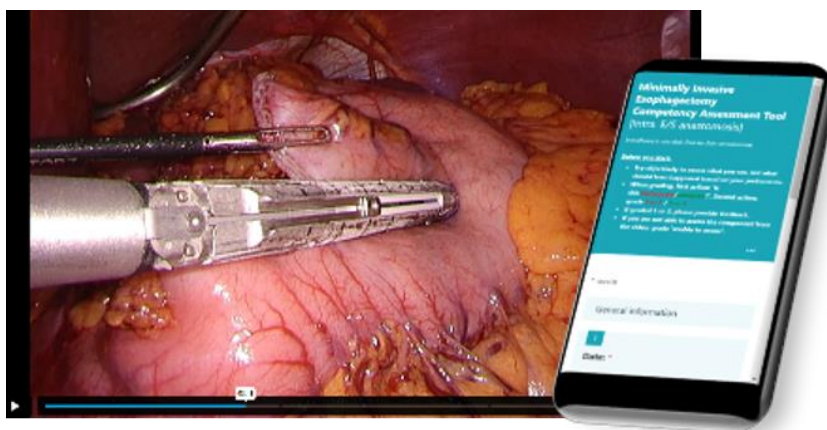# Supplemental Online Content

eMethods 1. MIE-CAT Score Calculation

MIE-CAT overview:

Procedural Phase	MIE-CAT score, based on Delphi lymph nodes	MIE-CAT score, based on center's lymph nodes
1. Mobilization of the greater curvature		
2. Mobilization of the lesser curvature		
3. Dissection of abdominal lymph nodes	*	*
4. Dissection of the hiatus		
5. Creation of the gastric tube		
6. Mobilization of the thoracic esophagus		
7. Dissection of thoracic lymph nodes	*	*
8. Creation of the anastomosis	[a]	[a]

Phase scores ranged 4 to 16, quality component scores 8-32 and total MIE-CAT score 32-128.

[a]The online MIE-CAT version with anastomosis techniques:

Minimally Invasive Esophagectomy Competency Assessment Tool [Intrathoracic S/S anastomosis]

Minimally Invasive Esophagectomy Competency Assessment Tool [Intrathoracic E/S anastomosis]

Minimally Invasive Esophagectomy Competency Assessment Tool [Cervical E/E anastomosis]

Minimally Invasive Esophagectomy Competency Assessment Tool [Cervical E/S anastomosis]

*Differences of lymph node dissection scoring:

Phase 3: Dissection of abdominal lymph nodes

	MIE-CAT score, based on Delphi lymph nodes	MIE-CAT score, based on center's lymph nodes
Exposure		
Execution		
Adverse events		
End-product quality	* 14, 15, 16, 17 proximal, 18	* example center 1: 15, 16, 17

Phase 7: Dissection of thoracic lymph nodes

	MIE-CAT score, based on Delphi lymph nodes	MIE-CAT score, based on center's lymph nodes
Exposure		
Execution		
Adverse events		
End-product quality	*9, 11, 12, 13 right pulmonary ligament	* example center 1: 2, 6, 7, 8, 9 10, 11, 12, 13 right pulmonary ligament

eMethods 2. Multilevel Confounders

Overview of confounders used for the multilevel analysis.

Covariates	Definition
Sex	Sex of the patient (female or male)
Age	Age of the patient at time of surgery (>18)
BMI	Body mass index (kg/m^2)
Comorbidity	ASA classification before resection (ASA 1&2 or ASA 3&4)
Neoadjuvant therapy	Neoadjuvant treatment before resection (no, chemotherapy or chemoradiotherapy)
Clinical T-stage	Tumor size or area of cancer (T1&2, T3 or T4)
Clinical N-stage	Spread to lymph nodes (N0, N1, N2 or N3&N+)
Tumor location	Location of the tumor with low (intrathoracic distal & gastro-esophageal junction) or high (cervical, intrathoracic proximal & intrathoracic middle)
Anastomosis type	Type of anastomosis (cervical or intrathoracic & intra-abdominal)
Case difficulty	Abdominal and thoracic case difficulty, scored during video assessment with a 1-5 Likert scale with 1 being very easy and 5 being very difficult

