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# Morbidity and mortality in complex robot-assisted hiatal hernia surgery: 7-year experience in a high-volume center

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## Abstract

**Introduction** Published data regarding robot-assisted hiatal hernia repair are mainly limited to small cohorts. This study aimed to provide information on the morbidity and mortality of robot-assisted complex hiatal hernia repair and redo anti-reflux surgery in a high-volume center.

**Materials and methods** All patients that underwent robot-assisted hiatal hernia repair, redo hiatal hernia repair, and anti-reflux surgery between 2011 and 2017 at the Meander Medical Centre, Amersfoort, the Netherlands were evaluated. Primary endpoints were 30-day morbidity and mortality. Major complications were defined as Clavien–Dindo ≥ IIIb.

**Results** *Primary surgery* 211 primary surgeries were performed by two surgeons. The median age was 67 (IQR 58–73) years. 84.4% of patients had a type III or IV hernia (10.9% Type I; 1.4% Type II; 45.5% Type III; 38.9% Type IV, 1.4% no herniation). In 3.3% of procedures, conversion was required. 17.1% of patients experienced complications. The incidence of major complications was 5.2%. Ten patients (4.7%) were readmitted within 30 days. Symptomatic early recurrence occurred in two patients (0.9%). The 30-day mortality was 0.9%. *Redo surgery* 151 redo procedures were performed by two surgeons. The median age was 60 (IQR 51–68) years. In 2.0%, the procedure was converted. The overall incidence of complications was 10.6%, while the incidence of major complications was 2.6%. Three patients (2.0%) were readmitted within 30 days. One patient (0.7%) experienced symptomatic early recurrence. No patients died in the 30-day postoperative period.

**Conclusions** This study provides valuable information on robot-assisted laparoscopic repair of primary or recurrent hiatal hernia and anti-reflux surgery for both patient and surgeon. Serious morbidity of 5.2% in primary surgery and 2.6% in redo surgery, in this large series with a high surgeon caseload, has to be outweighed by the gain in quality of life or relief of serious medical implications of hiatal hernia when counseling for surgical intervention.

**Keywords** Hiatal hernia · Reflux · Anti-reflux · Surgery · Redo · Robotics

Minimally invasive surgery is the preferred approach for hiatal hernia repair and anti-reflux procedures with reported success rates of up to 90% in specialized centers [1–3]. While conventional laparoscopy has gained rapid acceptance over open surgery as the golden standard, this approach is known to be technically demanding. Robotic systems were designed to overcome part of the technical limitations of conventional laparoscopy [4–6].

Several previous studies have demonstrated the safety and feasibility of robot-assisted approach in hiatal hernia repair and anti-reflux surgery [7–11], including a paper on the early results from our center comparing conventional laparoscopic to robotic-assisted surgery [9]. The majority of current publications focus on more common anti-reflux procedures in the absence of hiatal herniation or type 1 hiatal hernia. In contrast, publications on relatively rare complex hiatal hernia repairs remain limited to a few single-center, low-volume case series and a few small comparative studies [7–9, 12, 13]. As the utilization of robotic systems is expected to grow in complex endoscopic procedures, larger series are crucial

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to evaluate the potential gain and risks related to surgical intervention in this setting.

This study focuses on the 30-day morbidity and mortality of robot-assisted laparoscopic surgery for complex hiatal hernia or problems after previous hiatal hernia or anti-reflux surgery. The goal was to provide objective information on surgical risks as background information in preoperative counseling. Data have to be interpreted in relation to the experience of the surgeon. The two surgeons involved in this series had extensive experience and a high annual caseload, and the center involved serves as a tertiary center for large hiatal hernias and recurrent problems after prior surgery.

Robotic assistance was used in repairs of large type 3 or type 4 hiatal hernias, all redo procedures and in conditions that may increase difficulty, such as earlier gastric surgery or high BMI. Currently, this reflects about 50% of patients operated on for reflux and/or hiatal hernia in this center.

