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Outcomes after anti-reflux procedures: Nissen, Toupet, magnetic sphincter augmentation or anti-reflux mucosectomy?

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Abstract

Background Surgical treatment options of gastroesophageal reflux disease have changed significantly in the last 50 years. Magnetic Sphincter Augmentation (MSA) and Anti-reflux Mucosectomy (ARMs) are gaining traction but there is a paucity of literature comparing these novel options to Toupet fundoplication and gold standard Nissen fundoplication.

Methods This is a retrospective review of a prospectively maintained database, evaluating patients undergoing Nissen, Toupet, MSA, and ARMs. Pre-operative, intra-operative, and post-operative variables including Reflux symptom index (RSI), Gastroesophageal Reflux Disease-Health Related Quality of Life questionnaire (GERD-HRQL), and Dysphagia scores were compared between groups.

Results During the study period, 649 patients underwent anti-reflux surgery. Patients who underwent Nissen or Toupet were younger than those undergoing MSA or ARMs (65 ± 12 and 67 ± 14 years vs 56 ± 14 and 56 ± 18 years, $P < 0.01$). Average operative time for Nissen was 127 ± 40 min which was similar to a Toupet at 122 ± 32 min. These durations were significantly longer than for MSA, averaging 79 ± 29, and ARMs, at a mean 35 ± 3 min (all $P < 0.001$). Length of stay was significantly different among all four groups with Nissen, Toupet, MSA, and ARMs patients staying a median of 31, 24, 7, and 3 h post operatively, respectively (all $P < 0.001$). Complications and re-admissions were similarly low among all groups. Despite minor differences in RSI and GERD-HRQL scores at isolated follow-up time points, quality of life scores seems to be similar overall at up to 5 years follow-up. Gas bloat and dysphagia did not differ among groups at any time point.

Conclusions Novel anti-reflux surgery options provide similar GERD-related quality of life compared to traditional full or partial fundoplications with the added benefit of shorter operative time and faster recovery.

Keywords Nissen · Toupet · Magnetic sphincter augmentation · Anti-reflux mucosectomy · GERD · Quality of life

The surgical treatment of gastroesophageal reflux disease (GERD) has changed tremendously since the Nissen fundoplication was first performed over 60 years ago. Just as partial fundoplications have grown in popularity, new methods to treat GERD have emerged. Magnetic sphincter augmentation (MSA) is becoming increasingly utilized due to a shorter operative time, ease of reversibility, and less post-operative gas bloat [1, 2]. One of the least invasive treatment options is the Anti-reflux Mucosectomy (ARMs) which uses endoscopic mucosal resection to tighten the gastroesophageal junction by inducing scaring [3].

There has been extensive research comparing Nissen and Toupet Fundoplications [4–6]. Additionally, many studies have investigated the efficacy and safety of MSA compared to Nissen [7, 8]. However, there have been few studies comparing MSA to Toupet and studies that compare all four anti-reflux procedures do not exist in the current literature [9]. A paucity of data comparing these procedures prevents providers from having an informed discussion with patients regarding the full range of treatment options.

This study is the first to compare Nissen, Toupet, MSA and ARMs with an emphasis on both perioperative and long-term quality of life outcomes. We hypothesize that novel treatment options such as MSA and ARMs provide

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similar patient outcomes compared to traditional operations with shorter operative time and length of stay.

Materials and methods

Data acquisition

An institutional review board approved this study utilizing a quality gastroesophageal database. This database is prospectively maintained as described in numerous prior publications [10, 11]. In brief, patients are entered into the database at first clinical encounter relating to gastroesophageal symptoms and are followed by research assistants and research fellows throughout their treatment course. Data from pre-operative, intra-operative, and post-operative time periods are prospectively collected through the electronic medical record. In addition to post-operative visits, online surveys are sent to all patients prior to surgery, as well as at various time points after their procedure [11].

The gastroesophageal database was queried for all patient undergoing anti-reflux procedures between 2008 and 2021. These procedures include laparoscopic Nissen fundoplication, laparoscopic Toupet fundoplication, laparoscopic magnetic sphincter augmentation, and anti-reflux mucosectomy. Patients undergoing re-do anti-reflux procedures or combination procedures were excluded.

