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REVIEWS

Thoracoscopic esophagectomy in the prone position

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Abstract
Background Minimally invasive esophageal surgery has arisen in an attempt to reduce the significant complications associated with esophagectomy. Despite proposed technical and physiological advantages, the prone position technique has not been widely adopted. This article reviews the current status of prone thoracoscopic esophagectomy.
Methods A systematic literature search was performed to identify all published clinical studies related to prone esophagectomy. Medline, EMBASE and Google Scholar were searched using the keywords "prone," "thoracoscopic," and "esophagectomy" to identify articles published between January 1994 and September 2010. A critical review of these studies is given, and where appropriate the technique is compared to the more traditional minimally invasive technique utilising the left lateral decubitus position.
Results Twelve articles reporting the outcomes following prone thoracoscopic oesophagectomy were tabulated. These studies were all non-randomised single-centre prospective or retrospective studies of which four compared the technique to traditional minimally invasive surgery. Although prone esophagectomy is demonstrated as being both feasible and safe, there is no convincing evidence that it is superior to other forms of esophageal surgery. Most authors comment that the prone position is associated with superior surgical ergonomics and theoretically offers a number of physiological benefits.
Conclusion The ideal approach within minimally invasive esophageal surgery continues to be a subject of debate since no single method has produced outstanding results. Further clinical studies are required to see whether ergonomic advantages of the prone position can be translated into improved patient outcomes.

Keywords Esophagectomy · Esophageal neoplasms · Minimally invasive surgery · Prone position

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Esophageal carcinoma is the eighth commonest type of cancer worldwide [1]. For invasive carcinoma, open transthoracic esophagectomy is accepted as the best oncologic operation [2], partly because it allows the most extensive lymphadenectomy [3]. Even in experienced hands it is associated with significant morbidity and mortality [4]. The significant trauma of thoracotomy and/or laparotomy is a key disadvantage and is associated with a pronounced systemic inflammatory response [5].

Despite improvements over the last 30 years in staging, patient selection, neoadjuvant therapy, surgical technique, and intensive care methods, complication rates have remained high, global inpatient mortality rate is 10% [6], and 5 years survival is 32% [7]. Complications of particular concern include respiratory failure and pneumonia, which are associated with an up to 20% risk of mortality [8]. Postoperative pain leads to further compromise of pulmonary function [9]. This morbidity has led to increased interest in endoscopic mucosal resection and radiofrequency ablation for non-invasive malignant disease [10, 11]. There has been some evidence to suggest that definitive chemoradiation may be associated with better outcomes for some groups of patients previously considered as surgical candidates [12, 13]. Given this, there is significant pressure on esophageal surgeons to produce better results.

Minimally invasive techniques have arisen in an attempt to reduce these complications. Techniques described to date include laparoscopic transhiatal esophagectomy [14–16], thoracoscopic/laparoscopic two-stage (Ivor–Lewis) esophagectomy [17–19], and thoracoscopic/laparoscopic three-stage esophagectomy in which the surgeon may choose to do one or both of the first two phases in a minimally invasive approach [20–22].

The transhiatal technique was introduced in the 1980s with the obvious advantage being the lack of thoracotomy. A number of large studies have associated the technique with reduced complications when compared to the open transthoracic approach [15, 23, 24]. However, when balanced with the ergonomic and technical difficulties in mobilising the middle third of the oesophagus, especially when aiming for good nodal dissection [25], it is not surprising that a recent international survey of 269 surgeons revealed that only 26% favoured transhiatal esophagectomy [26].

Thoracoscopic mobilisation of the oesophagus as part of a three-stage procedure was first reported in 1993 and is now considered at the forefront of techniques attempting to reduce morbidity and mortality [27]. This is traditionally performed in the left lateral decubitus position (LDP). Early results of this technique were disappointing, which may explain its poor uptake and relative unpopularity [28–30]. More recent non-randomised studies have associated it with a lower rate of major complications than open surgery [20–22, 31–37] but a large systematic review has reiterated that evidence is still lacking to confirm any real benefit in terms of long-term outcome, safety, and oncological quality [38, 39].

Cuschieri [40] performed the first prone-position (PP) thoracoscopic esophageal mobilisation in 1994, and despite proposed technical and physiological advantages over the LDP, the technique has not been widely adopted by esophageal surgeons and research into it has remained very limited.

Methods

The literature was systematically searched to identify all published studies related to prone esophagectomy. An electronic search of Medline (PubMed interface), EMBASE, and Google Scholar databases was undertaken for articles published between January 1990 and September 2010 using the keywords "prone," "esophagectomy," and "thoracoscopic." The search was expanded using the related articles function and reference lists of key studies. Included articles were retrieved, critically reviewed, and summarised in this review. Twelve articles reported outcomes, with four of these comparing them to traditional lateral decubitus surgery. These are tabulated in Tables 1, 2 and 3.

Indications and technique

Indications for PP are similar to those for open surgery, i.e., both malignant and benign conditions such as refractory strictures, end-stage achalasia, diverticula, and perforation [40–43].

Following induction of general anaesthetic with or without the use of a double-lumen endotracheal tube, the patient is placed in the prone position with the right arm abducted to 90° and the forearm flexed, which aids rotation of the scapula [44]. The head should be well supported (e.g., in a Mayfield head rest) to avoid tube displacement. Both surgeon and assistant stand at the right of the patient, with the scrub nurse to the right and a video monitor directly opposite on the left of the patient. This situation can be compared to LDP, where with the patient's right side up, the surgeon stands behind the patient and an assistant to the front making use of a total of four ports with two screens visible [31].