## Materials and methods

All patients that underwent robot-assisted hiatal hernia repair and/or anti-reflux surgery between January 2011 and July 2017 at the Meander Medical Centre, Amersfoort, the Netherlands were evaluated. This also included all patients undergoing reoperation due to primary procedure failure or postoperative dysphagia within 30 days. Patients with achalasia where a Heller myotomy with concomitant 180° anterior (Dor) fundoplication was performed or patients with a non-hiatal hernia were excluded due to distinct underlying pathophysiology and a different surgical approach.

### Data collection

Preoperative, intraoperative, and postoperative data were collected retrospectively from the electronic patient records. This included patient demographics, American Society of Anesthesiologists (ASA) score, history of previous abdominal surgeries, hiatal hernia type, performed fundoplication and crural reinforcement, operative time, conversion, length of hospital stay, early complications, and mortality. The hiatal hernia type was scored by reviewing the radiological, upper endoscopic, and perioperative findings. Hiatal hernias were classified according to the definition stated in the 2013 SAGES guidelines for the management of hiatal hernia (Table 1) [14]. Operative times were recorded both as time from incision to skin closure and total time in the OR. Institutional Review Board approval was obtained.

### Study endpoints

The primary endpoints were postoperative complications and mortality occurring within 30 days after surgery. Any deviation from a normal postoperative course was considered a postoperative complication. All postoperative complications were recorded, meaning that the total number of complications can exceed the number of patients with complications. Complications were scored using the Clavien–Dindo classification of surgical complications [15]. Clavien–Dindo scores of IIIb and higher were regarded as major complications. In case of multiple major complications in a single patient, the highest Clavien–Dindo classification was used for further analysis.

### Statistical analysis

Categorical data are presented as absolute numbers or percentages and were analyzed with Pearson's Chi-square or Fisher's exact test where appropriate. Continuous data are presented as means with standard deviation for normally distributed data or medians and interquartile ranges (IQR) when not normally distributed. Independent samples *t* test and Mann–Whitney *U* test were used as appropriate to compare the differences between groups.

A double-sided $p$ value of $< 0.05$ was considered statistically significant. All statistical analyses were carried out using the IBM Statistical Package for Social Sciences for Windows, version 25.0 (SPSS Inc., IBM Corporation, Armonk, NY, USA).

### Surgical technique

All procedures were carried out by two surgeons using the 4-arm da Vinci Si HD Surgical System (Intuitive Surgical

**Table 1** Classification of Hiatal Hernias

| Type | Definition |
|---|---|
| Type I | Sliding hiatal hernias, where the gastroesophageal junction migrates above the diaphragm. The stomach remains in its usual longitudinal alignment and the fundus remains below the gastroesophageal junction |
| Type II | Pure paraesophageal hernias (PEH): the gastroesophageal junction remains in its normal anatomic position but a portion of the fundus herniates through the diaphragmatic hiatus adjacent to the esophagus |
| Type III | Hernias are a combination of Types I and II, with both the gastroesophageal junction and the fundus herniating through the hiatus. The fundus lies above the gastroesophageal junction |
| Type IV | Characterized by the presence of a structure other than stomach, such as the omentum, colon, or small bowel within the hernia sac |

Inc., Sunnyvale, CA). Key steps for hiatal hernia surgery included complete hernia sac dissection and esophageal mobilization to achieve reduction of the herniated contents into a tensionless intra-abdominal position and a tension-free position of the GE-junction below the diaphragm. Esophageal dissection was carried out mostly in a blunt fashion, at as much distance as possible from the muscular tube. The hernia sac was not excised routinely to avoid damage to the anterior vagal nerve branches, in these cases, it was left intra-abdominally after dissection if it did not interfere with the rest of the procedure. Crural closure was performed with or without the use of mesh or pledgets for reinforcement as deemed necessary by the surgeon and was followed, in most cases, by an anti-reflux procedure. In most cases, a partial fundoplication was performed. In our center, based on recent research [16–21], the preferred approach is a partial fundoplication. In several patients, a valvuloplasty was performed instead of a fundoplication; a 270-degree intussusception of the esophagus. The procedure used in our center has previously been described in more detail by Tolboom et al. [22].

