Original Article

Prediction and management of a low-lying costal arch which restricts the operative working space during laparoscopic cholecystectomy

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Running head: Low-lying costal arch in laparoscopic cholecystectomy

Abstract

Background: Laparoscopic cholecystectomy is difficult to perform in patients with a low-lying costal arch that entirely covers the liver. We conducted this study to clarify the factors related to a low-lying costal arch and establish countermeasures to circumvent this characteristic.

Methods: The study included 103 consecutive patients who underwent a laparoscopic cholecystectomy. The possible clinical factors associated with the low-lying costal arch restricting the operative working space were analyzed. The position of the liver against the costal arch and the presumed surgical visual angle for laparoscopic cholecystectomy, comprising the hepatic porta, umbilicus, and costal arch, were estimated with an abdominal multi-detector computed tomography (MDCT).

Results: Seven (7%) patients had a low-lying costal arch presenting an inadequate exposure of the Calot's triangle and restricted instrument mobility during laparoscopic cholecystectomy, and three patients required conversion to a laparotomy. A low-lying costal arch was significantly associated with an advanced age, shorter stature, lighter body weight, co-existing kyphoscoliosis, gallbladder pathology, laparotomy conversion, and most of all the liver edge lying above the costal arch and a narrow surgical visual angle upon MDCT. Among the seven patients with a critical low-lying costal arch, four underwent a successful laparoscopic cholecystectomy by lifting the right costal arch to create a workable surgical field, and the rib-lifting procedure was planned as part of the scheduled procedure in the last three patients because the preoperative MDCT examination indicated a poor working space for a laparoscopic cholecystectomy.

Conclusions: A low-lying costal arch is a substantial risk factor for conversion to a laparotomy when performing a laparoscopic cholecystectomy. However, the operative difficulty related to a low-lying costal arch is predictable using the preoperative MDCT images and can be managed with proper planning and the appropriate use of the rib-lifting technique.

Introduction

Laparoscopic cholecystectomy is the gold standard for managing most gallbladder diseases. This procedure can be performed safely with less patient pain, a faster recovery, a shorter hospital stay, and better cosmesis, as well as lower morbidity and mortality rates, than an open cholecystectomy.¹ Therefore, the laparoscopic approach is widely recommended, not only for benign gallbladder pathologies but also for selected malignant, complex, and severe gallbladder diseases,¹⁻³ even in the elderly.⁴⁻⁶ However, some difficult situations cannot be managed laparoscopically and a laparotomy conversion is often required.⁴⁻⁷ Patients with severe kyphoscoliosis present specific challenges to the laparoscopic surgeon because of their rigid costovertebral deformity, which limits the operative working space and instrument mobility.^{8,9} We recently encountered operative difficulties when performing a laparoscopic cholecystectomy in an elderly female patient with gallbladder torsion and severe kyphoscoliosis, in whom a low-lying costal arch caused by the spinal deformity entirely covered the liver, resulting in an extremely limited working space.¹⁰ We herein clarify the clinical factors related to a low-lying costal arch, which hinders surgical access to the gallbladder during laparoscopic cholecystectomy, and we also describe several countermeasures to circumvent these difficulties.

Patients and Methods

We reviewed 103 cases of consecutive patients who underwent laparoscopic cholecystectomy for benign diseases of the gallbladder between January 2007 and August

2009. An abdominal multi-detector computed tomography (MDCT) was performed in all patients with or without a contrast agent prior to laparoscopic cholecystectomy. The MDCT was conducted using a 64-row scanner (Aquilion 64; Toshiba Medical Systems, Tochigi, Japan) with a slice thickness of 2.0 mm.

Laparoscopic cholecystectomy was performed under general anesthesia, with the patient placed in the reverse Trendelenburg position and the patient's right side facing up. The first port for a 10 mm 30 degree telescope was inserted into the umbilicus by an open technique. After creating a pneumoperitoneum, we placed three additional standard ports for laparoscopic cholecystectomy. The intra-abdominal pressure was maintained at approximately 8-10 mm Hg during the procedure.