Subgroup analysis was performed on patients excluding paraesophageal hernias and hiatal hernias greater than 2 cm. Hiatal hernia measurements were taken cranially caudally and acquired preferentially from operative notes. If not available, data were gleaned from pre-operative esophograms.

Operative protocol

Choice of anti-reflux procedure was left to the discretion of the operating surgeon after informed discussion with each patient. Patients were only offered Magnetic Sphincter Augmentation if manometry results met criteria for insertion. Instructions for insertion recommended patients have distal esophageal motility greater than 35 mmHg peristaltic amplitude on wet swallows or greater than 70% (propulsive) peristaltic sequences [12]. Our institution only offers MSA in those with 80% normal swallows. Anti-reflux mucosectomy was only offered to patients with a hiatal hernia measuring less than or equal to 2 cm [3, 13]. Our institution's operative protocols for all four procedures are well described previously [14].

Clinical follow-up

Patients are seen in clinic at 2–4 weeks after surgery for post-operative check. Additionally, patients are given Reflux Symptom Index (RSI), GERD-health related quality of life (GERD-HRQL), and Dysphagia Score surveys via email at 3 weeks, 6 months, 1 year, 2 years, and 5 years after surgery. These scores are described in the literature and our prior publications [10, 15, 16]. Briefly, RSI asks nine questions exploring atypical GERD symptoms and scores each question as 0 (no problem) to 5 (severe problem). The highest and worst score possible is 45. Scores greater than 13 suggest severe reflux. GERD-HRQL asks ten questions exploring typical GERD symptoms and scores each question 0 (no symptoms) to 5 (symptoms are incapacitating). The highest and worst score possible is 50. Gas bloat was evaluated based on the answer to question 9 on the GERD-HRQL (i.e., Do you have bloating or gassy feelings?), and dysphagia frequency was evaluated based on question 7 (i.e., Do you have difficulty swallowing?).

Statistical methods

Patient and clinical characteristics were summarized using mean with standard deviation, median with interquartile range or frequency with percentage. Comparisons between surgical procedure types were made using the Kruskal–Wallis test with Dwass, Steel, Critchlow–Flinger method to adjust for multiple comparisons for numeric variables and χ^2 or Fisher's exact tests with the Bonferroni correction for categorical variables. Subgroup analysis of patients with a hiatal hernia of 2 cm or less was also performed. All statistical tests were two-tailed and performed using SAS 9.4 (SAS Institute, Cary, NC) with statistical significance set at $P < 0.05$.

Results

Demographic information

During the study period, 649 patients underwent anti-reflux surgery. Basic demographic and pre-operative information is demonstrated in Table 1. There were a few differences noted between groups. Patients who underwent Nissen were older than patients in the MSA and ARMs groups (65 ± 12 vs. 56 ± 14 years and 56 ± 18 years, $P < 0.001$, $P < 0.01$). Similarly, patients who underwent Toupet had an average age of 67 ± 14 years which was older than patients in MSA and ARMs groups ($P < 0.001$, $P = 0.003$). Patients in the ARMs group had a lower body mass index than both Nissen and Toupet patients