Redo procedures were carried out in a similar fashion; however, the procedure differed based on preoperative complaints (i.e., reflux symptoms or dysphagia) and anatomical abnormalities (i.e., wrap disruption, slipped fundoplication, intra-thoracic wrap migration). Typically, any previously created fundoplication was taken down and a new fundoplication was created. Occasionally, a previously created fundoplication was (partly) preserved or extended and fixated below the diaphragm after the hiatal repair was performed. In select cases of extreme dysphagia, usually occurring after several previous surgeries, widening of the hiatus was performed without creation of a new fundoplication.

## Results

### Patients

A total of 362 robot-assisted procedures were performed. Patient demographics are presented in Table 2. Median patient age was 65 (IQR 55–71), 71.8% were female. Patients that underwent a primary procedure were significantly older compared to patients in the redo group; 67 years (IQR 58–73) versus 60 years (IQR 51–68). The majority of patients had an ASA score of 2, patients from the primary procedure group had significantly higher ASA scores.

### Primary procedure

Perioperative results are summarized in Table 3. In total, 211 primary procedures were performed. The median total OR time was 149 (IQR 129–170) minutes, the skin–skin surgery duration was 99 (IQR 82–119) minutes. Most patients presented with a symptomatic type 3 or 4 hiatal herniation (45.5% and 38.9%, respectively). Hiatal hernia repair was combined with a fundoplication in all but two patients. In 73.5%, an anterior (Dor) fundoplication was created, followed by a posterior (Toupet) fundoplication in 18.0%. Three concomitant procedures were performed; one cholecystectomy and two pyloroplasties. Adequate intra-abdominal esophageal length was achieved by appropriate esophageal mobilization in all repairs, no lengthening procedures were performed.

#### Conversions

Conversion to an open procedure was required in seven cases: due to the inability to reduce the hernia because of strong adherence of herniated contents in the thorax ($N=3$), limited overview of the hiatal region due to adhesions or intra-abdominal fat ($N=3$), or extent of the hernia where the complete stomach, transversal colon, and a significant portion of the small intestine loops herniated intrathoracically ($N=1$).

### Postoperative outcomes

Median hospital stay was 3 days (IQR 3–5).

#### Postoperative complications

Table 4 shows postoperative complications categorized by severity according to the Clavien–Dindo classification. One or more early postoperative complications occurred in 36 (17.1%) patients which comprised 47 complications in total. Eleven (5.2%) patients suffered from major complications.

All recorded postoperative complications classified by diagnosis and treatment are depicted in Table 5. The most common complication was pneumonia which was seen in 13 (6.2%) patients, followed by dysphagia requiring temporary enteral feeding by means of a nasoduodenal feeding tube in seven (3.3%) and atrial fibrillation in five (2.4%) patients. The majority of complications required only conservative treatment or minor interventions. Surgical management of major complications was required in eight patients and was related to abdominal ($N=3$) or thoracic ($N=1$) infections, early hernia recurrence ($N=2$), iatrogenic damage to the small intestine ($N=2$).

#### Readmissions

There were nine readmissions during the 30-day postoperative period. Six were associated with dysphagia. Three

