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ORIGINAL ARTICLE / ÖZGÜN MAKALE

Transthoracic robotic plication for diaphragmatic elevation

Diyafragmatik elevasyonda transtorasik robotik plikasyon

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ABSTRACT

Background: This study aims to evaluate the feasibility, safety, and efficacy of transthoracic robot-assisted surgery for diaphragmatic plication and to describe our surgical approach in detail.

Methods: Between January 2014 and January 2020, a total of 13 patients (11 males, 2 females; median age: 55 years; range, 24 to 70 years) who underwent diaphragmatic plication with the robotic system were retrospectively analyzed. The changes in the Medical Research Council dyspnea scale, forced expiratory volume in 1 sec, body mass index, and quality of life scale scores of the patients before the operation and at the first year of follow-up were examined.

Results: Twelve of the operations were performed on the left side. The median pre- and postoperative Medical Research Council dyspnea scores were 2 (range, 1 to 4) and 1 (range, 1 to 4), respectively, indicating a statistically significant improvement (p=0.008). A significant improvement was detected in the forced expiratory volume in 1 sec of the patients in the first year after surgery (p=0.036). In terms of quality of life parameters, only, in the physical health subscale, the scores were statistically significantly different in the pre- and postoperative first-year follow-up (p=0.002). Median time to chest tube removal was 1 (range 1-5, IQR=0,5) days. Median total length of hospital stay was 2 (range 2-18, IQR=3) days.

Conclusion: Owing to its technical dexterity, the robot enables the plication to be performed easily and safely. Late improvement in respiratory functions is reflected in quality of life.

Keywords: Diaphragmatic plication, minimally invasive surgery, robot-assisted thoracoscopic surgery, transthoracic robotic plication.

ÖZ

Amaç: Bu çalışmada diyafragma plikasyonu için transtorasik robot yardımlı cerrahinin fizibilitesi, güvenliliği ve etkinliği değerlendirildi ve cerrahi yaklaşımımız ayrıntılı olarak sunuldu.

Çalışma planı: Ocak 2014 - Ocak 2020 tarihleri arasında, robotik sistem ile diyafragma plikasyonu yapılan toplam 13 hasta (11 erkek, 2 kadın; medyan yaş: 55 yıl; dağılım, 24-70 yıl) retrospektif olarak incelendi. Hastaların ameliyat öncesi ve birinci yıl izleminde Tıbbi Araştırma Konseyi dispne ölçeği, birinci saniye zorlu ekspiratuvar volüm, vücut kütle indeksi ve yaşam kalitesi ölçeği skorlarındaki değişiklikler incelendi.

Bulgular: Ameliyatların 12'si sol taraftan yapıldı. Ameliyat öncesi ve sonrası medyan Tıbbi Araştırma Konseyi dispne skorları sırasıyla 2 (dağılım, 1-4) ve 1 (dağılım, 1-4) olup, istatistiksel olarak anlamlı iyileşme gösterdi (p=0.008). Ameliyattan sonra ilk yılda hastaların birinci saniye zorlu ekspiratuvar volümünde anlamlı bir iyileşme izlendi (p=0.036). Yaşam kalitesi parametreleri açısından, yalnızca fiziksel sağlık alt ölçeğinin skorları, ameliyat öncesi ve sonrası birinci yıl izlemde istatistiksel olarak anlamlı düzeyde farklı idi (p=0.002). Göğüs tüpünün çıkarılmasına kadar geçen medyan süre 1 (dağılım, 1-5, IQR=0,5) gün idi. Hastanede medyan toplam kalış süresi 2 (dağılım, 2-18, IQR=3) gün idi.

Sonuç: Robot, teknik mahareti sayesinde plikasyonun kolay ve güvenli bir şekilde yapılmasını sağlar. Solunum fonksiyonlarındaki geç düzelme yaşam kalitesine yansır.

Anahtar sözcükler: Diyafragma plikasyonu, minimal invaziv cerrahi, robot yardımlı torakoskopik cerrahi, transtorasik robotik plikasyon.