Table 1 Demographics and pre-operative information

	Nissen	Toupet	MSA	ARMs
Total patients, *N*	356	207	46	40
Age, years [mean ± SD]	**65 ± 12MA**	**67 ± 14MA**	**56 ± 14^{NT}**	**56 ± 18^{NT}**
Body Mass Index [mean ± SD]	**29.6 ± 4.9^{A}**	**29.0 ± 4.5^{A}**	28.7 ± 4.5	**26.8 ± 4.1^{NT}**
Male [*N* (%)]	**99 (27.8)^{TM}**	**74 (35.7)^{N}**	**21 (45.7)^{N}**	14 (35.0)
Smoking status [*N* (%)]				
Never	196 (55.1)	118 (57.0)	34 (73.9)	28 (70.0)
Former	147 (41.3)	86 (41.5)	12 (26.1)	11 (27.5)
Current	13 (3.7)	3 (1.4)	0 (0.0)	1 (2.5)
Prior medical history [*N* (%)]				
MI/CAD	29 (8.1)	21 (10.1)	1 (2.2)	1 (2.5)
Hypertension requiring medication	**41 (11.5)^{T}**	**48 (23.2)^{N}**	10 (21.7)	8 (20.0)
Pneumonia	22 (6.2)	21 (10.1)	4 (8.7)	2 (5.0)
COPD	13 (3.7)	12 (5.8)	1 (2.2)	3 (7.5)
Diabetes	29 (8.1)	19 (9.2)	2 (4.3)	2 (5.0)
Pre-operative symptoms [*N* (%)]				
Heartburn	258 (72.5)	154 (74.4)	35 (76.1)	24 (60.0)
Regurgitation	224 (62.9)	134 (64.7)	34 (73.9)	19 (47.5)
Dysphagia	**156 (43.8)^{A}**	**91 (44.0)^{A}**	16 (34.8)	**9 (22.5)^{NT}**
Cough	113 (31.7)	64 (30.9)	20 (43.5)	15 (37.5)
Epigastric chest pain	122 (34.3)	73 (35.3)	15 (32.6)	13 (32.5)
Preop proton pump inhibitor use [*N* (%)]	319 (89.6)	174 (84.1)	43 (93.5)	33 (82.5)
Esophageal motility [*N* (%)]				
Normal	**288 (80.9)^{T}**	**79 (38.2)^{NMA}**	**42 (91.3)^{T}**	**35 (87.5)^{T}**
Ineffective	**23 (6.5)^{T}**	**91 (44.0)^{NMA}**	**4 (8.7)^{T}**	**5 (12.5)^{T}**
No manometry report	**45 (12.6)**	**37 (17.9)^{MA}**	**0 (0.0)^{T}**	**0 (0.0)^{T}**
Hernia type [*N* (%)]				
None	**7 (2.0)^{TMA}**	**33 (15.9)^{NA}**	**7 (15.2)^{NA}**	**37 (92.5)^{NTM}**
Hiatal	**102 (28.7)^{MA}**	**53 (25.6)^{M}**	**32 (69.6)^{NTA}**	**3 (7.5)^{NM}**
Paraesophageal	**247 (69.4)^{MA}**	**121 (58.5)^{MA}**	**7 (15.2)^{NT}**	**0 (0.0)^{NT}**

P-value of < 0.05 is considered statistically significant

MSA magnetic sphincter augmentation, *MI/CAD* myocardial infarction, coronary artery disease, *COPD* chronic obstructive pulmonary disease

^{N}Significant compared to Nissen

^{T}Significant compared to Toupet

^{M}Significant compared to MSA

^{A}Significant compared to ARMs

Bold values are statistically significant

(26.8 ± 4.1 vs. 29.6 ± 4.9 and 29.0 ± 4.5, $P = 0.003$, $P = 0.04$). Lastly, a smaller proportion of patients who underwent Nissen were male compared to Toupet and MSA (27.8% vs. 35.7% and 45.7%, $P = 0.049$, $P = 0.013$). Smoking history and prior medical history was similar among all groups with the exception of a greater percentage of Toupet patients having hypertension compared to Nissen (23.2% vs. 11.5%, $P = 0.003$). Notably, the proportion of patients with COPD was equivalent between all groups. Taken together, these data suggest some of these groups differed in age, BMI, and gender but were similar regarding pertinent medical history.

Peri-operative symptoms, motility, and hernia type

Pre-operative symptoms, motility and hernia type are also described in Table 1. Symptoms were similar among all groups with typical heartburn being the most commonly reported symptom in all groups. The highest percentage of patients in each group experiencing typical heart burn. A higher proportion of patients in the Nissen and Toupet groups experienced dysphagia compared to ARMs (43.8% and 44% vs. 22.5% $P = 0.01$, $P = 0.011$). In terms of motility, 44% of the Toupet group had ineffective motility which was significantly higher than 6.5% in the Nissen group, 8.7% in

the MSA group and 12.5% in the ARMs group ($P < 0.001$ for each). Distribution of hiatal hernia type differed between groups. Consistent with our practice pattern, nearly all of the patients who underwent ARMS (92.5%) had no hiatal hernia which was significantly more than the patients who underwent Nissen (2%), Toupet (15.9%) or MSA (15.2%) ($P \leq 0.001$ for each). A similar percentage of patients who underwent Nissen and Toupet had paraesophageal hernias which was significantly more than both MSA and ARMs (69.4% and 58.5% vs. 15.2% and 0%, $P \leq 0.001$ for each). These data demonstrate that symptoms were similar among groups but motility and type of hernia differed.