**Table 2** Baseline characteristics

| | Total ($n=362$) | Primary procedure ($n=211$) | Redo procedure ($n=151$) | $p$ value |
|---|---|---|---|---|
| Age (years, median, IQR) | 67 (55–71) | 67 (58–73) | 60 (51–68) | <0.001* |
| Gender (*N*, %) | | | | |
| Male | 102 (28.2%) | 58 (27.5%) | 44 (29.1%) | 0.731 |
| Female | 260 (71.8%) | 153 (72.5%) | 107 (70.9%) | |
| ASA (*N*, %) | | | | |
| 1 | 72 (19.9%) | 38 (18.0%) | 34 (22.5%) | 0.012* |
| 2 | 244 (67.4%) | 137 (64.9%) | 107 (70.9%) | |
| 3–4 | 46 (12.7%) | 36 (17.1%) | 10 (6.6%) | |
| Body mass index (kg/m$^2$, median, IQR) | 27 (24–30) | 27 (25–31) | 27 (24–30) | 0.770 |
| Previous intra-abdominal surgery (*N*, %) | | | | |
| Yes | 235 (64.9%) | 84 (39.8%) | 151 (100.0%) | <0.001* |
| No | 127 (35.1%) | 127 (60.2%) | 0 (0.0%) | |
| Comorbidities (Yes, *N*, %) | | | | |
| Cardiac | 33 (9.1%) | 25 (11.8%) | 8 (5.3%) | 0.033* |
| Vascular | 78 (21.5%) | 52 (24.6%) | 26 (17.2%) | 0.090 |
| Diabetes | 23 (6.4%) | 16 (7.6%) | 7 (4.6%) | 0.257 |
| Pulmonary | 64 (17.7%) | 3 (18.5%) | 25 (16.6%) | 0.636 |
| Neurologic/psychiatric | 17 (4.7%) | 11 (5.2%) | 6 (4.0%) | 0.582 |
| Gastro-intestinal | 8 (2.2%) | 5 (2.4%) | 3 (2.0%) | 1.000 |
| Urogenital | 18 (5.0%) | 10 (4.7%) | 8 (5.3%) | 0.809 |
| Thrombosis/coagulation | 10 (2.8%) | 8 (3.8%) | 2 (1.3%) | 0.204 |
| Neuromuscular | 4 (1.1%) | 2 (0.9%) | 2 (1.3%) | 1.000 |
| Endocrinological | 23 (6.4%) | 16 (7.6%) | 7 (4.6%) | 0.257 |
| Musculoskeletal | 28 (7.7%) | 17 (8.1%) | 11 (7.3%) | 0.786 |
| Infectious | 1 (0.3%) | 1 (0.5%) | 0 (–) | 1.000 |

Values are expressed as median (IQR) or number of patients (%)

*$p$ value < 0.05

patients required no intervention, their complaints subsided with additional dietary advice. Temporary enteral feeding by means of a nasoduodenal feeding tube was started in two patients; one patient underwent endoscopic balloon dilatation of the gastroesophageal junction. The remaining three readmissions were due to a subphrenic abscess which was successfully drained percutaneously, conservatively treated wound infection, and abdominal complaints.

### Early recurrences

Evaluation of recurrence was only performed on indication. There were two symptomatic early recurrences of hiatal herniation. Both underwent open correction on postoperative day 2 and 7. The first patient suffered an iatrogenic esophageal perforation in the redo procedure, treated by endoscopic esophageal stent placement and admission to the intensive care unit. Both patients fully recovered.

### Mortality

Mortality within 30 days after primary surgery was 0.9% (N = 2). The first patient, a 86-year-old woman, developed postoperative mediastinitis and underwent emergency surgery on postoperative day 4. An esophageal perforation was diagnosed and treated with endoscopic stent placement and total parenteral feeding. The patient initially responded well but later refused further medical treatment and requested to be transferred to a hospice where she passed away on postoperative day 30. The second patient, a 78-year-old woman, was readmitted on postoperative day 6 after a previously uncomplicated clinical course due to abdominal pain. After enema application, the patient developed clinical signs of abdominal sepsis and a perforation of the recto-sigmoid was seen upon explorative laparotomy. The patient died on postoperative day 18 due to refractory sepsis unresponsive to operative and antibiotic treatment.