Clinical Data

The patients were divided into two groups, according to whether the patients had operative difficulties related to a low-lying costal arch during laparoscopic cholecystectomy; namely, inadequate exposure of the Calot's triangle and restricted instrument mobility, including poor traction of the fundus of the gallbladder above the liver, due to a small working space. We analyzed the possible clinical factors associated with the low-lying costal arch, including the age, gender, height, body weight, underlying gallbladder diseases, co-existing kyphoscoliosis, and the incidence of conversion to open surgery. We also analyzed the original MDCT data and evaluated whether the lower liver edge lay above or below the costal arch using a non-shaded volume rendering (VR) image (**Figure 1**). The surgical visual angle for laparoscopic cholecystectomy was estimated using the multi-planar reformation (MPR) image, where the "surgical visual angle" is substituted for the presumed surgical

working space for laparoscopic cholecystectomy, and it is expressed as the degree of an angle formed between the lines from the hepatic porta to the umbilicus and the costal arch in the vertical plane. To obtain the surgical visual angle, the umbilicus was focused in both the axial and sagittal MPR images (**Figures 2A, 2B**). The sagittal-oblique view was then turned around the umbilicus to target the hepatic porta, and the degree of the same angle was measured (**Figure 2C**).

Statistical Analyses

We compared the groups, first using standard univariate statistical tests; namely, the chi-square test, two-tailed Fisher's exact test, and Mann-Whitney's *U*-test, where appropriate, to identify the variables which were associated with the low-lying costal arch and a small working space. Significant variables were then entered into a multivariable logistic regression analysis. P-values of less than 0.05 were considered to be statistically significant. All confidence intervals were at the 95% level.

Results

The 103 patients comprised 30 male and 73 female subjects with a mean age of 70 years (range 24-97 years). The gallbladder disorders consisted of cholecystolithiasis (n=94), benign polyps (n=6), and torsion of the gallbladder (n=3). Eighty-seven patients underwent elective surgery and 16 required emergency surgery.

A low-lying costal arch covering the liver entirely, causing difficulties in the laparoscopic cholecystectomy due to the restricted working space, was encountered in 7 (7%)

of the 103 patients. The clinical features of these patients are summarized in **Table 1**. All seven patients were small, slender women with a mean age of 83 years (range, 69-94 years), with moderate to severe kyphoscoliosis. The gallbladder disorders were cholecystolithiasis in four patients and gallbladder torsion in three patients. On the VR image of the MDCT, the liver was located above the costal arch in all patients (**Figure 3**). The estimated surgical visual angle for laparoscopic cholecystectomy ranged from 34° to 43° (**Figure 4**). The extremely restricted working space necessitated conversion to laparotomy in three patients (**Figure 5**). However, laparoscopic cholecystectomy was successfully completed in the other four patients by using the rib-lifting method¹⁰ to obtain a workable surgical field (**Figures 6A, 6B**), in which the right costal arch was lifted by the one or two sutures placed across both 9th and 10th ribs. An assistant surgeon pulled the sutures up during laparoscopic cholecystectomy in the first case of the rib-lifting method. However, in the last three patients the rib-lifting technique was planned as part of the scheduled procedure, with preparations of surgical instruments for hanging the rib-lifting sutures (**Figure 6C**), because the preoperative MDCT examination indicated a poor working space for performing a laparoscopic cholecystectomy.

A comparison of the clinical characteristics of the two study groups with or without a low-lying costal arch is summarized in **Table 2**. In the univariate analyses, an advanced age, shorter stature, lighter body weight, co-existing kyphoscoliosis, gallbladder pathology, a liver edge above the costal arch, a narrow surgical visual angle, and a laparotomy conversion were strongly associated with a low-lying costal arch. The liver edge was above the costal arch on the VR image of MDCT in 12 patients, and a low-lying costal arch restricting the working space was observed at the first laparoscopic view in seven of these patients. The average

estimated surgical visual angle in patients without a low-lying costal arch was 83° (range 47-118°), and was 38° (range, 34-43°) in patients with a low-lying costal arch.

A multivariable logistic regression analysis of the eight factors univariately associated with the low-lying costal arch identified the location of the liver edge on the VR image ($p=0.042$) and the surgical visual angle on the sagittal-oblique MPR image ($p=0.014$) as the most notable factors associated with a low-lying costal arch restricting the working space (**Table 3**). The odds ratios were 5.13 (95% CI, 1.2 to 19.2) for patients whose liver edge was above the costal arch versus those whose liver edge was below the costal arch, and 10.44 (95% CI, 1.1 to 9.7) for patients with a narrow surgical visual angle ($\leq 45^\circ$) versus those with a wide surgical visual angle (greater than 45°). The surgical visual angle narrowed with aging and a strongly significant ($p<0.001$) inverse correlation ($r=0.632$) was observed between the surgical visual angle and the patient's age according to Pearson's correlation coefficient test.

Discussion

A low-lying costal arch predisposing patients to operative difficulty and limited surgical access to the gallbladder was identified in 7 (7%) of 103 consecutive patients who underwent a laparoscopic cholecystectomy. Conversion to a laparotomy was necessitated by the restricted working space in three of these seven patients, but laparoscopic cholecystectomy was successfully accomplished in the other four by lifting the costal arch to create a clear surgical field.