A three-port technique can be utilised in the PP, since a port required for lung retraction as in the LDP is not required: a 10 mm 30° scope in the seventh intercostal space in the posterior axillary line (video camera), a 5 mm port in the fifth intercostal space in the posterior axillary line (grasping forceps), and a 5 mm port in the ninth intercostal space in the posterior axillary line (coagulation hook, scissors, needle holder, and clip applicator) [45, 46]. The use of a transitory CO_2 pneumothorax (which may be introduced prior to port insertion with a Veress needle [47]), with pressures of between 6 and 14 mmHg, aids exposure combined with the use of a partially or fully

Table 1 Benefits and limitations of prone esophageal surgery

Potential advantages	Potential disadvantages
Shortened learning curve	Longer setup time to position
Ergonomic position of hands	Not an established method
Fewer thoracoscopic ports required	Emergency conversion to open procedure difficult in prone position
Theoretical improved oxygenation in prone position	Difficult airway management if displacement of endotracheal tube
Lungs and blood do not obscure operative field due to effects of gravity	Limited clinical data
One-lung ventilation not necessarily required	Unfamiliar thoracoscopic views

Table 2 Studies comparing prone and lateral decubitus three-stage esophagectomy (prone vs. lateral)

Author	No. of patients	Thoracoscopy time (min)	Blood loss (ml)	Total No. of nodes retrieved	30 days mortality (%)	Overall morbidity (%)	Respiratory morbidity (%)	Anastomotic leak (%)	Conversion rate (%)	Postop stay (days)
Fabian et al. [83]	21 vs. 11	86 (55–138) vs. 123 (93–150) ($p = 0.0001$)	65 (20–150) vs. 85 (50–150) ($p = 0.14$)	15.5 (7–30) vs. 14.6 (6–22) ($p = 0.69$)	5 vs. 0 ($p = 1.0$)	48 vs. 55 ($p = 1.0$)	8 vs. 9 (p = NA)	4 vs. 18 (p = NA)	0 vs. 0	10 (7–52) vs. 9 (7–33) ($p = 1.0$)
Kuwabara et al. [81]	22 vs. 58	196 vs. 205 total op time (p = NS)	50 vs. 101 (p = NA)	20.5 vs. 18 (p = NS)	0 vs. 3 (p = NS)	27 vs. 44 (p = NS)	5 vs. 29 (p = NA)	14 vs. 26 (p = NS)	5 vs. 2 (p = NA)	16.5 vs. 22 (p = NA)
Noshiro et al. [49]	43 vs. 34	307 ± 66 vs. 272 ± 58 ($p = 0.021$)	142 ± 87 vs. 295 ± 416 ($p = 0.045$)	49.6 ± 16.4 vs. 51.2 ± 23.1 ($p = 0.750$)	2.4 vs. 0 ($p \geq 0.999$)	34.9 vs. 35.3 ($p \geq 0.999$)	11.6 vs. 14.7 ($p = 0.742$)	7 vs. 0 ($p = 0.251$)	0 vs. 5.9 (p = NA)	NA
Song et al. [82]	15 vs. 7	191 ± 42 vs. 154 ± 41 ($p = 0.062$)	NA	NA	NA	NA	NA	NA	NA	NA

NA not available, *NS* not significant

deflated lung [44]. The pneumothorax depresses the diaphragm caudally and the right lung anteriorly, as well as encourages extraction of coagulation smoke [48].

The general operative technique following port insertion is similar to that of a traditional three-stage LDP procedure. The grasper is held in the left hand and hook electrocautery in the right. The mediastinal pleura overlying the anterior esophagus is incised and the arch of the azygos vein is divided using a vascular endo-GIA stapler (Covidien, Norwalk, CT, USA) or ligated with ties and/or clips and divided using scissors. The parietal pleura posterior to the esophagus is opened from the azygos vein to the crus and blunt dissection is used to identify thoracic duct and arterial branches, which are clipped and transected using diathermy or a harmonic scalpel (Ethicon, Somerville, NJ, USA) [48]. The esophagus is mobilised from the thoracic inlet superiorly to the hiatus inferiorly and paraesophageal, subcarinal, paratracheal, bilateral tracheobronchial, and right peripulmonary artery and vein nodes are dissected to remain en bloc with the specimen [44]. The esophagus can also be encircled with a Penrose drain stapled to form a ring and held in the left hand to give good counter tension during mobilisation. Following mobilisation the drain can be left tucked under a pleural flap to allow its retrieval from the neck later [44]. After the insertion of one or two chest tubes (e.g., 28 Fr), the patient is repositioned to the supine position. At this stage, if a double-lumen endotracheal tube was used, this is replaced with a single-lumen one.

Technical advantages of the prone position technique

The learning curve associated with traditional LDP surgery is particularly steep for a number of reasons [31]: First, unlike traditional laparoscopy, the surgeon operates in a plane perpendicular to the view of the camera, increasing the chance of disorientation. Second, accurate port placement is far more important due to the rigidity of the chest wall. Improper placement leads to unnecessary force being placed on instruments and early operator fatigue in an operation that can easily last many hours. Excessive force applied to intercostal spaces may also contribute to postoperative pain. Third, the lungs obscure the operative field, even during one-lung ventilation, requiring the resources of a skilled assistant and a spare port to retract. The esophagus also lies in the most dependent portion of the chest and is thus often obscured by overlying blood. Alternation of instruments between suction, cautery and clips can slow progress leading to frustration and fatigue [48].

