Review Article

Thymectomy for juvenile myasthenia gravis: a narrative review

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Background and Objective: Thymectomy as a management strategy for juvenile myasthenia gravis (JMG) has been increasingly adopted with the advent of minimally invasive surgical techniques. This review evaluates existing evidence regarding the surgical management of JMG, including the benefits of surgical compared to medical therapy, important considerations when evaluating surgical candidacy and determining optimal timing of intervention. In addition, we provide an overview of the open, thoracoscopic and robotic surgical approaches available for thymectomy and compare the existing data to characterize optimal surgical management.

Methods: A thorough literature review was conducted for full length research articles, including systematic reviews, retrospective cohort studies and case series, published between January 2000 and July 2023 regarding open, thoracoscopic or robotic thymectomy for management of JMG. Reference lists of the identified articles were manually searched for additional studies. Evidence was summarized in a narrative fashion with the incorporation of the authors' knowledge gained through clinical experience.

Key Content and Findings: Although data specific to JMG are limited to small retrospective cohort studies, available evidence supports equal to greater disease control following thymectomy versus pharmacologic management. Furthermore, outcomes may be optimized when surgery is performed earlier in the disease course, particularly for patients who are post-pubertal with generalized or severe disease and those necessitating high-dose steroid administration thereby limiting its metabolic and growth inhibitory effects. Open transsternal resection is the historic gold-standard; however, as surgeons become more comfortable with thoracoscopic and robotic-assisted thymectomy, an increasing proportion of patients are expected to undergo thymectomy. At present, the data available is unable to support conclusions regarding which surgical approach is superior; however, minimally invasive approaches may be non-inferior while offering superior cosmesis and decreased morbidity.

Conclusions: Higher-level investigation through the use of multi-institutional databases and randomized prospective trials is warranted in order to understand which child warrants thymectomy, at what point in their disease course and their development, and which surgical approach will optimize postoperative outcomes.

Keywords: Myasthenia gravis (MG); thymectomy; thoracoscopy; robotic surgical procedures; pediatrics

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Introduction

Myasthenia gravis (MG), an incumbering autoimmune disease with prevalence of 150–200 cases per million people, is a result of antibodies directed against antigens located at the postsynaptic endplate of the neuromuscular junction (1). When present, antibodies most commonly target the acetylcholine receptor; therefore, the neurotransmitter is out-competed impeding motor nerve to skeletal muscle impulse resulting in weakness and fatigability (1-3). Juvenile MG (JMG), defined as symptom onset prior to 18 years old, accounts for 15% of patients with MG (4). JMG is most often limited to oculomotor symptoms (e.g., ptosis, diplopia and ophthalmoplegia); however, this may be accompanied with or progress to generalized muscle weakness, involving the bulbar, facial, limb and respiratory muscles. While those with pure ocular-type JMG more often have pre-pubertal onset, those with post-pubertal onset are more likely to have generalized disease (5).

The thymus is rich with anti-acetylcholine receptor (anti-AChR) antibody-promoting antigens; therefore, making it the target of surgical management (6). While ocular JMG can often be controlled medically, through an astute combination of cholinesterase inhibitors, corticosteroids and/or immunomodulators, those with generalized or medically-refractory JMG may warrant thymectomy (2,7). However, much of the evidence directing the management of JMG is a result of the extrapolation of data from adult MG studies (8-18). Even still, the only prospective randomized evidence regarding the efficacy of surgical management in adults is limited to the Thymectomy Trial in Non-Thymomatous Myasthenia Gravis Patients Receiving Prednisone Therapy (MGTX) which demonstrated superior outcomes following open transsternal thymectomy when compared to pharmacotherapy for generalized non-thymomatous seropositive MG (19-21). However, caution should be taken when applying adult studies to JMG as there are significant differences in the demographics of and prognosis for these diseases (5,22). Despite this, thymectomy as a management strategy for JMG has become generally accepted, and attention is pivoting to attempt to understand which child warrants intervention, when surgery should take place and by which approach.

The objective of this review is to evaluate the existing evidence regarding the surgical management of JMG, including the benefits of surgical versus medical management and important considerations to make when determining surgical candidacy and timing of intervention. In addition, we provide an overview of the approaches available to perform thymectomy for JMG and compare existing data to characterize its optimal surgical management. We present this article in accordance with the Narrative Review reporting checklist (available at https://med.amegroups.com/article/view/10.21037/med-23-41/rc).

Methods

The search strategy is outlined in *Table 1*. A thorough literature review was conducted using the PubMed database in July of 2023. A free text search was performed with the following search terms: ("thymectomy") AND ("juvenile" OR "children" OR "pediatric") AND ("myasthenia gravis"). Full length research articles in English, including systematic reviews, retrospective cohort studies and case series, published between January 2000 and July 2023 regarding open, thoracoscopic or robotic thymectomy for management of JMG were included. In addition, reference lists of the identified articles were manually searched for additional studies. Case studies, editorials and commentaries were excluded as well as those with content or study population extending beyond the surgical management of JMG. Article selection is visualized in *Figure 1*.

Surgical *vs.* medical management

There are no prospective studies which compare complete stable remission (CSR), disease improvement, or change in medication requirement for thymectomy relative to medical management for JMG, such as the MGTX trial did for MG; however, we identified four retrospective studies (*Table 2*) and two systematic reviews (*Table 3*) which evaluate thymectomy and compare it to medical management for JMG. Available data consist of small and heterogeneous populations limiting cohort comparisons; however, patients who undergo thymectomy have less postoperative corticosteroid and cholinesterase inhibitor use in addition to comparable if not higher rates of CSR (4,23,26). Furthermore, thymectomy has been shown to decrease the number of days spent intubated, in the intensive care unit and hospitalized (23). An analysis of the KID database demonstrated between 2003 and 2012 there was stability in the number of thymectomies performed in children for JMG (27). However, data estimating the number of pediatric thymectomies performed before and after the publication of the MGTX trial in 2016 is not available at present.