**Table 3** Perioperative details

| | Total ($N=362$) | Primary procedure ($N=211$) | Redo procedure ($N=151$) | $p$ value |
|---|---|---|---|---|
| Surgery duration[a] (min, median, IQR) | 99 (81–120) | 99 (82–119) | 101 (79–120) | 0.932 |
| Total operative time (min, median, IQR) | 148 (128–174) | 148 (129–170) | 148 (125–176) | 0.870 |
| Hiatal herniation (*N*, %) | – | | – | – |
| No herniation | | 3 (1.4%) | | |
| Type 1 | | 23 (10.9%) | | |
| Type 2 | | 3 (1.4%) | | |
| Type 3 | | 96 (45.5%) | | |
| Type 4 | | 82 (38.9%) | | |
| Unknown | | 4 (1.9%) | | |
| Herniated contents (*N*, %) | | | | < 0.001* |
| No organ herniation | 125 (34.5%) | 29 (13.7%) | 96 (63.6%) | |
| Stomach (partial) | 149 (41.2%) | 100 (47.4%) | 49 (32.5%) | |
| Stomach (full) including omentum | 63 (17.4%) | 59 (28.0%) | 4 (2.6%) | |
| Stomach (full) including omentum and ≥ 1 other abdominal organ | 25 (7.0%) | 23 (10.9%) | 2 (1.3%) | |
| Number of anti-reflux procedures performed previously (*N*, %) | – | – | | – |
| 1 | | | 107 (70.9%) | |
| 2 | | | 38 (25.2%) | |
| 3 | | | 5 (3.3%) | |
| 4 | | | 1 (0.7%) | |
| Latest fundoplication performed in patient (*N*, %) | – | – | | |
| Toupet | | | 54 (35.8%) | |
| Dor | | | 22 (14.6%) | |
| Nissen | | | 62 (41.1%) | |
| Valvuloplasty | | | 7 (4.6%) | |
| Belsey | | | 1 (0.7%) | |
| Other | | | 5 (3.3%) | |
| Performed procedure (*N*, %) | | | | < 0.001* |
| Hiatal hernia repair + fundoplication | 316 (87.3%) | 209 (99.1%) | 107 (70.9%) | |
| Hiatal hernia repair | 16 (4.4%) | 2 (0.9%) | 14 (9.3%) | |
| Fundoplication | 21 (5.8%) | 0 (0.0%) | 21 (13.9%) | |
| Other | 8 (2.2%) | 0 (0.0%) | 8 (5.3%) | |
| Missing | 1 (0.3%) | 0 (0.0%) | 1 (0.7%) | |
| Fundoplication type performed (*N*, %) | | | | < 0.001* |
| None | 24 (6.6%) | 2 (0.9%) | 22 (14.6%) | |
| Nissen | 3 (0.8%) | 0 (0.0%) | 3 (2.0%) | |
| Toupet | 86 (23.8%) | 38 (18.0%) | 48 (31.8%) | |
| Dor | 225 (62.2%) | 155 (73.5%) | 70 (46.4%) | |
| Valvuloplasty | 21 (5.8%) | 16 (7.6%) | 5 (3.3%) | |
| 360 | 2 (0.6%) | 0 (0.0%) | 2 (1.3%) | |
| Missing | 1 (0.3%) | 0 (0.0%) | 1 (0.7%) | |
| Crural reinforcement (*N*, %) | | | | < 0.001* |
| None | 105 (29.0%) | 40 (19.0%) | 65 (43.0%) | |
| Pledgets | 229 (63.3%) | 153 (72.5%) | 76 (50.3%) | |
| Mesh | 27 (7.5%) | 18 (8.5%) | 9 (6.0%) | |
| Missing | 1 (0.3%) | 0 (0.0%) | 1 (0.7%) | |
| Adhesiolysis (*N*, %) | | | | < 0.001* |
| Yes | 97 (26.8%) | 11 (5.2%) | 87 (57.6%) | |
| No | 263 (72.7%) | 200 (94.8%) | 62 (41.1%) | |
| Missing | 2 (0.6%) | 0 (0.0%) | 2 (1.3%) | |
| Conversion (*N*, %) | | | | 0.531 |
| Yes | 10 (2.8%) | 7 (3.3%) | 3 (2.0%) | |
| No | 352 (97.2%) | 204 (96.7%) | 148 (98.0%) | |
| Hospital stay (days, median, IQR) | 3 (IQR 3–5) | 3 (IQR 3–5) | 3 (IQR 2–5) | 0.025* |

**Table 3** (continued)

*$p$ value < 0.05

[a]Surgery duration is defined as time from first incision to skin closure

**Table 4** Postoperative complication details by severity

| | Total ($N=362$) | Primary procedure ($N=211$) | Redo procedure ($N=151$) | $p$ value |
|---|---|---|---|---|
| No complication | 310 (85.6%) | 175 (82.9%) | 135 (89.4%) | |
| Minor complication | 37 (10.2%) | 25 (11.8%) | 12 (7.9%) | |
| Major complication[a] | 15 (4.1%) | 11 (5.2%) | 4 (2.6%) | 0.227 |
| CD I | 2 (0.6%) | 1 (0.5%) | 1 (0.7%) | |
| CD II | 28 (7.7%) | 19 (9.0%) | 8 (6.0%) | |
| CD IIIa | 7 (1.9%) | 5 (2.4%) | 2 (1.3%) | |
| CD IIIb | 3 (0.6%) | 1 (0.5%) | 1 (0.7%) | |
| CD IVa | 5 (1.4%) | 4 (1.9%) | 1 (0.7%) | |
| CD IVb | 6 (1.7%) | 4 (1.9%) | 2 (1.3%) | |
| CD V | 2 (0.6%) | 2 (0.9%) | 0 (–) | |