The diaphragm undertakes most of the body's respiratory work, and its elevation due to thoracic or abdominal pathologies causes changes in respiratory mechanics.[1] It is seen more frequently on the left side and in males, is also mostly asymptomatic or has very mild symptoms. Therefore, it is difficult to identify the true incidence of this condition.[2]

Diaphragmatic plication is the process of pulling the thinned, non-functional, elevated diaphragm back to its original position by folding it on itself.[3,4]

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Following this procedure, active contraction of the diaphragm may not be achieved, but it eliminates pulmonary parenchymal compression, reduces the effects of organ displacements, and positively affects respiratory function by ending the paradoxical movement between the two hemidiaphragms.[3,4] Currently, open, videothoracoscopic, laparoscopic and robotic approaches are used transthoracically or transabdominally.[2-4]

In this study, we aimed to present the surgical approaches to and clinical outcomes of patients undergoing transthoracic diaphragmatic plication with the da Vinci® robotic system in our institution. This is one of the largest series of diaphragmatic plications performed with the transthoracic approach.

PATIENTS AND METHODS

This single-center, retrospective study was conducted at Gülhane Training and Research Hospital, Department of Thoracic Surgery between January 2014 and January 2020. A total of 13 consecutive patients (11 males, 2 females; median age: 55 years; range, 24 to 70 years) who underwent diaphragmatic plication with the robotic system were included. The characteristics of the patients, including age, sex, body mass index (BMI), and etiology of diaphragmatic elevation were recorded. All procedures were performed by a thoracic surgeon specialist who is experienced in robotic surgery. The feasibility, safety, and efficacy of robot-assisted surgery for diaphragmatic plication were evaluated and the surgical approach was described in detail.

A detailed medical history, physical examinations, and anteroposterior chest X-rays were taken as standard. All patients were evaluated with thoracic and abdominal computed tomography (CT) to rule out additional pathologies. Seven patients underwent fluoroscopic examination that confirmed diaphragmatic paralysis. To identify the degree of preoperative dyspnea, pulmonary function test (PFT) and Medical Research Council (MRC) dyspnea scale scores were recorded. The MRC breathlessness scale is a five-point scale, with 1 describing shortness of breath experienced only during heavy exercise and 5 describing dyspnea when completing such simple tasks as undressing and not leaving the home.[5] While the MRC tests were repeated at the end of the first postoperative year, the PFT was repeated at the first month, sixth month, and first year postoperatively.

The decision to operate was made by the Clinical Council based on the patient's symptomatic status, socioeconomic and environmental conditions, and PFT scores. In radiological examinations, the criterion to be a candidate for surgery was that the diaphragm should be at least 2 cm above its normal position. The Council supports the use of laparoscopy when additional abdominal pathology is present and prefers thoracotomy or video-assisted thoracoscopic surgery (VATS) in cases of thoracic CT findings of intense pleural adhesions. While deciding on the most optimal type of operation, the Council considered the technical feasibility, cost, presence of pleural adhesions, necessity of minimizing labor loss, and patient preference.

Three patients in whom diaphragmatic elevation had an iatrogenic etiology had a history of bypass surgery; these surgeries were performed more than two years previously. All patients were given a liquid diet for three days before the operation. Intestinal cleansing was achieved by two enemas, administered 12-h apart, the day before the operation.

Failure of surgery was defined as non-displacement of the diaphragm compared to its preoperative possession or a lack of change in the patient's symptoms. Recurrence was defined as elevation of the diaphragm on the operated side along at least two intercostal spaces compared to the immediate postoperative period and relapsed respiratory symptoms.

Surgical technique

All surgical procedures were performed by the same surgical team using arms in the da Vinci® S system (Surgical Intuitive, CA, USA). The patients were anesthetized with combined intravenous and inhaled general anesthesia and double-lumen endotracheal tubes were administered. A perioperative nasogastric tube was applied to all patients to decrease gastric compression and placed in a lateral decubitus position. The localization of the trocars was determined according to the position of the scapula. A 12-mm trocar for a binocular camera was placed in the seventh intercostal space posterior to the scapula, and carbon dioxide (CO_2) insufflation was performed at a preset pressure of 6 to 10-mmHg with a flow of 8 to 9 L/min. The CO_2 insufflation was decreased as the diaphragm moved toward the abdomen, which was the most important part of a successful surgery. A port for arm one was placed in the fourth intercostal space anterior to the scapula, and another port for arm two was placed in the ninth intercostal space below the camera port. The assistant port was placed in the ninth intercostal space below the camera arm (Figure 1). Gastric decompression and a good vision were easily achieved by CO_2 insufflation (Figure 2a). We placed a large needle driver on arm one and Cadière forceps on arm two to avoid injuring the

