

Laparoscopic approach to hydatid liver cysts

Is it logical? Physical, experimental, and practical aspects

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Abstract

Background: In recent years attempts have been made to treat hydatid liver cysts laparoscopically. The purpose of this study was to evaluate different aspects of this approach and to examine whether a reasonable model could be developed.

Methods: Three different subjects were analyzed. In the first, physical aspects related to transmembrane pressures were analyzed to demonstrate that evacuation of the cyst under pneumoperitoneum does not carry increased risk of spillage, and may even offer an advantage when the proper technique is used. In the second subject, an isolated liver model of a goat was used to study several techniques for evacuating hydatid cysts without spillage. This was tested qualitatively by demonstrating scolices in the fluid medium around the isolated liver after surgical manipulations. In the third subject, the implication of the technique was evaluated in human patients.

Results: According to basic physical assumptions, the following conclusions were reached: (1) The increase in intracystic pressure is equal to or less than the increase in intraperitoneal pressure after pneumoperitoneum. (2) Aspiration of parasitic cysts by laparoscopic needle through a large cannula under "vacuum" or by sealing the cannula and adhering it to the liver by cyanoacrylate or fibrin glue was found to be very safe. Simple needle aspiration failed to prevent spillage. (3) A new transparent cannula 18 mm in diameter with a beveled tip was designed that enables good accessibility to liver cysts and safe evacuation even of huge and complex cysts.

Conclusions: The novel technique to manage hydatid liver cysts, described in the study, is feasible, sensible, and safe.

The isolated goat liver containing hydatid cysts can be used as a reliable animal model to test new techniques in the future.

Key words: Hydatid liver cyst — Laparoscopic approach — Echinococcal cyst — Pneumoperitoneum

In recent years, since the revolutionary development of laparoscopic surgery, there have been various attempts to treat hydatid cysts of the liver laparoscopically [1, 4, 12, 13, 15, 16, 19, 20]. In general, the main purpose of the surgical treatment is to neutralize the parasite and excise it together with the cystic germinal layers, while avoiding any spillage of the pressurized contents into the peritoneal cavity. The aims are to prevent anaphylaxis, dissemination of disease, and recurrence. Obviously, in cases of giant cysts, we prefer to avoid total excision of the pericyst.

The laparoscopic approach may be imagined as the evacuation and removal of an elastic membrane through the external wall of a playball, which contains a noxious fluid under high pressure, through a small aperture in a surrounding sealed box. This must be accomplished without rupturing its wall and with no spillage. Although the exact physical properties of the "ball" (cyst) membranes are not defined, it seems to us that basic physical principles can be applied to analyze such a model, with implications concerning the laparoscopic approach *in vivo*.

When a novel surgical technique is proposed, it should meet several criteria. First, a convincing argument should be made that the laparoscopic approach to hydatid cysts of liver is reasonable and does not carry a greater risk of spillage than the conventional open approach. In other words, there must be assurance that manipulations under pressure (pneumoperitoneum) are safe. Second, an experimental model should be implemented to test the efficacy and safety of various techniques. Third, the technique should be efficacious.

This study was divided into three sections, and we shall

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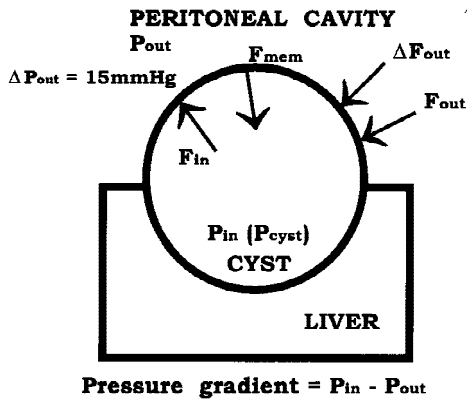


Fig. 1. The sphere as an idealization of a liver hydatid cyst and the net forces acting on its membrane. For further explanation see text.

expand individually on these points. As far as we know, the laparoscopic approach to treat hydatid cysts has never been thoroughly investigated before.

