3 Intrathoracic Extracorporeal Lengthening (Foker technique)

Go Miyano and Atsuyuki Yamataka

General Background

Esophageal atresia affects approximately 1 in 4000 newborns. Within this group, approximately 15% will have esophageal atresia (EA) where primary esophageal anastomosis is impossible. The exact definition of long-gap EA (LGEA) is controversial with multiple options; Spitz defined it as "inability to achieve primary end-to-end anastomosis" [1], others believe only type-A EA can be classified as LGEA, some authors use 2 cm as an arbitrary cut-off length to classify a gap as being long or short, while others define short gap as 1 cm or less, intermediate gap as 1–2.5 cm, and long gap as more than 2.5 cm distance between the two atretic ends of the esophagus [2]. There is also no clear consensus on the preferred treatment for LGEA [3, 4].

While conservation of the native esophagus is generally considered to be a priority, a recent international survey on the management of esophageal atresia found that 23% of pediatric surgeons would perform esophageal replacement without any attempt at primary anastomosis for infants with gap lengths greater than 5 cm [5] despite esophageal replacement being technically challenging as well as being associated with postoperative complications and functional problems, while 47% of pediatric surgeons responded they would attempt elongation of the atretic ends.

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A. Pimpalwar (ed.), *Esophageal Preservation and Replacement in Children*,
https://doi.org/10.1007/978-3-030-77098-3_3

Elongation Techniques

Continuous Stretching

The period of maximal natural growth of the esophagus is during the first 2–3 months of life [6], and at some centers, LGEA is managed initially by allowing the esophagus to grow for 2 months while maintaining adequate nutritional support. Continuous stretching of the atretic ends of the esophageal segments conserves the native esophagus to establish continuity of the esophagus by stimulating natural growth of the esophagus and is feasible and practical. Gentle constant force exerted by a bougie both dilates and strengthens the blind ends which will facilitate their eventual anastomosis.

Technique A standard nasogastric tube, with or without a probe at the tip of the tube, is used as a bougie and introduced via the mouth into the upper (proximal) atretic esophageal segment with enough downward force to stretch the esophagus as it grows. Stretching of the lower (distal) atretic esophageal segment is achieved using the same kind of tube as a bougie introduced via the gastrostomy to exert upward force. We prefer to use a Hegar bougie, especially for stretching the distal end. The size of Hegar bougie to use is always determined by the height of the patient. We perform all bougie insertions under fluoroscopic control in the radiology department even though it is common for only the first insertion to be performed under fluoroscopic control and subsequent reinsertions to be performed on the floor. We also perform esophagography each time to confirm that the bougie is positioned accurately, that there are no injuries, and that no false passage has been created. Reported frequency/force of stretching varies; some recommend 10–15 minutes once a day, others 3–5 minutes twice a day. Our protocol is 10–20 minutes once a day with less force on the lower end and more force on the upper end.

Note: Adhesions Irrespective of the protocol for stretching, repeated stretching of the proximal esophagus can be the cause of dense adhesions between the esophagus and the trachea (Fig. 3.1-Lt).

Foker's Intrathoracic Elongation

Foker's intrathoracic elongation technique was introduced in 1990s and involves daily adjustment of continuous traction applied to the atretic esophageal ends externally to elongate them before an anastomosis is performed through a thoracotomy [7]. He hypothesized that the native esophagus will grow if stimulated by traction and elongation will be achieved primarily by traction and distraction.

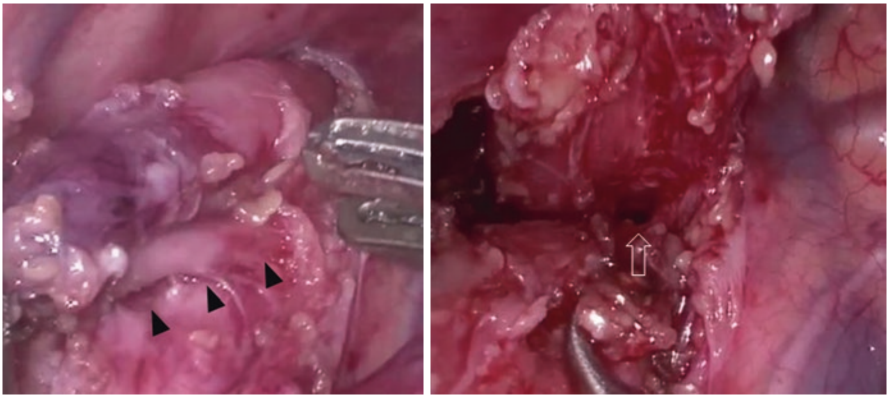

Fig. 3.1 Thoracoscopic dissection between the esophagus and trachea, in a case after repeated bougienage. Repeated stretching of the proximal esophagus can be the cause of dense adhesions between the esophagus and the trachea (arrowheads). Conventional thoracoscopic dissection caused perforation of the trachea (arrow)