Mobilisation in the PP is thought to reduce this steep learning curve partly because the effect of gravity is such that the lungs and blood do not obscure the operative field in the same way as with the patient lying in the lateral position. The reduced requirement for skilled retraction and

Table 3 Individual studies investigating prone three-stage esophagectomy

Author/method	No. of patients	Thoracoscopy time (min)	Total blood loss (ml)	Total no. of nodes retrieved	30 days mortality (%)	Overall morbidity (%)	Respiratory morbidity (%)	Anastomotic leak (%)	Conversion rate (%)	Postop stay (days)
Dapri et al. [44]	15	75 (60–90)	700 (100–2,400)	4 (2–13) mediastinal 10 (3–22) abdominal	0	40	13.3	26.7	6.7	14 (7–480)
Kim et al. [70] Robotic	21	108.8 ± 46.3	150 (50–2,300)	11.6 ± 6.2 mediastinal 21.1 ± 9.8 abdominal	0	71.5	0	19	0	21 (11–45)
Liebman et al. [84] Total thoracoscopic/laparoscopic approach	25	90 (55–140)	300	9 (1–18) mediastinal 10 (2–20) abdominal	0	64	28	8	0	11 (7–49)
Martin et al. [85] Thoracoscopy and laparotomy/laparoscopy	36	240 (190–360) for combined three stages	200 (0–1,500)	NA	5.5	41	NA	19	5.5	16 (8–61)
Palanivelu et al. [47] Total thoracoscopic/laparoscopic approach	130	220 (160–450) for combined three stages	180 (100–400)	18 (11–32)	1.54	1.54	2.31	2.31	0	8 (4–68)
Smithers et al. [20][a] Total thoracoscopic/laparoscopic approach	23	90 (55–120)	300 (15–1,000)	17 (9–33)	0	61	30	4	8	11 (7–49)
Smithers et al. [20][a] Thoracoscopy and laparotomy	309	90 (30–240)	400 (0–1,500)	17 (2–59)	2.3	62	26	5.5	3	13 (8–123)
Zingg et al. [86][a] Thoracoscopy and laparoscopy/laparotomy	56	250.2 (for combined three stages)	320	5.7	3.6	34.5	30.9	20	5.5	NA

NA not available

[a] Data extracted for prone technique from these comparative studies

suctioning may decrease the total number of instrument changes, thus reducing fatigue. In addition, the surgeon operates in a plane parallel to the camera, similar to traditional abdominal laparoscopy, increasing ease of the operation. Dissection with long endoscopic instruments is more ergonomic due to the port's entrance site being located at the elbow level of the surgeon [45]. These combined effects may allow better quality dissection and lymphadenectomy, with enhanced visibility of the esophagus and aortopulmonary window. The natural anterior tension on the esophagus in the prone position aids its mobilisation. The ease with which the PP allows good dissection around the left recurrent laryngeal nerve lymph nodes may also explain the technique's popularity in the East, given their proposed oncological significance [49]. Better lymphadenectomy has the potential for improving patient prognosis, especially at the early stage of lymphatic spread [50–52]. The improved view may also reduce complications such as tracheobronchial injury/necrosis, which is known to be more common during minimally invasive rather than open esophagectomy [30].

The enhanced operative view means that three ports are usually required rather than four as in the LDP. This reduction in ports may reduce postoperative pain and the chance of intercostal vessel injury. A retracting stitch in the diaphragm through an additional space that is usually placed during the LDP is also not necessary.

The volume–outcome relationship in esophagectomy is well known, with outcomes from high-volume experienced centres better in terms of in-hospital mortality, morbidity, and long-term survival [2]. The fact that significant benefits from LDP esophagectomy have not yet been seen may well be because the learning curve is so significant and has not yet been surpassed in most centres [53–55]. Therefore, the potential for markedly reducing the learning curve using the PP should be considered by surgeons who are attempting to enhance adoption of minimally invasive esophageal surgery in their centres.

Physiological changes

The beneficial effects of prone positioning on arterial oxygenation were first described over 30 years ago [56] and it is known that pulmonary perfusion is more uniform in the prone position [57]. Research has shown that PP can be associated with a 60–70% increase in oxygenation in acute lung injury patients [58–60]. Mechanisms suggested for these changes include improved redistribution of ventilation towards better perfusion of dorsal lung areas, more tidal volume distribution associated with alterations in chest wall mechanics [61], alveolar recruitment [62], redirection of compressive forces exerted by the heart on the lungs [63], and better secretion clearance [64]. The functional residual capacity of the ventilated lung in the LDP is decreased in comparison to PP because of a decrease in neural output to the diaphragm and an increase in expiratory tone of the abdominal wall muscles which lead to an increase in intra-abdominal pressure leading to displacement of the diaphragm cephalad. The ventilated lung is also under pressure in the lateral position from the mediastinum which may predispose to atelectasis [65, 66].

Trials investigating the physiological effect of prone positioning in esophagectomy have thus far been limited. Atsuta et al. [67] prospectively compared a group of 16 patients who underwent LDP esophagectomy and ten patients who underwent PP surgery. Whilst there were no differences in perioperative outcomes, the PaO_2/FiO_2 ratio was significantly higher in the prone group. However, maximum perioperative $PaCO_2$ was higher in the prone group suggesting a tendency towards hypercapnia. Better pulmonary oxygenation and reduced pulmonary shunt have been confirmed in other small studies, albeit ones comparing PP and open esophagectomy in the left lateral position [66, 68]. Watanabe et al. [69] conducted a prospective randomised trial in which patients who underwent LDP three-stage esophagectomy and who were hypoxemic and still ventilated on postoperative day 5 were randomised to being positioned in either the prone or the supine position for periods over four consecutive days. The prone group showed significantly better oxygenation with subsequent improved outcomes (shorter ventilation and postoperative stay). This trial was small and to some degree the positive conclusions can be applied only to postoperative hypoxemic esophagectomy patients rather than intraoperative positioning, which is the main focus of this review.

