Introduction

Esophageal cancer is a disease in increasing prevalence worldwide, whose main axis of curative treatment is surgical resection with radical lymphadenectomy (1). Although this is considered a complex intervention, therapeutic advances, refinement of surgical procedures, standardization of minimally invasive approach and the centralization in specialized centers have contributed to reduce the morbidity and mortality of this procedure.

However, pulmonary complications after esophageal resection are the major cause of postoperative morbidity and mortality. Almost half of the patients undergoing open esophagectomy (OE) will develop postoperative severe respiratory complications, that increase the need for intensive care unit, global hospital stay and overall mortality. In addition, these complications condition a severe concerning in the health-related quality of patient life (2,3).

Firts minimally invasive esophagectomy (MIE) was introduced by Cuschieri et al. (4) in 1992 with a series of five patients. They described the video-assisted thoracoscopic mobilization combined with a laparotomy. Subsequently, several studies worldwide reported different hybrid techniques combining minimally invasive surgery with open surgery (laporoscopy/thoracotomy, laparotomy/thoracostomy) for esophageal resection, in benign or malignant conditions, demonstrating its feasibility and good outcomes (5,6).

Over the years, several systematic reviews suggesting the benefits of MIE have been published. But these systematic reviews are based mostly on observational studies, so these conclusions should be taken with prudence (7-13) (Table 1).
Table 1 Systematic reviews and meta-analysis in MIE

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Type of study</th>
<th>n</th>
<th>Endpoint</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Van Workum (7)</td>
<td>2017</td>
<td>SR and meta-analysis</td>
<td>1,681</td>
<td>Comparation MIE and HIE Ivor-Lewis vs. McKeown</td>
<td>Ivor_lewis is associated with less recurrent laryngeal nerve trauma, hospital length stay and blood loss</td>
</tr>
<tr>
<td>Zhou (8)</td>
<td>2015</td>
<td>SR and meta-analysis</td>
<td>5,537</td>
<td>To explore superiority of MIE reducing AL</td>
<td>Moore proofs are needed to clarify the strengths or weaknesses of MIE in preventing AL</td>
</tr>
<tr>
<td>Zhou (9)</td>
<td>2015</td>
<td>Meta-analysis</td>
<td>14,311</td>
<td>To explore effect of MIE vs. OE on the occurrence of in-hospital mortality</td>
<td>MIE is superiority over OE in-hospital mortality</td>
</tr>
<tr>
<td>Koyanagi (10)</td>
<td>2016</td>
<td>SR</td>
<td></td>
<td>To assess its benefits of MIE in prone position</td>
<td>Studies have not verified this</td>
</tr>
<tr>
<td>Markar (11)</td>
<td>2013</td>
<td>SR and meta-analysis</td>
<td></td>
<td>To examine the main technical parameters that impact on anastomotic integrity</td>
<td>No significant difference in the incidence of anastomotic leakage was demonstrated for technical factors</td>
</tr>
<tr>
<td>Hanna (12)</td>
<td>2012</td>
<td>SR</td>
<td>50</td>
<td>To assess the use of MIE for cancer</td>
<td>There is need to reach a consensus regarding surgical approaches in MIE</td>
</tr>
<tr>
<td>Biere (13)</td>
<td>2009</td>
<td>SR and meta-analysis</td>
<td>1,081</td>
<td>To evaluate the effects of MIE vs. OE on outcome</td>
<td>A faster postoperative recovery and reduction in morbidity can be achieved with MIE</td>
</tr>
</tbody>
</table>

MIE, minimally invasive esophagectomy; AL, anastomotic leakage; OE, open esophagectomy.

Nowadays, around ten RCT have been published analyzing surgical outcomes, morbidity (mostly respiratory complications) mortality and quality of life comparing the different approaches (open, hybrid, minimally invasive, Robot). Topics such as aspects of surgical technique (patient position, anastomosis, pre-conditioning of gastric conduit), oncology therapeutics and antithrombolic prophylaxis, as well as nutritional issues were also discussed (Table 2).

The common characteristic of these RCTs is the low number of patients included, which limits the reliability of the conclusions. Surgery is an area where RCTs are complex to perform. The usual difficulties of the design of this type of study are added those of the surgical patients. For this reason, a group of authors (ROMIO study group) designed a study to establish efficient methods to perform a main trial of MIE versus OE, defining a list of feasibility objectives (20).