The presence of a low-lying costal arch was strongly associated with advanced age, short stature, low body weight, kyphoscoliosis, and gallbladder pathology, in this series. The seven patients with a low-lying costal arch were small, elderly female patients with kyphoscoliosis. Three of these patients underwent surgery for torsion of the gallbladder, a rare clinical entity most frequently encountered in slender female patients over 60 years of age.¹¹⁻¹³ The factors that have been postulated to predisposing patients to gallbladder torsion in elderly patients include kyphoscoliosis and loss of visceral fat with liver atrophy.¹¹⁻¹⁵ Conversely, a low-lying costal arch was recognized in four other patients with cholecystolithiasis who did not have gallbladder torsion.

Marked kyphoscoliosis with an anteflexion of the thoracic cage results in a low-lying costal arch which entirely covers the liver, limiting the operative working space in laparoscopic cholecystectomy. Laparoscopic cholecystectomy is usually performed using the standard four-port technique, placing the first port for a telescoping laparoscope through the umbilicus. Therefore, using the MDCT images we calculated the surgical visual angle, which was measured as the degree of the angle formed between the lines starting from the hepatic porta and extending to the umbilicus and the costal arch in the vertical plane of the sagittal-oblique MPR image. The univariate and multivariate analyses revealed that the surgical visual angle accurately reflected the operative difficulties in performing laparoscopic cholecystectomy, because the low-lying costal arch narrows the surgical visual angle: the average angles in patients with and those without a low-lying costal arch were 38° (range, 34-43°) and 83° (range 47-118°), respectively. The non-shaded VR image on the MDCT for estimating the position of the liver against the costal arch also reflected the operative difficulties caused by the low-lying costal arch. It is straightforward to reconstruct VR images

on MDCT, and these images are particularly helpful for the visualization and delineation of a patient's complex anatomy.¹⁶ We therefore recommend that the laparoscopic surgeon evaluate the location of the liver in relation to the costal arch using MDCT when laparoscopic cholecystectomy is planned for a small, slender elderly patient with kyphoscoliosis. If the liver edge is above the costal arch, the surgical visual angle for a laparoscopic cholecystectomy should be calculated as part of the surgical plan to avoid an unnecessary conversion to a laparotomy.

Owing to continual advances in laparoscopic techniques and surgical expertise, a laparoscopic cholecystectomy is now performed for complex and severe gallbladder diseases, even in the extremely elderly. The laparoscopic surgeon would most likely encounter a patient with a low-lying costal arch restricting the working space, because the present study demonstrated that the surgical visual angle for laparoscopic cholecystectomy narrows with aging. The low-lying costal arch is a challenging and substantial risk factor for laparotomy conversion in laparoscopic cholecystectomies. However, the benefits of laparoscopic surgery can be extended to patients with a rigid costovertebral deformity, since the operative difficulty related to a low-lying costal arch is predictable using the preoperative MDCT images and can therefore be managed with proper planning, preparation of surgical hanging instruments, and the use of the rib-lifting technique.

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Figure Legends

Figure 1. A non-shaded volume rendering (VR) image of an abdominal multi-detector computed tomography (MDCT) scan of an 87-year-old female patient with cholecystolithiasis. The VR image depicts the low-lying liver edge below the costal arch.

Figure 2. Multi-planar reformation (MPR) images of an abdominal multi-detector computed tomography (MDCT) for calculating the surgical visual angle for laparoscopic cholecystectomy. First, the umbilicus is focused on both the axial (A) and sagittal (B) MPR images. The sagittal-oblique view is then turned around the umbilicus to target the hepatic porta in the vertical plane (C), and the degree of the angle formed between the lines from the hepatic porta to the costal arch (a) and the umbilicus (b) is measured. In this patient, the surgical visual angle for a laparoscopic cholecystectomy was calculated as 85°.

Figure 3. A non-shaded volume rendering (VR) image of an abdominal multi-detector computed tomography (MDCT) scan of an 83-year-old female patient with gallbladder torsion. The MDCT scan shows the liver entirely above the costal arch.

Figure 4. The narrow surgical visual angle for laparoscopic cholecystectomy in the patient with gallbladder torsion as in Figure 3. The surgical visual angle was calculated to be 42° in this patient.

Figure 5. Laparoscopic view of an extremely small working space caused by a low-lying costal arch in a 69-year-old female patient with cholecystolithiasis. A conversion to a laparotomy was required.

