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Diaphragmatic Hernia After Living Donor Right Hepatectomy: Proposal for a Screening Protocol

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Background. Living donor hepatectomy (LDH) is increasingly being used to improve access to liver transplantation for those with end-stage liver disease. Although recipient outcomes are equivalent, donor complication rates range from 10% to 41%. A rare, but potentially serious complication is occurrence of a diaphragmatic hernia (DH), of which 9 cases have been reported so far in the literature. The purpose of this work was to review the clinical impact of DH post-LDH, including risk factors (RF) in hope of mitigating impact. **Methods.** A literature review was performed identifying all previous reports of post-operative DH in living liver donors. Demographic and outcome data were gathered to help identify RF. We also report 2 cases from our own institution. **Results.** Reported incidences range from 0.6% to 2.3%, of which the majority are delayed (≥ 19 months). Obstruction or intestinal strangulation was present in 45%, 60% of whom required an intestinal resection. The most common RF was right lobe donation. **Conclusions.** Postoperative DH is a rare but serious complication of LDH. The major RFs are right lobe donation and potentially conditions resulting in increased intraabdominal pressure. Diaphragmatic hernia frequently lead to intestinal obstruction and strangulation and should be repaired when identified. The implementation of a screening protocol for early identification could lead to repair before the development of complications. We propose the addition of screening chest x-ray to follow-up protocols to aid in the identification and subsequent repair of postoperative DH. Such a practice could hopefully reduce the clinical impact of this complication.

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Liver transplantation (LT) is the only lifesaving treatment for end-stage liver disease, affording 5-year survival rates greater than 75%¹; however, current organ availability is insufficient to meet demand, and wait list death and drop off rates in North America are 11% and 19%, respectively.^{1,2} The use of partial grafts from healthy living donors has improved access to transplantation for patients in need of

transplantation. Currently, live donor (LD) LT accounts for 3.6% and 19.6% of all liver transplants in the United States and Canada, respectively.^{1,2}

Although the use of living donors has improved access to LT, it must be remembered that the primary goal in the evaluation of these patients is ensuring the care and safety of the LD. The reported complication rates for LD hepatectomy range from 10% to 41%,³⁻⁷ although the vast majority of these are Clavien grades 1 and 2 complications.^{3,5} More severe complications are rare but pose a significant threat to the life of the donor. One such complication is the development of a diaphragmatic hernia (DH). To date, there have only been 9 reported cases of this rare complication, all of which required operative repair.⁸⁻¹³ Here, we report 2 cases of DH post-LD right hepatectomy (RH) and propose a screening protocol to aid in the early diagnosis of these hernias, allowing for repair before the development of severe complications, such as obstruction or strangulation.

MATERIALS AND METHODS

Patient data were obtained from the Organ Transplant Tracking Record (chronic care solutions, Omaha, NB). Literature review was performed by Pubmed search using the terms: “diaphragmatic hernia” + “liver transplant,” “living donor” + “diaphragmatic hernia,” and “diaphragmatic hernia” + “liver resection (LR).” All articles describing a DH after LD hepatectomy (LDH) in either the title or abstract were reviewed in detail. Email correspondence was sent to authors of all

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previous published reports in attempt to obtain missing outcome and demographic data. For the search terms “DH” + “LR”, only articles describing a large case series or review were evaluated in detail. Diaphragmatic hernia rates, in percent, were calculated by the following formula: %DH = {[number of DH reported/total number of LDH performed] × 100}. Diaphragmatic hernia rates were only calculated if the total number of LDH performed was either included in the article or conveyed by email correspondence. Right hepatectomy, left hepatectomy (LH), and left lateral segmentectomy specific DH rates were calculated if those numbers were provided. Due to a general lack of data and small sample size, detailed statistical analysis was not performed.