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Table 1 The search strategy summary

Items	Specification
Date of search	July 24, 2023
Databases and other sources searched	PubMed
Search terms used	Free text search including the terms: ("thymectomy") AND ("juvenile" OR "children" OR "pediatric") AND ("myasthenia gravis")
Timeframe	Jan 2000 to Jul 2023
Inclusion and exclusion criteria	Inclusion: full length research articles written in the English language regarding open, thoracoscopic or robotic thymectomy for pediatric/juvenile myasthenia gravis Exclusion: case reports, commentaries/editorials, articles purposed to evaluate medical or anesthetic management of juvenile myasthenia gravis, cohort contained patients undergoing thymectomy for disease other than juvenile myasthenia gravis
Selection process (who conducted the selection, whether it was conducted independently, how consensus was obtained, etc.)	Article selection was collectively performed by M.C. and S.U.
Any additional considerations, if applicable	Reference lists for relevant articles were manually searched for additional studies

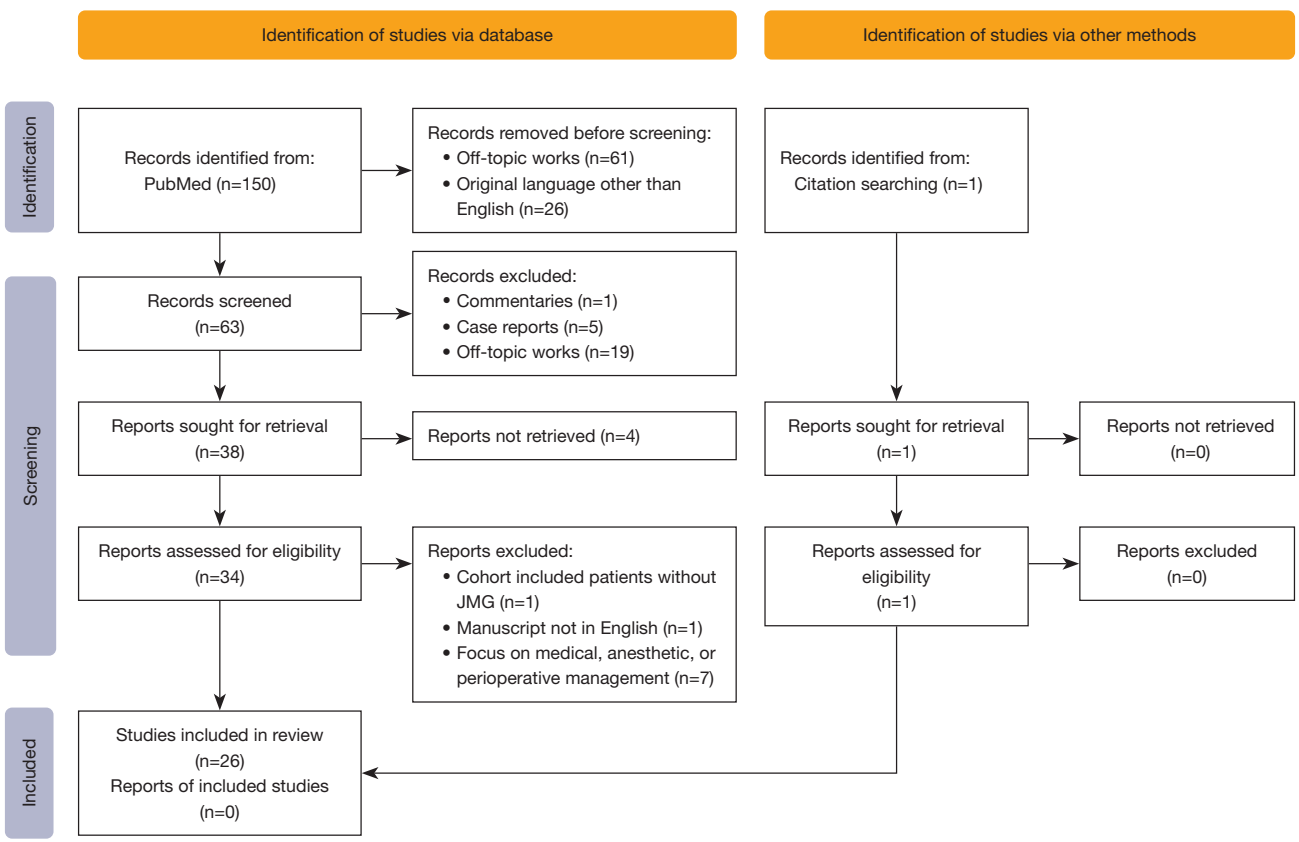

Figure 1 Flow chart demonstrating article selection for evaluating thymectomy for management of juvenile myasthenia gravis. JMG, juvenile myasthenia gravis.

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Table 2 Retrospective studies comparing surgical and medical management for juvenile myasthenia gravis

Authors, year published	Surgical approach [n]	Mean [range] age at thymectomy	Mean [range] disease duration prior to thymectomy	Key findings
Tracy *et al.* (23), 2009	Thymectomy, unspecified [13] *vs.* non-surgical [32]	10 years 10 months [17 months–18 years 7 months]	9.2 months [17 days–2 years 9 months]	(I) 62% improvement, 31% CSR (II) Mean time from onset to surgery longer in those who did not improve (397 *vs.* 198 days) (III) Thymectomy resulted in a reduction in days intubated, in the intensive care unit, and in the hospital
Wang *et al.* (24), 2013	Thymectomy, unspecified [52] *vs.* non-surgical [24]	NR	NR	(I) No significant association between thymectomy and delayed bone age and height based on chronological age (II) Delayed bone age and height retardation in JMG thought to be related to past cumulative prednisone intake and age at disease onset might be a factor
Popperud *et al.* (25), 2021	Thymectomy, unspecified [32] *vs.* non-surgical [15]	17 [2–33] years	21 [9–31] months	(I) Patients who undergo thymectomy have evidence of premature immunosenescence not related to age at surgery (II) No clinical consequence of premature immunosenescence demonstrated at last follow-up {median [IQR] 12 [7–26] years}
Li *et al.* (4), 2022	Robotic [47] *vs.* non-surgical [20]	NR	16 [7–25] months	(I) Patients who underwent robotic thymectomy had a significantly shorter disease duration, greater preoperative steroid use and larger proportion were anti-AChR+ (II) Median [IQR] follow-up 47 [30–94] months (III) Robotic thymectomy cohort had higher proportion as well as significantly higher 5-year cumulative probability of CSR (IV) Robotic thymectomy cohort experienced a reduction in daily dose of cholinesterase inhibitors and corticosteroids while the non-surgical group did not (V) 19.1% postoperative complication rate

anti-AChR+, anti-acetylcholine receptor antibody positive; CSR, complete stable remission; IQR, interquartile range; JMG, juvenile myasthenia gravis; NR, not reported.

Surgical candidacy

While thymoma is rare in children, affecting just over 2% of children with JMG, thymomatous JMG is always surgical (22,28-30). As such, after diagnosis of JMG, either magnetic resonance imaging or computed tomography is performed to evaluate for the presence of thymic enlargement or thymoma (31). When imaging suggests non-thymomatous disease, there is lack of consensus regarding the indications for surgical management. This is perpetuated by a lack of standardized classification system between existing pediatric studies. Likewise, available evidence regarding the role of thymectomy for patients with ocular *vs.* generalized disease, pre- *vs.* post-pubertal age at surgery, and seropositive *vs.* seronegative antibody status remain insufficient (26).