Open Foker Technique

Thoracotomy is performed through the fifth intercostal space (ICS). The proximal esophagus is dissected extensively toward the neck, and the distal esophagus is dissected gently and mobilized down to the diaphragm. Pledgeted Prolene sutures are placed in both atretic ends of the esophagus and marked with clips. The suture material from each end is crossed and brought out through the chest wall above and below the thoracotomy incision where they are tied together over a small piece of nasogastric tube to exert traction. Patients must be kept sedated, intubated, and paralyzed postoperatively and managed in a neonatal intensive care unit. Traction is readjusted daily, and the progress of gap closure is monitored using X-ray radiography.

Minimally Invasive Foker Technique

Thoracoscopic elongation procedures in the neonatal period have been reported [8], and similarly, a staged thoracoscopic approach using internal traction has also been reported [9]. We perform a variation of Foker technique, intrathoracically without externalizing the suture material.

After dissecting both ends of the esophagus, pledgeted sutures are placed in both ends and the suture material tied to approximate the ends without crossing or exteriorizing the suture material (Fig. 3.2). If there is still a large gap between the two ends, we strongly recommend conversion to open thoracotomy, rather than persevering with thoracoscopy.

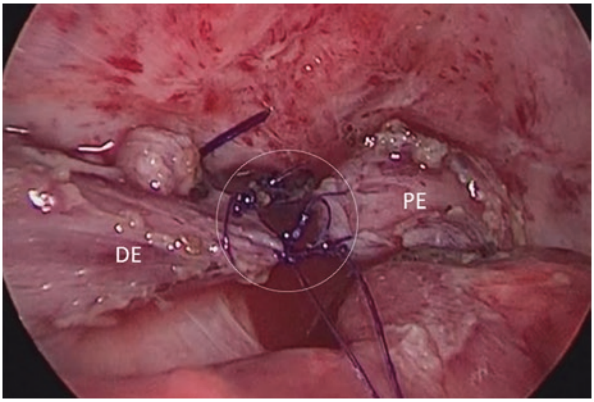

Fig. 3.2 Intrathoracic Foker technique. Sutures between the proximal and distal atretic ends of the esophagus are tied and approximated (circle) without exteriorizing the traction sutures

The depth of suturing, the type of suture material, and the appropriate duration of traction are important issues for success of the Foker technique. We use 5–0 or 6–0 monofilament suture material, taking good bites during placement, and apply traction for 5–7 days, adhering to the commonly held belief that traction longer than 10 days could induce extensive adhesion formation. A common initial problem is tearing of traction sutures through the atretic ends of esophagus causing leakage and requiring redo surgery to replace the ineffective traction sutures and continue the interrupted traction process. To prevent this, Hadidi et al. reported using silastic tube fixation at the atretic ends of the esophagus to apply external traction in four patients with LGEA and achieved primary anastomosis without any sutures tearing through the esophagus [10]. Mochizuki et al. reported their modified Foker technique in which they attached two polyvinyl chloride tubes to each atretic end of the esophagus to sandwich it without penetrating the end. A nylon suture was passed through each tube and brought out to the skin for external traction [11] (Fig. 3.3). The traction sutures for the upper atretic end were exteriorized from the thorax through the lower intercostal space, and the traction sutures for the lower atretic end were either exteriorized from the thorax or attached to the parietal pleura (Fig. 3.4).

Our Experience

Our procedure of choice for treating type-A LGEA was reconstruction of the esophagus using esophagoesophagostomy with or without thoracoscopy after a transitional period of elongation achieved using one of the techniques mentioned earlier. Overlapping of the two ends is difficult to achieve; from experience, primary anastomosis becomes possible once the gap between the atretic ends is less than 2 vertebrae in length or less than 10 mm. When the two ends of the esophagus appear to be amenable to primary anastomosis, patients are taken to the operating room for thoracotomy/thoracoscopy and esophagoesophagostomy.