Intraoperative and post-operative comparisons

Peri-operative information is shown in Table 2. Average operative time of a Nissen was 127 ± 40 min which was similar to a Toupet at 122 ± 32 min. These durations were significantly longer when compared to MSA averaging 79 ± 29 min ($P < 0.001$, $P < 0.001$). The shortest procedure was ARMs at a mean 35 ± 3 min ($P < 0.001$ for each). Intraoperative complications were similarly low in all groups. Length of stay was significantly different among all four groups with Nissen, Toupet, MSA, and ARMs patients staying a median of 31, 24, 7, and 3 h post operatively ($P < 0.001$ for each). Days until return to activities of daily living was shorter in the ARMs group who required a median 1 day compared to 5 days in both Nissen and Toupet groups ($P < 0.001$, $P < 0.001$). Readmission within 30 days was low in all groups. Hernia recurrence occurred in 10.7% of patients after Nissen compared to 4.3% of patients after Toupet ($P < 0.001$) but the Nissen group also had nearly double the length of follow-up time (28 ± 19 vs. 15 ± 14 months, $P = 0.047$). There have been no hernia recurrences after MSA thus far. Taken together, MSA and ARMs were shorter procedures leading to faster recovery despite similarly low complication and readmission rates when compared to traditional anti-reflux surgery. Hernia recurrence is difficult to interpret due to wide variation in follow-up and differences in group hernia characteristics.

Quality of life outcomes

Quality of life data in the pre- and post-operative period are shown in Table 3. Pre-operative scores were similar among groups with the exception of a higher GERD-HRQL score in the MSA group compared to Nissen signifying worse typical GERD symptoms in this group (19.4 ± 9.6 vs. 13.9 ± 11.6, $P = 0.043$). RSI, gas bloat and dysphagia scores were similar among all groups preoperatively.

At 3 weeks follow-up, MSA patients had higher RSI and GERD-HRQL scores than Toupet patients signifying worse atypical and typical GERD symptoms at this time point (15.4 ± 10.1 vs. 9.5 ± 8.6, $P = 0.044$ and 9.6 ± 7.2 vs. 4.8 ± 5.3, $P = 0.043$). By 6 months, these differences resolved with all four groups having similar RSI and GERD-HRQL scores.

At 1 year follow-up, MSA patients had a GERD-HRQL score of 6.9 ± 5.5 which was significantly higher than to 2.5 ± 3.6 in the ARMs group ($P = 0.048$). This difference did not persist at 2 years follow-up, though at 5 years follow-up, MSA patients had a statistically significantly higher RSI score compared to Toupet (17.8 ± 7.7 vs. 4.9 ± 5.7, $P = 0.024$). Gas bloat and dysphagia scores were similar among all four groups at all five time points.

Taken together, despite minor differences in typical and atypical GERD symptoms at isolated follow-up time points,

Table 2 Peri-operative data

	Nissen	Toupet	MSA	ARMs
Operative time, minutes [mean ± SD]	**127 ± 40MA**	**122 ± 32MA**	**79 ± 29^{NTA}**	**35 ± 3^{NTM}**
Intraoperative complication [*N* (%)]	14 (3.9)	8 (3.9)	0 (0.0)	0 (0.0)
Length of stay, hours [median (*Q*1–*Q*3)]	**31 (24–48)^{TMA}**	**24 (24–48)^{NMA}**	**7 (6–8)^{NTA}**	**3 (3–6)^{NTM}**
Return to activity, days [median (*Q*1–*Q*3)]	**5 (2–7)^{A}**	**5 (3–7)^{A}**	3 (1–7)	**1 (1–2)^{NT}**
30 day readmission [*N* (%)]	28 (7.9)	20 (9.7)	2 (4.3)	1 (2.5)
Hernia recurrence [*N* (%)]	**38 (10.7)^{TM}**	**9 (4.3)^{N}**	**0 (0.0)^{N}**	NA
Months to recurrence [mean ± SD]	**28 ± 19^{T}**	**15 ± 14^{N}**		
Follow-up, months [median (*Q*1–*Q*3)]	**20 (3–48)^{TA}**	**11 (3–22)^{NM}**	**22 (5–39)^{TA}**	**5 (1–25)^{NM}**