The first categorization system developed, the Osserman Score, was introduced in 1958 (32). Ranging from Class I to IV based on symptom severity and progression, Class I involves only the ocular muscles while Classes II-IV represent progressive and increasing severity of generalized muscle involvement (32). Hans Oosterhuis published his scoring system in the 1980s after observing more than

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Table 3 Systematic reviews evaluating outcomes following thymectomy for juvenile myasthenia gravis

Authors, year published	Years included	Number of articles	Key findings
Madenci *et al.* (26), 2017	2000–2016	16	(I) 488/1,131 (43%) underwent thymectomy
			(II) Preoperative severity: 50% Osserman stage I, 30% stage II, 14% stage III, 6% stage IV
			(III) Approach: 82% transsternal, 17% thoracoscopic, 1% transcervical
			(IV) 77% had post-operative improvement, 29% CSR
			(V) Postoperative complications were rare (range, 0–30%), most common pneumonia/atelectasis and mechanical ventilation
			(VI) 0.2% cause-specific mortalities
			(VII) 3 studies compared surgical and non-operative management, 1 reported trend toward higher CSR with thymectomy, 1 reported thymectomy to be protective against the development of generalized symptoms, 1 reported similar CSR rates
			(VIII) 4 studies compared open to thoracoscopic thymectomy, 3 concluded thoracoscopic to be non-inferior in terms of reduction in disease severity, 1 noted incomplete resection with thoracoscopic; thoracoscopic was associated with less blood loss, shorter length of stay, lower to similar complication rate
			(IX) Studies were entirely retrospective, power limited and with heterogeneous populations
Ng and Hartley (22), 2021	1997–2020	17	(I) 588 patients underwent thymectomy
			(II) 77% improvement, 40% CSR
			(III) Overall, surgical outcomes may be associated with early intervention, post-pubertal intervention, AChR+, more severe disease, presence of thymic hyperplasia
			(IV) 6 studies compared open and thoracoscopic thymectomy, overall report similar clinical outcomes with reduced length of stay and improved cosmesis with thoracoscopic
			(V) Pathology: 62% hyperplasia, 24% normal, 2% thymoma
			(VI) Mixed results regarding seropositivity, 1 found improved outcomes while 1 found no difference
			(VII) Studies limited by retrospective nature, variable follow-up times, lack of control groups and statistical power

CSR, complete stable remission; AChR+, anti-acetylcholine receptor antibody positive.

400 patients with MG. Scores of 1–4 represent increasing degree of disability while 0 represents complete remission and 5 mechanical ventilatory dependence (33). In 2000, the Myasthenia Gravis Foundation of America (MGFA) published the Quantitative MG Score (QMG) intended as the first objective system based on a patient's strength when performing specified actions (34). This system was utilized in the MGTX trial; however, it has not been adopted widely by pediatric studies which continued to use the Osserman or Oosterhuis classifications for grading preoperative disease severity (22). However, the QMG was modified for pediatric patients by eliminating the grip strength test and incorporating a straw for bulbar strength evaluation to create the first JMG-specific scoring system that is both more developmentally appropriate and less impacted by a child's cooperability (35).

Despite this heterogeneity, most JMG cohorts are described as to whether disease is pure ocular or with generalized involvement. Although pure ocular disease is more common, nearly two-thirds of children who undergo thymectomy have generalized JMG (30). In addition, there is a trend in some studies toward greater response to thymectomy for those with generalized and/or more severe disease than those with pure ocular type (22). However, this was not found across all studies (22,36,37).

Approximately 80% and 3.5% of JMG patients have anti-AChR and anti-muscle specific tyrosine kinase (anti-MuSK) antibodies, respectively (22,30). Overall, data regarding

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the influence of seropositivity in response to surgery is insufficient (26). The presence of anti-AChR antibodies has been shown to correlate with greater surgical response; therefore, anti-AChR seropositivity often contributes to the determination to pursue thymectomy (22,38). However, some patients who are anti-AChR negative respond to thymectomy; therefore, the role of surgery remains ambiguous for those with anti-MuSK antibodies or who are seronegative (22,39).

Still, there remains significant controversy surrounding the appropriate age and timing from symptom onset to thymectomy. Delaying thymectomy affords a chance for spontaneous remission, an event which occurs as often as 20–29% of the time in children (40). Furthermore, the thymus is critical in the growth and development of a child's immune system; therefore, many argue that surgery should be postponed due to concern that removing the thymus while the immune system is still in development will have negative consequences later in life (22,41-43). As such, a study performed by Popperud *et al.* confirmed that thymectomy for JMG performed at median (range) age at thymectomy of 17 [2–33] years can lead to premature immunosenescence, including a reduced number of B cells, naive cytotoxic T cells and helper T cells and increased memory T cells at median (interquartile range) 12 [7–26] years after thymectomy was performed. However, these findings were not related to age at thymectomy nor with any discernible clinical consequence (25). However, it is necessary to mention a 2023 case-control study in adults with MG who are five years or more post-thymectomy found thymectomized patients have not only decreased production of CD4+ and CD8+ lymphocytes and higher levels of proinflammatory cytokines but also a higher incidence of cancer and all-cause mortality compared to their non-thymectomized counterparts (44).

There is also controversy regarding the impact of age and timing from symptom onset on the efficacy of thymectomy. A study with 31% CSR and 62% symptom improvement rates following thymectomy in 13 patients with mean (range) age at thymectomy of 10.8 (1.4–18.6) years and mean (range) time from disease onset of 9.2 (0.6–33.0) months found that time from onset to surgery was a mean 199 days longer in those who did not respond to thymectomy (23). In a study performed on 141 patients with JMG with median (range) age at onset of 6 [1–18] years who underwent open transsternal resection at median (range) age of 12 [3–18] years found improved CSR rates if surgery is performed when patients are at least 12 years old (37). However, the same study, demonstrated improved postsurgical outcomes when thymectomy was performed within 12 months of onset of generalized symptoms (37). Conversely, a study by Kim *et al.* including 50 patients with JMG who underwent thoracoscopic thymectomy at mean (standard deviation, SD) age of 10.5 (0.8) years and mean (SD) time to thymectomy of 19.6 (4.2) months with 51.0% of patients with thymectomy within one year of disease onset found no difference in outcome when evaluating age or timing of thymectomy relative to symptom onset (45). A systematic review including 17 articles published between 1997 and 2020 encompassing 588 JMG patients who underwent thymectomy concluded that improved surgical outcomes may be associated with both early intervention and post-pubertal intervention (22). Moreover, by performing surgery early, children avoid growth failure, delay in bone aging and detrimental metabolic effects experienced by JMG patients who require prolonged corticosteroids (24). Overall, there may be benefit to performing surgery early relative to symptom onset, particularly for patients who are post-pubertal or with severe disease requiring prolonged use of high-dose steroids.