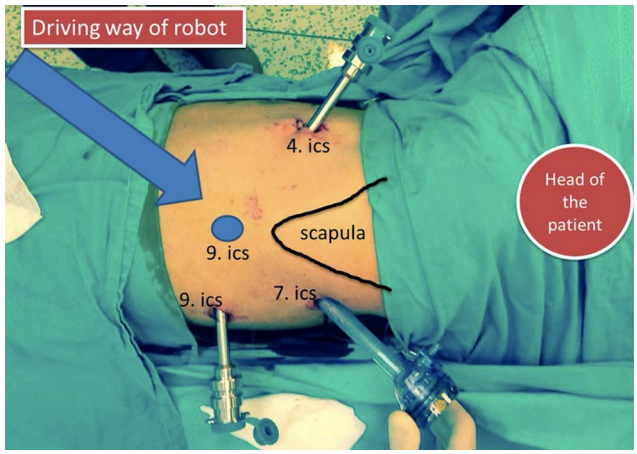

Figure 1. Port positions for robot-assisted thoracoscopic diaphragmatic plication.

diaphragm. This first suturing was more difficult to perform than other U sutures, as it may be out of the reach of robotic arm one (Figure 2b, c). This first U suture was knotted carefully with the help of pledgets. This knotting made it easier to pass the other five or six U sutures to achieve the plication (Figure 2d). Care should be taken not to sew too tight, as excessive tension may cause such problems as shortness of breath and indigestion due to increased abdominal distension in patients. After completing the plication, a single 32-Fr chest drainage tube was inserted into the thoracic cavity. The mean console time (time for the surgeon to complete the plication) was 24 min. As soon as the patient's bowel movements resumed, the nasogastric tube was terminated and a liquid diet was started orally.

Quality of life assessment

The World Health Organization Quality of Life-BREF (WHOQOL-BREF) scale recommended by the World Health Organization's quality of life group was used to objectively evaluate the change in patients' quality of life. This score provides a versatile assessment that is not affected by cross-cultural changes. The WHOQOL-BREF consists of 26 questions and evaluates general health status together with psychosocial, physical, and environmental factors and social relationships.[6] The WHOQOL-BREF scale was applied preoperatively and at one-year follow-up postoperatively.

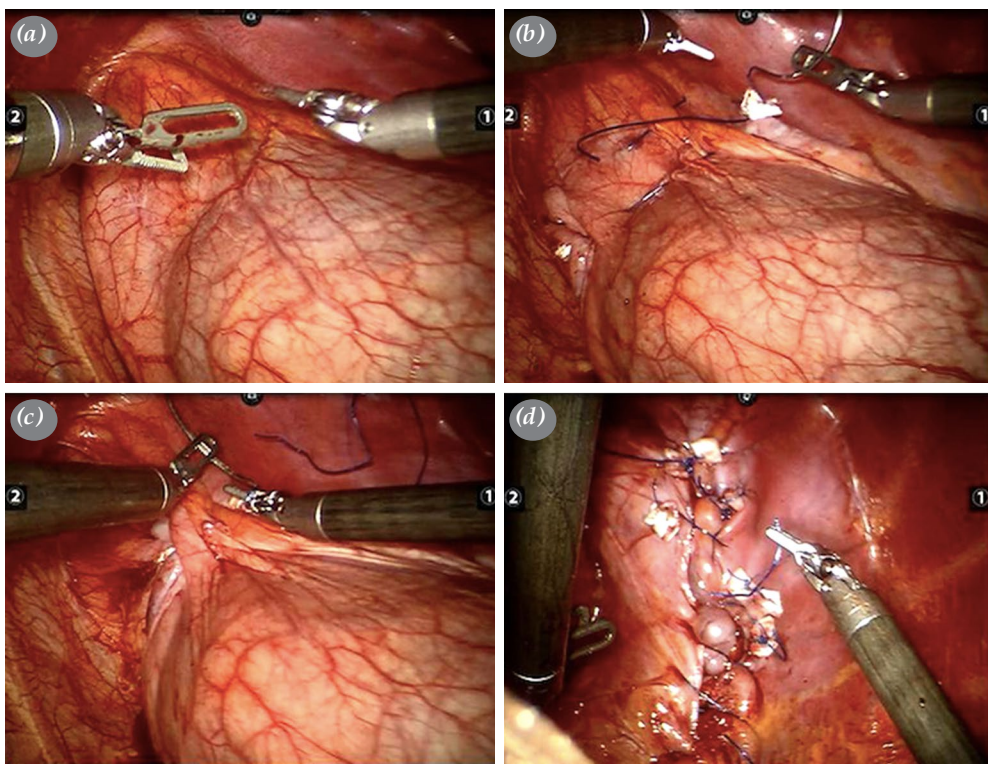

Figure 2. (a) The diaphragm was decreased toward the abdomen and CO_2 insufflation provided a perfect exposure and room for plication. **(b, c)** The first U suturing with 1 prolen was placed near to lateral chest wall part of the diaphragm. **(d)** After placed 5 or 6 U sutures, we placed a continue suture over the U sutures for strengthening.