CASES

Patient 1

A 25-year-old healthy woman underwent RH as an LD for her mother. She was discharged on postoperative day (POD) 6 without complication. Five years later, at 38 weeks gestation, she presented abdominal pain, nausea, and vomiting that persisted after vaginal delivery. X-rays suggested a small bowel obstruction, and at laparotomy, she was found to have a DH containing incarcerated, but viable, colon, and omentum at the level of the hepatic flexure. She underwent an uncomplicated DH repair (details of repair not indicated in correspondence documents with our centre) and was discharged on POD 7.

Patient 2

A 23-year-old obese man (BMI 34) underwent uncomplicated RH as a LD for his father. Bilirubin and International Normalized Ratio rose transiently (peak, 43 $\mu\text{mol/L}$ and 1.9), but returned to normal by discharge on POD 6, and

no significant fluid collections, biliary, or vascular abnormalities were identified on routine Doppler ultrasound. He presented to the emergency department with intermittent abdominal pain at 11 (Figure 1A), 12 (Figure 1B), and 17 (no x-rays) months postoperatively. Examination and laboratory studies were unremarkable, and x-rays were reported as right diaphragmatic eventration without hernia and colonic fecal loading. He represented at 19 months with nausea, vomiting, and severe abdominal and chest pain. He was acidotic with lactate of 6.2 mmol/L and a leukocyte count of $25.9 \times 10^9/\text{L}$. Chest x-ray (CXR) reported only a right diaphragmatic eventration, but computed tomography demonstrated a 4-cm DH containing colon and small intestine (Figures 1C-F). At laparotomy, the entire transverse colon and a significant length of jejunum were found to be ischemic requiring resection without anastomosis. At second look laparotomy, he underwent completion right colectomy, restoration of intestinal continuity, and primary DH repair without mesh. Aside from a pneumonia, his postoperative course was uncomplicated, and he was discharged on POD 14.

RESULTS

Between April 1999 and June 2015, there were 151 living donor liver transplants performed at the University of Alberta. The percentage of right lobe (RL), left lobe (LL), and left lateral segment donors is 57.6%, 8.6%, and 33%. Diaphragmatic hernia occurred in only 2 patients, both of whom donated RL and required surgical intervention. Our total DH rate is 1.6%, and RL specific rate is 2.3%. Demographics, potential risk factor (RF), and postoperative complications are listed in Table 1. Patient presentation, diagnosis, details of repair, and DH rates are listed in Table 2.

Nine other cases of DH have been previously reported¹⁸⁻¹⁴ and were reviewed in addition to the 2 cases presented here.