P-value of < 0.05 is considered statistically significant

MSA magnetic sphincter augmentation, *ARMs* anti-reflux mucosectomy

^{N}Significant compared to Nissen

^{T}Significant compared to Toupet

^{M}Significant compared to MSA

^{A}Significant compared to ARMs

Bold values are statistically significant

Table 3 Quality of life outcomes

	Nissen	Toupet	MSA	ARMs
Preop	$N=165$	$N=110$	$N=33$	$N=9$
RSI	17.4 ± 11.9	17.6 ± 10.1	21.3 ± 9.9	18.5 ± 10.8
GERD-HRQL	**13.9 ± 11.6^{M}**	15.6 ± 10.2	**19.4 ± 9.6^{N}**	14.9 ± 11.3
Gas/Bloat	2.2 ± 1.7	2.0 ± 1.4	2.1 ± 1.4	1.9 ± 1.6
Dysphagia Score	1.3 ± 0.6	1.3 ± 0.8	1.3 ± 0.6	1.3 ± 0.8
3 Weeks	$N=147$	$N=81$	$N=21$	$N=15$
RSI	10.2 ± 8.3	**9.5 ± 8.6^{M}**	**15.4 ± 10.1^{T}**	12.9 ± 7.2
GERD-HRQL	5.8 ± 6.6	**4.8 ± 5.3^{M}**	**9.6 ± 7.2^{T}**	7.4 ± 6.9
Gas/Bloat	1.7 ± 1.5	1.3 ± 1.2	1.9 ± 1.7	1.1 ± 1.4
Dysphagia Score	2.1 ± 0.9	2.0 ± 1.0	2.1 ± 0.5	1.9 ± 0.9
6 Months	$N=71$	$N=51$	$N=14$	$N=19$
RSI	9.3 ± 8.6	7.5 ± 7.5	12.2 ± 8.3	9.6 ± 7.6
GERD-HRQL	4.9 ± 6.4	5.3 ± 7.3	6.8 ± 6.6	5.7 ± 5.7
Gas/Bloat	1.8 ± 1.4	1.9 ± 1.3	1.2 ± 1.3	1.2 ± 1.5
Dysphagia Score	1.1 ± 0.4	1.4 ± 0.7	1.4 ± 0.6	1.1 ± 0.3
1 Year	$N=116$	$N=88$	$N=17$	$N=11$
RSI	8.4 ± 9.0	7.7 ± 8.0	10.2 ± 6.2	8.7 ± 4.6
GERD-HRQL	4.6 ± 6.6	4.5 ± 5.6	**6.9 ± 5.5^{A}**	**2.5 ± 3.6^{M}**
Gas/Bloat	1.5 ± 1.4	1.8 ± 1.3	1.5 ± 1.2	0.7 ± 1.2
Dysphagia Score	1.1 ± 0.4	1.2 ± 0.6	1.4 ± 0.6	1.3 ± 0.6
2 Years	$N=135$	$N=63$	$N=23$	$N=8$
RSI	9.9 ± 10.2	7.2 ± 8.0	12.1 ± 10.1	10.8 ± 8.5
GERD-HRQL	5.6 ± 8.1	4.5 ± 6.3	6.3 ± 6.1	6.4 ± 3.9
Gas/Bloat	1.9 ± 1.5	1.6 ± 1.5	1.6 ± 1.3	0.9 ± 1.5
Dysphagia Score	1.1 ± 0.4	1.2 ± 0.6	1.2 ± 0.4	1.3 ± 0.5
5 Years	$N=85$	$N=19$	$N=6$	$N=2$
RSI	9.0 ± 9.6	**4.9 ± 5.7^{M}**	**17.8 ± 7.7^{T}**	1.5 ± 0.7
GERD-HRQL	5.0 ± 7.4	3.7 ± 3.7	9.3 ± 7.3	3.5 ± 0.7
Gas/Bloat	1.5 ± 1.4	1.7 ± 1.3	1.3 ± 1.6	1.0 ± 0.0
Dysphagia Score	1.2 ± 0.6	1.3 ± 0.9	1.3 ± 0.8	1.0 ± 0.0

P-value of <0.05 is considered statistically significant

MSA magnetic sphincter augmentation, *ARMs* anti-reflux mucosectomy, *RSI* Reflux Symptom Index, *GERD-HRQL* gastroesophageal reflux disease health related quality of life

^{N}Significant compared to Nissen

^{T}Significant compared to Toupet

^{M}Significant compared to MSA

^{A}Significant compared to ARMs

Bold values are statistically significant

quality of life scores seems to be similar after Nissen, Toupet, MSA and ARMs overall.