The aim of this article is to assess the current scientific evidence of the different points of interest concerning to MIE, such as surgical techniques, approach, patient position, morbidity, mortality and oncological outcomes available in the medical literature, in order to clarify concepts.

**Open vs. introduction of minimal invasive surgery**

**Pathological examination and oncological outcomes**

Two considerations must be taken into account in oncological surgery when a new surgical procedure is evaluated; pathological analysis of the specimen must be comparable between the different surgical techniques, as well as the biological evolution of the tumor (oncological outcomes).

Of the 7 randomized, controlled trials, published, only 2 reported the histopathologic findings of examinations of the resected specimens. Mariette et al. found no significant differences between hybrid minimally invasive esophagectomy (HMIE) and OE according to the pathological characteristics of the tumor, its relationship with the resection margins or with the total number of lymph nodes harvested or their involvement. Also, TIME-trial demonstrated similar results in relation to R0 resection (MIE 54 vs. OE 47; P=0.106) and the total number of lymph nodes retrieved in both approaches (MIE 20 vs. OE 21; P=0.469) (21).

Long-term 3-year follow-up from TIME-trial, showed similar rates for overall and disease-free survival in patients who underwent MIE or OE (37.3%; 95% CI, 23.5–49% vs. 42.9%; 95% CI, 28.6–55.4%), even when the analysis was stratified for age, gender and disease-stage. The overall survival and the disease-free survival at 5 years between HIE and OE did not differ significantly in Mariette’s RCT (22) although it should be noted that tumor recurrence and overall survival were not part of primary end points.
<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
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<th>Follow-up</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maas (14)</td>
<td>2015</td>
<td>MIE/OE</td>
<td>144/115</td>
<td>Primary: postop pulmonary infection 1 year</td>
<td></td>
<td>MIE is associated with better quality of life compared to OE</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Secondary: other postoperative complications, quality of life</td>
<td></td>
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<tr>
<td>Mariette (11)</td>
<td>2019</td>
<td>OE/HIE</td>
<td>104/103</td>
<td>Primary: major complications during 3-year surgery or within 30 days after</td>
<td>3-year</td>
<td>HIE is associated with a 77% lower risk of major intraoperative and</td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td>surgery</td>
<td></td>
<td>postoperative complications than OE</td>
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<td></td>
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<td>Secondary: postoperative death within 30 days, intraoperative and</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>postoperative overall complications</td>
<td></td>
<td></td>
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<tr>
<td>Biere (15)</td>
<td>2017</td>
<td>MIE/OE</td>
<td>55/52</td>
<td>Post-operative respiratory infections (not exactly specified)</td>
<td></td>
<td>BMI ≥26 and open approach are independent predictive factors for post-operative respiratory infections</td>
</tr>
<tr>
<td>Straatman (16)</td>
<td>2017</td>
<td>MIE/OE</td>
<td>59/56</td>
<td>Primary: 3-year disease-survival</td>
<td>3-year</td>
<td>Equally outcomes regarding survival and disease-free survival</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Secondary: operative and post-operative data, overall survival</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tao (17)</td>
<td>2019</td>
<td>JF/NF</td>
<td>58/62</td>
<td>Perioperative complications, major nutritional status, survival rates,</td>
<td>Mean: 19 months</td>
<td>JF more economical, safer, long-lasting, better QOL and nutritional rates</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>length of hospital stay</td>
<td></td>
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<tr>
<td>Berkelmans</td>
<td>2019</td>
<td>OF/JF</td>
<td>65/67</td>
<td>Primary outcome: time to functional recovery</td>
<td></td>
<td>OF does not affect functional recovery and does not increase complications</td>
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<tr>
<td>(NUTRIENT II)</td>
<td></td>
<td></td>
<td></td>
<td>Secondary outcomes: anastomotic leakage, pneumonia rate and other</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>surgical complications</td>
<td></td>
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<tr>
<td>Sun (19)</td>
<td>2018</td>
<td>EOF/LOF</td>
<td>140/140</td>
<td>Primary outcomes: postoperative complications</td>
<td>24 weeks after surgery</td>
<td>EOF group had a quicker recovery of bowel function and improved short-term QOL</td>
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<td></td>
<td></td>
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<td>Secondary outcomes: bowel function recovery, QOL</td>
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</tbody>
</table>

MIE, minimally invasive esophagectomy; OE, open esophagectomy; HE, hybrid minimally invasive esophagectomy; QOL, quality of life; JF, jejunostomy feeding; NF, nasogastric feeding; OF, oral feeding; EOF, early oral feeding; LOF, later oral feeding.