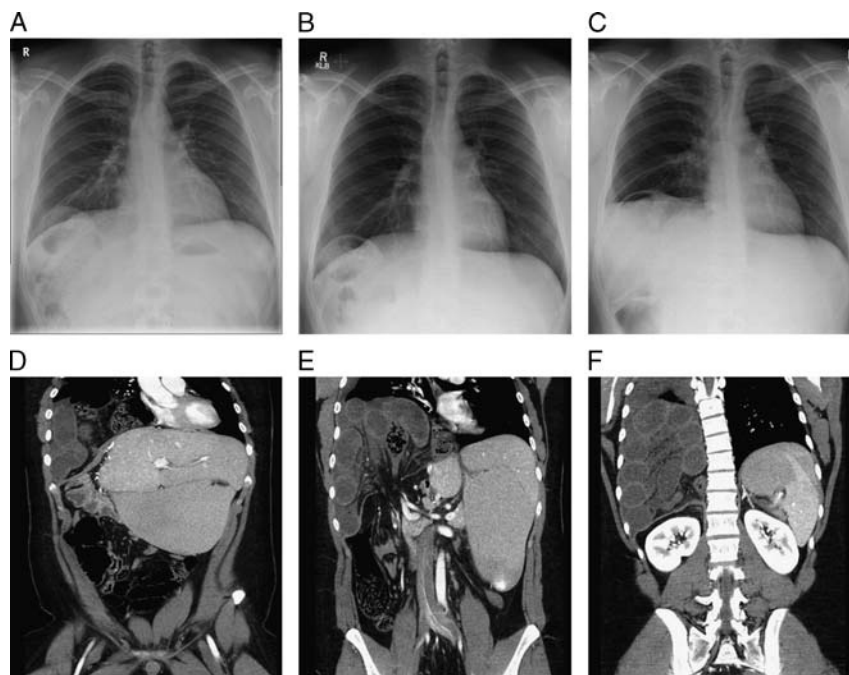


FIGURE 1. Postoperative diaphragmatic hernia. Patient 2 underwent right hepatectomy for live donation. He presented with complaints of upper abdominal pain multiple times over a period of 19 months. A, CXR 11 months posthepatectomy, reported as a diaphragmatic eventration. B, CXR at 12 months, reported as normal. C, CXR at 19 months, at the time of presentation to emergency department, reported as a diaphragmatic eventration. D-E, CT at 19 months, demonstrating hypertrophied left hepatic lobe, diaphragmatic defect, and large right enterothorax.

TABLE 1.**Demographics and early postoperative outcomes after donor hepatectomy for previously reported cases of DH post-liver donor hepatectomy**

Study	Age (at donation)	Sex (M/F)	BMI	Graft	Operative time	Postoperative complications
Dieter, 2011 ⁸	NR	NR	NR	RL	NR	NR
	NR	NR	NR	RL	NR	NR
Hawxby et al, 2006 ⁹	54	M	NR	RL	NR	Bile leak—ERCP + sphincterotomy, incisional hernia
Kousoulas et al, 2011 ¹⁰	NR	NR	NR	RL	NR	NR
	NR	NR	NR	RL	NR	NR
Mizuno et al, 2014 ¹¹	43	M	30 ^a	LL + C	8 h 44 min ^a	None
Vernadakis et al, 2012 ¹²	43	F	NR	RL	NR	None
Jeng et al, 2015 ¹⁵	42	F	NR	RL	NR	NR
Tabrizian et al, 2012 ¹⁴	27	M	27 ^a	RL ^a	NR	None ^a
Patient 1	25	F	22	RL	4 h 5 min	None
Patient 2	23	M	34	RL	5 h 13 min	None

^a Personal communication from the author.

C, caudate; ERCP, endoscopic retrograde cholangiopancreatography; NR, not reported; M, male; F, female.

Early postoperative complications were uncommon, in fact, complications during the index admission, a bile leak treated by endoscopic retrograde pancreatography and sphincterotomy, were reported in only 1 of 11 patients (Table 1). Diaphragmatic hernia occurred almost exclusively after right lobe donation (91%) and was generally delayed (≥ 19 months), with the exception of 1 patient who presented on POD 20. Intestinal obstruction or strangulation was a frequent feature at presentation occurring in 45% (5/11) patients, and when present necessitated an intestinal resection in 60% (3/5).

DISCUSSION

Living donor liver transplantation has significantly improved access to LT for patients with end stage liver disease, with experienced centres reporting survival outcomes equivalent to deceased donor transplantation.¹⁵ However, LD hepatectomy places a healthy, altruistic individual at significant risk of complications and potential mortality. Reported complication rates range from 10% to 41%.^{3,6,16} Although the vast majority of complications are minor (Clavien grade I-II),^{3,5,7} life-threatening complications still occur in a small percentage of patients. One such complication is the development of a DH, which can lead to bowel obstruction or strangulation, resulting in the need for urgent operative repair. Including the 2 patients presented here, there have been a total of 11 cases of DH reported post-LD hepatectomy.⁸⁻¹³ The incidence rates of DH in the reported series ranges from 0.6-2.3%, which is similar to the rate reported following hepatectomy for other indications such as malignancy. In the only large published series examining DH as a complication of hepatectomy for all indications, Tabrizian et al,¹⁴ reported 10 cases of post-hepatectomy DH in 993 patients. The DH rates were: 1% total, 1.9% RH, 0.4% LH, and 5.4% for hepatectomy with concomitant diaphragmatic resection. Right hepatectomy (80% of cases) and concomitant diaphragm resection (hazard ratio, 5.4) were the only significant RF.