Kim et al. [70] prospectively analysed 21 patients who underwent robotic prone esophagectomy. Their analysis showed that the prone position led to an increase in central venous pressure and mean pulmonary artery pressure, and a decrease in static lung compliance (a similar change in compliance is also seen in LDP). Despite these changes, cardiac index and mean arterial pressure were well maintained with acceptable ranges of PaO_2 and $PaCO_2$. The increase in peak airway pressure and plateau airway pressure that they observed is not surprising given the decrease in static lung compliance, but they attributed the relatively stable $PO_2/PaCO_2$ to an increase in functional residual capacity and better ventilation/perfusion in the prone position [70].

During PP the enhanced operative view is such that some surgeons have been able to operate without the use of one-lung ventilation via a double-lumen endotracheal tube [35, 48]. This potentially avoids repeated deflation and reinflation of the lungs which cause the production of inflammatory mediators [71]. The use of two-lung ventilation, or at least partial lung deflation in PP, has the potential to reduce pulmonary-related complications but this has not been clinically proven [44].

Robot-assisted prone surgery

Robot-assisted thoracoscopic esophagectomy was first described in 2004 [72]. Systems such as the da Vinci® device (Intuitive Surgical, Inc., Sunnyvale, CA, USA) have been developed to overcome some of the conventional limitations of open and scope-based surgery. The advantages include increased magnification, a 3D view, more degrees of freedom, and filtering of the surgeon's tremor [73, 74]. Postoperative pain during thoracoscopy can be significant due to the articulation of instruments in the intercostal spaces. Robotic systems may cause reduced pain due to the articulation of instruments inside the pleural cavity as opposed to against the chest wall [75].

The article reporting prone robotic esophageal mobilisation on the largest number of patients is by Kim et al. [70], in which 21 patients underwent a three-stage procedure by a single surgeon with low surgical volume and no prior experience of minimally invasive surgery. Apart from a relatively high anastomotic leak rate of 19%, results were comparable with other esophagectomy methods and the group did not encounter any pneumonia, respiratory failure, or 90 days mortality. What was most remarkable about the results was that robot console time was significantly reduced from 176.3 $\pm$ 12.3 min in the first six patients to 81.7 $\pm$ 16.5 min in the latter 15 patients ($p = 0.000$). In addition, the latter group had significantly less blood loss, more extubations in the operating room, and increased numbers of mediastinal nodes dissected. A study by Osugi et al. [76] showed that in a series of 80 thoracoscopic esophagectomies, a plateau in operating technique was not reached until 34 cases had been performed. This implies that robotic prone esophagectomy may have a particularly short learning curve.

Limitations of the prone position technique

The prone position is one with which most surgeons are unfamiliar. Adequate prone positioning takes longer and can prolong overall operating time [44]. Other disadvantages with the technique mainly relate to perioperative complications. In the case of massive bleeding, whilst posterior thoracotomy can be performed, it is a technique with which most are unfamiliar [48]. Given the difficulty in conversion, some have suggested that the prone position should not be used in the case of bulky tumours treated with neoadjuvant chemoradiation [48] and large tumours adjacent to the aorta, azygos vein, or tracheobronchus [77]. Problems with endotracheal tube displacement are also difficult to overcome with the prone position, as experienced by Smithers et al. [78] in their early cases using PP until they adopted the use of a Mayfield head rest.

One of the largest series on minimally invasive esophagectomy (adopting the LDP approach) is by Luketich et al. [22]. This study included 222 patients and had a mortality rate of 1.4% and an impressive 7 days hospital stay. However, the decreased 5 years survival seen in this study for stage II cancer patients (20%) compared to around 50% for conventional surgery may be due to the more challenging lymphadenectomy associated with minimally invasive surgery [3, 79]. A more recent study by Smithers et al. [20] showed more comparable results with respect to cancer survival, but despite this, until further strong evidence is published, surgeons are likely to continue to have some concerns regarding the oncologic quality of both PP and LDP mobilisation of the esophagus.

The above limitations are likely to explain why the majority of centres have not adopted or tried the procedure. The barriers to adoption are multiplied by the fact that esophageal surgeons spend many years learning traditional resection techniques with an already significant learning curve and prone thoracoscopic views during surgery are then likely to be unfamiliar. The lack of a clear benefit in terms of clinical data is a further barrier as it suggests that the prone position does not add much to an already challenging and long procedure.

Clinical results

No prospective randomised trials have directly compared minimally invasive to open esophagectomy [2]. This is unlikely to happen for some period given the wide variety of techniques available and relatively small numbers of the procedure performed per institution [80]. Therefore, it is not surprising that the data comparing PP to the LDP technique is particularly sparse.