The physical basis of the laparoscopic approach to parasitic liver cysts

We use a basic heuristic model of an elastic sphere to demonstrate that the slight increase in intraperitoneal pressure during laparoscopy (15 mmHg) does not increase the risk of rupture or spillage of the high-pressure cyst during manipulations (puncture, evacuation, etc.). We propose the sphere as an idealization of a human liver hydatid cyst. To prevent incidental spillage, safety demands that the pressure gradient across the cyst membrane ($P_{\text{cyst}} - P_{\text{peritoneum}}$) does not increase or even decrease ($\Delta P_{\text{cyst}} < \Delta P_{\text{peritoneum}}$) as we increase the intraperitoneal pressure to 15 mmHg.

We have not measured the elastic properties of the cystic wall that protrude outside the liver. This wall is composed of a germinal layer and the pericyst, that might vary in thickness, stiffness, and tissue components. We therefore discuss different parameters that affect the model.

Membrane characteristics

Assuming that the cyst wall may have arbitrary elastic properties from rigid to high elasticity, we first consider the wall of the sphere to be stiff and incompressible. The net forces acting on the membrane perpendicular to its surface in equilibrium state are zero:

$$F_{\text{in}} - (F_{\text{mem}} + F_{\text{out}}) = 0 \text{ (Fig. 1).} \quad (1)$$

F_{in} and F_{out} are derived from the pressure inside and outside the cyst. F_{mem} , the force derived from the surface membrane tension, is perpendicular and directed toward the cyst inside. The tension is the force per unit length. Increasing the intraperitoneal pressure (pneumoperitoneum) results in increased F_{out} that acts on the membrane.

$$F_{2\text{out}} = F_{1\text{out}} + \Delta F, \quad (2)$$

where indexes 1 and 2 correspond to the situation before and after creation of pneumoperitoneum. ΔF is the force created by the pneumoperitoneum. The stiff membrane will

apply the same force in the opposite direction according to Newton's third law (action equal to reaction):

$$F_{2\text{mem}} = F_{1\text{mem}} - \Delta F. \quad (3)$$

Thus, $F_{1\text{in}} = F_{2\text{in}}$, and the radius of the sphere remains constant. Because pressure is the force per unit surface area ($P = F/\Delta S$), the pressure inside the sphere will not change; the pressure gradient will be less than before ($\Delta P_{\text{peritoneum}} > \Delta P_{\text{cyst}}$); and it will oppose leakage at the exact moment of puncture. To repeat the point, if the sphere wall is rigid, external pressure will decrease the pressure difference across the wall.

If the cyst membrane is elastic, if stress is proportional to strain (linear or Hooke's law region), and if the fluid inside it is incompressible (ideal fluid), we can apply Laplace's law that relates the pressure differences across a closed elastic membrane to the tension in the membrane [5, 7, 8]. Laplace's law for a spherical membrane dictates that

$$P_{\text{in}} - P_{\text{out}} = 2\gamma/r, \quad (4)$$

where P_{in} and P_{out} are the pressures inside and outside the sphere, respectively; γ is the wall tension; and r is the radius of the sphere.

Because we are dealing with an equilibrium state of the forces acting on the membrane ($\sum F_i = 0$), we can easily substitute $P = F/\Delta S$ in Laplace's equation (Eq. 4) and relate it to Eq. 1. Thus

$$F_{\text{mem}} = F_{\text{in}} - F_{\text{out}} = \Delta S \times 2\gamma/r, \quad (5)$$

where ΔS is the surface area, and the forces due to the pressures are perpendicular to the surface at each point.

During pneumoperitoneum, F_{out} increases, but the volume of the sphere, and hence its radius r , does not change (ideal fluid), and thus F_{mem} does not change either. The main point here is that equilibrium (Eq. 5) is maintained. F_{in} will increase by the same amount as F_{out} , and hence the pressure increases proportionately. Thus, the pressure gradient across the wall will remain the same. For example, if we increase the intraperitoneal pressure by 15 mmHg, the new pressure inside the cyst will increase by 15 mmHg also. Practically, an ordinary cyst wall has physical properties intermediate to those just described. Thus the pressure gradient across the wall probably decreases slightly (cystic $\Delta P < \text{outside } \Delta P$).

