Principles of physics in surgery: the laws of flow dynamics physics for surgeons—part 1. *Indian J Surg* 71:182–187. doi:10.1007/s12262-009-0064
- Srivastava A, Sood A, Joy PS, Mandal S, Panwar R, Ravichandran S, Sarangi S, Woodcock J (2010) Principles of physics in surgery: the laws of mechanics and vectors physics for surgeons—part 2. *Indian J Surg* 72(5):355–361. doi:10.1007/s12262-010-0155-8
- Chintamani, Bansal A, Saxena S (2005) Half versus full vacuum suction drainage after modified radical mastectomy for breast cancer—a prospective randomized clinical trial [ISRCTN24484328]. *BMC Cancer* 5:11
- Arya PK. Applications of Basic Physics for a Surgeon. *Indian J Surg.* 2016;78(3):254. doi:10.1007/s12262-015-1405-6
- Winterton RHS (1999) Contemporary physics. Taylor and Francis Ltd, 40(3):205–212
- Robert W Fox, Alan T McDonald. Introduction to Fluid Mechanics. Singapore: John Wiley and Sons – 4th ed. pp 33, 297
- Benjamin, Larry. (2007). The Physics of Wound Closure, Including Tissue Tactics. 10.1007/978-3-540-68041-3\_1.