The largest trial to date is by Kuwabara et al. [81] who retrospectively compared outcomes between 22 patients who underwent esophagectomy with PP and 76 who underwent esophagectomy with LDP (18 of whom were done with a flexible thoracoscope with one TV monitor, and 58 of whom were done with a 30° scope and two monitors). They found that esophagectomy in the prone position was superior subjectively in terms of operating field and lymph node dissection and in terms of total blood loss and respiratory tract complications. There was no remarkable difference in thoracoscopy time, mortality, short-term overall morbidity, or postoperative stay [81]. A study by Noshiro et al. [49] retrospectively comparing the results of 43 PP and 34 LDP patients supported these findings in terms of significantly reduced blood loss in the prone position, and they also found no difference in overall short-term morbidity or mortality. They also found the prone position to be associated with significantly longer thoracoscopy times, a finding supported by Song et al. [82]. This longer time is likely to be due to the increased difficulty and unfamiliarity with positioning patients in the prone position, although one study by Fabian et al. [83] found thoracoscopy was significantly quicker in the prone position.

From the individual studies reporting results of using PP, results are fairly unremarkable when compared with results from established open and minimally invasive surgery techniques in the left lateral position, apart from a series of 130 patients by Palanivelu et al. [47]. In this series by a highly experienced surgeon in India, the reported respiratory morbidity was only 2.3%, major morbidity 21%, an average harvest of 18 lymph nodes, and a postoperative stay of 8 days. The remarkably low complications in this series may well be because this surgeon uses a single-lumen endotracheal tube, avoiding one-lung ventilation and its associated negative consequences. A potential disadvantage for placing a single-lumen tube is that if an emergency conversion to thoracotomy was required, one-lung ventilation would be particularly helpful.

Conclusions

Although not confirmed by any large multi-institutional randomised trials, minimally invasive surgery in esophagectomy has started to show some benefits over conventional techniques in selected patients. The uptake of the technique when compared to abdominal laparoscopic surgery has been slow and is likely due to the significant learning curve associated with such major surgery. The ideal approach within minimally invasive surgery continues to be a subject of controversy, simply because no technique has consistently outshone the other. Prone esophageal mobilisation was first described in 1994 and limited research has suggested that it has a number of theoretical physiological and ergonomic advantages to patient and surgeon. Despite this, to date the technique has failed to become clinically relevant due to lack of mature supporting data and significant barriers to adoption, meaning the technique has not been tried or adopted in most centres. Further application of this technique is required with careful scrutiny to establish whether it is of any true value in terms of improved patient outcome or simply an alternative without significant benefit to other established procedures.

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References

1. Kamangar F, Dores GM, Anderson WF (2006) Patterns of cancer incidence, mortality, and prevalence across five continents: defining priorities to reduce cancer disparities in different geographic regions of the world. J Clin Oncol 24:2137–2150
2. Decker G, Coosemans W, De Leyn P, Decaluwe H, Nafteux P, Van Raemdonck D, Lerut T (2009) Minimally invasive esophagectomy for cancer. Eur J Cardiothorac Surg 35:13–20 Discussion 20–21
3. Mariette C, Piessen G, Triboulet JP (2007) Therapeutic strategies in oesophageal carcinoma: role of surgery and other modalities. Lancet Oncol 8:545–553
4. Millikan KW, Silverstein J, Hart V, Blair K, Bines S, Roberts J, Doolas A (1995) A 15 years review of esophagectomy for carcinoma of the esophagus and cardia. Arch Surg 130:617–624
5. Ni NC, Redmond HP (2006) Cell response to surgery. Arch Surg 141:1132–1140
6. Jamieson GG, Mathew G, Ludemann R, Wayman J, Myers JC, Devitt PG (2004) Postoperative mortality following oesophagectomy and problems in reporting its rate. Br J Surg 91:943–947
7. Rudiger JS, Feith M, Werner M, Stein HJ (2000) Adenocarcinoma of the esophagogastric junction: results of surgical therapy based on anatomical/topographic classification in 1,002 consecutive patients. Ann Surg 232:353–361
8. Atkins BZ, Shah AS, Hutcheson KA, Mangum JH, Pappas TN, Harpole DH Jr, D'Amico TA (2004) Reducing hospital morbidity and mortality following esophagectomy. Ann Thorac Surg 78:1170–1176 Discussion 1170–1176
9. Roberts JR (2006) Postoperative respiratory failure. Thorac Surg Clin 16:235–241 vi
10. Ell C, May A, Gossner L, Pech O, Gunter E, Mayer G, Henrich R, Vieth M, Muller H, Seitz G, Stolte M (2000) Endoscopic mucosal resection of early cancer and high-grade dysplasia in Barrett's esophagus. Gastroenterology 118:670–677
11. Sharma VK, Wang KK, Overholt BF, Lightdale CJ, Fennerty MB, Dean PJ, Pleskow DK, Chuttani R, Reymunde A, Santiago N, Chang KJ, Kimmey MB, Fleischer DE (2007) Balloon-based, circumferential, endoscopic radiofrequency ablation of Barrett's esophagus: 1 year follow-up of 100 patients. Gastrointest Endosc 65:185–195
12. Stahl M, Stuschke M, Lehmann N, Meyer HJ, Walz MK, Seeber S, Klump B, Budach W, Teichmann R, Schmitt M, Schmitt G, Franke C, Wilke H (2005) Chemoradiation with and without surgery in patients with locally advanced squamous cell carcinoma of the esophagus. J Clin Oncol 23:2310–2317
13. Chiu PW, Chan AC, Leung SF, Leong HT, Kwong KH, Li MK, Au-Yeung AC, Chung SC, Ng EK (2005) Multicenter prospective randomized trial comparing standard esophagectomy with chemoradiotherapy for treatment of squamous esophageal cancer: early results from the Chinese University Research Group for esophageal cancer (CURE). J Gastrointest Surg 9:794–802
14. DePaula AL, Hashiba K, Ferreira EA, de Paula RA, Grecco E (1995) Laparoscopic transhiatal esophagectomy with esophagogastroplasty. Surg Laparosc Endosc 5:1–5
15. Swanstrom LL, Hansen P (1997) Laparoscopic total esophagectomy. Arch Surg 132:943–947 Discussion 947–949
16. Avital S, Zundel N, Szomstein S, Rosenthal R (2005) Laparoscopic transhiatal esophagectomy for esophageal cancer. Am J Surg 190:69–74
17. Watson DI, Davies N, Jamieson GG (1999) Totally endoscopic Ivor Lewis esophagectomy. Surg Endosc 13:293–297
18. Nguyen NT, Follette DM, Lemoine PH, Roberts PF, Goodnight JE Jr (2001) Minimally invasive Ivor Lewis esophagectomy. Ann Thorac Surg 72:593–596