Commonly postulated RF for posthepatectomy DH include: direct thermal injury to the diaphragm during liver mobilization, delayed healing due to the constant motion of the diaphragm, poor nutrition, and pressure differences between the abdominal and thoracic cavities.¹⁷ Based on our review, RH is the greatest RF for DH, accounting for 91% of cases after living donation, and 80% of cases for all

indications.¹⁴ The right diaphragmatic attachments to the liver cover a larger surface area and substantially more adherent than the left; increasing the risk of inadvertent injury during mobilization. In addition, RH exposes a large area of diaphragm previously shielded by the liver, allowing the colon and small intestine to fill the subdiaphragmatic space, and placing them in a prime position for herniation through a newly exposed congenital or subsequently acquired traumatic diaphragmatic defect.

Another potential RF is the presence of conditions that result in increased intra-abdominal pressure, such as preoperative obesity, postoperative weight gain or pregnancy. The resultant higher abdominal pressures may contribute to the enlargement of a small diaphragmatic defect, or the migration of abdominal organs into the thoracic cavity resulting in incarceration and strangulation. Interestingly, these conditions were present in 3 of the reported cases, with 1 patient presenting during a subsequent pregnancy (patient 1), and 2 others who had elevated preoperative BMI of 30 or greater (34 and 30) (Table 1).

The development of a DH post-LDH should be viewed as a serious complication, which when recognized requires operative repair. Like other traumatic DH, they carry a significant risk of incarceration and strangulation of abdominal contents.¹⁸ Bowel obstruction or strangulation was a presenting feature in 45% patients, 60% of whom required an intestinal resection. Early identification can allow for repair before the development of complications, potentially through minimally invasive approaches. So far, no previous authors have proposed postoperative screening of living donors for the development of a DH. The rarity of these events would suggest that any potential screening test would need to be low cost and minimally invasive.

Our current follow-up (FU) protocol involves: postdischarge laboratory work at 1, 3, and 6 months, then annually for 10 years; and Doppler ultrasound of the liver on POD 5, then annually for 2 years. The addition of FU CXR for all right lobe donors is minimal in terms of cost and invasiveness. Although the traditionally reported sensitivity of CXR for traumatic diaphragmatic injuries is only 40%, a recent study by Hirano et al¹⁹ found that suggestive findings such as hemidiaphragm elevation, pneumothorax, and hemothorax were present in 81% traumatic diaphragm injuries.

TABLE 2.**Time to diagnosis, presentation, diagnosis and management of reported DH in living donors post-hepatectomy**

