Thoracoscopic esophagectomy using prone positioning

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Thoracotomic esophagectomy followed by cervical and abdominal procedures has been conventionally performed as the best curable operative procedure for treating invasive thoracic esophageal carcinoma. Despite improvements in the survival rate, the procedure is associated with significant operative morbidity and mortality rates due to the extreme invasiveness of an extensive dissection of the lymph nodes. Minimally invasive esophagectomy (MIE) was developed to reduce surgical invasiveness. Recently, the use of thoracoscopic esophagectomy performed in the prone position has stimulated new interest in minimally invasive approaches. However, the advantages and disadvantages of this technique are not well known. In this review, the literature to date, including series and comparative studies of minimally invasive esophagectomy performed in the prone position, is summarized, and the various lessons learned and controversies surrounding this technique are addressed.

Keywords: thoracoscopic esophagectomy, prone position

Introduction

Esophageal carcinoma is the eighth most common type of cancer according to a recent survey of cancer incidences worldwide, and the global incidence has increased by 50% in the last two decades. For the past two decades, esophagectomy via thoracotomy followed by cervical and abdominal procedures has conventionally been performed as the best curable operative procedure for treating invasive thoracic esophageal carcinoma. It allows for the most extensive lymphadenectomy in order to manage extremely aggressive characteristics of lymph node metastasis in the tumor. In addition to the establishment of a surgical strategy, increased detection of early-stage cancer due to the use of surveillance programs and advances in staging, patient selection, neoadjuvant therapy and intensive care methods have achieved a 5-year survival rate of 19%–47%. Despite improvements in the survival rate, the procedure is associated with significant operative morbidity and mortality rates due to the extreme invasiveness of extensive dissection of the lymph nodes. The mortality rate ranges up to 15.4%. One of the most significant concerns raising mortality is the development of respiratory complications, which occurs in up to 20%–30% of the patients who undergo the conventional thoracotomic procedure. Respiratory complications are associated with a further compromise of the pulmonary function due to postoperative pain arising from trauma to the chest and abdomen as well as an impaired function of the trachea, bronchi and lungs due to extended lymph node dissection. In order to reduce surgical invasiveness, the administration of agents against systemic inflammatory response syndrome causing acute lung injury is widely used; however, the extent of surgery should not be reduced due to a lack of evidence exactly identifying metastatic and nonmetastatic lymph node stations pre- or intraoperatively.

As the use of minimally invasive surgery reduces both pain and the systemic inflammatory response, minimally invasive...
invasive esophagectomy (MIE) was introduced in an obvious attempt to reduce the incidence of respiratory complications. In a recent study using an administrative database, the UK hospital episode statistics reported that MIE was used in 15% of cases of 7502 esophagectomy procedures performed over a 4-year period ending in April 2009.\textsuperscript{13} According to the latest Japanese report in 2009,\textsuperscript{14} the rate of thoracoscopic esophagectomy for esophageal cancer is approximately 20%. A variety of procedures has been reported, including laparoscopic transhiatal esophagectomy,\textsuperscript{15} thoracoscopic/laparoscopic two-stage (Ivor–Lewis) esophagectomy,\textsuperscript{16} and thoracoscopic/laparoscopic three-stage esophagectomy in which the surgeon may choose to perform one or both of the first two phases in a minimally invasive approach.\textsuperscript{17,18} In the 1980s, the transhiatal procedure was introduced with the definite advantage of preventing the need for thoracotomy. However, technical difficulties in mobilizing the middle third of the esophagus and dissecting around the aortic arch and pulmonary hilum do not allow surgeons to achieve sufficient nodal dissection.\textsuperscript{19} In the early 1990s, thoracoscopic mobilization of the esophagus as part of a three-stage procedure was reported.\textsuperscript{20} This procedure was originally performed in the left lateral decubitus position (LLDP). Recent nonrandomized studies have shown a lower rate of major complications than that observed in open surgery;\textsuperscript{17,18,21} however, a large systematic review concluded that the actual benefits remain obscure in terms of short- and long-term outcomes.\textsuperscript{22} On the other hand, in 1994, Cuschieri\textsuperscript{23} first reported the cases of six patients treated with thoracoscopic esophageal mobilization in the prone position (PP). Since the proposed technical and physiological advantages over LLDP are not fully understood, the technique has not become widely spread among esophageal surgeons. Palanivelu\textsuperscript{24} reported the excellent surgical results based on his experience with 130 patients treated with thoracoscopic esophagectomy in the prone position in 2006, which stimulated new interest in this approach among many esophageal surgeons.\textsuperscript{25} This review summarizes the literature to date, including both large series on MIE performed in the PP and retrospective or prospective comparisons of PP versus LLDP, and addresses the various lessons learned and controversies surrounding the use of MIE performed in the PP.

