Physics for Surgeons Part 3: Why Cyst Is Spherical in Shape?

Darakshan Qaiser¹ · Anurag Srivastava¹ · Piyush Ranjan¹ · Kamal Kataria¹

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Abstract Physical examination of any swelling is the first step in making a diagnosis. Many a times we see a patient with a spherical swelling, which is usually a cyst. The interpretation of physical signs should be based on sound principles of physics. In the present paper, we explain physical characteristics of a swelling (cyst) using principles of fluid mechanics.

Keywords Cyst · Surface tension · Pascal's law · Density

Introduction

Swelling or a tumour may be composed of different types of tissues. It may be entirely solid or may contain some fluid. Cyst (Greek) is a thin-walled cavity containing fluid shown in Fig. 1. The palpation of a swelling may provide us information about its composition. Cysts can be simple or complex depending upon the amount of solid component present. In most of the cases, cysts (especially micro-cysts) are not painful and not progressive [1].

Cyst Formation Whenever there is epithelial proliferation (hyperplasia), the mass reaches a critical size at which the diffusion of blood /oxygen/ nutrients within the epithelial mass cannot keep pace with the metabolic demand. This discrepancy (lack of nutrients) results in degeneration and death

of the cells located at the centre of the mass with subsequent liquefaction which in turn causes formation of a cavity in the epithelial mass. However, epithelial cells closer to the stroma remain viable.

Cyst Growth The degradation of the central cells in the cyst results in an increased osmotic pressure gradient to the surrounding stroma (Van't Hoff effect) [2, 3]. This gradient draws water into the cavity (to balance the osmotic pressure), resulting in an increase in hydrostatic pressure inside the cyst in comparison to the surrounding. The volume expansion stretches the epithelial layer inducing division of the epithelial cells in order to maintain the intact epithelial lining. The osmotic gradient pressure is maintained throughout the constant shedding of cells into the cavity. However, the surrounding stroma tries to compensate by increasing the production of varying amounts of collagen fibres and reorganising them into the so-called capsule [4].

This fluid-filled swelling (cyst) Fig. 1b, c, on palpation, may feel soft, firm or hard. This difference in the feeling is dependent on the relative density. The following figures (Fig. 2) explain why the air-filled swelling feels very soft, liquid-filled swelling feels firm and solid swelling feels hard. The compressibility of a swelling is due to loosely packed molecules which on external pressure come closer. However, solid substance has very little intermolecular space; hence, our fingers are not able to compress them anymore. A schematic diagram showing intermolecular distance can be better understood in Fig. 2.

A fluid is a substance which flows. Fluid constituent's particles constantly change their position relative to one another because it cannot withstand a shearing stress [5, 6]. Fluid is further divided into two categories: liquid and gases. Spacing and latitude of motion is extremely large in the case of gases than liquid [7]. Liquid possess properties like, density, thrust and surface tension [8]. Since cyst

✉ Anurag Srivastava
dr.anuragsrivastava@gmail.com

¹ Department of Surgical Disciplines, All India Institute of Medical Sciences, Ansari Nagar, New Delhi 110029, India

Fig. 1 **a** Swelling in the hand shows the physical appearance of a cyst. **b** A cyst consisting of fluid. **c** After removal of fluid from a cyst

contains fluid, therefore it will obey the laws of static fluid mechanics. In cyst, fluid exerts a force in the direction perpendicular to its own surface.

Properties of Liquid

Density

A quality which describes the incompressibility of fluid is called density. Density and pressure of liquid vary from point to point. Density at a point in fluid can be measured as [5].

$$\text{Density}(\rho) = \text{Mass}(m) / \text{Volume}(V)$$

In fluid, it is assumed that a fluid sample is large relative to atomic dimension; hence, sample is smooth (i.e. fluid have uniform density). Density of liquids does not vary considerably because it is not readily compressible. Density of a material changes with temperature and pressure. This variation is small in case of solids and liquids [9]. Increasing the pressure on the substance which decreases the volume of material results in increase of density (like a cancerous mass or lymph node). Volume of material increases by increasing temperature which results in decrease of density. Thus, an infected/inflamed cyst or

Fig. 2 Schematic diagram demonstrating the relative density and degree of freedom of molecules

Fig. 3 **a** Schematic diagram of a cyst showing Pascal's law. **b** Surgical picture of a cyst. **c** Radiological picture of a cyst [11]

an abscess would feel softer than a cyst consisting of normal tissue fluid [5, 10] at body temperature.