Statistical analysis

Statistical analysis was performed using the IBM SPSS version 25.0 software (IBM Corp., Armonk, NY, USA). Descriptive data for normally distributed variables were presented using means and standard deviations, and non-normally distributed and ordinal variables were presented using medians and interquartile range (IQR). The Wilcoxon test was used to compare the MRC scores at baseline (preoperative) and 12 months postoperatively. A paired samples t-test was used to compare BMI values and WHOQOL-BREF scores at baseline and 12 months postoperatively. During the investigation of the associations between non-normally distributed and/or ordinal variables, the correlation coefficients and their significance were calculated using the Spearman test. A p value of <0.05 was considered statistically significant.

Table 1. Characteristics of patients

Demographics	n	%	Mean±SD	Median	Min-Max	IQR
Age (year)				55	24-70	35
Sex						
Male	11					
Female	2					
Etiology						
Unknown	5	38.5				
Iatrogenic	4	30.8				
Traumatic	3	23.1				
Neurological	1	7.7				
Side of diaphragmatic elevation						
Left	12	92.3				
Right	1	7.7				
Median FEV1 (%)						
Preoperative				63.9	36.7-92	27.8
Postoperative 1 month				71.9	40-94	20.6
Postoperative 6 month				73.1	54.6-97	21.5
Postoperative 1 year				79.5	51.9-97	20.2
Median MRC dyspnea score						
Preoperative				2	1-4	2
Postoperative 1 year				1	1-4	0
Median BMI						
Preoperative				30.12	18.28-35.13	6.22
Postoperative 1 year				29.4	24.22-35.15	6.04
Mean WHOQOL-BREF score (preoperative/postoperative)						
General health			6.2±0.4 / 7.3±0.5			
Physical health			24.6±1.2 / 28.6±1.6			
Psychological health			22.3±1.1 / 23.8±1.36			
Social relationship health			11.1± 0.9 / 11.0±0.91			
Environmental health			28.9±1.1 / 29.0±1.2			
Total score			93.8±3.4 / 99.8±3.3			
Median time of operation (min)				100	86-135	17
Median length of drain (day)				1	1-5	0.5
Median length of hospital stay (day)				2	2-18	3

SD: Standard deviation; IQR: Interquartile range; FEV1: Forced expiratory volume in 1 sec; MRC: Medical Research Council; BMI: Body mass index; WHOQOL-BREF: The World Health Organization Quality of Life-BREF.

RESULTS

The etiology was iatrogenic in 30.8% (n=4) of the patients, traumatic in 23.1% (n=3), neurological in 7.7% (n=1), and idiopathic in 38.5% (n=5). Twelve of the operations were performed on the left side. The median preoperative forced expiratory volume in 1 sec (FEV1) 63.9% (range, 36.7 to 92%) of the predicted value, on average. The median preoperative BMI of the patients was 30.12 (range, 18.28 to 35.13) kg/m^2. The patient characteristics are presented in Table 1.

The median preoperative MRC dyspnea score was 2 (range, 1 to 4). The median postoperative MRC dyspnea score at 12 months was 1 (range 1-4, IQR=0). The change between the preoperative and 12-month postoperative MRC scores was found to be statistically significant (p=0.008). No statistically significant difference was observed between the preoperative and 12-month postoperative BMI values (p=0.759). No significant correlation was found between preoperative BMI and MRC score (p=0.83). No significant improvement was detected in the median FEV1 values in the first month postoperatively (p=0.284); however, at six months postoperatively, a significant improvement in FEV1 was observed compared to preoperative values (p<0.001). When the preoperative and 12-month postoperative FEV1 values were compared, the change in FEV1 level was found to be significant (p=0.036).

The total WHOQOL-BREF scores were not significantly different before surgery and at 12 months postoperatively (p>0.05). In terms of subscale, general health, psychological factors, social relationships, and environmental subscales did not differ preoperatively and one year postoperatively (p=0.017, p=0.117, p=0.337, p=0.337, respectively). However, in the physical health subscale, the scores differed statistically significantly preoperatively and one year postoperatively (p=0.002).