**Methods**

The literature was systematically reviewed using the key words of “esophagectomy,” “thoracoscopic” and “prone” in electronic searches of Medline (PubMed interface), the OVID SP version of Medline and the Google Scholar database. Using the “AND” operator between January 1994 and July 2013, the corresponding titles and abstracts of 301 papers were identified in a search using the key words “esophagectomy” and “thoracoscopy,” and 32 full papers were obtained with the addition of “prone.” The search was expanded using the related articles function of the PubMed interface and references to the identified studies. The retrieved articles were critically reviewed and summarized. With respect to a head-to-head comparison, we identified six nonrandomized clinical studies comparing thoracoscopic surgery in the prone position (PP) to that performed in the LLDP. However, no randomized control trials, meta-analyses or large studies using the propensity scoring were found.

**Respiratory and Circulatory Physiology in the Prone Position**

The benefits of prone positioning were originally reported in association with an improved pulmonary function as the distribution of pulmonary perfusion becomes more uniform in the prone position.\textsuperscript{26} The following mechanisms underlying the respiratory effects observed in the prone position have been suggested: improved redistribution of ventilation in the dorsal lung areas, an increased tidal volume in relation to modulated chest wall movement,\textsuperscript{27} alveolar recruitment,\textsuperscript{28} alterations in compressive forces exerted by the heart on the lungs\textsuperscript{29} and improved clearance of secretions.\textsuperscript{30} In contrast to that observed in the lateral decubitus position, in the prone position, the mediastinal structures lie naturally and the chest and abdomen are free of compression.\textsuperscript{31} The ventilated lung is also under pressure in the lateral position from the mediastinum, which may predispose the patient to atelectasis.\textsuperscript{32} There are few clinical trials investigating the physiological effects of prone positioning during esophagectomy. Atsuta, et al.\textsuperscript{33} reported the results of a prospective nonrandomized study comparing arterial oxygenation between LLDP and PP surgery performed under one-lung ventilation. In that study, the maximum perioperative $\text{PaCO}_2$ levels and the $\text{PaO}_2/\text{FiO}_2$ ratios were higher in the prone group. A comparative study between thoracoscopic surgery performed in the PP and open surgery performed in the LLDP showed better pulmonary oxygenation and reduced pulmonary shunting than that observed in other studies.\textsuperscript{32} The effects were shown to be independent of...
the ventilation modes of volume-controlled (VCV) or pressure-controlled ventilation (PCV) during one-lung ventilation (OLV). Zou, et al. compared the intraoperative ventilation/perfusion in the prone position. The study showed that the cardiac index and mean arterial pressure were well maintained with acceptable ranges of the PaO2 and PaCO2 levels, while an increase in central venous pressure and mean pulmonary artery pressure and a decrease in static lung compliance were observed. The increase in peak airway pressure and plateau airway pressure was associated with the decrease in static lung compliance: however, the authors attributed the relatively stable PO2/PaCO2 to an increase in the functional residual capacity and superior ventilation/perfusion in the prone position.