eTable 1. Characteristics of the Participating Hospitals

Experience	
Surgical experience as consultant surgeon (incl. training), mean (SD, min-max), years	21 (6.3, 10-32)
Surgical esophageal experience (incl. training and open surgery), mean (SD, min-max), years	15 (6.4, 4-26)
MIE experience (incl. training), mean (SD, min-max), years	10 (3.7, 4-19)
Responsible for training and/or education (of fellows and surgeons in training), N (%)	
Surgical training and/or education	15 (100)
MIE specific training	14 (93)
Surgeons in training	15 (100)
Fellows	14 (93)
MIE fellows	9 (60)
Start with MIE in hospital, year (min-max)	2011 (2001-2017)
Primary MIE anastomosis technique, N (%)	
Intrathoracic	10 (67)
Cervical	5 (33)
Type of surgery, N (%)	
Laparoscopic and thoracoscopic	8 (53)
Robot-assisted	7 (47)
- Abdominal laparoscopic, thoracic part robot-assisted	4 (27)
Technique	
Number of MIEs/year with primary technique (n = 15), N (%)	
5 – 25	6 (40)
25 – 50	6 (40)
50 – 75	2 (13.3)
> 75	1 (6.7)
Number of MIEs performed during career (n = 15), N (%)	
40-80 MIEs	2 (13.3)
80-120 MIEs	1 (6.7)
> 120 MIEs	12 (80)
Primary intrathoracic anastomosis (n = 10), N (%)	
Circular stapled End-to-Side	3 (30)
Linear stapled Side-to-Side	5 (50)
Robot-assisted End-to-Side	2 (20)
Primary cervical anastomosis (n = 5), N (%)	
Hand-sewn End-to-End	1 (20)
Hand-sewn End-to-Side	4 (80)
Lymph node dissection	
Abdominal lymph node stations (during routine primary MIE technique), N (%)	
Paracardial	
• Left (#14/JPN 1)	15 (100)
• Right (#14/JPN 2)	15 (100)
Left gastric artery (#15/JPN 3a&7)	15 (100)
Left gastric vein (#15/JPN 3a&7)	15 (100)
Celiac trunk (#16/JPN 9)	14 (93.3)
Splenic artery	
• Proximal (#17/JPN 11p)	15 (100)
• Distal (#17/JPN 11d)	5 (33.3)
Common hepatic artery (#18/JPN 8a&p)	14 (93.3)
Hepatoduodenal ligament	
• Portal vein (#19/JPN 12p)	6 (40)
Proper hepatic (#19/JPN 12a&16)	6 (40)
Thoracic lymph node stations (during routine primary MIE technique), N (%)	
Cervical superficialis (#1/JPN 100)	1 (6.7)
Cervical paraoesophageal (#2/JPN 101)	2 (13.3)

Upper paratracheal (#6/JPN 106pre&rec)	3 (20)
Lower paratracheal (#7/JPN 106tb)	8 (53.3)
Aortopulmonary window (#8/JPN 113)	5 (33.3)
Subcarinal (#9/JPN 107&109)	15 (100)
Mediastinal paraoesophageal	
• Upper (#10/JPN 105)	11 (73.3)
• Middle (#11/JPN 108)	15 (100)
• Lower (#12/JPN 110&111)	15 (100)
Pulmonary ligament	
• right (#13/JPN 112pulR)	14 (93.3)
left (#13/JPN 112pulLoa)	13 (86.7)

Characteristics of the 15 Dutch hospitals, containing experience, technique, and standard lymph node dissection .
If > 1 surgeon has filled in this questionnaire, the surgeon with the most experience was included.