[a]Clavien–Dindo scores of IIIb and higher were regarded as major complications

*CD* Clavien–Dindo grade

**Table 5** Postoperative morbidity and treatment in the primary procedure group

| Complication | Treatment | Total | CD |
|---|---|---|---|
| Minor | | | |
| Pneumonia | Antibiotics | 13 | II |
| Atrial fibrillation | Antiarrhythmic agents | 5 | II |
| Passage disorders | Nasoduodenal feeding tube | 3 | IIIa |
| | Total parenteral nutrition | 3 | II |
| | Endoscopic GEJ dilatation | 2 | IIIa |
| Asthma/COPD exacerbation | Corticosteroids, bronchodilators | 2 | II |
| Anemia | Transfusion | 1 | II |
| Wound infection | Conservative treatment | 1 | I |
| Intra-abdominal infection | Percutaneous drainage | 1 | IIIa |
| Pleural effusion | Drainage | 1 | IIIa |
| Iatrogenic damage to other organs | Conservative treatment | 1 | I |
| Total | | 33 | |
| Major | | | |
| Intra-abdominal infection | Surgical management | 3 | IIIb, IVb, V |
| Intra-thoracic infection | Multiple surgeries with aggressive antibiotic treatment | 1 | V |
| Early recurrence | Surgical repair | 2 | IIIb |
| Iatrogenic GI tract injury | Surgical management | 2 | IVb |
| Pulmonary embolism | Anticoagulants | 1 | IVa |
| Asthma/COPD exacerbation requiring ICU admission | Mechanical ventilation | 1 | IVa |
| Undefined respiratory insufficiency | | | |
| Post-extubation laryngeal edema | Symptomatic treatment | 2 | IVa, IVb |
| Cardiac decompensation | Reintubation, corticosteroids | 1 | IVa |
| | Transfer to another hospital | 1 | IVa |
| Total | | 14 | |

Values are expressed as number of patients. All postoperative complications were recorded, this results in a total number of complications exceeding the number of patients with complications (e.g., [36])

*CD* Clavien–Dindo grade, *GEJ* gastroesophageal junction

## Redo procedure

The perioperative results of performed redo procedures are depicted in Table 3. In total, 151 redo procedures were performed. The median total OR time was 148 (IQR 125–176) minutes, while the median surgery time (skin–skin) was 101 (IQR 79–120) minutes. Hiatal hernia repair was performed combined with fundoplication in the majority of patients (70.9%). Hiatal repair alone was performed in 14 (9.3%) patients where a previously created fundoplication was not taken down completely but partly preserved and fixated below the diaphragm. Fundoplication without additional hiatal repair was performed in 21 (13.9%) patients that underwent reoperation either due to persistent reflux or dysphagia after previous surgery. In patients with primarily reflux complaints, the preferred type of fundoplication was a 270° posterior (Toupet) fundoplication, where in patients mainly reporting dysphagia, a 180° anterior (Dor) fundoplication was created. There were four patients in whom a Toupet fundoplication was created at a previous surgery but later experienced severe dysphagia. In these patients, the fundoplication was taken down and the hiatus was widened by removing one or more crural sutures. In four other redo cases, the procedure was aborted due to dense adhesions.

The most common fundoplication type performed was an anterior (Dor) fundoplication (46.4%), followed by 270° posterior (Toupet) fundoplication (31.8%). In two patients that previously underwent Toupet fundoplication but presented with persisting reflux symptoms, a 360° wrap was created. Five concomitant procedures were performed. One patient underwent a concomitant cholecystectomy due to symptomatic cholecystolithiasis. Pyloroplasty was performed in four patients that suffered from severe gastric motility disorders. Adequate intra-abdominal esophageal length was achieved by appropriate mediastinal esophageal mobilization in all repairs, no lengthening procedures were performed.