Study	Time to hernia	Symptoms	Diagnostic investigations	Findings	OR/Repair	Total LDLT	Hernia rate	Complication rates
Dieter, 2011 ⁶	NR	Abdominal and thoracic symptoms	Unspecified radiographs	Incarcerated SB	Thoracotomy, prolene mesh repair	NR	NR	NR
Hawby et al, 2006 ⁹	NR	Abdominal and thoracic symptoms	Unspecified radiographs	Incarcerated SB	Thoracotomy, prolene mesh repair	NR	NR	NR
	>3 y	Abdominal symptoms	(1) CT—R posterior DH, without contents. (2) Thoracoscopy—DH containing omentum and colon	4 cm R posterior defect	Thoracotomy, interrupted pledgeted prolene suture repair	NR	NR	NR
Kousoulas et al, 2011 ¹⁰	NR	NR	NR	NR	Method not specified	RL—36, LL—4, LLS—47	2.3% total, 5.5% RL	Mortality—0%, Infectious—8%, Biliary—4.6%, PVT—1.1%, Incisional hernia—4.6%
Mizuno et al, 2014 ¹¹	NR	NR	NR	NR	Method not specified	^a RL—77, ^a LL—55, ^b LLS—20	0.7% total, 1.3% LL + LLS	^b Biliary—6% ^b Mortality—0%
	34 mo	Epigastric pain, NV	(1) CXR—L chest mass with mediastinal shift. (2) CT—L sided DH with partial gastric obstruction	4 × 3 cm L medial DH containing ischemic stomach + omentum	Partial gastric resection, nonabsorbable monofilament suture repair			
Vernatakis et al, 2012 ¹²	2.5 y	Abdominal pain, NV	CT—R sided DH containing SB with obstruction	4-5 cm R posteromedial DH containing ischemic SB + omentum	20 cm jejunal resection, 2 row nonabsorbable monofilament suture repair	Total—164	0.6%	NR
Jeng et al, 2015 ¹⁵	20 d	Abdominal + back pain, diaphoresis	CT—R-sided DH containing SB	4 × 4 cm R-sided DH containing strangulated SB	No resection, nonabsorbable suture repair	Total—49	2%	NR
Tabrizian et al, 2012 ¹⁴	24 mo	Abdominal pain	CT—R-sided DH, containing colon	5-10 cm R DH containing colon	Nonabsorbable suture repair	^a RL—80%, ^a LL—10%, ^a LLS—10%	^c ~2%, 2.7% RL	^b ^a Mortality—0%, ^b ^a Infectious—16%, ^b ^a Biliary—2.7%, ^b ^a DVT—2.7%
Patient 1	60 mo	Abdominal pain, NV	AXR—SBO	R-sided DH containing colon and omentum	Repair method not specified ^d	RL = 87, LL = 13, LLS = 51	1.3% total, 2.3% RL	Mortality—0%, incisional hernia—3.9%, bile leak—2.6%, intra-abdominal bleed—2.6%, infectious—1.3%
Patient 2	19 mo	Abdominal and chest pain, NV, sepsis	CT—4 cm R DH containing colon and SB with obstruction	R DH containing ischemic colon and SB	Segmental colon + jejunal resections, delayed completion R colectomy. Interrupted suture repair of DH.			

^a Personal communication from the author.^b Based on publication of 36 right donor hepatectomies.²⁰^c Donor right hepatectomy specific complications.^d DH presented while living in another country, details of repair were not given in correspondence with our center.

AXR, abdominal x-ray; CXR, chest x-ray; RUQ, right upper quadrant; NV, nausea and vomiting; LLS, left lateral segment; SB, small bowel; SBO, bowel obstruction; CT, computed tomography.

Hemidiaphragm elevation accounted for 84% of all suspicious findings. Diaphragmatic abnormalities such as elevation or eventration that would limit the use of CXR as a screening tool are common in transplant recipients, likely as a cause of phrenic nerve injury during suprahepatic caval clamping, but unexpected in LDs. The presence of such abnormalities on CXR in a LD should raise suspicion of a diaphragmatic injury or hernia, leading to further evaluation with more specific tests such as focused ultrasound, computed tomography, or magnetic resonance imaging, especially if accompanied by symptoms. For example, patient 2 had a reported eventration on CXR 8 months before presenting with sepsis secondary to strangulation of the colon and small intestine. Because most hernias presented in a delayed fashion (with the latest reported case being at 5 years), it seems reasonable to screen for at least up to 5 years postoperatively to capture most occurrences. We have proposed adding a CXR to our FU protocol at 1 and 6 months and annually for 5 years.

In conclusion, any complication in an LD can be considered a serious event, and every effort should be made to avoid them. Minimizing the risk of living donation can potentially result in more people being willing to donate, which directly benefits those waiting for LT. The development of a DH post-LDH is a rare but significant complication that often results in obstruction or strangulation of intestinal contents and should be repaired as soon as identified. The addition of routine FU CXR for screening of high-risk individuals could identify early signs of DH leading to pre-emptive intervention and an improvement in the overall safety of living donation.

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