19. Bizekis C, Kent MS, Luketich JD, Buenaventura PO, Landreneau RJ, Schuchert MJ, Alvelo-Rivera M (2006) Initial experience with minimally invasive Ivor Lewis esophagectomy. Ann Thorac Surg 82:402–406 Discussion 406–407
20. Smithers BM, Gotley DC, Martin I, Thomas JM (2007) Comparison of the outcomes between open and minimally invasive esophagectomy. Ann Surg 245:232–240
21. Nguyen NT, Follette DM, Wolfe BM, Schneider PD, Roberts P, Goodnight JE Jr (2000) Comparison of minimally invasive esophagectomy with transthoracic and transhiatal esophagectomy. Arch Surg 135:920–925
22. Luketich JD, Alvelo-Rivera M, Buenaventura PO, Christie NA, McCaughan JS, Litle VR, Schauer PR, Close JM, Fernando HC (2003) Minimally invasive esophagectomy: outcomes in 222 patients. Ann Surg 238:486–494 Discussion 494–485
23. Hulscher JB, van Sandick JW, de Boer AG, Wijnhoven BP, Tijssen JG, Fockens P, Stalmeier PF, ten Kate FJ, van Dekken H, Obertop H, Tilanus HW, van Lanschot JJ (2002) Extended transthoracic resection compared with limited transhiatal resection for adenocarcinoma of the esophagus. N Engl J Med 347:1662–1669
24. Hulscher JB, Tijssen JG, Obertop H, van Lanschot JJ (2001) Transthoracic versus transhiatal resection for carcinoma of the esophagus: a meta-analysis. Ann Thorac Surg 72:306–313
25. Nguyen NT, Roberts P, Follette DM, Rivers R, Wolfe BM (2003) Thoracoscopic and laparoscopic esophagectomy for benign and malignant disease: lessons learned from 46 consecutive procedures. J Am Coll Surg 197:902–913
26. Boone J, Livestro DP, Elias SG, Borel RIH, van Hillegersberg R (2009) International survey on esophageal cancer: part I surgical techniques. Dis Esophagus 22:195–202
27. Collard JM, Lengele B, Otte JB, Kestens PJ (1993) En bloc and standard esophagectomies by thoracoscopy. Ann Thorac Surg 56:675–679
28. Robertson GS, Lloyd DM, Wicks AC, Veitch PS (1996) No obvious advantages for thoracoscopic two-stage oesophagectomy. Br J Surg 83:675–678
29. McAnena OJ, Rogers J, Williams NS (1994) Right thoracoscopically assisted oesophagectomy for cancer. Br J Surg 81:236–238
30. Dexter SP, Martin IG, McMahon MJ (1996) Radical thoracoscopic esophagectomy for cancer. Surg Endosc 10:147–151
31. Ashrafi AS, Keeley SB, Shende M, Luketich J (2007) Minimally invasive esophagectomy. Eur Surg 39:141–150
32. Narumiya K, Nakamura T, Ide H, Takasaki K (2005) Comparison of extended esophagectomy through mini-thoracotomy/laparotomy with conventional thoracotomy/laparotomy for esophageal cancer. Jpn J Thorac Cardiovasc Surg 53:413–419
33. Watson DI, Jamieson GG, Devitt PG (2000) Endoscopic cervico-thoraco-abdominal esophagectomy. J Am Coll Surg 190:372–378
34. Berrisford RG, Wajed SA, Sanders D, Rucklidge MW (2008) Short-term outcomes following total minimally invasive oesophagectomy. Br J Surg 95:602–610
35. Palanivelu C, Prakash A, Parthasarathi R, Senthilkumar R, Senthilnathan PR, Rajapandian S (2007) Laparoscopic esophagogastrectomy without thoracic or cervical access for adenocarcinoma of the gastroesophageal junction: an Indian experience from a tertiary center. Surg Endosc 21:16–20
36. Hamouda AH, Forshaw MJ, Tsigritis K, Jones GE, Noorani AS, Rohatgi A, Botha AJ (2010) Perioperative outcomes after transition from conventional to minimally invasive Ivor-Lewis esophagectomy in a specialized center. Surg Endosc 24:865–869
37. Nagpal K, Ahmed K, Vats A, Yakoub D, James D, Ashrafian H, Darzi A, Moorthy K, Athanasiou T (2010) Is minimally invasive surgery beneficial in the management of esophageal cancer? A meta-analysis. Surg Endosc 24:1621–1629