**Overall complication**

Recently, Mariette group published a multicenter and randomized controlled trial (RCT) that compared patients with resectable cancer of middle or lower third esophagus submitted to transthoracic OE or HMIE. Hybrid esophagectomy consisted of a laparoscopic gastric mobilization and open right thoracotomy. The primary endpoint was major complication during surgery or in the 30 days later. They found that HIE was associated with a 77% lower risk of major intraoperative and postoperative complications than OE. Furthermore, HIE showed a 50% lower risk of major pulmonary complications than open surgery (22), interestingly, at the expense of laparoscopic approach in abdominal field.

**Pulmonary complications**

As in most areas of foregut cancer surgery, minimally invasive approach for esophageal cancer provides a faster postoperative recovery and fewer rate of complications, specially in the respiratory tract (15). MIE associates a lower overall morbidity and a shorter hospital stay, with an equivalent oncological result to those of OE.

Different cohort studies have proven that both HIE and MIE are associated with a significant lower incidence of
postoperative pulmonary morbidity compared to OE. The minor trauma surgical-access thoracoscopy related added with the best ventilation and oxygenation of prone position would contribute to produce a less basal lung atelectasis than consequently causing lower lung infections (14,23).

In this way, Biere et al. compared postoperative pulmonary complications after MIE and OE, verifying that the rate is higher in patients undergoing open surgery. The same working group in order to identify those predictive factors responsible for respiratory infections performed a multivariate analysis. This showed that the patients who underwent OE and who had a body mass index ≥26 had a threefold higher incidence of pneumonia (16). This data is still interesting given the underlying positive association between obesity and esophageal adenocarcinoma, whose incidence is increasing (17).

**Pain**

Moreover, up to 30–50% of patients undergoing thoracotomy may suffer post-thoracotomy pain syndrome (18,19). It is a widely described disturbance that consists in the presence of pain along the thoracotomy scar that persists 2 months after surgery. It results from the combination of neuropathic (intercostal nerve damage) and nociceptive components (myofascial damage). Postoperative pain affects the quality of life of patients, so this would be one of the reasons that would explain better results in these terms in patients undergoing MIE. With MIE myofascial damage and wounds length are circumscribed.

**Recurrent laryngeal nerve injury**

Biere et al. demonstrated that there was significantly more recurrent nerve palsy in patients undergoing OE than those operated by MIE (15% vs. 2% P=0.012), without being related to lung infections (16). The same results in relation to this complication were observed by Maas et al. (24).

Explanations for these results could be the use of the double lumen tube in OE, although some authors also use it in MIE, and that the diffusion of carbon dioxide from the thoracic cavity in the MIE to the neck would facilitate the dissection.

**Nutrition**

Early nutrition in patients undergoing esophageal resection surgery is one of the key points for faster recovery and the decrease of postoperative complications. Advantages of enteral nutrition over parenteral nutrition have been broadly described.

However, in recent years, concepts such as the access route of enteral nutrition (direct oral, nasogastric tube, jejunostomy) and the beginning of it have been the objective of study. Three RCT assessed these parameters. While Tao et al. (25) focused on determining the best method of enteral nutrition administration, between jejunostomy and nasogastric tube, Berkelmans et al. in their study introduced, in the context of the ERAS protocol, the onset of direct oral nutrition after esophageal surgery (26). Along the same lines, Sun et al. showed that patients who started oral diet early (1st day after surgery), did not present a greater number of complications compared to those who started the seventh day after surgery (25.0% vs. 27.9%; 95% CI, −13.2% to 7.4%). In addition, this group presented a faster recovery of bowel transit (median of 3 vs. 4 days, P<0.001) and a better short-term QOL (27).