Median time to chest tube removal was 1 (range 1-5, IQR=0.5) days. Median total length of hospital stay was 2 (range 2-18, IQR=3) days. One patient developed a complete atrioventricular block requiring medication on the first postoperative day. No recurrence or failure was observed in any patient who underwent robotic diaphragmatic plication.

DISCUSSION

Since the success of the plication technique was first described by Morrison[7] in 1923, research on both the transabdominal and transthoracic approaches have been contributed to the literature.[1-4,8] The superiority of either approach to the other has not been proven. The chosen approach depends on the experience of the surgeon and the conditions of the center.[8] The first robotic thoracoscopic diaphragmatic plication was performed by Kwak et al.[9] in 2012. Since then, the robotic dexterity in plication has been emphasized in various studies.[8-14]

The transthoracic approach provides a clear view, as there is no obstruction by the liver or intestine. The CO_2 at a low pressure pushes the diaphragm down and reduces resistance to plication, making it relatively easy. Freeman et al.[3] reported that thoracoscopic plication was equivalent in efficiency to plication with thoracotomy. However, limitations of the approach have been reported, such as the necessity of one-lung ventilation and the observability of only a single hemidiaphragm.

We believe that robotic diaphragmatic plication is technically superior. The CO_2 insufflation provides a significantly better workspace, provides adequate diaphragmatic folds for suturing, and avoids injury to the abdominal organs. Also, the robot has more intuitive movements, greater flexibility, and high-definition three-dimensional vision, which can overcome the limitations of VATS and open surgery. Complete thoracoscopic diaphragmatic plication using CO_2 insufflation has been reported with good results, with particular mention of its improvement of the working space. The restricted freedom of movement and poor ergonomics are the major undesirable features of VATS.[9,12]

Robotic diaphragmatic plication has some disadvantages, such as high cost, technical difficulties, lack of contact with the device, lack of tactile feedback, and lack of knowledge of how forcefully the tissue is crushed.[8,14] This approach also prevents the patient's position from being changed after docking. As it is impossible to perceive how strongly the suture materials are tightened while using the robotic technique, it is very common for monofilament sutures, such as prolene, to break during knotting, depending on the surgeon's experience. Experience is, thus, of utmost importance to successfully perform this surgical technique.

Long-term effects are more difficult to detect, but they represent the criteria for the success of an operation.[1,3,15,16] The use of PFT alone to measure these criteria would provide an incomplete determination of the true contribution of this technique.[16] Over time, patients may encounter additional problems and their existing diseases may progress, which may adversely affect the apparent positive contribution of the surgery in the long term. Therefore, quality of life

scores would provide a more realistic result regarding the contribution of this surgery. The significant postoperative improvement in the WHOQOL-BREF of the patients in our study supports the contribution of surgery. The WHOQOL-BREF is a more individualized reflection of the benefits of the surgery.

It can be argued that satisfaction with social relations and environmental parameters depends on economic conditions rather than directly on health. In our study, a significant improvement in physical health parameters was detected in patients who underwent surgery. The physical health parameter can be directly linked to the skills the patient gained or lost due to their illness; thus, this parameter is the true illustration of recovery after surgery.

Nonetheless, this study has several limitations. First, as a single-center, retrospective study, it is prone to selection bias. The study also has a small sample size including only adult patients. In addition, we collected follow-up information only one year postoperatively and, therefore, we did not have information about changes in the respiratory function of patients after the first year.

In conclusion, although diaphragmatic plication does not cause a significant improvement in PFT scores in the early postoperative period in symptomatic patients, it creates a significant improvement in quality of life. We recommend robotic plication of the diaphragm owing to its safety, feasibility, and technically superior aspects compared to other minimally invasive techniques and open techniques.

Ethics Committee Approval: The study protocol was approved by the University of Health Sciences Non-Interventional Research Ethics Committee Ethics Committee (date: 25.02.2020, no: 2020/04). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Idea/concept: M.S.I., K.K., H.I.; Design: M.S.I., O.G.; Control/supervision: K.K., S.G., H.C., O.G.; Data collection and/or processing: M.S.I., E.I.S., H.I., E.S.;Analysis and/or interpretation: M.S.I., H.C.; Literature review: M.S.I., E.I.S., E.S; Writing the article: M.S.I., K.K., H.I.; Critical review: K.K., S.G., H.C., O.G.

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