eTable 2. Overview of Surgeons in Participating Centers

Center	Number of attending esophageal surgeons	Number of attending esophageal surgeons in videos	MIE regularly assisted by non-attending surgeons (yes/no)
1	2	2	Yes
2	3	2	No
3	3	2	Yes
4	3	3	No
5	3	2	Yes
6	5	2	Yes
7	2	2	No
8	2	2	Yes
9	3	3	No
10	3	1	No
11	3	3	Yes
12	3	2	Yes
13	4	3	Yes
14	4	3	Yes
15	3	3	No

eTable 3. Patient Characteristics

		Low n = 102	Medium n = 617	High n = 219	p-value
Age, mean (SD), y		65.0 (8.3)	67.1 (9.1)	66.3 (9.2)	0.06
Sex, N, male (%)		83 (81.4)	432 (70.1)	179 (81.7)	< 0.01
BMI, mean (SD)		26.3 (4.1)	25.6 (4.5)	26.4 (4.6)	0.07
ASA, N (%) I II III IV		7 (6.7) 63 (62.4) 31 (30.7) 0	45 (7.4) 356 (58.5) 203 (33.3) 5 (0.8)	5 (2.3) 127 (58.0) 78 (35.6) 9 (4.1)	0.01
Tumor type, N (%) Adenocarcinoma SCC Other		85 (83.3) 15 (14.7) 2 (1.9)	490 (68.3) 102 (17.0) 7 (1.2)	185 (84.5) 25 (11.4) 9 (4.1)	0.20
Tumor location, N (%) Cervical Proximal thoracic Mid thoracic Distal thoracic GE Junction		0 1 (1.0) 8 (8.0) 86 (86.0) 5 (5.0)	1 (0.2) 3 (0.5) 84 (13.9) 426 (70.7) 89 (14.8)	0 1 (0.5) 13 (5.9) 162 (74.0) 43 (19.6)	0.01
Clinical T-Stage, N (%) cTis cT1 cT2 cT3 cT4 cTx		0 4 (3.9) 17 (16.7) 71 (69.6) 5 (4.9) 5 (4.9)	0 9 (14.6) 82 (13.3) 482 (78.1) 23 (3.7) 21 (3.4)	1 (0.5) 3 (1.4) 42 (19.2) 165 (75.3) 6 (2.7) 2 (0.9)	0.08
Clinical N-Stage, N (%) cN0 cN1 cN2 cN3 cN+ cNx		32 (31.4) 38 (37.3) 26 (25.5) 4 (3.9) 0 2 (2.0)	238 (38.6) 223 (36.1) 110 (17.8) 16 (2.6) 11 (1.8) 19 (3.1)	74 (33.8) 77 (35.2) 55 (25.1) 11 (5.0) 1 (0.5) 1 (0.5)	0.08
Neoadjuvant therapy, N (%) None Chemoradiotherapy Chemotherapy		6 (5.9) 5 (4.9) 91 (89.2)	22 (3.5) 55 (8.9) 540 (87.5)	5 (2.3) 9 (4.1) 205 (93.6)	0.04
Anastomosis location, N (%) Intrathoracic Cervical		74 (73.3) 27 (26.7)	445 (72.5) 169 (27.5)	209 (95.9) 9 (4.1)	< 0.01
Peroperative complications, N (%)		8 (7.8)	28 (4.5)	6 (2.7)	0.12
Conversion, N (%)		9 (8.9)	20 (3.2)	4 (1.8)	0.01
Postoperative complications < 30 days, N (%) All Of which Clavien-Dindo ≥ 3 Anastomotic leakage		67 (65.7) 40 (39.2) 18 (17.7)	378 (61.3) 174 (28.2) 91 (14.8)	101 (46.1) 41 (18.7) 10 (4.5)	< 0.01 < 0.01 < 0.01
Textbook outcome, N (%)		51 (50.0)	305 (49.4)	144 (65.8)	< 0.01
ICU stay, mean (min-max), days		2.6 (6.9)	3.2 (7.6)	2.2 (5.4)	0.17

Removed lymph nodes, N (min-max)		27.0 (10.5)	33.0 (13.7)	29.3 (9.6)	< 0.01
R0 resection, N (%)		97 (95.1)	589 (95.9)	182 (94.8)	0.77
30-day mortality, N (%)		3 (2.9)	16 (2.6)	8 (3.7)	0.72
Re-intervention, N (%)		27 (26.5)	168 (27.4)	35 (16.0)	0.01
Re-admission, N (%)		22 (22.0)	104 (17.5)	32 (14.7)	0.27