Small or absent hiatal hernia subgroup analysis

A subgroup analysis was performed including only patients without hiatal hernia or with hernia size less than 2 cm. Basic demographic and pre-operative information is shown in Supplementary Table 1 and demonstrates a more matched cohort. All four groups are similar in terms of age, body mass index, gender, medical history and presenting symptoms. Peri-operative information of this new cohort is shown in Table 4.

With paraesophageal and large hiatal hernias excluded, Nissen has a shorter mean operative duration than in the original analysis at 104 ± 32 min, but still significantly longer than both MSA at 71 ± 19 min and ARMs at 35 ± 3 min ($P<0.001$, $P<0.001$). The Toupet group exhibits a similar change with a shorter mean operative duration of 102 ± 31 min, but remains significantly longer than both the MSA and ARMs groups ($P<0.001$, $P<0.001$). Complications remain low across all groups. Length of stay remained significantly different among all four groups with Nissen, Toupet, MSA, and ARMs patients staying a median of 24, 20, 7, and 3 h post operatively ($P<0.01$ for each). Days until return to activities of daily living was significantly shorter in the ARMs group, with a median of 1 day, compared to 4 days in both Nissen and Toupet groups ($P=0.004$, $P=0.007$). This was not significantly shorter than the MSA group. Readmission after 30 days remained equally low among the four groups. Hernia recurrence in this subgroup was also similarly low but small sample size prevented statistical comparison of time to recurrence. Median follow-up was shortest in the ARMs group at 5 months compared to 21 months and 23 months in the Nissen and MSA groups, respectively ($P=0.012$, $P=0.047$). Table 5 demonstrates quality of life outcomes with all four groups reporting similar RSI, GERD-HRQL, gas bloat, and dysphagia scores at all time points. Follow-up data at 5 years were excluded due to small sample size.

This subgroup analysis of patients with 2 cm or smaller hiatal hernias confirms differences noted in the original analysis; MSA and ARMs had a shorter operative time and shorter length of stay compared to traditional anti-reflux surgery with low rates of complications and re-admissions. Post-operative typical and atypical reflux symptoms, presence of gas bloat and dysphagia rates were equivalent after all four procedures at up to 2 years of follow-up.

Table 4 Peri-operative data in patients with small or absent hiatal hernia

	Nissen	Toupet	MSA	ARMs
Operative time, minutes [mean ± SD]	**104 ± 32MA**	**102 ± 31MA**	**71 ± 19^{NTA}**	**35 ± 3^{NTM}**
Intraoperative complication [*N* (%)]	3 (5.6)	2 (3.3)	0 (0.0)	0 (0.0)
Length of stay, hours [median (*Q*1–*Q*3)]	**24 (24–34)^{TMA}**	**20 (8–24)^{NMA}**	**7 (6–8)^{NTA}**	**3 (3–6)^{NTM}**
Return to activity, days [median (*Q*1–*Q*3)]	**4 (2–7)^{A}**	**3 (2–7)^{A}**	3 (2–7)	**1 (1–2)^{NT}**
30 day readmission [*N* (%)]	3 (5.6)	5 (8.2)	1 (4.3)	1 (2.5)
Hernia recurrence [*N* (%)]	5 (9.3)	2 (3.3)	0 (0.0)	NA
Months to recurrence [mean ± SD]	32 ± 30	3 ± 1		
Follow-up, months [median (*Q*1–*Q*3)]	**21 (8–51)^{A}**	12 (5–20)	**23 (6–41)^{A}**	**5 (1–25)^{NM}**