Surgical approach

Once the decision has been made to perform surgery, patients should be optimized medically and myasthenic symptoms well-controlled which may necessitate intravenous immunoglobulin administration or plasma exchange therapy (4). Traditionally performed through median sternotomy, the decision to pursue surgery required a careful consideration of the known risks of open thoracic surgery. The development of minimally invasive surgical (MIS) approaches, including both thoracoscopic and robotic thymectomy, was driven by the desire for decreased postoperative morbidity. However, as incomplete clearance of thymic tissue is associated with reduced remission rates, complete thymic resection in both thymomatous and non-thymomatous JMG is critical. As such, experts have voiced concern that MIS approaches provide inadequate visualization, and therefore, incomplete extirpation of mediastinal fat and ectopic foci of thymic tissue (46-49). Despite this controversy, there is paucity of high-level evidence to support an optimal approach to thymectomy in children (50). We identified twenty retrospective studies (*Table 4*) and two systematic reviews (*Table 3*) which evaluate and/or compare surgical approaches to thymectomy for JMG.

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Table 4 Retrospective studies evaluating approach to thymectomy for juvenile myasthenia gravis

Authors, year published	Surgical approach [n]	Mean [range/± SD] age at thymectomy	Mean [range/± SD] disease duration prior to thymectomy	Key findings
Kolski, Vajsar and Kim (51), 2000	Thoracoscopic, right [6]	10.5 years	NR	(I) 0 postoperative complications (II) Mean follow-up 22 months (III) 100% with improvement, 50% in remission at mean follow-up 22 months
Kolski, Kim and Vajsar (52), 2001	Thoracoscopic, right [6] *vs.* open, transsternal [6]	11.3 [1.7–14.7] *vs.* 8.1 [1.9–15.8] years	0.8 [0.1–3.4] *vs.* 0.7 [0.1–1.4] years	(I) Thoracoscopic had shorter length of stay and less postoperative complications compared to open (II) 100% improved, 33% thoracoscopic were in CSR, 66% open CSR
Essa *et al.* (53), 2003	Open, transsternal-transcervical [30]	13.2 [4–16] years	19.3 [2–144] months	(I) Before surgery all patients underwent plasmapheresis and steroids weaned off (II) 90% effective, CSR 43.4% at mean follow-up 53.5 (range, 9–180) months (III) 33.3% ectopic thymic tissue which was found to be a significant poor prognostic factor for response to thymectomy
Seguier-Lipszyc *et al.* (54), 2005	Thoracoscopic, left [2]	10.75 years	4.5 years	(I) Ultrasound utilized intraoperatively to visualize the thymus (II) 0 complications (III) 100% improvement, 0% CSR
Wagner *et al.* (55), 2006	Thoracoscopic [6] *vs.* open, transsternal/ transcervical [5/3]	9.8 [2–24] *vs.* 9.5 [7–15] years	0.8 [0.5–2] *vs.* 2.8 [0.5–8.0] years	(I) No difference in operative time (II) Thoracoscopic had significantly less blood loss and shorter length of stay than open (III) No difference in surgical effectiveness at mean follow-up of 43 (range, 4–111) months
Kanzaki *et al.* (56), 2008	Open [3]	13.3 [12–15] years	11.3 [5–20] months	(I) Extended thymectomy combined with postoperative high-dose steroid therapy (II) 100% improvement, 33% CSR
Yeh *et al.* (57), 2011	Thoracoscopic-assisted, subxiphoid [4]	NR	NR	(I) 100% improvement, 25% CSR
Ware, Ryan and Kornberg (58), 2012	Thoracoscopic [9] or open, transsternal [1]	11.3 [4–14] years	15.3 [3–38] months	(I) 70% effective (II) 30% refractory to thymectomy—2 underwent repeat surgery and 1 had residual thymus confirmed on path and subsequently improved
Parikh, Vaidya and Jain (59), 2011	Thoracoscopic, right [4]	9.25 [2.5–16.0] years	5 [3–8] months	(I) Operative time 55 min–2.5 hours (II) Chest drain removed within 24 hours (III) 75% effective (2 steroid free, 1 steroids at lower dose) at follow-up time of 6 to 46 months

Table 4 *(continued)*

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Table 4 *(continued)*

Authors, year published	Surgical approach [n]	Mean [range/± SD] age at thymectomy	Mean [range/± SD] disease duration prior to thymectomy	Key findings
Cheng *et al.* (37), 2013	Open, transsternal [141]	12 [3–18] years	NR	(I) 6.4% perioperative complication rate (II) 7.1% with postoperative myasthenic crisis (III) 91.1% response rate (25.2% CSR, 20.7% in pharmacologic remission, 45.2% improved, 3.7% unchanged, 5.2% worsened) (IV) 43.2% cumulative remission rate at 10 years (V) Disease onset >6 years had higher CSR rates (VI) >12 years old at thymectomy had higher CSR rates (VII) Early thymectomy for generalized (within 12 months of onset) associated with better response to thymectomy (VIII) No corticosteroid use postoperatively associated with better response to thymectomy
Christison-Lagay *et al.* (60), 2013	Thoracoscopic, right [15]	11.3 [2.0–15.9] years	12.5 [3–40] months	(I) Mean operative time 145 min (decreased throughout study) (II) 0 postoperative complications (III) 47% in medical remission or CSR (IV) Postoperative symptom trend: 50% improved at 1 year, 86% at 2 years, 75% at 3 years
Castro *et al.* (3), 2013	Thoracoscopic [4] or open, transsternal [28]	NR	NR	(I) 75% improvement (II) Of 25% that didn't improve, half underwent repeat thymectomy as they had undergone primary thoracoscopic (III) Path: 21% thymic hyperplasia, 6% thymoma
Heng *et al.* (38), 2014	Open, transsternal [20]	Median 11 years 1 month	Median 9 months	(I) 10% required intensive care unit support postoperatively (5% required preoperatively) (II) 20% had surgical site infections which responded to antibiotics alone (all on steroids) (III) 95% improvement with 30% CSR postoperatively at median follow-up of 32 months
Özkan *et al.* (61), 2015	Thoracoscopic, right [40]	14.8 [±2.2] years	15.9 [±28.9] months	(I) Mean surgical time 48.9 (±31.3) min (II) 7.5% postoperative complications (1 reintubation, 1 chest re-drainage, 1 atelectasis requiring bronchoscopy) (III) Mean chest tube duration 20.5 (±12.1) hours (IV) Mean length of stay 1.8 (±1.0) days