The preceding description of the sphere's membrane does not take into account the thickness of the cyst wall. If the pericyst has an elastic and compressible wall that can change its thickness, the model can be described as composed of many tiny springs perpendicular to its surface and acting with force

$$F = -K \times \Delta X, \quad (6)$$

where K is the spring constant, which may be variable, reflecting the different elasticities of individual cyst walls, and ΔX is its length displacement that reflects the changes in cyst membrane thickness. An increase in the intraperitoneal pressure will be partially transformed into potential energy to compress those tiny springs that represent the sphere wall.

$$\text{Potential energy} = 1/2 K_m (\Delta X_m)^2 = P_{\text{out}} Y 4 r^2 \times \Delta X_m = P \times \Delta V, \quad (7)$$

where m stands for membrane, ΔV is the change in volume of the cyst wall, and Y is the fraction of the cyst wall exposed to the peritoneum. X_m and K_m are defined in Eq. 6 and attributed to the membrane.

The external force applied on the compressible cyst wall will cause plastic deformity shared by the neighboring structures (i.e., the liver), so only part of it will be applied on the cyst content. Thus the cystic pressure increase (ΔP_{cyst}) should be somewhat smaller than the peritoneal pressure increase (ΔP_{out}), independent of fluid characteristics. In addition, the instantaneous external force (affecting the cyst contents) as pneumoperitoneum is applied will be reduced because there is a cushioning effect due to the compressible wall.

Cyst fluid characteristics

When the cyst contains fluid that is noncompressible, the only parameter affecting the intracystic pressure is the cystic wall, which was already discussed earlier.

However, when the cyst contains fluid that is slightly compressible (because it may contain small bubbles of gas, etc.), applying additional external force will reduce the volume and thus the radius of the cyst. When the radius of the cyst decreases, the elastic force F_{mem} acting toward the interior of the cyst, which can be obtained from Eq. 5, slightly reduces because its magnitude is directly proportional to the radius of the sphere (ΔS is proportional to r^2). Consequently, the increase in F_{in} will be slightly less than the increase in F_{out} , and thus the pressure gradient will decrease.

Extending the model

In the preceding sections we described a model that depends on the membrane and the fluid characteristics of the cyst. Does such a schematic model really represent the situation *in vivo*? Is it possible to have a reduced pressure gradient due to pneumoperitoneum, even when considering an ideal fluid and elastic membrane ($\Delta P_{\text{cystic}} < \Delta P_{\text{peritoneal}}$)?

The cyst is partially embedded in the liver, which is anatomically included within the peritoneal cavity, and apparently is exposed to the same pressures as the cyst. Actually, the situation *in vivo* is different. The liver drains through the hepatic veins to the inferior vena cava outside the peritoneal cavity and its high pressure environment. Additionally, pneumoperitoneum causes reduction in portal and hepatic blood flow [6, 9]. Consequently, during pneumoperitoneum, the liver becomes less congested and more compressible. Thus, the wall of the cyst, which is embedded within the liver, might be exposed to less external (hepatic) pressure and resistance.

Before the pneumoperitoneum is created, the membrane tension is equal on both sides of the cyst wall, inside the liver, and outside toward the peritoneal cavity. When pneumoperitoneum is applied, the sphere is being pushed toward the liver, so the membrane facing the peritoneal cavity is less tense than the intrahepatic membrane, and a new steady state is created:

$$F_{m(2)\text{hepatic}} > F_{m(1)\text{hepatic}} \quad (8)$$

$$F_{m(1)\text{hepatic}} = F_{m(1)\text{peritoneal}}$$

$$F_{m(1)\text{peritoneal}} > F_{m(2)\text{peritoneal}}$$

where $F_{m(1)\text{hepatic}}$ and $F_{m(2)\text{hepatic}}$ are the tension forces being applied by the cyst membrane on the hepatic side of the cyst, and $F_{m(1)\text{peritoneal}}$ and $F_{m(2)\text{peritoneal}}$ are the tension forces being applied by the cyst membrane on the peritoneal side of the cyst, before and after pneumoperitoneum, respectively.