P-value of < 0.05 is considered statistically significant

MSA magnetic sphincter augmentation, *ARMs* anti-reflux mucosectomy

^{N}Significant compared to Nissen

^{T}Significant compared to Toupet

^{M}Significant compared to MSA

^{A}Significant compared to ARMs

Bold values are statistically significant

Table 5 Quality of life outcomes in patients with small or absent hiatal hernia

	Nissen	Toupet	MSA	ARMs
Preop	*N* = 24	*N* = 38	*N* = 17	*N* = 31
RSI	22.0 ± 10.7	20.3 ± 10.0	21.8 ± 7.6	18.5 ± 10.8
GERD-HRQL	14.8 ± 13.6	19.1 ± 9.8	17.6 ± 10.0	14.9 ± 11.3
Gas/Bloat	2.8 ± 1.6	2.2 ± 1.4	2.5 ± 1.2	1.9 ± 1.6
Dysphagia Score	1.1 ± 0.3	1.2 ± 0.7	1.4 ± 0.7	1.3 ± 0.8
3 Weeks	*N* = 28	*N* = 26	*N* = 11	*N* = 15
RSI	12.0 ± 7.2	11.4 ± 8.5	12.6 ± 10.8	12.9 ± 7.2
GERD-HRQL	6.4 ± 5.0	6.3 ± 6.1	8.4 ± 6.8	7.4 ± 6.9
Gas/Bloat	2.0 ± 1.3	1.4 ± 1.2	1.9 ± 1.6	1.1 ± 1.4
Dysphagia Score	2.0 ± 0.8	2.2 ± 1.0	2.3 ± 0.6	1.9 ± 0.9
6 Months	*N* = 15	*N* = 18	*N* = 7	*N* = 19
RSI	12.0 ± 7.0	10.9 ± 8.1	13.7 ± 8.2	9.6 ± 7.6
GERD-HRQL	6.1 ± 8.2	8.4 ± 8.4	7.9 ± 8.0	5.7 ± 5.7
Gas/Bloat	2.1 ± 1.4	2.2 ± 1.2	1.3 ± 1.3	1.2 ± 1.5
Dysphagia Score	1.2 ± 0.6	1.6 ± 0.8	1.4 ± 0.8	1.1 ± 0.3
1 Year	*N* = 20	*N* = 30	*N* = 9	*N* = 11
RSI	11.2 ± 12.3	11.1 ± 8.9	9.7 ± 6.7	8.7 ± 4.6
GERD-HRQL	6.6 ± 9.7	6.1 ± 7.4	6.8 ± 5.5	2.5 ± 3.6
Gas/Bloat	1.9 ± 1.5	2.0 ± 1.2	1.7 ± 1.2	0.7 ± 1.2
Dysphagia Score	1.1 ± 0.3	1.3 ± 0.6	1.6 ± 0.7	1.3 ± 0.6
2 Years	*N* = 22	*N* = 20	*N* = 13	*N* = 8
RSI	11.6 ± 11.9	9.3 ± 8.5	10.5 ± 9.5	10.8 ± 8.5
GERD-HRQL	6.4 ± 9.7	5.1 ± 6.5	6.2 ± 5.3	6.4 ± 3.9
Gas/Bloat	2.1 ± 1.7	2.0 ± 1.4	1.9 ± 1.4	0.9 ± 1.5
Dysphagia Score	1.1 ± 0.3	1.1 ± 0.3	1.2 ± 0.4	1.3 ± 0.5

MSA magnetic sphincter augmentation, *ARMs* anti-reflux mucosectomy, *RSI* Reflux Symptom Index, *GERD-HRQL* gastroesophageal reflux disease health related quality of life

Discussion

This is the first study comparing perioperative data and long-term quality of life outcomes after Nissen, Toupet, MSA and ARMs. The cohorts differed in some ways that are likely a reflection of practice patterns. For example, MSA and ARMs were performed on a younger, less obese patient population who had small or absent hiatal hernias. Motility was normal in the gross majority of patients who underwent Nissen, MSA or ARMs, in contrast to patients who underwent Toupet. All four procedures had low complication and readmission rates. ARMs patients had the shortest operative time, length of stay, and return to normal activity; MSA had the second shortest operative time and length of stay. Recurrence was highest after Nissen but differences in follow-up time make this finding difficult to interpret. Typical and Atypical GERD symptoms were similar overall after the four procedures with only isolated non-sustained differences at certain time points. Specifically, neither symptoms of gas bloat nor dysphagia differed among any of the procedures at any timepoint. These findings were confirmed in a subcohort of patients with small or absent hiatal hernias who underwent anti-reflux surgery. The results of this study suggest that novel anti-reflux surgery options provide similar improvements in GERD-related quality of life compared to traditional full or partial fundoplications with the added benefit of shorter operative time and faster recovery.