Numerical: One-way ANOVA and Binary/Ordinal: Chi-square test

eTable 4. Multilevel Analysis of Oncologic Results

RR (95% CI) Outcome vs. MIE-CAT (component)	Three experts n = 876	External reviewer n = 733[a]	Dutch experts n = 733[a]
R0 resection vs.			
Total MIE-CAT	1.000 (0.995, 1.005)	0.984 (0.997, 1.002)	1.000 (0.998, 1.002)
Phase 4	1.004 (0.971, 1.028)	0.997 (0.983, 1.007)	0.998 (0.971, 1.016)
Phase 4 EPQ	0.989 (0.780, 1.033)	0.978 (0.870, 1.021)	1.013 (0.917, 1.037)
Phase 6	1.018 (0.992, 1.037)	1.004 (0.988, 1.015)	1.002 (0.985, 1.014)
Phase 6 EPQ	1.041 (0.977, 1.066)	1.002 (0.544, 1.042)	1.012 (0.958, 1.032)
Phases 4&6	1.009 (0.992, 1.024)	0.999 (0.988, 1.008)	1.000 (0.988, 1.010)
Phases 4&6 EPQ	1.025 (0.969, 1.054)	0.980 (0.878, 1.021)	1.008 (0.975, 1.026)
Removed lymph nodes (#) vs.			
Total MIE-CAT	0.936 (0.449, 1.640)	1.125 (0.660, 1.705)	0.871 (0.480, 1.419)
Phase 3	1.601 (0.142, 3.062)	1.865 (0.308, 3.092)	0.220 (0.001, 2.989)
Phase 3 EPQ	3.189 (0.009, 3.205)	2.266 (0.000, 3.275)	3.258 (0.000, 3.275)
Phase 7	0.173 (0.000, 3.194)	0.201 (0.001, 3.128)	0.000 (0.000, 1.490)
Phase 7 EPQ	3.205 (3.205, 3.205)	0.000 (0.000, 2.596)	3.275 (2.495, 3.275)
Phases 3 & 7	1.287 (0.139, 2.913)	1.490 (0.199, 2.998)	0.065 (0.001, 1.857)
Phases 3 & 7 EPQ	3.202 (0.267, 3.205)	3.267 (0.000, 3.275)	3.275 (0.000, 3.275)