Table 4 *(continued)*

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Table 4 *(continued)*

Authors, year published	Surgical approach [n]	Mean [range/± SD] age at thymectomy	Mean [range/± SD] disease duration prior to thymectomy	Key findings
Kitagawa *et al.* (36), 2015	Mediastinoscopic-assisted, subxiphoid [14]	9.4 [4–15] years	[3 months–7 years]	(I) Mean operative time 182 (±44 min) (II) Mean blood loss 34 (±43) cc (III) Chest tube removed postoperative day 1 (IV) Median length of stay 4.5 days (range, 4–6 days) (V) 2 patients with temporary incomplete paralysis of right recurrent laryngeal nerve (hoarseness resolved at 1 month and 3 months) (VI) 93% improved, 43% CSR at median follow-up of 27 months (range, 6–72 months)
Goldstein *et al.* (35), 2015	Thoracoscopic, right [12] *vs.* open, transsternal [16]	14 [±5.8] *vs.* 13 [±3.8] years	NR	(I) Utilized modified QMG score (II) Open had more severe disease preoperatively (mean MGFA 2.63 *vs.* 1.92) and lower pyridostigmine dose (III) Thoracoscopic had fewer complications, shorter postoperatively length of stay (IV) No difference in postoperative QMG score, steroid or pyridostigmine use between open and thoracoscopic approach at median follow-up of 23 months (thoracoscopic) and 44 months (open) (V) No difference in steroid dose pre- and postoperatively
Ashfaq *et al.* (62), 2016	Thoracoscopic, right [12]	Median 11 [3–17] years	Median 418 [75–1,756] days	(I) 0 postoperative complications (II) 100% improvement rate by DeFilippi classification
Kim *et al.* (45), 2019	Thoracoscopic, left [50]	10.5 [3–17] years	19.6 [0–168] months	(I) 0 postoperative complications (II) 45.5% Osserman I with no conversion to ≥ II postoperatively (III) Mean follow-up duration 37.9±4.2 months (IV) 49.8% of patients showed improvement after surgery (V) Increasing cumulative probability of improved status on Kaplan-Meier analysis at 3.5 years follow-up (VI) Weight-adjusted total daily steroid intake (mg/kg/day) decreased significantly over 3.5 years of follow-up
Jastrzebska *et al.* (63), 2019	Thoracoscopic [23] or open, transsternal [16] or thymectomy, unspecified [34]	14.6 [6–22] years	1 [0–8] years	(I) Path: 2.2% thymoma, 2.2% thymic atrophy, 95.7% hyperplastic thymus (II) 90% improved, 11.9% in CSR, 11.9% in pharmacologic remission
Derderian *et al.* (64), 2020	Open [18] *vs.* thoracoscopic, left/right [15/1]	15.6 [±4.4] *vs.* 11.9 [±4.3] years	10.3 [±8.8] *vs.* 10.7 [±7.1] months	(I) Thoracoscopic had longer operative time, less blood loss, shorter length of stay, and shorter duration of intravenous narcotic use compared to open (II) No difference in clinical improvement or CSR (III) Surgical pathology not predictive of outcome

CSR, complete stable remission; MGFA, Myasthenia Gravis Foundation of America; NR, not reported; QMG, quantitative myasthenia gravis score; SD, standard deviation.

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Open thymectomy

First performed by Alfred Blalock in the 1940s, today's proponents for open thymectomy believe transsternal open thymectomy is the most reproducible method to achieve maximal dissection (65). As such, as of 2016 greater than 80% of thymectomies for JMG were performed by an open approach (26). When performed in children, disease improvement rates as high as 90–100% have been reported alongside CSR rates of 25–66% (37,38,52,56).

Earliest reports of thymectomy are described in the 19th century when it was performed through a cervical incision in infants and young children due to a belief that thymic enlargement caused respiratory obstruction and sudden death (66). Transcervical thymectomy was first reported for JMG in 1912 by Ferdinand Sauerbach to be replaced with the transsternal approach with advances in thoracic surgery (66,67). However, attempts at reducing morbidity and simplifying recovery after thymectomy lead to the reintroduction of the transcervical approach in the 1960s in young adults (66). A transverse incision is made just above the suprasternal notch through the platysma. The sternohyoid and sternothyroid muscles are retracted laterally and the cervical aspect of the thymus identified enabling traction upward and dissection and deliverance of the mediastinal portion of the thymus up above the manubrium (66). However, many find the inferior and lateral thymus to be poorly visualized in this technique making it susceptible to residual thymus end procedure (68,69). In a study using a hybrid transcervical-transsternal approach, as many as 33.3% of patients had ectopic thymic tissue which was associated with poor response to thymectomy (53). Today, transcervical thymectomy accounts for as few as 1% of thymectomies for JMG (26).

Hybrid approaches incorporating a subxiphoid incision assisted by either mediastinoscopy or thoracoscopy have aimed to improve visualization while still avoiding median sternotomy (36,57). Although data boast impressive improvement rates of 93–100% and CSR rates of 25–43%, little is published on these approaches. Perhaps for good reason in the case of subxiphoid-mediastinoscopy, as 14% of patients experienced incomplete right recurrent laryngeal nerve paralysis which resolved between 1 and 3 months postoperatively (36).

Thoracoscopic thymectomy

As the thymus resembles the anterior mediastinal and cervical fat it lies within and is laterally bounded by the phrenic nerves, adequate visualization is imperative to a safe and complete resection. However, the postoperative morbidity and cosmetic appearance following open thoracic surgery are suboptimal; therefore, the thoracoscopic approach to thymectomy was developed with the goal of achieving equivalent visualization, thymic resection and disease control as is achieved with the transsternal approach while decreasing postoperative recovery time and improving cosmesis.

Patients are positioned in a semi-lateral position at a 30° to 45° angle. Often, tracheal intubation affords superior exposure over selective endobronchial intubation as sufficient working space and visualization of the mediastinum are provided by capnopneumothorax with insufflation pressures of 4–8 mmHg while selective intubation results in a collapse of the chest wall (59). A 30° thoracoscope and three 5–10 mm ports are utilized, including at the anterior axillary line, the inframammary midclavicular line and in the posterior axillary line at the 3rd or 4th intercostal space.

Some surgeons prefer a right sided thoracoscopic approach due to a larger working space afforded by the right thoracic cavity as well as the superior ability to visualize the superior vena cava and trace it to the left brachiocephalic vein (35). However, those in favor of the left sided approach feel the left portion of the thymus is easier to approach from this side as it is oftentimes larger and can extend under the left phrenic nerve and up to the aortopulmonary window, a frequent location of ectopic thymus (70,71). Due to unique benefits afforded by both the right and left approaches, some support a bilateral thoracoscopic approach (52). Irrespective, a thoracostomy drain is typically left end-procedure and removed within the first 24 hours postoperatively, and the consequence of two thoracostomy drains should be considered if debating between a unilateral and bilateral approach.

