

## REVIEW ARTICLE

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# Management of diaphragmatic peritoneal carcinomatosis: surgical anatomy guidelines and results

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## Summary

Surgical resections, such as peritoneal stripping (peritonectomy) or full-thickness resection of the diaphragm (FTDR), are performed for disseminated diaphragmatic lesions in patients with peritoneal carcinomatosis (PC).

This article presents the anatomical steps of diaphrag-

matic surgery in order to avoid intraoperative and post-operative complications and to decrease the morbidity and mortality of cytoreductive surgery in patients with PC.

**Key words:** diaphragmatic surgery, peritoneal carcinomatosis

## Introduction

Three decades ago, the first observation was reported about the successful application of procedures in order to remove diaphragmatic metastasis with acceptable morbidity in patients undergoing cytoreduction for PC [1].

Surgical procedures to treat diaphragmatic disease increase the rate of cytoreduction and correlate with improved survival compared to patients optimally debulked without diaphragmatic surgery being performed [2].

On the other hand, procedures such as diaphragmatic stripping (DS) and/or FTDR were not utilized from 1940 to 1976, respectively by surgeons during primary surgery for PC, due to lack of familiarity and proof of efficacy, or concerns about morbidity [3].

The aim of this review was to focus in anatomical essentials and surgical results in diaphragmatic surgery for PC [4].

## Diagnosis and patterns of diaphragmatic involvement

The frequency of finding diaphragmatic macroscopic tumor deposits intraoperatively is deci-

sively affected by the surgeon's attentiveness to carefully explore the abdominal cavity and his efforts to remove all visible disease.

A sufficient exploration of the diaphragm, even in cases with small-volume disease, demands adequate exposure which means, at least, partial liver mobilization. Different studies revealed diaphragmatic involvement in approximately 80% of ovarian cancer patients, 60% in PC from colorectal cancer, and 40% in PC from gastric cancer [5-8]. The right hemidiaphragm is affected more extensively and frequently, alone in approximately 20% of the cases and in 80% combined with the left hemidiaphragm.

A possible explanation for this right hemidiaphragm prevalence is the preferential flow of intraperitoneal fluid along the right paracolic gutter, liver capsule and diaphragm [9]. Another mechanism is the relatively fixed position of the liver in relation to the right hemidiaphragm in combination with larger contact area that ensure only a limited translocation during the respiratory movements and a long contact time of tumor cells to the diaphragmatic surfaces.

The involvement of the left diaphragm is more frequent after initial debulking surgery due to two possible mechanisms: first, due to the cell-en-

trapment phenomenon [10] and second, due to adhesions accompanying the operation which affect the flow of intraperitoneal fluid.

### Anatomic key-points

Knowledge about both the hepatic attachments and the retroperitoneal vasculature is required for diaphragmatic surgery. Liver is attached to the diaphragm and the posterior portion of the anterior abdominal wall by ligaments and loose connective tissue, corresponding to the so-called bare area of the liver, a surface area devoid of peritoneal covering. The ligaments, blended into each other, surround the bare area and represent solely a transition from the parietal to the visceral peritoneum either directly (also referred to as reflection) or in the form of peritoneal duplication.

The falciform ligament attaches the liver to the abdominal wall anteriorly and is comprised of the ligamentum teres, the reinforced caudal edge containing the remnant of the foetal umbilical vein, and a membranous portion, being a simple duplication of the parietal peritoneum. Superiorly, it continues into the anterior leaf of the right and left coronary ligaments which provides a direct peritoneal transition from the liver to the diaphragm. Then the surgeon can proceed laterally and dorsally on each side, and coalesce with the posterior leaf of the right or left coronary ligaments to form the right and left triangular ligaments, respectively. These fix the liver to the diaphragm and, on the right side, to the renal fascia, the so-called Gerota's fascia. On the left side, the triangular ligament continues laterally to the fibrous appendix, into which the tip of the left lobe of the liver tapers off, additionally connecting the liver to the diaphragm.

The ligaments mentioned above have to be dissected in order to mobilize the liver and expose the diaphragm. The above subsequent opening of the retroperitoneal space between the bare area of the liver and the central portion of the diaphragm, which contains relevant vasculature, ensures access to a disease-free area of the diaphragm, but involves the risk of an injury to the following vessels:

The superior (major) set of hepatic veins is comprised of 2-3 veins (right and left-middle; right, middle and left), which leave the liver cranially empty into the inferior vena cava (IVC) [11], which is located dorsally to the cranial splay of the peritoneal duplication of the falciform ligament and the medial part of the anterior leaf of

the right coronary ligament, respectively. In 95% of the cases a varying number of accessory hepatic veins (interior/minor set) drains into the retrohepatic segment of the IVC [12]. These commonly associated anatomical variations in hepatic vascular anatomy necessitate awareness as an important prerequisite for the avoidance of potential surgical complications.