Using the PP to improve the operative view, some surgeons have been able to operate without the use of one-lung ventilation via a double-lumen endotracheal tube. The absence of one-lung ventilation reduces arteriovenous shunting with superior preserved oxygenation. Therefore, the use of two-lung ventilation, or at least partial lung deflation, in the PP may reduce the incidence of collapsed lung and the need for reinflation of the lungs which are well known to produce inflammatory mediators, possibly resulting in a reduction in the frequency of pulmonary-related complications, although this hypothesis remains unproven clinically. The adverse effects of prone positioning under one-lung ventilation have been reported. Zou, et al. compared the intraoperative hemodynamic status in 21 patients treated with thoracoscopic esophagectomy under one-lung ventilation in the PP to that observed in 23 patients treated in the LLDP. In the group treated in the LLDP, the cardiac output (CO), cardiac index (CI) and stroke volume index (SVI) did not exhibit significantly differ after altering the patients’ positions from the LLDP to the supine position. However, the patients who underwent thoracoscopic esophagectomy in the PP had lower CO, CI and SVI values than those treated in the LLDP during the thoracoscopic stage. Nevertheless, no significant influence on the occurrence of postoperative complications was observed.

Surgical Technique

There are no differences in the surgical indications between the procedures performed in the prone position versus other positions. Generally, the patient is placed in the prone position with the right arm abducted and the forearm flexed, which allows for both rotation of the scapula and expansion of the intercostal space in addition to exposure of the right axillar fossa. The head should be well supported to prevent tube displacement, and the face is placed toward the right to facilitate the suction of the sputum with a bronchial scope and prevent increasing the ophthalmic pressure. All surgeons and assistants stand to the right of the patient in the prone position, with a video monitor on the opposite side. There is a wide variety of insertion sites for surgical ports. The use of reduced port surgery with a three-port technique is enabled in the PP involving a 10-mm scope placed in the seventh intercostal space in the posterior axillary line (video camera), a 5-mm port placed in the fifth intercostal space in the posterior axillary line (grasping forceps) and a 5-mm port placed in the ninth intercostal space in the posterior axillary line (operator’s use). The creation of a carbon dioxide pneumothorax with a pressure of 6 to 14 mmHg expands the mediastinum and deflates the lung partially or fully, providing good exposure of the operative fields. Performing pneumothorax depresses the diaphragm caudally and the right lung anteriorly and promotes the extraction of mist produced after coagulation. The general surgical procedures performed in the PP following port insertion are generally similar to those of traditional three-stage surgery performed in the LLDP.

Potential Advantages of the Prone Position Procedure

In comparison to the lateral position, many advantages of the prone position technique are expected. Enhanced visualization and improved surgeon’s ergonomics for surgeons may provide higher quality mobilization and lymphadenectomy and appear to contribute to enhancing the learning curve. First, similar to traditional laparoscopy, the surgeon can operate according to the parallel view of the camera. Second, the lungs are spontaneously dislocated from the operative field due to the effects of both gravity and pneumothorax, even without the use of one-lung ventilation. Third, exudate accumulates in the anterior chest apart from the operative field in the prone position. When traditional laparoscopic instruments are used, performing dissection is more ergonomic because both arms and hands of the surgeon are stable due to the port’s entrance site being located at the surgeon’s elbow level. In the lateral position, the tension on the esophagus must be maintained against natural gravity in order to facilitate exposure for mobilization. The prone position provides better visualization in the subaortic arch and subcarinal...
and suprarenal regions. The ease with which the PP allows for good dissection around the left recurrent laryngeal nerve lymph nodes may also explain the technique’s popularity among surgeons, given the proposed oncological significance of these lymph nodes. Higher quality lymphadenectomy may also improve survival outcomes, especially in the early stage of lymphatic spread. The improved view and surgeon’s ergonomics may also reduce the incidence of complications, such as recurrent laryngeal nerve palsy or tracheobronchial injury, which is known to be more common during minimally invasive surgery than in open esophagectomy. Due to the enhanced operative view, the use of thoracoscopic surgery with reduced ports is enabled in the PP. The reduction in ports may contribute to decreasing postoperative pain and the chance of intercostal vessel and nerve injury.