Small noncomparative studies evaluating outcomes following right and left thoracoscopic approaches demonstrate 50–100% disease improvement rates with minimal to no postoperative complications (45,51,54,59-62). As mentioned, critics have argued that thoracoscopic thymectomy results in incomplete clearance of thymic tissue and is associated with lower remission rates compared to open thymectomy (3,48,49,72-75). However, retrospective studies comparing thoracoscopic and open thymectomy for JMG have found thoracoscopic thymectomy to have less operative blood loss, shorter postoperative length

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of stay, improved cosmesis and either a comparable or lower postoperative complication rate with no difference in postoperative disease control (22,26,35,52,55,64,76). However, and notably, one study has identified incomplete resection with thoracoscopy (3,26).

Thoracoscopy's non-inferiority of resection extent and post-operative disease control has not been prospectively evaluated in adults or children to date (46,47,68). Despite this, it is suspected that as familiarity with thoracoscopic thymectomy continues to increase, not only will the proportion of thymectomies performed thoracoscopically increase, but as patients evade the morbidity of thoracotomy, the risk benefit ratio of surgical management will shift and thymectomy will be offered to an increasing proportion of JMG patients.

Robotic-assisted thymectomy

The first robotic-assisted thymectomy was performed for MG in 2003 (77), and since multiple approaches have been developed including left- and right-sided, bilateral and subxiphoid (71,77-80). However, the adoption of robotic-assisted surgery in children has been slow compared to adult surgery (24,25). We identified one study meeting our inclusion criteria which utilized robotic-assisted thymectomy for JMG (4). Employing the same procedural principles and considerations regarding sidedness as the thoracoscopic approach, the robotic approach delivers several technical advantages compared to traditional thoracoscopy. The robot camera affords a three-dimensional and magnified view of the operative field as well as operator control improving visuospatial orientation. In addition, the robotic articulating instruments provide a more natural dexterity than thoracoscopic instruments. This improves dissection capabilities, particularly for difficult to reach tissue planes, while eliminating instability secondary to tremor.

When compared to non-operative management, patients who underwent robotic thymectomy for JMG had a higher 5-year cumulative CSR rate as well as reduced daily dose of cholinesterase inhibitors and corticosteroids; however, with a 19.1% postoperative complication rate. Although studies have not yet compared robotic-assisted thymectomy to other surgical approaches for JMG, studies completed in adults, including comparisons between robotic-assisted and thoracoscopic thymectomy, have demonstrated its safety alongside comparable clinical outcomes relative to sternotomy and superior outcomes compared to thoracoscopy (14,78,81). However, increased cost and infrastructure requirements in addition to time required for docking or conversion to open in the event of emergent bleeding are significant barriers to the use of robotic-assisted thymectomy in JMG (71).

Limitations

As mentioned, data evaluating surgical management of JMG is restricted to small retrospective analyses leaving them limited by both power and selection bias. When comparisons are able to be made between cohorts, they are reduced by heterogenous populations often differing in one or more important confounding variables such as preoperative disease severity, patient age, symptom duration, antibody status and follow-up duration—all factors which contribute to a patient's response to thymectomy. Multicenter retrospective studies are a first and necessary step to enable corrected comparisons to be made. Furthermore, randomized prospective evaluation comparing optimal surgical to optimal medical management is necessary in order to appropriately understand the role of thymectomy in the management of JMG.

Conclusions

This review evaluated the role of surgical management for patients with thymectomy including important considerations when determining candidacy, timing and surgical approach. Although data specific to JMG are limited, available evidence supports equal if not improved disease control following thymectomy relative to medical management. Furthermore, data do not suggest any degree of immunodeficiency following thymectomy regardless of patient age at surgery, and outcomes may be optimized when surgery is performed earlier in the disease course, particularly for patients who are post-pubertal with generalized or severe disease and those necessitating high-dose steroid administration. Open transsternal resection was the historic gold-standard; however, as surgeons become more comfortable with thoracoscopic and robotic-assisted thymectomy, we anticipate increasing proportion of patients with JMG will undergo thymectomy and in a minimally invasive manner. As such, higher-level data, through the use of multi-institutional databases and randomized prospective evaluation, which compares surgical to medical therapy is warranted to understand which child warrants thymectomy, at what point in their disease course and their

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development, and which surgical approach will optimize their postoperative outcomes.

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Footnote

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References

1. Gilhus NE. Myasthenia gravis and congenital myasthenic syndromes. Handb Clin Neurol 2023;195:635-52.
2. Della Marina A, Trippe H, Lutz S, et al. Juvenile myasthenia gravis: recommendations for diagnostic approaches and treatment. Neuropediatrics 2014;45:75-83.
3. Castro D, Derisavifard S, Anderson M, et al. Juvenile myasthenia gravis: a twenty-year experience. J Clin Neuromuscul Dis 2013;14:95-102.
4. Li Z, Li F, Zhang H, et al. Outcomes of Juvenile Myasthenia Gravis: A Comparison of Robotic Thymectomy With Medication Treatment. Ann Thorac Surg 2022;113:295-301.
5. Chiang LM, Darras BT, Kang PB. Juvenile myasthenia gravis. Muscle Nerve 2009;39:423-31.
6. Seybold ME. Thymectomy in childhood myasthenia gravis. Ann N Y Acad Sci 1998;841:731-41.
7. Sanders DB, Wolfe GI, Benatar M, et al. International consensus guidance for management of myasthenia gravis: Executive summary. Neurology 2016;87:419-25.
8. Jurado J, Javidfar J, Newmark A, et al. Minimally invasive thymectomy and open thymectomy: outcome analysis of 263 patients. Ann Thorac Surg 2012;94:974-81; discussion 981-2.
9. Rückert JC, Ismail M, Swierzy M, et al. Thoracoscopic thymectomy with the da Vinci robotic system for myasthenia gravis. Ann N Y Acad Sci 2008;1132:329-35.
10. Tomulescu V, Ion V, Kosa A, et al. Thoracoscopic thymectomy mid-term results. Ann Thorac Surg 2006;82:1003-7.
11. Marulli G, Schiavon M, Perissinotto E, et al. Surgical and neurologic outcomes after robotic thymectomy in 100 consecutive patients with myasthenia gravis. J Thorac Cardiovasc Surg 2013;145:730-5; discussion 735-6.
12. Zielinski M, Hauer L, Hauer J, et al. Comparison of complete remission rates after 5 year follow-up of three different techniques of thymectomy for myasthenia gravis. Eur J Cardiothorac Surg 2010;37:1137-43.
13. Calhoun RF, Ritter JH, Guthrie TJ, et al. Results of transcervical thymectomy for myasthenia gravis in 100 consecutive patients. Ann Surg 1999;230:555-9; discussion 559-61.
14. Goldstein SD, Yang SC. Assessment of robotic thymectomy using the Myasthenia Gravis Foundation of America Guidelines. Ann Thorac Surg 2010;89:1080-5; discussion 1085-6.
15. Jaretzki A 3rd, Sonett JR. Evaluation of results of thymectomy for MG requires accepted standards. Ann Thorac Surg 2007;84:360-1; author reply 361.
16. Kattach H, Anastasiadis K, Cleuziou J, et al. Transsternal thymectomy for myasthenia gravis: surgical outcome. Ann Thorac Surg 2006;81:305-8.
17. Rea F, Marulli G, Bortolotti L, et al. Experience with the "da Vinci" robotic system for thymectomy in patients with myasthenia gravis: report of 33 cases. Ann Thorac Surg 2006;81:455-9.
18. Shrager JB, Nathan D, Brinster CJ, et al. Outcomes after 151 extended transcervical thymectomies for myasthenia gravis. Ann Thorac Surg 2006;82:1863-9.