The force applied by the inside cyst medium on its wall, $F_{(2)\text{cyst}}$, is in equilibrium with the sum of the external forces being applied on the cyst and by the cystic wall tension force on both sides of the cyst:

$$F_{(2)\text{cyst}} = F_{m(2)\text{hepatic}} + F_{(2)\text{hepatic}} \quad (9)$$

$$F_{(2)\text{cyst}} = F_{m(2)\text{peritoneal}} + (F_{(2)\text{peritoneal}} + \Delta F) \quad (10)$$

As the radius of the peritoneal part of the cyst becomes smaller, $F_{m(2)\text{peritoneal}}$ is less than $F_{m(1)\text{peritoneal}}$ (see Eqs. 4 and 5 regarding Laplace's law), and thus the increase in $F_{(2)\text{cyst}}$ is smaller than the increase in $F_{(2)\text{peritoneal}}$ (ΔF). Consequently, the pressure gradient that depends on the difference between $F_{(2)\text{peritoneal}}$ and $F_{(2)\text{cyst}}$ decreases.

In conclusion, our model shows that creation of pneumoperitoneum does not increase the rupture risk of the high-tension cyst. Pressure gradient is maintained as constant, or even as less than before pneumoperitoneum is applied. Practically, although the pressure gradient is still high at the moment of puncture (due to the high intracystic pressure), pneumoperitoneum does not carry increased risk of rupture. Surgical manipulations might become safer laparoscopically than with the usual open procedure when the proper technique is used.

The experimental animal model

In this section we suggest an experimental model for qualitatively evaluating (under atmospheric and slight hyperbaric pressure of 15 mmHg) diverse techniques for evacuating parasitic cysts without spillage, which is a requirement.

Materials, methods and techniques

A 25 × 25 × 40-cm sealed box with glass walls similar to an aquarium was built. It has a removable cover made of an elastic rubber membrane, which enables inflation of the box, introduction of laparoscopic cannulae, and surgical manipulations under high pressure atmosphere. All the goats in the Yarka village slaughterhouse (located in the center of an endemic *echinococcal* area in Western Galilee) underwent veterinarian examination immediately after slaughter. When hepatic cystic lesions were noticed, the liver was harvested, preserved in a refrigerator, and sent immediately (within 30 to 40 min) to our laboratory, where it was washed and put in a plastic bag containing normal saline, then placed inside the sealed box.

We evaluated several techniques for aspiration and evacuation of the cysts:

1. Simple aspiration of the cyst by a fine laparoscopic needle.
2. Aspiration (with the same needle) of the cyst through a

12-mm transparent cannula connected via a two-way stopcock to a suction apparatus. This creates a "vacuum" inside the cannula that enables the tip to grip the liver and cyst surface. With such a technique, any spillage around the needle is aspirated by the large-bore cannula.

3. After introduction and positioning of the large cannula, *n*-butyl-2-cyanoacrylate (Hystoacryl blue, B. Braun, Melsungen AG, Germany) or fibrin glue (Tisseel, Immune US, Inc.) was introduced through a thin silicone tube around the cannula tip to further seal its attachment to the liver, especially in cases of accidental suction failure. We searched for any sign of spillage associated with either technique.

Detection of spillage

After aspiration of the cyst but before detachment of the equipment, the liver was gently flooded with saline solution. The fluid in the plastic bag was collected and left overnight in a conic container to get a concentrated sediment, which was further concentrated and sent for parasitologic analysis. Any evidence of scolices was considered a failure of technique because this indicated spillage. The aspirated fluid was sent for analysis to validate the existence of scolices in these cysts. In parallel, spillage was detected by evacuating and filling the cysts with 20% hypertonic saline, transhepatically, through a long fine needle, and any change in electrolyte concentration was detected after manipulation in the fluid around the liver. We did not validate complete removal of the cyst contents in this model because it was not the aim of our work. *In vivo*, the most important and dangerous step is the initial puncture and aspiration of the cystic fluid. After the introduction of scolicalid solution and lowering of the intracystic pressure, the next surgical steps become relatively safe.

Results

The techniques were evaluated for the presence or absence of cystic leakage. Five *echinococcal* cysts were tested for spillage after aspiration through transparent cannula under "vacuum." In five cysts we used cyanoacrylate with suction, and in two cysts cyanoacrylate alone. In two cysts we used fibrin glue together with suction. There was no evidence of spillage in any of these trials. Six cysts were tested for spillage after aspiration through needle alone, and scolices were detected in the saline sediment in three. Statistical analysis, performed by using the Fisher test, compared our technique (14 cysts, 0 spillage) to simple aspiration (6 cysts, 3 spillage). The difference was found to be significant ($t = 0.0175$).