### Conversions

Conversion to an open procedure was required in three cases due to the inability to laparoscopically reduce the hernia because of strong intra-thoracic adherence of the herniated contents ($N=2$), or gastric perforation combined with an impaired overview of the anatomy ($N=1$).

## Postoperative outcomes

Median hospital stay was 3 days (IQR 2–5).

### Postoperative complications

Table 4 shows postoperative complications categorized by severity according to the Clavien–Dindo classification. One or more early postoperative complications occurred in 16 (10.6%) patients which comprised 22 complications in total. Major postoperative complications occurred in 4 (2.6%) patients. Recorded postoperative complications classified by diagnosis and accompanying treatment are shown in Table 6. The most common complications were pneumonia and pneumothorax, which were seen in 5 (3.3%) patients each. The majority of complications required only conservative treatment or minor interventions. Surgical management of complications was required in four patients and was related to thoracic infection ($N=2$), early hernia recurrence ($N=1$), and intra-abdominal luxation of a drain which had to be surgically removed ($N=1$).

### Readmissions

There were three readmissions during the 30-day postoperative period. One patient presented with gastroparesis for which temporary nasoduodenal tube feeding was started. In one patient, anemia was diagnosed and treated by a one-time transfusion. One readmission due to persistent postoperative pain was successfully treated with temporary oral pain medication.

### Early recurrences

No routine evaluation of recurrence was performed. One symptomatic early recurrence was observed in the redo group. Correction was performed on a postoperative day 3 via laparotomy. Upon surgical revision, takedown of the fundoplication revealed a gastric perforation which was repaired with closure of the defect and an omental patch. Antibiotic and surgical treatment of mediastinitis led to complete recovery.

### Mortality

None of the patients in the redo group died in the 30-day postoperative period.

# Discussion

In this study, we investigated the short-term postoperative outcomes in a large cohort undergoing robot-assisted laparoscopic repair of large symptomatic diaphragmatic

**Table 6** Postoperative morbidity and treatment in the redo procedure group

| Complication | Treatment | Total | CD |
|---|---|---|---|
| Minor | | | |
| Pneumonia | Antibiotics | 5 | II |
| Pneumothorax | Drainage | 5 | IIIa |
| Atrial fibrillation | Antiarrhythmic agents | 2 | II |
| Passage disorders | Nasoduodenal feeding tube | 1 | IIIa |
| Asthma/COPD exacerbation | Corticosteroids, bronchodilators | 1 | II |
| Anemia | Transfusion | 1 | II |
| Wound infection | Conservative treatment | 1 | I |
| Hypertension | Antihypertensive agents | 1 | II |
| Total | | 17 | |
| Major | | | |
| Intra-thoracic infection | ICU, surgical drainage | 1 | IVa |
| | ICU, multiple surgeries with aggressive antibiotic treatment | 2 | IVb |
| Early recurrence | Surgical correction | 1 | IIIb |
| Intra-abdominal luxation of a drain | Surgical removal | 1 | IIIb |
| Total | | 5 | |

Values are expressed as number of patients. All postoperative complications were recorded, this results in a total number of complications exceeding the number of patients with complication (e.g., 17)

*CD* Clavien–Dindo grade

hernias and anti-reflux surgery, as well as redo surgery, at a national referral center in the Netherlands.

After primary repair, 17.1% of patients experienced complications of any severity, with an incidence of major complications of 5.2%. The 30-day mortality was 0.9%. After redo surgery, the incidence of complications of any severity was 10.6%, while the incidence of major complications was 2.6%. No patients died in the 30-day postoperative period after redo surgery. The low number of complications in the redo group was not significantly different from the primary procedure group. There are many factors contributing to morbidity and mortality in surgical outcomes, and it is important to note that the primary repair group had previous intra-abdominal surgery in 39.8% of cases.