Possible Disadvantages of the Prone Position Procedure

First, both the setting of the patient and the operative view in the prone position are unfamiliar to most surgeons. Establishing the prone positioning is burdensome and takes a significant amount of time. The prone thoracoscopic views used during surgery are unfamiliar to traditional esophageal surgeons. Therefore, the operative time can be prolonged; however, this issue is controversial because the change in view is compensated for by the advantageous factors of the PP procedure. The procedure is not established for use in emergencies requiring a thoracotomic procedure such as massive bleeding. Posterior thoracotomy is available; however, the ability to perform emergent thoracotomy is limited in the lower intercostal space, where the management of complications may be difficult if such complications occur in the upper mediastinum. Therefore, some authors have suggested that the prone position procedure should not be employed in patients with bulky tumors treated with preoperative chemoradiation or large tumors adjacent to the aorta or tracheobronchus. When one-lung ventilation is used, problems associated with endotracheal tube displacement are also difficult to overcome in the prone position.

Surgical Outcomes of the Prone Procedure

Recently, a prospective randomized clinical trial comparing minimally invasive surgery to open esophagectomy was published by Biere, et al. Patients with resectable esophageal or esophagogastric junctional cancer were randomly assigned to receive either open transhiatal surgery in the LLDP using one-lung ventilation or minimally invasive transhiatal esophagectomy in the PP under partial collapse of the right lung using an 8-mm Hg pneumothorax. In a comparison of the 56 patients in the open esophagectomy group and the 59 patients in the minimally invasive esophagectomy group, 16 (29%) and 19 (34%) patients in the open group developed pulmonary infections in the first two weeks and during the entire stay in the hospital, compared with five (9%) and seven (12%) patients in the minimally invasive group, respectively. This was the first report of a randomized trial to provide evidence for the short-term benefits of minimally invasive esophagectomy in patients with resectable esophageal cancer. However, there were many complications in this study, possibly associated with the surgical outcomes, for example, open vs. minimally invasive surgery, LLDP vs. PP, one- vs. two-lung ventilation, without vs. with pneumothorax. The surgical outcomes of six head-to-head comparative studies are summarized in Tables 1 and 2. We found the prone position to be associated with significantly longer thoracoscopy times and a similar finding was observed by other researchers. This longer time is unlikely due to the increased difficulty of and unfamiliarity with positioning patients in the prone position. On the contrary, Fabian, et al. and Feng, et al. showed that the thoracoscopic procedure is performed significantly more quickly in the prone position. Since the number of procedures performed per institution is relatively small, data directly comparing PP to the LDP technique are particularly sparse. Therefore, the surgical results obtained using PP are not remarkable. A series of 130 patients reported by Palanivelu, et al., a highly experienced surgeon in India, is striking (Table 3). In this series, the rate of the respiratory morbidities was extremely low at 2.3%, the rate of major morbidities was 21%, and the length of the postoperative hospital stay was 8 days. A summary of a large series of nonrandomized studies of minimally invasive esophagectomy performed in the prone position reported a slightly lower pulmonary complication rate than that observed when the technique was performed in the lateral decubitus position. Lin, et al. did not confirm the superiority of the semi-prone position during thoracoscopic esophagectomy over the LLDP in terms of major surgical outcomes or oncological clearance in their analysis of 150 (60 in the PP vs. 90 in the LLDP) patients. However, the setting of the patients in the semi-prone group (leaned forward 45°) should not be classified into the category of the prone position. The effects of an
enhanced surgical view and improved surgeon’s ergonomics in the prone position on postoperative palsy of the recurrent laryngeal nerve are controversial based on the findings of Tables 2 and 3. One reason for this is that the definition of postoperative laryngopharyngeal dysfunction (vocal cord palsy, hoarseness and aspiration) used to judge recurrent laryngeal nerve palsy is unclear. Jarral, et al.51 addressed the controversy of the prone versus left lateral decubitus position during the thorascoscopic phase of three-stage minimally invasive esophagectomy in a review of 31 papers, seven of which represented the best evidence available. The authors’ conclusions were that the studies were small in size, had significant limitations, and did not uniformly demonstrate superiority in outcomes for either technique.51