Figure 6. The rib-lifting technique used in an 83-year-old female patient with cholecystolithiasis. **A:** The first laparoscopic view revealed a small working space caused by a low-lying costal arch (arrowheads). **B:** The right costal arch was lifted (arrowheads) after placing a suture across both the 9th and 10th ribs with the abdominal wall to create a clear surgical field. **C:** A surgical instrument was previously arranged on the right side of the patient for hanging the rib-lifting sutures.

Table 1. Clinical characteristics of the seven patients in whom laparoscopic cholecystectomy was made difficult by a low-lying costal arch restricting the working space

Case number:	1	2	3	4	5	6	7
Pathology of the gallbladder	GB stone	GB stone	GB torsion	GB torsion	GB torsion	GB stone	GB stone
Age (years)	69	94	83	84	85	84	83
Sex	Female	Female	Female	Female	Female	Female	Female
Height (cm)	152	142	144	146	132	140	141
Body weight (kg)	36	40	48	43	34	35	41
Kyphoscoliosis	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Liver edge above the costal arch ^a	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Estimated surgical visual angle for LC (°) ^b	37	38	42	35	34	43	40
Operative procedure	LC→OC	LC→OC	LC→OC	LC	LC	LC	LC
Reason for laparotomy conversion	Small WS	Small WS	Small WS	-	-	-	-
Retraction of the costal arch	No	No	No	Yes	Yes	Yes	Yes
Operative time (min)	114	128	125	235	113	105	132
Blood loss (gr)	45	60	160	20	120	15	76

GB: gallbladder

LC: laparoscopic cholecystectomy

OC: open cholecystectomy

WS: working space

^a; The location of the lower liver edge against the costal arch was examined using MDCT.

^b; The angle formed between the lines starting from the hepatic porta to the costal arch and to the umbilicus on MDCT

Table 2. Univariate analysis of the clinical factors associated with a low-lying costal arch restricting the working space during laparoscopic cholecystectomy

Variables	Overall (n = 103)	Low-lying costal arch		P value
		Yes (n = 7)	No (n = 96)	
Age (years) (mean $\pm$ SD)	70.2 $\pm$ 14.9	83.3 $\pm$ 7.3	68.7 $\pm$ 15.9	0.015
Gender				0.103
Male	30	0 (0)	30 (100)	
Female	73	7 (10)	66 (90)	
Height (cm)	153.8 $\pm$ 10.2	144.5 $\pm$ 7.8	154.6 $\pm$ 9.8	0.006
Body weight (kg)	55.0 $\pm$ 11.2	39.7 $\pm$ 5.5	55.8 $\pm$ 9.7	< 0.001
Pathology of the gallbladder				< 0.001
Cholecystolithiasis	94	4 (4)	90 (96)	
Gallbladder polyp	6	0 (0)	6 (100)	
Gallbladder torsion	3	3 (100)	0 (0)	
Kyphoscoliosis				< 0.001
Yes	16	7(44)	9 (56)	
No	87	0 (0)	87 (100)	
Liver edge ^a				< 0.001
Above the costal arch	12	7 (58)	5 (42)	
Below the costal arch	91	0 (0)	91 (100)	
Estimated surgical visual angle for LC (°) ^b	80.2 $\pm$ 21.3	38.4 $\pm$ 3.4	83.1 $\pm$ 17.7	< 0.001
Conversion to open cholecystectomy				0.002
Yes	5	3 (60)	2 (40)	
No	98	4 (4)	94 (96)	

Values in parentheses are percentages of row totals.

^a; The location of the lower liver edge against the costal arch was examined using MDCT.

^b; The angle formed between the lines starting from the hepatic porta to the costal arch and to the umbilicison on MDCT

Table 3. Multivariate analysis of the clinical factors associated with a low-lying costal arch restricting the working space during laparoscopic cholecystectomy

Variables	Odds ratio	95% CI	<i>p</i> -value
Age (years)	1.27	0.6-2.3	0.414
Height (cm)	4.15	0.5-4.3	0.794
Body weight (kg)	1.39	0.8-2.0	0.667
Pathology of the gallbladder	1.53	0.9–3.7	0.556
Kyphoscoliosis			
No	1	-	
Yes	4.25	0.5-34.3	0.186
Liver edge ^a			
Below the costal arch	1	-	
Above the costal arch	5.13	1.2-19.2	0.042
Estimated surgical visual angle for LC (°) ^b			
$\geq 45^\circ$	1	-	
$< 45^\circ$	10.44	1.1-9.7	0.014
Conversion to open cholecystectomy			
No	1	-	
Yes	5.71	0.6-27.5	0.575

95% CI: 95% confidence intervals

^a: The location of the lower liver edge against the costal arch was examined using MDCT.

^b: The angle formed between the lines starting from the hepatic porta to the costal arch and to the umbilicus on MDCT