The interior phrenic arteries present a lot of variety in their origin from the aorta or celiac trunk, running across the crura of the diaphragm obliquely upward and laterally, and divide into a medial and a lateral branch. Only the latter is encountered in its peripheral portion during diaphragmatic surgery for ovarian cancer and can be divided as required due to a sufficient supply by collaterals and anastomoses with the lower intercostal and the musculophrenic arteries.

The phrenic nerves divide into a variable number of branches (from 2 to 7) separating into anterior, lateral and posterior directions, 0.5-2 cm above the diaphragm. The branches diverge, enter the muscle or central tendon, run obliquely for a varying distance in its substance, and then appear underneath the diaphragm [13]. The postero-medial branch is usually the biggest and always runs dorsally in the same direction. On the right side the nerve passes through the vena cava hiatus, and on the left side it pierces the muscle or central tendon antero-laterally of the pericardial base. In addition, a risk of neural impairment is particularly taken into consideration on the left side and the area of FTDR should be extended as minimally as possible.

### Surgical approach

#### *Surgical exposure*

The patient should be placed on the operating table in the modified dorsal lithotomy position. Surgical access for cytoreduction is usually gained through a hypo and epigastric midline incision, which is extended to the sternum to the right or left of the xiphoid, or the xiphoid is often divided or in some cases removed [14].

A fixed retractor is definitely essential and ensures the superolateral retraction and elevation of the abdominal wall and costal margins, and, in addition, an optimal view into the subphrenic space. To our experience, the Thompson retractor is most commonly used.

#### *Liver mobilization*

After entering the abdominal cavity in the

course of incision for laparotomy, the falciform ligament, both the reinforced caudal edge (ligamentum teres) and its membranous portion, is dissected immediately along the inner surface of the anterior abdominal wall at first, then along the liver surface and finally at the position where the ligamentum teres goes into the liver. The realization is facilitated by a downward pressure on the liver and the traction on the ligament by means of clamps. This procedure for freeing the anterior hepatic attachment is defined as partial liver mobilization and has to be performed in every primary case to adequately explore the diaphragm by direct visualisation.

During dissection, the caudal end of the resected umbilical vein can be ligated plainly and simply. The challenge of this first step regarding liver mobilization is the complete removal of all tumor nodules at the entrance of the ligamentum teres into the liver and around the fissura ligamenti teretis, which requires very careful surgical handling to avoid injuring the liver capsule and vessels.

For a right- and left-sided complete liver mobilization, dissection is extended to the anterior and posterior leaf of the coronary and the triangular ligaments on the appropriate side (mono or bilateral) and is indispensable in all cases intended for extensive DS and FTDR. This dissection of ligaments, which means a peritoneal incision in the proper sense, is generally straightforward, and is facilitated by a rotating traction of the liver medially and anteriorly, and an elevating of the diaphragm with clamps.

Tumor nodules sometimes invade the liver surface and aggravate the line of transition from the parietal to the visceral peritoneum. Following entering into the retroperitoneal space between the bare area and the diaphragm, the mobilization is accomplished until a disease-free margin of the central diaphragm with a width of 2-3 cm. However, full exposure of the hepatic veins, the retrohepatic segment of IVC and even the phrenic nerve during right-sided preparation is not necessary since they are outside the plane of dissection in the majority of the cases. The retroperitoneal dissection on the left side is usually less extensive in cases with primary disease, due to the lower frequency and volume of left-sided diaphragm involvement and the smaller size of the left lobe.

#### *Types of diaphragmatic peritonectomies*

The surgical procedures for the management of diaphragmatic disease depend on the volume

and distribution of diaphragmatic tumor and can be categorized as follows:

(A): the simplest type is a superficial destruction (SD) or ablation, which is defined as coagulation of very small and thin nodules ( $\leq 2-3$  mm), using electrosurgery or other devices. For this approach, a partial liver mobilization is most sufficient and complications cannot be expected.

(B): diaphragmatic peritonectomy is defined as dissection of the peritoneum from the underlying diaphragm, modified according to the extent of disease. In less extended cases, a partial liver mobilization is sufficient and the peritoneum is incised around the affected area and is resected exposed by a downward traction. When a full hemidiaphragmatic peritonectomy is considered, complete liver mobilization is required. It recommended to start from the peripheral insertion of the diaphragmatic muscle at the thoracic wall and, thus, the peritoneum on this anterior edge is initially incised along the costal margin or, at least, laterally and anteriorly to the metastases intended for resection. The free peritoneal edge is tightly grasped with clamps (e.g. Allis), which are then retracted inferiorly to visualize the line of attachment between the diaphragm and its overlying peritoneum. The dissection is continued from anterior to posterior and from lateral to medial, usually by utilizing electrosurgery. The specimen can often removed en bloc, but a segmental resection might be helpful in some cases where there is a partial tumor involvement or the resection has to be widely extended caudally including the peritoneum of the paracolic gutter and the hepatorenal recess.