The oncological significance of the PP procedure is obscure due to the short follow-up periods used in previous studies. Dapri, et al.38 reported that in a median follow-up period of 19.1 months (range, 1.5–34 months), seven (47%) of 15 patients with the final pTNM stage 0 – III who had undergone the prone procedure died after a median period of 15 months (range, 1.5–23 months). Liebman, et al.52 found that 15 (60%) of 25 patients treated with the prone technique have developed recurrence of their cancer after surgery. The site of first recurrence was distant in 11 patients, locoregional in two patients and 2 distant and locoregional in two patients. The overall median survival was 32 months (range, 1–46 months). Martin, et al.53 reported that, in the Kaplan–Meir survival curve, the number of surgical procedures in 130 patients, the 3-year survival rates of the stage I, IIa, IIb and III patients were 75%, 50%, 45% and 18%, respectively. According to Smithers, et al.17 and Zingg,

### Table 1  Head-to-head comparisons between three-stage thoracoscopic esophagectomy in the PP versus LLDP

<table>
<thead>
<tr>
<th>Author</th>
<th>No. of cases</th>
<th>Conversion rate (%)</th>
<th>Total operation time (min)</th>
<th>Thorascoscopic time (min)</th>
<th>Blood loss (ml)</th>
<th>No. of nodes (total)</th>
<th>No. of nodes (mediastinal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fabian, et al.48</td>
<td>21 vs. 11</td>
<td>0 vs. 0</td>
<td>345 vs. 375 (p = 0.37)</td>
<td>86 vs. 123 (p = 0.001)</td>
<td>65 vs. 85 (p = 0.14)</td>
<td>15.5 vs. 14.6 NA</td>
<td>NA</td>
</tr>
<tr>
<td>Kuwabara, et al.62</td>
<td>22 vs. 58</td>
<td>5 vs. 2</td>
<td>NA</td>
<td>196 vs. 205 (p = NS)</td>
<td>50 vs. 101 (p = NA)</td>
<td>NA</td>
<td>20.5 vs. 18 (p = NS)</td>
</tr>
<tr>
<td>Noshiro, et al.40</td>
<td>43 vs. 34</td>
<td>0 vs. 5.9</td>
<td>572 vs. 562 (p = 0.192)</td>
<td>307 vs. 272 (p = 0.021)</td>
<td>142 vs. 295 (p = 0.045)</td>
<td>49.6 vs. 51.2 NA</td>
<td>27.0 vs. 26.8</td>
</tr>
<tr>
<td>Song, et al.46</td>
<td>7 vs. 15</td>
<td>NA</td>
<td>NA</td>
<td>154 vs. 191 (p = 0.062)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Feng, et al.49</td>
<td>52 vs. 41</td>
<td>0 vs. 2.4</td>
<td>202 vs. 217 (p = 0.016)</td>
<td>67 vs. 77 (p = 0.013)</td>
<td>123 vs. 142 (p = 0.012)</td>
<td>NA</td>
<td>11.6 vs. 8.9</td>
</tr>
<tr>
<td>Yatabe, et al.47</td>
<td>24 vs. 24</td>
<td>NA</td>
<td>NA</td>
<td>247 vs. 151 (p &lt;0.001)</td>
<td>209 vs. 474 (p = 0.002)</td>
<td>44 vs. 43 (p = 0.88)</td>
<td>NA</td>
</tr>
</tbody>
</table>

PP: prone position; LLDP: left lateral decubitus position; NA: not available; NS: not significant