These findings fit nicely into the existing literature. Gunter et al. performed an observational study of over 300 patients who underwent Nissen and Toupet fundoplication. The authors compared GERD-HRQL and Eckhardt dysphagia scores at 1, 3, and 5 years follow-up [17]. Similar to our data, the authors found no sustained differences in GERD quality of life, bloating or dysphagia between groups. Large meta-analyses support these findings though some studies

suggest worse dysphagia and gas bloat after Nissen that resolves at longer follow-up [18, 19]. As a new treatment therapy, MSA has been rigorously tested against the gold standard. Numerous trials have shown similar GERD-related quality of life outcomes to Nissen in addition to lower rates of gas bloat [20–22]. This is in contrast to our study which demonstrated similarly low gas bloat scores across all four procedures. The exact reason for this difference is unclear though it is worth noting that almost all of these previous studies do not report on follow-up beyond 1 year; it's conceivable that gas bloat improves over longer intervals, equalizing the discrepancy found at early follow-up. Few studies exist that specifically compare outcomes between MSA and Toupet fundoplication. One such study compared 238 patients who underwent either Toupet or MSA using propensity score matching [9]. Similar to our study, the authors found similar GERD-HRQL, gas bloat, and dysphagia scores. As previously stated, there are no prior studies, outside of our institution, comparing outcomes of ARMs to any of the three other treatment options. Overall, our results are consistent with existing data related to anti-reflux surgery.

Numerous additional interesting findings are worth addressing in our data. First, there were higher rates of pre-operative dysphagia in the Nissen and Toupet groups compared to ARMs. This finding can likely be explained by a larger proportion of these patients having large hiatal or paraesophageal hernias which tend to present as dysphagia. Second, although nearly 90% of MSA and ARMs patients had normal esophageal motility, we were surprised that nine patients with ineffective motility were still offered these treatment options, as this is seemingly against our practice pattern. In re-evaluating the manometry studies of these patients, we found that many had completely normal peristalsis but slightly anormal bolus transit, flagging them as ineffective motility but still remaining appropriate for both MSA or ARMs. Lastly, as discussed above, the similar rates of dysphagia and gas bloat in all groups was unexpected especially with highly powered existing data suggesting a higher incidence of both after Nissen compared to Toupet or MSA. This difference is difficult to reconcile but may be related to small sample size at certain time points and limited long-term data in the existing literature.

Several limitations are worth addressing. Our institution's practice pattern has migrated away from Nissen fundoplication, only offering this treatment to younger patients with normal manometry and specific intra-operative endoflip findings. Performing the majority of these procedures at an earlier time period may influence the results to some degree and this is evident when looking at hernia recurrence discrepancies between groups. Additionally, by comparing groups that include demographic, hiatal hernia type, and motility differences, bias may be introduced. For example, this study could conceivably compare a patient with a large paraesophageal hernia with ineffective esophageal motility undergoing a Toupet to a patient without a hiatal hernia and normal manometry undergoing ARMs. It is reassuring however, that in our subgroup analysis, excluding large hiatal and paraesophageal hernias, many of these differences disappeared and the results were still consistent with the original cohort. This study, not unlike the majority of anti-reflux surgery literature, suffers from a lack of objective pH monitoring.

In summary, our study is the first in the literature to compare Nissen, Toupet, MSA, and ARMs. The more novel procedures showed clear superiority in terms of operative duration and time to recovery without compromising safety or quality of life. The practical implications of this study are vast as it provides actionable data regarding each treatment modality to better facilitate a well-informed discussion between surgeon and patient.

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Declarations

Disclosures Dr. Ujiki is a consultant for Olympus, on the Boston Scientific advisory board, a consultant and speaker for Apollo Medical Devices, a speaker for Medtronic, and a speaker for Gore Medical. Dr. Callahan, Dr. Amundson, Dr. Su, Ms. Kuchta, have no conflicts of interest or financial ties to disclose.

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