38. Gemmill EH, McCulloch P (2007) Systematic review of minimally invasive resection for gastro-oesophageal cancer. Br J Surg 94:1461–1467
39. Law S (2006) Minimally invasive techniques for oesophageal cancer surgery. Best Pract Res Clin Gastroenterol 20:925–940
40. Cuschieri A (1994) Thoracoscopic subtotal oesophagectomy. Endosc Surg Allied Technol 2:21–25
41. Palanivelu C, Rangarajan M, Senthilkumar R, Velusamy M (2008) Combined thoracoscopic and endoscopic management of mid-esophageal benign lesions: use of the prone patient position: thoracoscopic surgery for mid-esophageal benign tumors and diverticula. Surg Endosc 22:250–254
42. Spinoglio G, Summa M, Quarati R, Testa S, Priora F, Lenti M, Ravazzoni F, Piscioneri D (2009) Thoracoscopic and laparoscopic esophagectomy in a case of spontaneous rupture of the esophagus (Boerhaave's syndrome). Eur J Trauma Emerg Surg 35:414–416
43. Denk PM, Gatta P, Swanstrom LL (2008) Multimedia article. Prone thoracoscopic thoracic duct ligation for postsurgical chylothorax. Surg Endosc 22:2742
44. Dapri G, Himpens J, Cadiere GB (2008) Minimally invasive esophagectomy for cancer: laparoscopic transhiatal procedure or thoracoscopy in prone position followed by laparoscopy? Surg Endosc 22:1060–1069
45. Cadiere GB, Torres R, Dapri G, Capelluto E, Hainaux B, Himpens J (2006) Thoracoscopic and laparoscopic oesophagectomy improves the quality of extended lymphadenectomy. Surg Endosc 20:1308–1309
46. Cadiere GB, Dapri G, Himpens J, Fodderie L, Rajan A (2010) Ivor Lewis esophagectomy with manual esogastric anastomosis by thoracoscopy in prone position and laparoscopy. Surg Endosc 24:1482–1485
47. Palanivelu C, Prakash A, Senthilkumar R, Senthilnathan P, Parthasarathi R, Rajan PS, Venkatachlam S (2006) Minimally invasive esophagectomy: thoracoscopic mobilization of the esophagus and mediastinal lymphadenectomy in prone position—experience of 130 patients. J Am Coll Surg 203:7–16
48. Fabian T, McKelvey AA, Kent MS, Federico JA (2007) Prone thoracoscopic esophageal mobilization for minimally invasive esophagectomy. Surg Endosc 21:1667–1670
49. Noshiro H, Iwasaki H, Kobayashi K, Uchiyama A, Miyasaka Y, Masatsugu T, Koike K, Miyazaki K (2010) Lymphadenectomy along the left recurrent laryngeal nerve by a minimally invasive esophagectomy in the prone position for thoracic esophageal cancer. Surg Endosc 24:2965–2973
50. Altorki NK, Girardi L, Skinner DB (1997) En bloc esophagectomy improves survival for stage III esophageal cancer. J Thorac Cardiovasc Surg 114:948–955 Discussion 955–946
51. Nishihira T, Hirayama K, Mori S (1998) A prospective randomized trial of extended cervical and superior mediastinal lymphadenectomy for carcinoma of the thoracic esophagus. Am J Surg 175:47–51
52. Siewert JR, Stein HJ (1999) Lymph-node dissection in squamous cell esophageal cancer—who benefits? Langenbecks Arch Surg 384:141–148
53. Hofstetter W, Swisher SG, Correa AM, Hess K, Putnam JB Jr, Ajani JA, Dolormente M, Francisco R, Komaki RR, Lara A, Martin F, Rice DC, Sarabia AJ, Smythe WR, Vaporciyan AA, Walsh GL, Roth JA (2002) Treatment outcomes of resected esophageal cancer. Ann Surg 236:376–384 Discussion 384–375
54. Orringer MB, Marshall B, Chang AC, Lee J, Pickens A, Lau CL (2007) Two thousand transhiatal esophagectomies: changing trends, lessons learned. Ann Surg 246:363–372 Discussion 372–364
55. Low DE, Kunz S, Schembre D, Otero H, Malpass T, Hsi A, Song G, Hinke R, Kozarek RA (2007) Esophagectomy–it's not just