### Table 2  Short-term surgical results of three-stage thoracoscopic esophagectomy in the PP versus LLDP

<table>
<thead>
<tr>
<th>Author</th>
<th>Mortality (%)</th>
<th>Overall morbidity (%)</th>
<th>Respiratory morbidity (%)</th>
<th>Recurrent nerve palsy (%)</th>
<th>Anastomotic leak (%)</th>
<th>Postop stay (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fabian, et al.48</td>
<td>5 vs. 0</td>
<td>48 vs. 55 (p = 1.0)</td>
<td>8 vs. 9 (p = NA)</td>
<td>0 vs. 9 (p = NA)</td>
<td>4 vs. 18 (p = NA)</td>
<td>10 vs. 9</td>
</tr>
<tr>
<td>Kuwabara, et al.62</td>
<td>0 vs. 3</td>
<td>27 vs. 44 (p = NS)</td>
<td>5 vs. 29 (p = NS)</td>
<td>22 vs. 34 (p = NS)</td>
<td>14 vs. 26 (p = NA)</td>
<td>16.5 vs. 22</td>
</tr>
<tr>
<td>Noshiro, et al.40</td>
<td>2.4 vs. 0</td>
<td>34.9 vs. 35.3 (p =0.999)</td>
<td>11.6 vs. 14.7 (p = 0.742)</td>
<td>14 vs. 18 (p = 0.756)</td>
<td>7 vs. 0 (p = 0.251)</td>
<td>NA</td>
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<tr>
<td>Song, et al.46</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Feng, et al.49</td>
<td>0 vs. 0</td>
<td>44.2 vs. 48.8 (p = NS)</td>
<td>9.6 vs. 9.76 (p = 0.662)</td>
<td>6 vs. 2 (p = 0.628)</td>
<td>7.7 vs. 22.0 (p = 0.049)</td>
<td>11.4 vs. 17.4</td>
</tr>
<tr>
<td>Yatabe, et al.47</td>
<td>4 vs. 0</td>
<td>25 vs. 58 (p = 0.24)</td>
<td>4 vs. 38 (p = 0.02)</td>
<td>NA</td>
<td>13 vs. 17 (p = 0.68)</td>
<td>23 vs. 35</td>
</tr>
</tbody>
</table>

PP: prone position; LLDP: left lateral decubitus position; NA: not available; NS: not significant