For an adequate exposure to perform DS, the liver lobe must to be rotated medially, which can cause a transient bradycardia and hypotension. Furthermore, light bleeding from small branches of the inferior phrenic artery and vein often occurs, but haemostasis is easily achieved with electrosurgery.

Despite of careful preparation, diaphragmatic penetrations might occur and, sometimes, a limited area of FTDR is performed although no deeper tumor infiltration can be found histologically. For this reason, after DS has been completed, a "bubble test" is recommended to identify small pleural opening [2,14,15]. This requires that the ipsilateral upper quadrant is filled with saline solution while the patient is in the Trendelenburg position and the lungs are hyperexpanded. Closing the defects detected is described below.

(C): this includes FTDR, which is defined as resection of the diaphragmatic muscle or central

tendon including the overlying peritoneum and pleura, mostly in combination with an extensive peritoneal DS. This procedure is required when no dissection plane can be found between the peritoneum and the underlying muscle or central tendon, and for bulky diaphragmatic lesions that penetrate through the peritoneal layer into the muscle, the tendon or to the pleural surface. The suspicion of full thickness involvement arises when tumor nodules are firmly fixed to the diaphragmatic muscle or tendon during the preparation for DS.

FTDR is preferentially performed using electrosurgical or scissor dissection. Small defects are closed with interrupted horizontal mattress or purse-string sutures, and larger openings of the pleural space after FTDR can be closed with limited tension using interrupted or running horizontal mattress sutures or figure – of – eight sutures. The material for suturing is absorbable or non-absorbable with a diameter of thread corresponding to U.SP. designation 0-1. To evacuate the air from the thorax in patients without intraoperative chest tube placement, the pleural cavity is finally under suction by means of catheter in the pleural space and during a ventilation break in pulmonary hyperexpansion [15,16].

The need of closing larger diaphragmatic defects with interposition of a permanent mesh or graft is extremely rare [17].

FTDR is the procedure with the highest risk of injuring the lung, vessels of the central vasculature and the phrenic nerves. The challenge is to reduce these immanent risks by paying atten-

tion to the following hints: permanent downward traction of the diaphragm, anatomical conformed microdissection reducing the resection area to a minimum and avoiding the resection of non-affected retroperitoneal parts of the diaphragm.

## Postoperative management

After the end of cytoreductive surgery and/or HIPEC, patients are moved into the recovery or ICU continuing a rapid weaning. Patients with FTDR have a chest tube placed intraoperatively and the time of removal depends on the amount of the drained fluid which should be less than 100ml in 24 hours.

### *Intraoperative complications due to diaphragmatic peritonectomy*

Except pleural effusion, intraoperative complications are presented in the Table 1 with anatomical tips to avoid them.

### *Postoperative complications due to diaphragmatic peritonectomy*

The most frequent postoperative complication is pleural effusion occurring in 50% of the cases [18]. The postoperative complications are presented in Table 2 with suggestions for their management. The contribution of diaphragmatic surgery to any complication observed in patients with cytoreductive surgery or the overall morbidity and mortality is impossible to quantify due to other associated surgical procedures performed.

**Table 1.** Intraoperative complications of diaphragmatic peritonectomy

<i>Complications</i>	<i>Phase of endangerment</i>	<i>Therapeutic option</i>
Injury of umbilical vein	Partial liver mobilization or during DS or FTDR	Vascular suture
Injury of phrenic veins	DS or FTDR	Vessels – dividing and vascular suture
Injury of IVC or hepatic veins	Complete liver mobilization	Vessels – obtaining vascular suture
Liver capsule laceration	Liver mobilization	Vascular suture or hemostatic patch
Lung laceration	FTDR	Suture and chest tube placement
Opening of pericardium	FTDR left sided	Suture

IVC: inferior vena cava, DS: diaphragmatic stripping, FTDR: full thickness diaphragmatic resection

**Table 2.** Postoperative complications of diaphragmatic peritonectomy

<i>Complications</i>	<i>Time of endangerment</i>	<i>Therapeutic options</i>
Pleural effusion	Peritonectomy	Chest tube insertion
Pneumothorax	FTDR	Chest tube with aspiration
Hemidiaphragm paralysis	FTDR	Surgery or breathing training
Subdiaphragmatic abscesses	DS or FDTR	Drainage

For abbreviations see footnote of Table 1

## Conclusion

Optimal cytoreduction in the management of PC demands peritonectomy procedures as described by Sugarbaker et al. [19].

Diaphragmatic peritonectomies are considered to be a major obstacle by many surgeons. Removing diaphragmatic disease is a crucial procedure, playing a major role in the overall survival of these patients.

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