eTable 5. Additional Multilevel Analysis Results

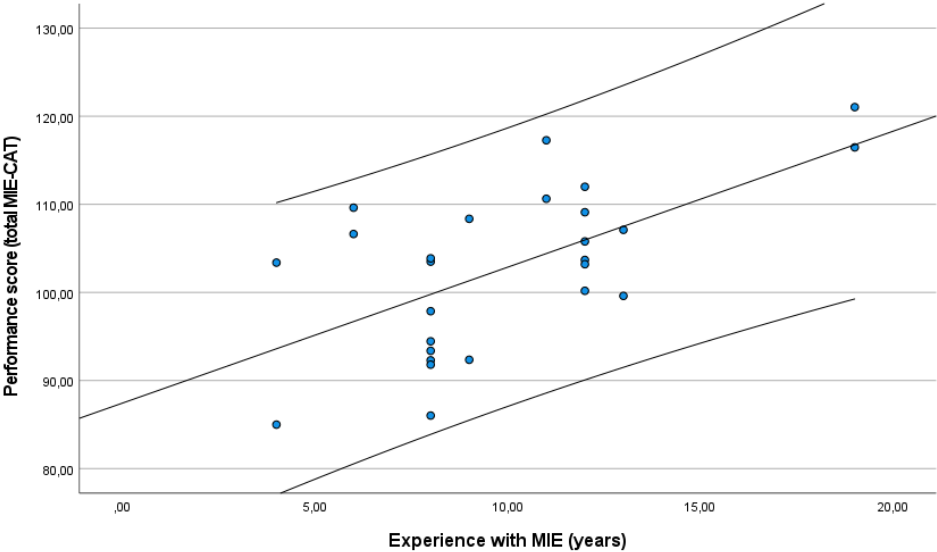| Performance vs. clinical outcome	Risk Ratio (RR), 95% CI
Severe postoperative complication (CD≥3) vs.	
• Surgical performance (total MIE-CAT)	0.504 (0.235, 0.991)
• Total adverse event	0.556 (0.278, 1.150)
Postoperative complication vs.	
• Surgical performance (total MIE-CAT)	0.537 (0.242, 0.959)
• Total adverse event	0.618 (0.342, 0.960)
Anastomotic leakage vs.	
• Surgical performance (total MIE-CAT)	0.360 (0.100, 1.200)
• Total adverse event	0.691 (0.239, 1.798)
• Creation of the gastric tube (p 5)	0.726 (0.330, 1.511)
• Creation anastomosis (p 8)	0.139 (0.061, 0.313)
Pulmonary complication vs.	
• Surgical performance (total MIE-CAT)	0.664 (0.381, 1.091)
• Total adverse event	0.821 (0.467, 1.431)
Peroperative complication vs.	
• Surgical performance (total MIE-CAT)	0.205 (0.044, 0.937)
• Total adverse event	0.223 (0.062, 0.782)
Conversion vs.	
• Surgical performance (total MIE-CAT)	0.211 (0.210, 0.212)
• Total adverse events	0.398 (0.395, 0.400)
Reintervention vs.	
• Surgical performance (total MIE-CAT)	0.545 (0.269, 1.030)
• Total adverse event	0.647 (0.373, 1.067)
• End-product quality	0.578 (0.285, 1.088)
ICU stay vs.	
• Surgical performance (total MIE-CAT)	0.220 (0.030, 1.554)
• Total adverse event	0.242 (0.058, 0.997)
• End-product quality	0.170 (0.028, 0.996)
Readmission vs.	
• Surgical performance (total MIE-CAT)	0.973 (0.502, 1.747)
• Total adverse event	0.940 (0.536, 1.564)
Textbook outcome vs.	
• Surgical performance (total MIE-CAT)	1.448 (0.951, 9.980)
• Total adverse event	1.234 (0.764, 4.770)
• End-product quality	1.288 (0.708, 7.040)
• Creation anastomosis (p 8)	1.448 (1.153, 6.440)
30-day mortality vs.	
• Surgical performance (total MIE-CAT)	1.440 (0.262, 6.822)
• Total adverse event	0.746 (0.149, 3.481)
R0 resection vs.	
• Surgical performance (total MIE-CAT)	1.006 (0.849, 1.059)
• Hiatus & thoracic esophagus dissection (p 4&6)	1.031 (0.959, 1.062)
• End-product quality of p 4&6	1.003 (0.997, 1.008)
Removed lymph nodes vs.	
• Surgical performance (total MIE-CAT)	0.204 (0.000, 3.205)
• End-product quality	0.019 (0.000, 3.205)
• Dissection of abdominal lymph nodes (p 3)	2.653 (0.002, 3.205)
• End-product quality p3	3.106 (0.041, 3.205)
• Dissection of thoracic lymph nodes (p 7)	1.111 (0.269, 2.414)
• End-product quality p7	3.195 (3.107, 3.204)
• Complete lymph node dissection (p 3,4,7)	1.799 (0.000, 3.205)
• End-product quality p3,4,7	3.179 (0.004, 3.205)

Multilevel risk ratio (RR) associations between (MIE-CAT (component) scores of the high- vs. low-performance hospitals and clinical outcomes. Two hospitals with missing phases were excluded for total MIE-CAT, but included for complete MIE-CAT component analysis.