**Mortality**

While it is true that esophageal resection is still considered a technique that implies high morbidity and mortality, the associated rates have decreased considerably thanks to the implementation of minimally invasive surgery, the standardization of surgical techniques and perioperative clinical care protocols (28) and their development in specialized centers.

Biere et al. demonstrated no statistically differences in relation to hospital mortality between both approaches (MIE/OE). Nor did Mariette and collaborators found differences between groups (HIE/OE) in relation to mortality 30 days after surgery. However, in this same study, at 5 years the percentage of patients who lived was higher in the hybrid group (60% vs. 40%), but the difference was not significant (16).

**Quality of life**

The term quality of life includes a wide range of concepts, meaning in the medical setting, as the perceived quality of an individual's daily life. In general terms, it is well known that minimally invasive treatments lead to promote improvements in the postoperative quality of patient life.

In 2015, Maas et al. in a multicenter randomized trial, showed that MIE is associated with a better mid-term 1 year quality of life than OE. They examined three
domains in health-related quality in patients’ life (physical activity, global health and pain) and MIE was superior in all three, especially regarding physical health and pain, compared to OE. Thus, the influence of the approach in relation to the quality of life goes beyond the first postoperative months (24). An explanation for these results could be the lower aggression produced by minimally invasive approach that would be responsible for a lower rate of post-thoracotomy syndrome.

However, a systematic review and a meta-analysis, published 2 years later by Kauppila et al. (29) that involve a total of 2,064 patients, demonstrated that those who underwent MIE showed better global outcomes in quality of life tests compared who were subjected to OE only in the first 3 months after surgery, matching after 6 months and 1 year of follow-up.

**Other technical aspects**

**Thoracoscopic approach: lateral vs. prone position**

Right thoracoscopic access for mobilization and resection of the thoracic esophagus can be done in two positions: lateral or prone.

Traditionally, MIE was carried out with the patient placed in the left lateral decubitus with double tracheal intubation and lung block. Subsequently, thoracoscopy in prone position gained popularity given its less invasion and better exposure of the operative field, achieving the partial collapse of the lung due to the effect of gravity and the insufflation of carbon dioxide at 8 mmHg or double-lumen endotracheal tube.

Hence, two retrospective studies showed that prone thoracoscopy shows less blood loss, less operative time and less post-operative respiratory infections. This approach allows a better ventilation and oxygenation of the right lung which is blocked in the lateral position, with a consequent lower rate of atelectasis (30,31).

**Robotics & esophagectomy**

Since in the 2000s, van Hillegersberg (32) and Kernstine (33) published the initial experiences of robotic-assisted surgery in esophagectomy (RAMIE) for esophageal cancer, several specialized high-volume centers have contributed their knowledge to demonstrate their safety and feasibility.

It is true that in centers with wide experience, the results that the robot provides are still motivating. Favorable RAMIE outcomes reported in terms of morbidity and mortality (34,35). However, high cost of Da Vinci robotic system and its annual maintenance makes the implementation of robotic technique difficult in most hospitals.

In the last year, a RCT have been carried out that include the robotic approach for esophageal cancer resection. van der Sluis et al. (36), in a single-center randomized trial, compared 112 patients with intrathoracic esophageal cancer who underwent RAMIE or OE. The primary endpoint was complications related to surgery. Overall, patients undergoing RAMIE had fewer postoperative complications (59%) compared those underwent OE (80%) (RR with RAMIE 0.74; 95% CI, 0.57–0.96; P=0.02), with lower percentage of cardiopulmonary complications and better recovery. In oncological terms, both techniques were comparable, with an average follow-up of 40 months. In order to establish solid conclusions, we will have to wait for the long-term results of the study designed by Yang et al., which compares RAMIE vs. MIE and which was started in 2017 (37).

**Conclusions**

Regarding to short-term results, although it seems that MIE is superior in certain aspects such as lower intraoperative risk, lower number of postoperative complications and better quality of life than the open approach, the heterogeneity of the studies and the low sample number, do not allow reach robust conclusions with a high level of evidence.

In the same way, the oncological outcomes between MIE/HIE and open surgery seem comparable, but data is still lacking in relation long-term survival rates.

**Acknowledgments**

None.

**Footnote**

*Conflicts of Interest:* The authors have no conflicts of interest to declare.

*Ethical Statement:* The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.
References


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