Implementation of the technique for human patients

A transparent cannula with a beveled tip was used because it has some advantages: (1) It allows the surgeon to inspect the process of evacuation inside the cannula. (2) Cannulae tips are beveled or cut straight. Beveled tips have an oval (elliptical) cross section and are usually cut at a 45-degree

angle (α). The area of a straight tip A is πr^2 , where r = the radius. In the case of a 12-mm diameter tip, $r = 6$ mm and $A = 113$ mm². For a beveled tip 12 mm in diameter, $A = \pi r^2 / \cos \alpha$, and if $\alpha = 45$ degrees, the area is 161 mm². Because $F = P \times A$, the beveled tip has an enlarged suction grip with respect to straight-cut round tips. (3) The beveled tip enables good surface grip to cysts located at a distance from the site of cannula introduction [3]. We occlude the holes at the tip of the cannula to enable creation of a force due to "vacuum."

Recently, we have developed a new larger cannula made of two transparent cannula 18 mm in diameter (Ethicon) connected firmly together in series to create one long tube, using a special adhesive tape and glue. Our new cannula has a 45-degree beveled tip and a special two-way stopcock. Besides its ability to reach cysts located under the diaphragm, the large bore enables us to insert various tools and do safe surgical manipulations inside the cannula, especially when simple aspiration is impossible due to numerous daughter cysts.

Thus since 1992 we have been able safely to evacuate more than 30 giant hydatid cysts of the liver in human patients after informed consent. The third technique (using cyanoacrylate) was used once, and the glue was excised and removed after evacuation. The pericysts were managed according to the preference of the surgeon. During follow-up of 5 years to 6 months, no recurrences were recorded.

Discussion

Recently, a number of reports were published concerning the laparoscopic approach to operating on hydatid cysts of liver [1, 4, 12, 13, 15, 16, 19, 20]. In most of the operations, the technique employed to safeguard against spillage of cyst contents was not described. In one report, spillage was discussed. In this case, it was managed by instillation of scolicalid solution (cefrimide) into the peritoneal cavity [1, 13, 15, 16, 20]. In another study, lowering the peritoneal pressure was advised to prevent excessive cystic pressure elevation and leakage during manipulations [20].

In this study, we have demonstrated that, theoretically, creation of pneumoperitoneum does not increase the risk of spillage and may even enhance safety. The experimental animal model has established the rationality and safety of the techniques we used, which were successfully implemented *in vivo*. In practice, even in cases when the suction grip is inactivated temporarily, the pneumoperitoneum creates a pressure gradient that causes the cyst contents to move through the cannula toward the outside of the peritoneum, and not inward. Butyl cyanoacrylate and fibrin glue were employed for better sealing and adherence of the contact area between the tip of the cannula and the cyst surface. In practice, the introduction of the hystoacryl glue should be through silicone tubes, which will prevent its polymerization before it reaches the cannula tip. The internal use of those materials is well known and safe [2, 10, 14]. Because the glue is removed with the pericyst (after evacuation), there is no reason to avoid its use when necessary.

In our opinion, simple needle aspiration is neither safe nor justified, even when the patient is being treated in addition by scolicalid medication (albendazole). Recently, it

was reported that hydatid cysts of liver were successfully treated percutaneously under ultrasonographic (US) and computed tomographic (CT) guidance (needle aspiration and injection of scolicedal solution) [11, 17, 18]. According to our laboratory findings and clinical experience, in many cases cyst contents cannot be aspirated. It is not a simple fluid and may contain numerous daughter cysts. The risk of spillage during needle aspiration is not negligible.

We therefore suggest that the laparoscopic approach to managing hydatid cysts as described in our study is efficacious, rational, and safe, and has some advantages: decreased leakage, better accessibility, and the capability of inspecting the cyst cavity, all in addition to the well-known minimalization of invasiveness associated with the laparoscopic approach.

The experimental animal model in this study can be used as a reliable model to test other new techniques for managing hydatid cysts.

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