eTable 6. Performance Scores Between International and Dutch Experts

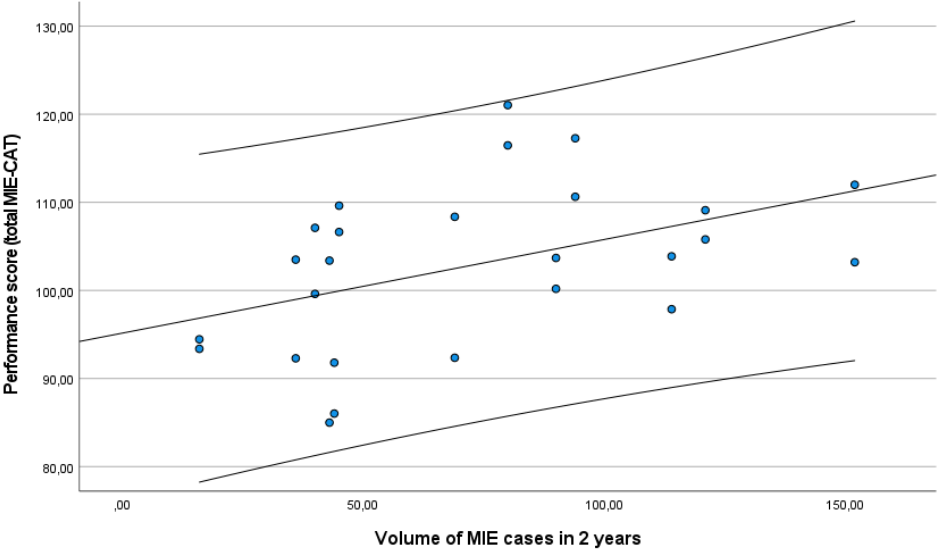| Center ID	Video ID	Anastomosis type	External expert, mean (SD)	Dutch experts, mean (SD)	Difference
1	1		X	69.7*	X
1	2		X	67.5*	X
2	1	Cerv E/E	97,7	103,6	-5,9
2	2	Cerv E/E	123,8	115,3	8,6
3	1	Intra E/S	112,0	94,3	17,7
3	2	Intra E/S	106,8	109,1	-2,3
4	1	Intra E/S	109,8	108,8	1,0
4	2	Intra E/S	105,3	106,0	-0,7
5	1		X	86.5**	X
5	2		X	65.4*	X
6	1	Intra E/S	121,5	110,3	11,3
6	2		X	103.2	X
7	1	Intra E/S	102,8	111,9	-9,1
7	2		X	109.6	X
8	1	Intra S/S	122,0	113,7	8,3
8	2	Intra S/S	128,0	117,1	10,9
9	1	Cerv E/S	72,0	105,2	-33,3
9	2	Intra E/S	102,6	104,8	-2,2
10	1		X	107.0	X
10	2		X	93.8**	X
11	1	Intra S/S	127,0	117,3	9,7
11	2	Intra S/S	111,8	110,0	1,8
12	1		X	97.9	X
12	2		X	103.9	X
13	1	Intra S/S	110,0	107,5	2,5
13	2	Intra S/S	82,2	97,5	-15,3
14	1	Intra S/S	92,6***	80,5***	12,0
14	2	Intra S/S	102,8	98,1	4,7
15	1	Intra S/S	82,8	86,1	-3,3
15	2	Intra S/S	101,5	103,4	-1,9

*The international expert reviewed 20 of the 30 videos. Absent scores are displayed with 'X'. *Missing components phase 5 and 8, ** missing component phase 5 and *** missing component phase 8*