Minimally Invasive Esophagoesophagostomy The first thoracoscopic repair of EA was performed by Rothenberg and Lobe in 1999 [12], and thoracoscopy has

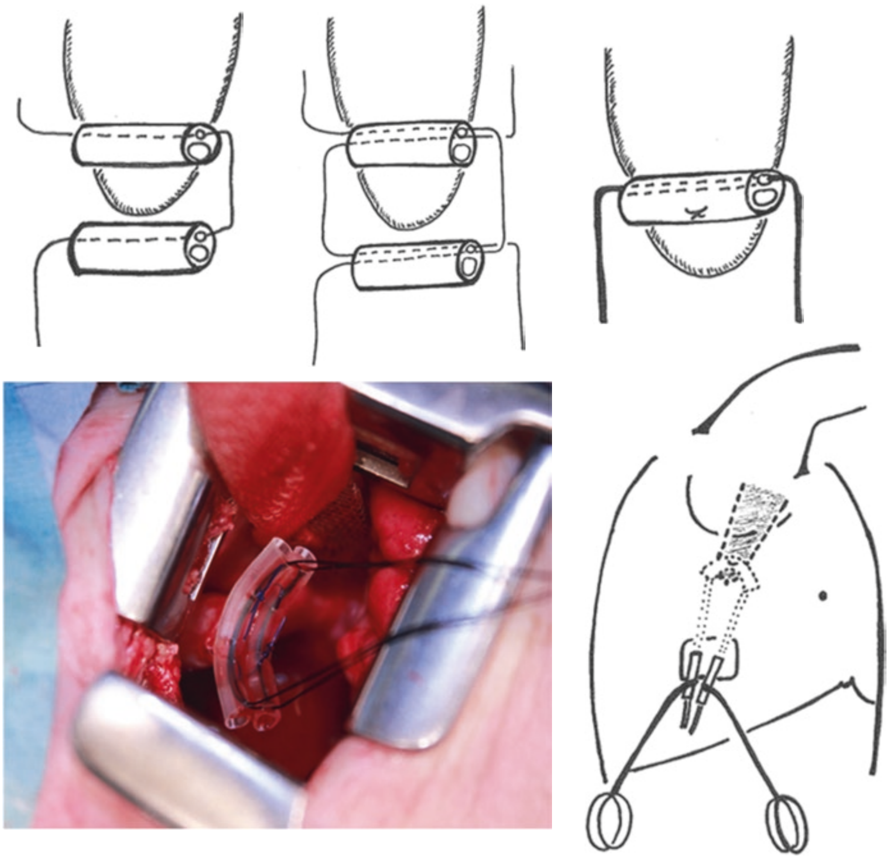

Fig. 3.3 Modified Foker elongation technique. Two polyvinyl chloride tubes have been applied to both atretic ends of the esophagus and nylon sutures passed through the tubes and exteriorized for external traction. (By courtesy of Dr. Mochizuki: Ref [11])

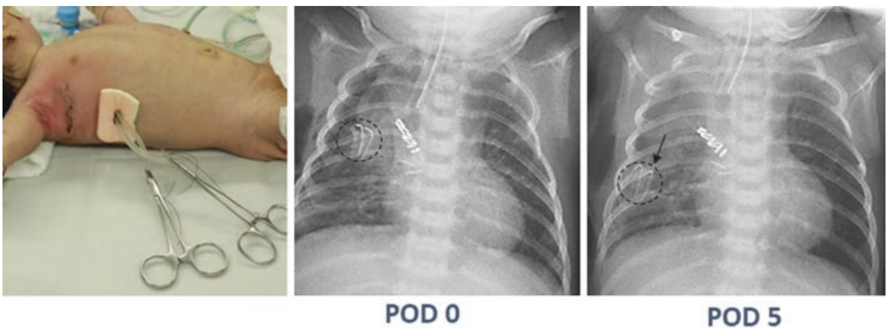

Fig. 3.4 Modified Foker elongation technique. Traction sutures for the upper esophagus are exteriorized from the thorax through the lower intercostal space, and traction sutures for the lower esophagus are either exteriorized or attached to the parietal pleura. (By courtesy of Dr. Mochizuki: Ref [11])