In case of cyst with large mass, the cyst will not be too much compressible. If we are encountering cyst which is hard in consistency, then we should think of malignancy. In cases of complex cyst, the FNAC should be taken from the solid component of the cyst.

Fluid Thrust

Fluid thrust is the total normal force exerted by a liquid at rest on any surface in contact with it. Fluids have weight and exert pressure on the walls of the container in which it is enclosed (Fig. 3a). Therefore, pressure (P) at any point is the ratio of thrust exerted by the fluid per unit area (A) around that point [5].

$$\text{Pressure}(P) = \text{Thrust}(t) / \text{Area}(A)$$

Surface Tension

Liquids can be distinguished from gases because they have a free surface. The free surface of liquid possesses certain mechanical properties because of cohesion (cohesive force). Cohesive force is the force of attraction between the molecules of the same substance [12]. This free surface on the liquid behaves like a stretched (elastic) thin membrane. This membrane under tension tries to contract. This property of liquid surface having contracting property is called surface tension.

$$T = F/L, \quad N/m \text{ or dyne/cm}$$

where T is the surface tension of liquid, F is the force on the surface and L is the length of surface. Surface tension is also known as interfacial tension. It is the force acting on the surface of liquid, which tries to minimise the surface area and form a drop (shown in Fig. 4a).

The liquids possess a moderate intermolecular force (IMF), which differentiate it from gases. This force of attraction is of the order of 10^{-9} m [12]. The net IMF acting over the molecule depends over the number and distribution of molecules around the chosen one. Because of net IMF, molecules remain in Brownian motion inside the liquid [14]. There is a force of attraction between molecules in liquids, and liquids can flow until they take on the shape that maximises this force of attraction. Below the surface of the liquid, the force of cohesion (literally, sticking together) between molecules is the same in all directions, as shown in the figure below (Fig. 4b, c). Molecules on the surface of the liquid, however, feel a net force of attraction that pulls them back into the body of the liquid. As a result, the liquid tries to take on the shape that has the smallest possible surface area, the shape of a sphere. The magnitude of the force that controls the shape of the liquid is called the surface tension. The stronger the bonds between the molecules in the liquid, the larger the surface tension.

All cysts are spherical because the fluid inside the cyst experience intermolecular attraction. Due to this force, the surface of the fluid acts like a stretched membrane. This stretched membrane tries to contract to minimise the surface area.

Fig. 4 **a** Fluid showing surface tension [13]. **b** Intermolecular forces between the molecules inside the liquid. **c** Force of attraction of the surface of liquid

Fig. 5 Angle of contact. **a** Obtuse angle of contact for spherical shape. **b** Acute angle of contact liquid not able to convert in the spherical shape

Angle of Contact

The angle between tangent to the liquid surface at the point of contact with the solid surface is termed as angle of contact. It is denoted by θ . The value of θ determines whether a liquid will spread on the surface or it will form a drop.

Let S_{la} , S_{sa} and S_{sl} are the three interfacial tensions at all the three surfaces: liquid-air, solid-air and solid-liquid, respectively. At the line of contact, the surface forces between the three media must be in equilibrium.

$$S_{la} \cos \theta + S_{sl} = S_{sa}$$

When θ is an obtuse angle then molecules of liquid are attracted strongly to themselves and weakly to those of solid and liquid does not wet the surface of solid (indicated in Fig. 5). This will happen only when the liquid becomes spherical in shape. Therefore, in case of cyst, the angle of contact is an obtuse angle; hence, molecules have strong attraction between them and take the shape of a sphere [14].

The cyst is spherical because of thrust, angle of contact and surface tension. The examination of a swelling suspected to be a cyst is carried out by test of fluctuation. This test is a clinical application of Pascal's law, first described by Blaise Pascal, a physicist of England [15].

Pascal's Law

It is a law of transmission of fluid pressure. It states that in fluid when pressure is exerted anywhere in a confined (enclosed) space fluid is transmitted equally throughout the walls such that same changes occur everywhere see Fig. 4a [15]. In Fig. 4, we can see the correlation between a spherical drop (4a), surgical view of cyst (4b) and a radiological view of cyst (4c). When fluid is at rest, the pressure P has the same value everywhere.

Pascal's law also helps in maintaining the spherical shape provided all the walls have the same tensile strength.

Tens Cystic Swelling Sometimes, fluid under excessive tension makes the swelling incompressible, which in turn feels hard to the feeling finger. This may be mistaken for malignancy.

Conclusion

If you find a rounded swelling, follow the Anurag's rule of cyst "A Cyst is spherical or a spherical swelling is usually a cyst".

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Compliance with Ethical Standards

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