about mortality anymore: standardized perioperative clinical pathways improve outcomes in patients with esophageal cancer. J Gastrointest Surg 11:1395–1402 Discussion 1402
56. Bryan AC (1974) Conference on the scientific basis of respiratory therapy. Pulmonary physiotherapy in the pediatric age group. Comments of a devil's advocate. Am Rev Respir Dis 110: 143–144
57. Nyren S, Mure M, Jacobsson H, Larsson SA, Lindahl SG (1999) Pulmonary perfusion is more uniform in the prone than in the supine position: scintigraphy in healthy humans. J Appl Physiol 86:1135–1141
58. Langer M, Mascheroni D, Marcolin R, Gattinoni L (1988) The prone position in ARDS patients. A clinical study. Chest 94: 103–107
59. Pappert D, Rossaint R, Slama K, Gruning T, Falke KJ (1994) Influence of positioning on ventilation-perfusion relationships in severe adult respiratory distress syndrome. Chest 106:1511–1516
60. Chatte G, Sab JM, Dubois JM, Sirodot M, Gaussorgues P, Robert D (1997) Prone position in mechanically ventilated patients with severe acute respiratory failure. Am J Respir Crit Care Med 155:473–478
61. Pelosi P, Tubiolo D, Mascheroni D, Vicardi P, Crotti S, Valenza F, Gattinoni L (1998) Effects of the prone position on respiratory mechanics and gas exchange during acute lung injury. Am J Respir Crit Care Med 157:387–393
62. Guerin C, Badet M, Rosselli S, Heyer L, Sab JM, Langevin B, Philit F, Fournier G, Robert D (1999) Effects of prone position on alveolar recruitment and oxygenation in acute lung injury. Intensive Care Med 25:1222–1230
63. Albert RK, Hubmayr RD (2000) The prone position eliminates compression of the lungs by the heart. Am J Respir Crit Care Med 161:1660–1665
64. Demory D, Michelet P, Arnal JM, Donati S, Forel JM, Gainnier M, Bregeon F, Papazian L (2007) High-frequency oscillatory ventilation following prone positioning prevents a further impairment in oxygenation. Crit Care Med 35:106–111
65. Froese AB, Bryan AC (1974) Effects of anesthesia and paralysis on diaphragmatic mechanics in man. Anesthesiology 41:242–255
66. Yatabe T, Kitagawa H, Yamashita K, Akimori T, Hanazaki K, Yokoyama M (2010) Better postoperative oxygenation in thoracoscopic esophagectomy in prone positioning. J Anesth 24:803–806
67. Atsuta J, Okutani R, Kobayashi M (2010) Which is less invasive procedure in thoracoscopic esophagectomy? Lateral vs. prone position. American Society of Anesthesiologists 2010 Meeting, San Diego October 16–20 2010, abstract A1083
68. Laface L, Abate E, Agosteo EA, Nencioni M, Asti E, Saino G, Bona D, Bonavina L (2010) 51st annual meeting of the society for surgery of the alimentary tract. New Orleans, LA May 1–5 2010, abstract T1646
69. Watanabe I, Fujihara H, Sato K, Honda T, Ohashi S, Endoh H, Yamakura T, Taga K, Shimoji K (2002) Beneficial effect of a prone position for patients with hypoxemia after transthoracic esophagectomy. Crit Care Med 30:1799–1802
70. Kim DJ, Hyung WJ, Lee CY, Lee JG, Haam SJ, Park IK, Chung KY (2010) Thoracoscopic esophagectomy for esophageal cancer: feasibility and safety of robotic assistance in the prone position. J Thorac Cardiovasc Surg 139(53–59):e51
71. Funakoshi T, Ishibe Y, Okazaki N, Miura K, Liu R, Nagai S, Minami Y (2004) Effect of re-expansion after short-period lung collapse on pulmonary capillary permeability and pro-inflammatory cytokine gene expression in isolated rabbit lungs. Br J Anaesth 92:558–563
72. Kernstine KH, DeArmond DT, Karimi M, Van Natta TL, Campos JH, Yoder MR, Everett JE (2004) The robotic, 2-stage, 3-field esophagolymphadenectomy. J Thorac Cardiovasc Surg 127:1847–1849
73. Ruurda JP, van Vroonhoven TJ, Broeders IA (2002) Robot-assisted surgical systems: a new era in laparoscopic surgery. Ann R Coll Surg Engl 84:223–226
74. Hanly EJ, Talamini MA (2004) Robotic abdominal surgery. Am J Surg 188:19S–26S
75. Dapri G, Himpens J, Cadiere GB (2006) Robot-assisted thoracoscopic esophagectomy with the patient in the prone position. J Laparoendosc Adv Surg Tech A 16:278–285
76. Osugi H, Takemura M, Higashino M, Takada N, Lee S, Ueno M, Tanaka Y, Fukuhara K, Hashimoto Y, Fujiwara Y, Kinoshita H (2003) Learning curve of video-assisted thoracoscopic esophagectomy and extensive lymphadenectomy for squamous cell cancer of the thoracic esophagus and results. Surg Endosc 17:515–519
77. Kuwabara K, Matsuda S, Fushimi K, Ishikawa KB, Horiguchi H, Fujimori K (2010) Quantitative comparison of the difficulty of performing laparoscopic colectomy at different tumor locations. World J Surg 34:133–139
78. Smithers BM, Gotley DC, McEwan D, Martin I, Bessell J, Doyle L (2001) Thoracoscopic mobilization of the esophagus. A 6 year experience. Surg Endosc 15:176–182
79. Mariette C, Piessen G, Balon JM, Van Seuningen I, Triboulet JP (2004) Surgery alone in the curative treatment of localised oesophageal carcinoma. Eur J Surg Oncol 30:869–876
80. Dunst CM, Swanstrom LL (2010) Minimally invasive esophagectomy. J Gastrointest Surg 14(Suppl 1):S108–S114
81. Kuwabara S, Katayanagi N (2010) Comparison of three different operative methods of video-assisted thoracoscopic esophagectomy. Esophagus 7:23–29
82. Song SY, Na KJ, Oh SG, Ahn BH (2009) Learning curves of minimally invasive esophageal cancer surgery. Eur J Cardiothorac Surg 35:689–693
83. Fabian T, Martin J, Katigbak M, McKelvey AA, Federico JA (2008) Thoracoscopic esophageal mobilization during minimally invasive esophagectomy: a head-to-head comparison of prone versus decubitus positions. Surg Endosc 22:2485–2491
84. Leibman S, Smithers BM, Gotley DC, Martin I, Thomas J (2006) Minimally invasive esophagectomy: short- and long-term outcomes. Surg Endosc 20:428–433
85. Martin DJ, Bessell JR, Chew A, Watson DI (2005) Thoracoscopic and laparoscopic esophagectomy: initial experience and outcomes. Surg Endosc 19:1597–1601
86. Zingg U, McQuinn A, DiValentino D, Esterman AJ, Bessell JR, Thompson SK, Jamieson GG, Watson DI (2009) Minimally invasive versus open esophagectomy for patients with esophageal cancer. Ann Thorac Surg 87:911–919