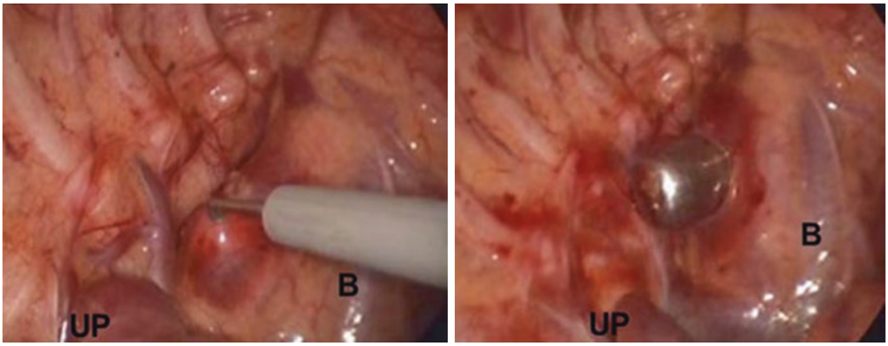

Fig. 3.5 Thoracoscopy after extrathoracic esophageal elongation. The proximal esophagus has been brought into the posterior mediastinum using thoracoscopy. UP upper lung, B brachiocephalic vein

been incorporated into the elongation process successfully [8, 13]. The first 5-mm trocar is inserted in the sixth ICS in the mid-axillary line for a 30-degree scope. Second and third trocars are placed in the axilla at the third and ninth ICS in the posterior axillary line, respectively; an additional fourth 3.9-mm trocar may be placed in the anterior axillary line for an assistant to use if necessary. The distance between the second and third trocars should reflect the type of EA present; wider in LGEA compared with classic type-C esophageal atresia (tracheoesophageal fistula). The pleural space is insufflated with CO_2 to a pressure of 4–8 mmHg at a flow rate 0.5–1.0 L/min. The proximal esophagus that has been elongated extrathoracically can be brought into the upper part of the posterior mediastinum through a space between the trachea and the vertebral column, under thoracoscopic control (Fig. 3.5) [14, 15]. The lower atretic end of the esophagus is mobilized toward the anastomosis site using the light of a gastrointestinal endoscope inserted through the gastrostomy site as a guide (Fig. 3.6-Lt). Next, the proximal and distal ends of the esophagus are transected transversally with scissors. The anastomosis is accomplished using six to eight interrupted sutures with 5–0 PDS (Fig. 3.6-Rt). We usually tie all knots extracorporeally and push them in place with the needle holder, but some surgeons recommend tying knots intracorporeally to prevent tearing of tissue during tying.

Despite all intentions, we have experienced cases of obvious gaps at the time of anastomosis after the ends were observed to overlap preoperatively, especially when the atretic ends are stretched. The distal end can appear to be longer depending on how the end is stretched during radiography (Fig. 3.7). In our experience, during open anastomosis, myotomy (see later) is an option, as well as intermittent intraoperative traction by pulling both ends of the esophagus closer to secure an anastomosis by placing multiple sutures in both atretic ends, tying under tension and waiting for 30–60 minutes before continuing which can create 5–10 mm that can assist with approximation.

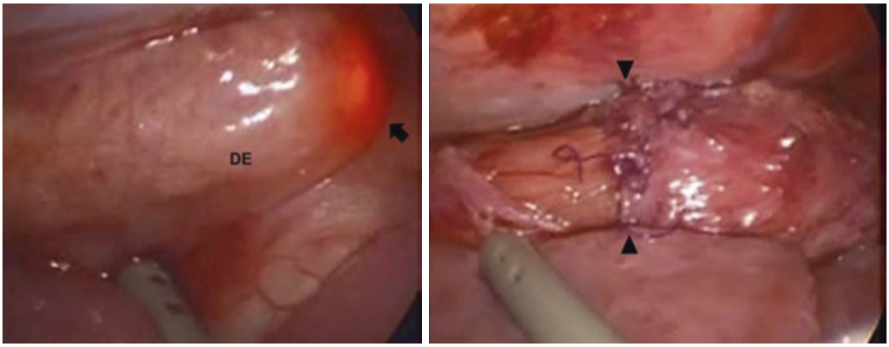

Fig. 3.6 Thoracoscopic esophagoesophagostomy after extrathoracic esophageal elongation. The lower segment of the esophagus is mobilized using the light from an endoscope inserted through the gastrostomy site into the atretic end (arrow) as a guide. Thoracoscopic anastomosis is performed using interrupted sutures (arrowheads). DE distal esophagus