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<table>
<thead>
<tr>
<th>Author</th>
<th>Method</th>
<th>No. of cases</th>
<th>Conversion rate (%)</th>
<th>Thoracoscopy time (min)</th>
<th>Blood loss (ml)</th>
<th>No. of nodes (mediastinal)</th>
<th>Mortality (%)</th>
<th>Overall morbidity (%)</th>
<th>Respiratory morbidity (%)</th>
<th>Recurrence nerve palsy (%)</th>
<th>Anastomotic leak (%)</th>
<th>Postop stay (days)</th>
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<tr>
<td>Dapri, et al.(^{28})</td>
<td>Thoracoscopy and laparoscopic approach</td>
<td>15</td>
<td>6.7</td>
<td>75</td>
<td>700</td>
<td>4</td>
<td>0</td>
<td>40</td>
<td>13.3</td>
<td>20.0</td>
<td>26.7</td>
<td>14</td>
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<tr>
<td>Liebman, et al.(^{63})</td>
<td>Total thoracoscopic/ laparoscopic approach</td>
<td>25</td>
<td>0</td>
<td>90</td>
<td>300</td>
<td>9</td>
<td>0</td>
<td>64</td>
<td>28</td>
<td>0</td>
<td>8</td>
<td>11</td>
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<tr>
<td>Martin, et al.(^{53})</td>
<td>Thoracoscopy and laparotomy/laparoscopy</td>
<td>36</td>
<td>5.5</td>
<td>240</td>
<td>200</td>
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<td>5.5</td>
<td>41</td>
<td>NA</td>
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<td>16</td>
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<td>Total thoracoscopic/ laparoscopic approach</td>
<td>130</td>
<td>0</td>
<td>220</td>
<td>180</td>
<td>NA</td>
<td>1.54</td>
<td>20.76</td>
<td>2.31</td>
<td>1.54</td>
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<td>23</td>
<td>8</td>
<td>90</td>
<td>300</td>
<td>3</td>
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<td>61</td>
<td>30</td>
<td>0</td>
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<td>Thoracoscopy and laparotomy</td>
<td>309</td>
<td>3</td>
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<td>400</td>
<td>4</td>
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<td>Zingg, et al.(^{61})</td>
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<td>56</td>
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<td>250.2</td>
<td>320</td>
<td>NA</td>
<td>3.6</td>
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<td>NA</td>
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<td>Total thoracoscopic/ laparoscopic approach</td>
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<td>4.9</td>
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<td>NA</td>
<td>2.4</td>
<td>NA</td>
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<td>17.1</td>
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<td>11</td>
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<td>NA</td>
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<td>140</td>
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<td>15.2</td>
<td>2.2</td>
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<td>15</td>
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<td>Thoracoscopy and laparoscopic/laparotomy</td>
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<td>6.9</td>
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<td>527</td>
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<td>Biere, et al.(^{45})</td>
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<td>200</td>
<td>NA</td>
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<td>NA</td>
<td>12</td>
<td>2</td>
<td>12</td>
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<td>Ozawa, et al.(^{68})</td>
<td>Thoracoscopy and laparoscopic/laparotomy</td>
<td>30</td>
<td>0</td>
<td>260</td>
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<td>13</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Goldberg, et al.(^{69})</td>
<td>Thoracoscopy and laparoscopic/laparotomy</td>
<td>42</td>
<td>NA</td>
<td>108</td>
<td>180</td>
<td>NA</td>
<td>4.8</td>
<td>71</td>
<td>NA</td>
<td>NA</td>
<td>9.5</td>
<td>8</td>
</tr>
</tbody>
</table>

PP: prone position; NA: not available
et al.,\textsuperscript{54} there are no differences in survival between patients treated with total minimally invasive esophagectomy in the PP and those treated with open esophagectomy when examined stage for stage, in which there are enough events to obtain a median survival. Regarding the LLDP approach, a more recent meta-analysis\textsuperscript{16} case-controlled studies conducted by Dantoc, et al.,\textsuperscript{55} the largest MIE series of 315 patients conducted by Ichikawa, et al.\textsuperscript{56} and the findings of the 5-year rates of symptomatic first recurrence after MIE reported by Thomson, et al.\textsuperscript{57} demonstrated comparable survival benefits and adequate locoregional control in MIE. Given the lack of evidence for the oncological quality of the PP procedure, surgeons should make an effort to establish the safety and feasibility of the procedure in patients with esophageal cancer.

### Robotically-Assisted Esophageal Surgery in the Prone Position

Robotic surgery has recently been developed to overcome some of the conventional limitations of open and scope-based surgery. The da Vinci surgical system (Intuitive Surgical Inc., Sunnyvale, California, USA) includes articulated movement of the robotic instruments, tremor filtering, scale motion and 3-dimensional imaging.\textsuperscript{58} The meticulous and precise movements of the robotic instruments is expected to provide many advantages during digestive tract surgery. Robotically-assisted esophagectomy (RAE) was first reported in 2004 by Kernstine and colleagues.\textsuperscript{59} RAE may reduce the incidence of postoperative pain in the intercostal space due to the articulation of instruments inside the thorax through the chest wall. The da Vinci robotic system is very beneficial during the thoracoscopic phase of esophageal resection and lymph node dissection, allowing for very precise dissection along the vital mediastinal structures.\textsuperscript{60}