© Mediastinum. All rights reserved.

19. Wolfe GI, Kaminski HJ, Aban IB, et al. Randomized Trial of Thymectomy in Myasthenia Gravis. N Engl J Med 2016;375:511-22.
20. Randomized Trial of Thymectomy in Myasthenia Gravis. N Engl J Med 2017;376:2097.
21. Wolfe GI, Kaminski HJ, Aban IB, et al. Long-term effect of thymectomy plus prednisone versus prednisone alone in patients with non-thymomatous myasthenia gravis: 2-year extension of the MGTX randomised trial. Lancet Neurol 2019;18:259-68.
22. Ng WC, Hartley L. Effectiveness of thymectomy in juvenile myasthenia gravis and clinical characteristics associated with better outcomes. Neuromuscul Disord 2021;31:1113-23.
23. Tracy MM, McRae W, Millichap JG. Graded response to thymectomy in children with myasthenia gravis. J Child Neurol 2009;24:454-9.
24. Wang H, Su Z, Luo C, et al. The effect of steroid treatment and thymectomy on bone age and height development in juvenile myasthenia gravis. Neurol Sci 2013;34:2173-80.
25. Popperud TH, Gul KA, Brunborg C, et al. Thymectomy in Juvenile Myasthenia Gravis Is Safe Regarding Long Term Immunological Effects. Front Neurol 2021;12:596859.
26. Madenci AL, Li GZ, Weil BR, et al. The role of thymectomy in the treatment of juvenile myasthenia gravis: a systematic review. Pediatr Surg Int 2017;33:683-94.
27. Catalano MA, Mullan CW, Rich BS, et al. Pediatric thymectomy: a study of national trends in demographics, short-term outcomes, and cost. Pediatr Surg Int 2019;35:749-57.
28. Drachman DB. Myasthenia gravis. N Engl J Med 1994;330:1797-810.
29. Ashraf VV, Taly AB, Veerendrakumar M, et al. Myasthenia gravis in children: a longitudinal study. Acta Neurol Scand 2006;114:119-23.
30. Lin Y, Kuang Q, Li H, et al. Outcome and clinical features in juvenile myasthenia gravis: A systematic review and meta-analysis. Front Neurol 2023;14:1119294.
31. Batra P, Herrmann C Jr, Mulder D. Mediastinal imaging in myasthenia gravis: correlation of chest radiography, CT, MR, and surgical findings. AJR Am J Roentgenol 1987;148:515-9.
32. OSSERMAN KE, KORNFELD P, COHEN E, et al. Studies in myasthenia gravis; review of two hundred eighty-two cases at the Mount Sinai Hospital, New York City. AMA Arch Intern Med 1958;102:72-81.
33. Oosterhuis HJ. Observations of the natural history of myasthenia gravis and the effect of thymectomy. Ann N Y Acad Sci 1981;377:678-90.
34. Besinger UA, Toyka KV, Hömberg M, et al. Myasthenia gravis: long-term correlation of binding and bungarotoxin blocking antibodies against acetylcholine receptors with changes in disease severity. Neurology 1983;33:1316-21.
35. Goldstein SD, Culbertson NT, Garrett D, et al. Thymectomy for myasthenia gravis in children: a comparison of open and thoracoscopic approaches. J Pediatr Surg 2015;50:92-7.
36. Kitagawa N, Shinkai M, Take H, et al. Mediastinoscopic extended thymectomy for pediatric patients with myasthenia gravis. J Pediatr Surg 2015;50:528-30.
37. Cheng C, Liu Z, Xu F, et al. Clinical outcome of juvenile myasthenia gravis after extended transsternal thymectomy in a chinese cohort. Ann Thorac Surg 2013;95:1035-41.
38. Heng HS, Lim M, Absoud M, et al. Outcome of children with acetylcholine receptor (AChR) antibody positive juvenile myasthenia gravis following thymectomy. Neuromuscul Disord 2014;24:25-30.
39. Sanders D. Disorder of Neuromuscular Transmission. Neurology in clinical practice. 1996;1995.
40. Lanska DJ. Indications for thymectomy in myasthenia gravis. Neurology 1990;40:1828-9.
41. Ramos SB, Garcia AB, Viana SR, et al. Phenotypic and functional evaluation of natural killer cells in thymectomized children. Clin Immunol Immunopathol 1996;81:277-81.
42. Rath J, Moser B, Zimprich F. Thymectomy in myasthenia gravis. Curr Opin Neurol 2023;36:416-23.
43. Haynes BF, Sempowski GD, Wells AF, et al. The human thymus during aging. Immunol Res 2000;22:253-61.
44. Kooshesh KA, Foy BH, Sykes DB, et al. Health Consequences of Thymus Removal in Adults. N Engl J Med 2023;389:406-17.
45. Kim AG, Upah SA, Brandsema JF, et al. Thoracoscopic thymectomy for juvenile myasthenia gravis. Pediatr Surg Int 2019;35:603-10.
46. Shigemura N, Shiono H, Inoue M, et al. Inclusion of the transcervical approach in video-assisted thoracoscopic extended thymectomy (VATET) for myasthenia gravis: a prospective trial. Surg Endosc 2006;20:1614-8.
47. Okumura M, Shintani Y, Funaki S, et al. VATS thymectomy—bilateral approach for extended resection. Mediastinum 2018;2:37.
48. Pompeo E, Nofroni I, Iavicoli N, et al. Thoracoscopic completion thymectomy in refractory nonthymomatous