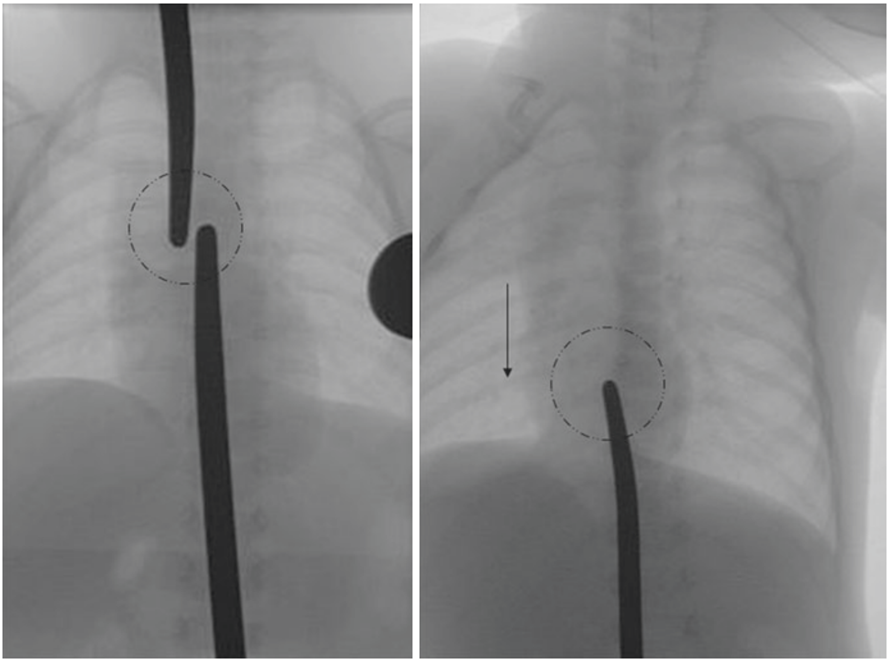

Fig. 3.7 Hegar bougies seen in the proximal and distal atretic ends of the esophagus under fluoroscopy. The distance between the atretic ends is easily influenced by angulation, especially distally

Special care must be taken when dissecting between the anterior wall of the upper atretic end and the posterior wall of the trachea. We experienced one case of perforation of the trachea during thoracoscopic repair of LGEA after repeated bougie elongation of both the proximal and distal atretic ends (Fig. 3.1-Rt); conversion to open surgery was necessary. Cases elongated by continuous stretching must be dissected cautiously.

Surgeons should be aware that vascular perfusion will be compromised with each surgical procedure performed. Thus, multiple elongation procedures over time result in the distal end in particular, tending to become ischemic and scarred which could contribute to anastomotic stricture formation, especially after extrathoracic esophageal elongation.

The gastroesophageal junction may move into the thorax because of traction. Various symptoms can develop that can be managed with antireflux medications, but disrupted vascular perfusion and some degree of stenosis usually necessitate intervention which might not only involve dilatation but could involve more specific antireflux surgery. In fact, we perform an antireflux procedure after almost all esophagoesophagostomies for LGEA.

Due to tension at the anastomosis after LGEA surgery, postoperative bougienage for stricture formation is usually required. In severe cases with pin-hole strictures, we have used magnetic compression revision, in which a pair of cylindrical Samarium-cobalt rare-earth 320 mT (3200 G) magnets, 15 × 5 mm (diameter × thickness), are inserted endoscopically via the mouth and the gastrocutaneous fistula on either side of the stricture, as close together as possible (Fig. 3.8). Over about a week, the magnets will connect, widening the stricture. The magnets will travel through the digestive tract and be excreted.