There are four articles related to three-stage RAE performed in the prone or semi-prone position (Table 4).\textsuperscript{35,60–62} In all four reports, no patients required conversion to either thoracoscopy or thoracotomy, and the rates of respiratory complications were quite low. In a study of the largest number of patients, Puntambekar, et al.\textsuperscript{61} reported a single institution experience of 32 RAE procedures in which mobilization of the esophagus was performed with the patient in the prone position. In that report, the mean total operative time was 210 minutes, the mean thoracoscopic time was 100 minutes, the average amount of blood loss was 80 mL and the mean number of retrieved mediastinal lymph nodes was 20. Two of 32 patients had

<table>
<thead>
<tr>
<th>Author</th>
<th>Method</th>
<th>No. of cases</th>
<th>Conversion rate (%)</th>
<th>Thoracoscopy time (min)</th>
<th>Blood loss (ml)</th>
<th>No. of nodes (mediastinal)</th>
<th>Mortality (%)</th>
<th>Morbidity (%)</th>
<th>Anastomotic leak (%)</th>
<th>Postop stay (days)</th>
<th>Recurrent nerve palsy (%)</th>
<th>Anastomotic leak (%)</th>
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<tbody>
<tr>
<td>Kim, et al.\textsuperscript{35}</td>
<td>Robot-thoracoscopic and robot/ laparoscopic approach</td>
<td>21</td>
<td>0</td>
<td>150</td>
<td>NA</td>
<td>11.6</td>
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<td>16.6</td>
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<td>28.6</td>
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<td>19.0</td>
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<td>Puntambekar, et al.\textsuperscript{60}</td>
<td>Robot-thoracoscopic/ laparoscopic approach</td>
<td>32</td>
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<td>100</td>
<td>80</td>
<td>20</td>
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<td>NA</td>
<td>0</td>
<td>6.2</td>
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<td>9</td>
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<tr>
<td>Suda, et al.\textsuperscript{60}</td>
<td>Robot-thoracoscopic/ laparoscopic approach</td>
<td>16</td>
<td>0</td>
<td>335.5</td>
<td>144.5</td>
<td>18.5</td>
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<td>38</td>
<td>6</td>
<td>38</td>
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<tr>
<td>Ishikawa, et al.\textsuperscript{62}</td>
<td>Robot-thoracoscopic/ laparoscopic approach</td>
<td>4</td>
<td>0</td>
<td>450</td>
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<td>NA</td>
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<td>0</td>
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<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

PP: prone position; NA: not available
pulmonary complications. The median hospital stay was 9 days. The authors considered that the operative stress to the surgeon is much less with the robotic procedure and concluded that magnification, the use of a 3-dimensional view, and the seven degrees of freedom resulted in decreased blood loss and better dissection.\(^{61}\) Kim, et al.\(^{35}\) reported 21 patients who underwent a three-stage robotic chest procedure in the prone position performed by a single surgeon with low surgical volume and no prior experience with conventional thoracoscopic esophagectomy. One of the most prominent results in that report was the particularly short learning curve regarding the robot console time. Moreover, the latest patient group exhibited significantly less blood loss, more frequent extubation in the operating room and a larger number of retrieved mediastinal nodes. Hence, the report of Kim, et al.\(^{35}\) implies that shortening of the learning curve may be accelerated by the use of a robot.

Recent review articles of robotic-assisted MIE have concluded that the data regarding robotic-assisted MIE indicate safety, feasibility and equivalent outcomes compared to open surgery or MIE. However, there are no data to suggest improved outcomes with robotic-assisted MIE in terms of operative morbidity, pain, length of stay, operative time or total costs.\(^{63}\)

**Conclusion**

Whether the prone technique is the best approach remains unclear, although the procedure is thought to have a number of theoretical physiological and ergonomic advantages for the patient and surgeon. For further advances in the adoption of this technique to occur, additional careful research is required to confirm any true benefits in patient outcomes or surgeon’s ergonomics.

**Disclosure Statement**

Drs. Hirokazu Noshiro and Shuusuke Miyake have no conflicts of interest or financial ties to disclose.

**References**

18) Luketich JD, Alvelo-Rivera M, Buenaventura PO, et al. Minimally invasive esophagectomy: outcomes in