Previous publications have demonstrated the safety and efficacy of robotic assistance in large hiatal hernia repair and anti-reflux surgery, reporting a 30-day postoperative complication rate of 15–23% and mortality rates of 0–2.5% [8, 12, 13]. However, currently available literature on this topic is limited to retrospective single institution series with low number of patients, usually operated on over a long period of time leading to a low number of patients per surgeon. Short-term outcomes in our series are comparable to those reported in the literature concerning the conventional laparoscopic approach with a reported overall 30-day morbidity of 4.0–14.5% [3, 23–28] and mortality 0–1.8% [2, 23–29]. However, these numbers should be interpreted with care due to differences in study design, varying number of patients, and non-standardized reporting of postoperative complications.

In contrast to the number of randomized controlled trials and reviews comparing conventional laparoscopic to robot-assisted laparoscopic approach in anti-reflux surgery [11, 28–31], only two recent comparative studies [7, 9] are available regarding the repair of hiatal hernias. Gehrig et al. [7] conducted a retrospective study including 42 patients where they compared the use of robotic assistance in paraesophageal hernia repair to conventional laparoscopy and open surgery. They showed both laparoscopic approaches to be a safe alternative to open surgery with reduction of intraoperative blood loss, less postoperative complications, and shorter hospital stay. In addition, no significant differences in these outcomes were found when comparing the two minimally invasive approaches. This led the authors to conclude that the use of robotic assistance was not superior to conventional laparoscopy in paraesophageal hernia repair. However, this study included only a limited number of patients (12 in the robot group) and did not provide information on hiatal hernia size or type, nor on specific advantages that might be expected from robotic utilization.

The second study, reporting on robot-assisted laparoscopic redo hiatal hernia repair and anti-reflux surgery, was carried out by Tolboom et al. [9] This study includes a subset of patients from the same cohort analyzed in the current study and the authors of the study are co-authors on the current paper. The study included 75 patients who underwent redo hiatal hernia and anti-reflux surgery with either

conventional laparoscopic or robot-assisted approach. They observed a statistically significantly lower conversion rate and shorter hospital stay in the robot-assisted group. The two groups did not differ in mortality, complication rate, and symptomatic outcome. The authors concluded that robotic support can be regarded beneficial in redo anti-reflux surgery, using a minimally invasive approach even in patients that underwent prior open primary repair.

Other reports described robotic assistance of significant value when performing complex, technically demanding procedures [4, 5, 12, 13]. Although conventional laparoscopy is nowadays the common approach for hiatal hernia repair and anti-reflux surgery, it can be very difficult. Mediastinal dissection of large diaphragmatic hernias, a history of multiple abdominal surgeries, or redo surgery constitute a technical challenge, often influencing the surgeon's decision to favor an open procedure over a laparoscopic approach. In these cases, the wrist-like motion of instruments and enhanced visualization provided by robotic systems can extend the possibilities of minimally invasive surgery while retaining the advantages of conventional laparoscopy such as reduced blood loss, lower postoperative morbidity and mortality, and shorter recovery period when compared to open repair [26–28]. The favorable ergonomic and working position of the surgeon during the complex phase of the intervention may also be of importance when multiple procedures are performed back-to-back by the same surgeon [32–38].

The results of this study in a large patient cohort show that a robot-assisted laparoscopic approach can be adopted in large, giant, or redo hiatal hernia repair at acceptable complication rates when compared to the available literature on the conventional laparoscopic approach. An uncomplicated postoperative course was observed in the large majority of patients.

This study is a single-arm, single-center retrospective study with limitations inherent to the study design. The present study does not report on outcomes outside of the 30-day postoperative period. Despite these limitations, this report presents the largest series of robot-assisted hiatal hernia repair to date and provides valuable information on the short-term safety and feasibility of this technique.

## Conclusion

Robot-assisted laparoscopic repair of large and redo hiatal hernias in a tertiary center showed a 2–6% major complication rate, with a less than 1% mortality within 30 days. This provides important background information for preoperative counseling, when gain of quality of life should be balanced against the risk of the surgical intervention.

## Compliance with ethical standards

**Conflict of interest** Dr. Broeders reports personal fees from Johnson & Johnson and Intuitive Surgical. Drs. Mertens, Tolboom, Zavrtanik, and Dr. Draaisma have no conflicts of interest or financial ties to disclose.

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