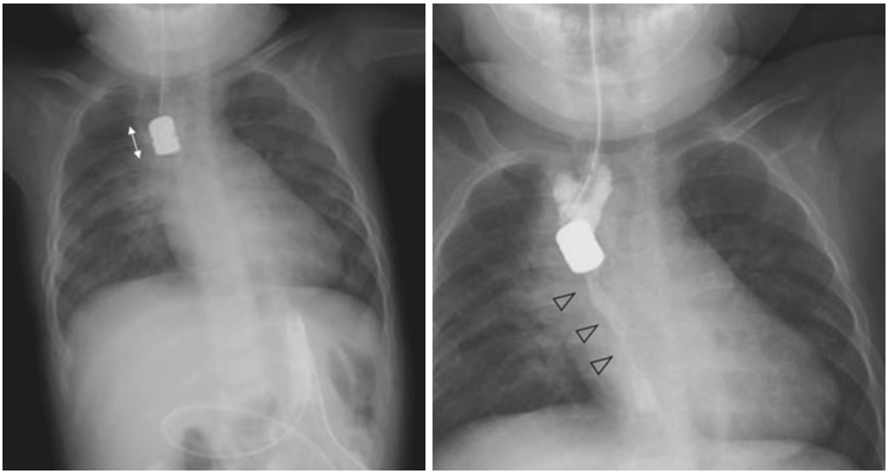

Fig. 3.8 Magnetic compression for anastomotic stricture. Magnets are placed endoscopically as close together as possible (arrow). They will connect over time and pass through the stricture (arrowheads)

Intrathoracic Elongation During Primary Esophagoesophagostomy (EA-TEF)

Esophageal Myotomy

Myotomy is effective for elongating the esophagus without serious disruption to vascular perfusion depending on the number of incisions made and for redistributing intraluminal pressure according to the width of each incision. Incisions must be planned to withstand both transient and persistent changes in pressure without ballooning and transferring extra force onto the anastomosis. Obviously, myotomy incisions must not be the cause of complications or motility disorders. Unfortunately, there is no single definitive technique that enables all of the above, and a combination of incisions made based on experience is required.

An IPEG (International Pediatric Endosurgery Group) survey of current patterns of practice and technique, conducted in 2013, revealed that spiral myotomy was performed for the repair of EA, including LGEA, by only 10% of respondents [16]. Despite there being no definitive evidence of esophageal dysmotility after myotomy, no documented risk to mucosal and submucosal vascular perfusion that affects peristalsis, and no significant difference in esophageal motility and swallowing in primary anastomosis esophageal atresia cases with or without myotomy [17] on long-term follow-up, it is currently hardly performed. The role of myotomy is as an additional option for relieving tension at the anastomosis.

Techniques Livaditis was the first surgeon to describe circular myotomy of the upper esophagus to gain extra length in 1973 [18]. Circular myotomy reduces tension by 50% and provides additional length of 0.5 cm. Various other similar maneuvers have been described, some with modifications such as using a balloon catheter to inflate the upper pouch [19, 20]. Kimura's spiral myotomy reportedly reduces pseudodiverticulitis and leakage rates [21, 22] by decreasing the pressure.

Alternative techniques include bilateral endoscopic submucosal myotomies performed experimentally in a swine model in 2012, reported to selectively divide circular fibers to enable perfusion near the anastomosis to be preserved and prevent long-term dilatations [23] and multiple V-myotomies reported recently in a lamb model (2019) with potential for better elongation per incision than the Livaditis or Kimura techniques [24].

Livaditis myotomy has been reported not to be able to prevent anastomotic leakage [25], and mucosal out-pouching seen on esophagography is the most common complication. Kimura's technique is more complicated and does not provide sufficient elongation so is used less frequently. Many myotomy techniques have been reported and it is a valid option for elongating the esophagus, but they are currently underutilized.

Gough's Flap

Gough's report in the early 1980s of fashioning a flap using the anterior aspect of the upper pouch that is turned down to the lower segment to reduce the gap between the atretic ends instead of opening the upper pouch at its most distal limit with sutures placed posteriorly and tied with little or no tension has the added benefit of creating a funnel-like structure leading to the anastomosis because the upper pouch is invariably large enough to allow the flap defect to be sutured without undue narrowing [26].

Nonsurgical Treatment

Clostridium botulinum Neurotoxin A

Recently, intramural injection of *Clostridium botulinum* neurotoxin A (*botulinum* toxin type A [BTX-A]) was reported as a possible new treatment option for LGEA [27]. BTX-A blocks acetylcholine release in neuromuscular junctions by cleaving t-SNAREs, hindering acetylcholine vesicles from flushing with presynaptic membranes, thereby achieving muscle relaxation [28]. Studies in piglets and rats have documented that intramural injection of BTX-A enhances esophageal elongation under tension as well as esophageal muscle regeneration at the anastomosis site [29]. Such encouraging results in rat and piglet animal models suggest that BTX-A toxin may have potential for use in human EA.

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