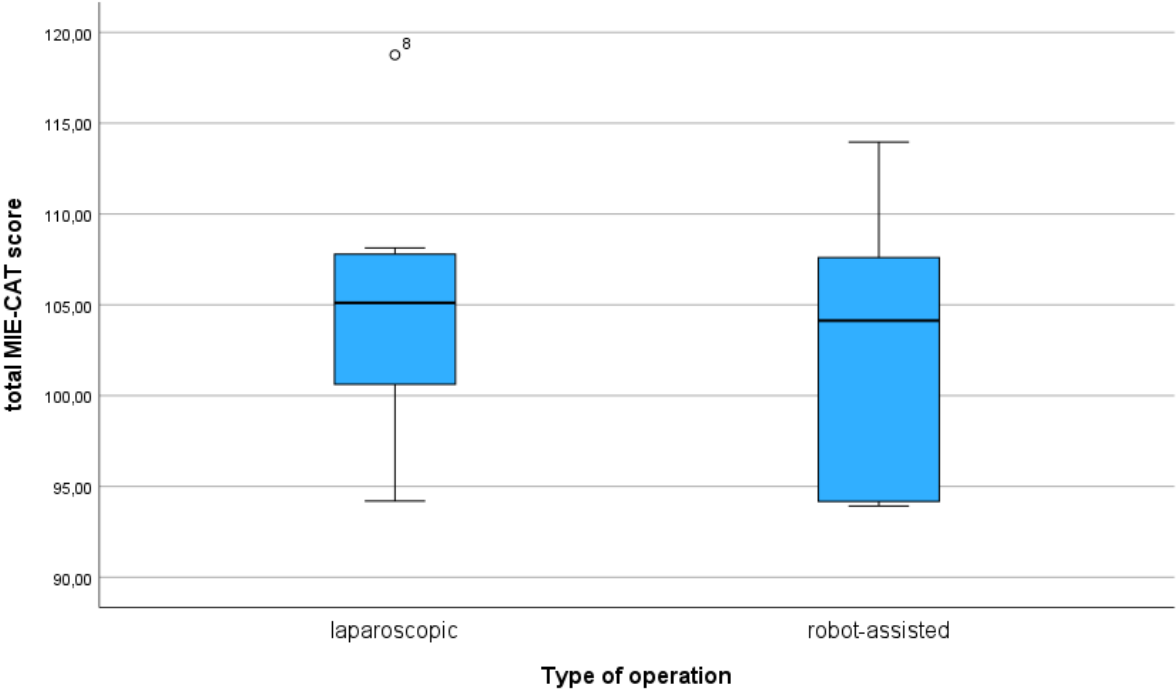**eFigure 1. Performance vs Experience (No. of MIEs Over 2 Years)**

Pearson's r = 0.614, 95% CI [0.297, 0.809]

eFigure 2. Performance vs Volume (No. MIE Cases Over 2 Years)

Pearson's r = 0.447, 95% CI [0.072, 0.711]

eFigure 3. Total MIE-CAT Score Per Operation Type

eAppendix. MIE-CAT Netherlands Collaborative Group

Participating hospitals	Study collaborator(s), first and last name
Amsterdam UMC, Amsterdam, the Netherlands	Suzanne Gisbertz Mark I. van Berge Henegouwen Nannet Schuring
Catharina Hospital Eindhoven, the Netherlands	Grard Nieuwenhuijzen Misha Luyer Tessa Geraedts
Erasmus MC University Medical Center Rotterdam, the Netherlands	Bas Wijnhoven Pieter van der Sluis Sjoerd Lagarde
Elisabeth-Tweesteden Hospital, Tilburg, the Netherlands	Joos Heisterkamp
Gelre Ziekenhuis, Apeldoorn, the Netherlands	Peter van Duijvendijk
Leiden University Medical Center, Leiden, the Netherlands	Wobbe de Steur
Maasstad Ziekenhuis, Rotterdam, the Netherlands	Peter-Paul Coene
Medical Center Leeuwarden, Leeuwarden, the Netherlands	Marloes Emous Jean-Pierre Pierie Daniël Hess
Netherlands Cancer Institute, Amsterdam, the Netherlands	Johanna van Sandick Koen (K.J.) Hartemink Xander (A.A.F.A) Veenhof
Queen Mary Hospital, Hong Kong, China	Simon Law
Radboud university medical center, Nijmegen, the Netherlands	Bastiaan Klarenbeek Camiel Rosman Merlijn Hutteman Frans van Workum Gerjon Hannink Inger Abma Mirte Ketel
Reinier de Graaf Groep, Delft, the Netherlands	Stijn van Esser Jan Willem Dekker
University Medical Center Groningen, University of Groningen, Groningen, the Netherlands	Jan Willem Haveman Frederieke Dijkstra
University Medical Center Utrecht, Utrecht, the Netherlands	Jelle Ruurda Richard van Hillegersberg
Hospital group Twente (ZGT), Almelo, the Netherlands	Marc J. van Det Ewout A. Kouwenhoven
Zuyerland, Heerlen, the Netherlands	Meindert Sosef Eric Belgers Bob Schaafsma