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myasthenia. Ann Thorac Surg 2000;70:918-23.
49. Zieliński M, Kuzdzał J, Staniec B, et al. Extended rethymectomy in the treatment of refractory myasthenia gravis: original video-assisted technique of resternotomy and results of the treatment in 21 patients. Interact Cardiovasc Thorac Surg 2004;3:376-80.
50. Prior DE, Cooper BA, Zhang B, et al. Developing outcome measures of disease activity in pediatric myasthenia. Muscle Nerve 2021;63:751-7.
51. Kolski H, Vajsar J, Kim PC. Thoracoscopic thymectomy in juvenile myasthenia gravis. J Pediatr Surg 2000;35:768-70.
52. Kolski HK, Kim PC, Vajsar J. Video-assisted thoracoscopic thymectomy in juvenile myasthenia gravis. J Child Neurol 2001;16:569-73.
53. Essa M, El-Medany Y, Hajjar W, et al. Maximal thymectomy in children with myasthenia gravis. Eur J Cardiothorac Surg 2003;24:187-9; discussion 190-1.
54. Seguier-Lipszyc E, Bonnard A, Evrard P, et al. Left thoracoscopic thymectomy in children. Surg Endosc 2005;19:140-2.
55. Wagner AJ, Cortes RA, Strober J, et al. Long-term follow-up after thymectomy for myasthenia gravis: thoracoscopic vs open. J Pediatr Surg 2006;41:50-4; discussion 50-4.
56. Kanzaki M, Obara T, Sasano S, et al. Long-term clinical outcome after extended thymectomy combined postoperative high-dose steroid therapy for juvenile myasthenia gravis. Ann Thorac Cardiovasc Surg 2008;14:119-22.
57. Yeh CM, Chen HC, Chou CM, et al. Hybrid combination of small subxiphoid incision and thoracoscopic thymectomy for juvenile myasthenia gravis. J Pediatr Surg 2011;46:780-3.
58. Ware TL, Ryan MM, Kornberg AJ. Autoimmune myasthenia gravis, immunotherapy and thymectomy in children. Neuromuscul Disord 2012;22:118-21.
59. Parikh K, Vaidya A, Jain R. Preliminary results of VATS thymectomy for pediatric myasthenia gravis. Pediatr Surg Int 2011;27:595-8.
60. Christison-Lagay E, Dharia B, Vajsar J, et al. Efficacy and safety of thoracoscopic thymectomy in the treatment of juvenile myasthenia gravis. Pediatr Surg Int 2013;29:583-6.
61. Özkan B, Demir A, Kapdagli M, et al. Results of videothoracoscopic thymectomy in children: an analysis of 40 patients†. Interact Cardiovasc Thorac Surg 2015;21:292-5.
62. Ashfaq A, Bernes SM, Weidler EM, et al. Outcomes of thoracoscopic thymectomy in patients with juvenile myasthenia gravis. J Pediatr Surg 2016;51:1078-83.
63. Jastrzębska A, Jastrzębski M, Ryniewicz B, et al. Treatment outcome in juvenile-onset myasthenia gravis. Muscle Nerve 2019;59:549-54.
64. Derderian SC, Potter DD, Bansal S, et al. Open versus thoracoscopic thymectomy for juvenile myasthenia gravis. J Pediatr Surg 2020;55:1850-3.
65. Ampollini L, Del Rio P, Sianesi M, et al. Transcervical video-assisted thymectomy: preliminary results of a modified surgical approach. Langenbecks Arch Surg 2011;396:267-71.
66. Kirschner PA, Osserman KE, Kark AE. Studies in Myasthenia Gravis: Transcervical Total Thymectomy. JAMA 1969;209:906-10.
67. Schumacher ED, Roth O. Thymektomie bei einem Fall von morbus Basedowi mit. Myasthenie: G. Fischer; 1912.
68. Jaretzki A 3rd. Thymectomy for myasthenia gravis: analysis of controversies--patient management. Neurologist 2003;9:77-92.
69. Yu L, Shan M, Jiang J, et al. Combined transcervical and unilateral-thoracoscopic thymectomy for myasthenia gravis: 2 years of follow-up. Surg Laparosc Endosc Percutan Tech 2008;18:489-92.
70. Mineo TC, Pompeo E, Ambrogi V. Video-assisted thoracoscopic thymectomy: from the right or from the left? J Thorac Cardiovasc Surg 1997;114:516-7.
71. Li F, Ismail M, Elsner A, et al. Surgical Techniques for Myasthenia Gravis: Robotic-Assisted Thoracoscopic Surgery. Thorac Surg Clin 2019;29:177-86.
72. Rückert JC, Walter M, Müller JM. Pulmonary function after thoracoscopic thymectomy versus median sternotomy for myasthenia gravis. Ann Thorac Surg 2000;70:1656-61.
73. Henze A, Biberfeld P, Christensson B, et al. Failing transcervical thymectomy in myasthenia gravis. An evaluation of transsternal re-exploration. Scand J Thorac Cardiovasc Surg 1984;18:235-8.
74. Sonett JR, Jaretzki A 3rd. Thymectomy for nonthymomatous myasthenia gravis: a critical analysis. Ann N Y Acad Sci 2008;1132:315-28.
75. Huang CS, Cheng CY, Hsu HS, et al. Video-assisted thoracoscopic surgery versus sternotomy in treating myasthenia gravis: comparison by a case-matched study. Surg Today 2011;41:338-45.
76. De Boer C, Zeineddin S, Ott K, et al. Measuring the Efficacy of Thymectomy for Pediatric Myasthenia Gravis Across Tertiary Children's Hospitals. Pediatr Neurol 2023;148:17-22.

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77. Ashton RC Jr, McGinnis KM, Connery CP, et al. Totally endoscopic robotic thymectomy for myasthenia gravis. Ann Thorac Surg 2003;75:569-71.
78. Rückert JC, Swierzy M, Ismail M. Comparison of robotic and nonrobotic thoracoscopic thymectomy: a cohort study. J Thorac Cardiovasc Surg 2011;141:673-7.
79. Kawaguchi K, Fukui T, Nakamura S, et al. A bilateral approach to extended thymectomy using the da Vinci Surgical System for patients with myasthenia gravis. Surg Today 2018;48:195-9.
80. Suda T, Tochii D, Tochii S, et al. Trans-subxiphoid robotic thymectomy. Interact Cardiovasc Thorac Surg 2015;20:669-71.
81. Renaud S, Santelmo N, Renaud M, et al. Robotic-assisted thymectomy with Da Vinci II versus sternotomy in the surgical treatment of non-thymomatous myasthenia gravis: early results. Rev Neurol (Paris) 2013;169:30-6.

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