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Robotic anatomic pulmonary segmentectomy: technical approach and outcomes.

Segmentectomia pulmonar anatômica robótica: aspectos técnicos e desfechos.

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A B S T R A C T

Objective: to report our initial experience with pulmonary robotic segmentectomy, describing the surgical technique, the preferred positioning of portals, initial results and outcomes. **Methods:** we collected data, from a prospective robotic surgery database, on patients undergoing robotic segmentectomy between January 2017 and December 2018. All patients had lung cancer, primary or secondary, or benign diseases, and were operated on with the Da Vinci system, by the three portals technique plus one utilitarian incision of 3cm. We dissected the hilar structures individually and performed the ligatures of the arterial and venous branches, of the segmental bronchi, as well as a parenchymal transection, with endoscopic staplers. We carried out systematic dissection of mediastinal lymph nodes for non-small cell lung cancer (NSCLC) cases. **Results:** forty-nine patients, of whom 33 were women, underwent robotic segmentectomy. The average age was of 68 years. Most patients had NSCLC (n=34), followed by metastatic disease (n=11) and benign disease (n=4). There was no conversion to laparoscopic or open surgery, or to lobectomy. The median total operative time was 160 minutes, and the median console time, 117 minutes. Postoperative complications occurred in nine patients (18.3%), of whom seven (14.2%) had prolonged hospitalization (>7 days) due to persistent air fistula (n=4; 8.1%) or abdominal complications (n=2.4%). **Conclusion:** robotic segmentectomy is a safe and viable procedure, offering a short period of hospitalization and low morbidity.

Keywords: Lung Neoplasms. Robotic Surgical Procedures. Thoracic Surgery, Video-Assisted. Indocyanine Green.

INTRODUCTION

The anatomical pulmonary segmentectomy is becoming more popular among thoracic surgeons in the last decade, as the improvement of tomography technology and the adoption of lung cancer screening with low-dose computed tomography (CT) in high-risk patients have been able of detecting a greater number of lung tumors in initial sages[1]. In addition, with the advent of new promising systemic therapies for other solid organ neoplasias and the quality of high-resolution CT, we have noted hum an increasing role of the anatomical segmentectomy also for treatment of lung metastases[2,3].

Compared to pulmonary lobectomy, anatomical segmentectomy is a more technically difficult procedure. It requires deep knowledge of the lung segmentation and of the anatomical variations, as it involves the precise identification and individual ligation of arteries, veins and bronchi of the resected segment. However, it has the advantage of sparing lung parenchyma, and consequently, preserving its function, which is important in patients with impaired pulmonary function or at high risk of tumor recurrence[4].

Minimally invasive segmentectomy has traditionally been performed by a video-assisted thoracoscopic surgery (VATS) techniques[5,6]. The first robotic segmentectomy (R-VATS) was reported in 2007, by Anderson *et al.*[7].

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Since then, few original studies have described the operative technique, the biggest one including 100 patients[8]. In Brazil, R-VATS is a recent reality, with few groups mainly performing pulmonary lobectomies.

The aim of this study was to report our initial experience with robotic segmentectomy, describing the operative technique, the preferred positioning of portals, initial results and outcomes.

METHODS

We obtained clinical data from patients undergoing robotic segmentectomy between January 2017 and December 2018 from a prospective robotic surgery database. This database contains information on patients operated on the same group of thoracic surgeons at five private tertiary hospitals in São Paulo and Rio de Janeiro since the beginning of our Robotic Thoracic Surgery Program, in April 2015.

This work was approved by the Institutional Ethics Committee with the following reference number: NP 1445/18.

Patient selection

We considered the anatomic pulmonary segmentectomy for patients with primary and secondary lung cancer, as well as for patients with some specific benign condition. In patients with primary lung cancer, we performed anatomic segmentectomy for subsolid nodules with less than 2cm in their largest diameter and no evidence of lymph node metastasis at clinical staging. Biopsy for confirmation of lung cancer was not obligatory if the nodule tomographic features led to high suspicion of primary lung cancer (solid, spiculated nodules or ground-glass opacities with solid components). We also performed anatomic segmentectomies for solid nodules smaller than 2cm when the patient presented borderline lung function.

For secondary lung cancer, we conducted anatomic segmentectomy in patients with controlled primary disease, without evidence of extra-pulmonary metastases (except in cases of liver metastases of colorectal cancer amenable to resection) and with pulmonary nodules in sites unsuitable to wedge resection, such as central or hilar nodules, or larger nodules.

For benign diseases, we opted for segmentectomy in patients with the disease anatomically located in one of the largest pulmonary segments, but not in the entire lobe, in order to preserve lung parenchyma.

Patient positioning, portal placement and operative technique

All surgical procedures were performed using selective intubation. We did not routinely use epidural catheter for postoperative analgesia. Alternatively, we performed an intercostal block with anesthetic solution under direct vision at the beginning of surgery. We positioned the patients in lateral decubitus, with two cushions under the axilae. The table was then flexed for better opening of the intercostal spaces.

We used four portals, three for the robotic arms and one for the assistant surgeon (Figure 1). The first incision was made on the mid axillary line at the seventh intercostal space (ICS) for upper lobes' segmentectomies and in the eighth intercostal space for lower lobes' segmentectomies. We placed a 12mm plastic trocar and introduced a 0 degree robotic camera. The heated and humidified CO_2 (8l/min flow) was then instilled into the chest to lower the diaphragm.

Figure 1. *(A) Incision planning for a segmentectomy (S4/S5) in the left upper lobe; CA= camera portal; SP= service portal; LA= left arm; RA= right arm; (B and C) placement of portals and robot docking.*

Under thoracoscopic visualization, we performed a nine-level, posterior intercostal nerve block (picb) (t3-t11) with local anesthetics (ropivacaine). Then we identified the diaphragm insertion into the chest wall at the tenth ICS level, where we inserted a 12mm plastic trocar, used by the assistant surgeon for exposure, aspiration, stapling, introduction and removal of materials (gauze), and removal of specimens for histopathological examination. Subsequently, we placed two other 8mm portals: the first on the anterior axillary line, one ICS superior to the camera portal and the second on the posterior axillary line, in the same ICS as the camera. We then introduced the robotic instruments into these two portals. In most cases, we used only two robotic tweezers, one bipolar "maryland" and one "grasper thoracic" clamp, or "cadiere". The position of these portals was caudal to the oblique fissure. The robot, a Da Vinci robotic platform (intuitive, Sunnyvale, CA), was set over the patient's shoulder at a 15 degree angle and attached to the three portals.

The surgical steps to complete the resection of each segment were similar to those previously reported by Cerfolio *et al*.[8]. We performed mediastinal lymph node dissection in cases of non-small cell lung cancer (NSCLC).

Finding the intersegmental plan and the use of green indocyanine

One of the most challenging aspects of the segmentectomy is the detection of the intersegmental plane, while preserving an appropriate surgical margin. The traditional method involves parenchymal insufflation after clamping of the segmental bronchus, but this technique is not always useful due to the collateral ventilation between the segments, through the pores of Kohn, especially if there is emphysema. Expansion of the remaining lung can also impair surgical view.

The use of green indocyanine has been described for this purpose. One technique involves injecting the substance through the segmental bronchus after segmental vein ligation. The intersegmental plane is then identified by a color change not only on the pleural surface, but also on the pulmonary parenchyma segment[9]. Another technique involves intravenous indocyanine injection after occlusion of the pulmonary segment artery. An endoscopic camera with fluorescent infrared light imaging system is then used to visualize the real time perfusion of indocyanine. When the substance is injected, it appears on screen in ten to 20 seconds and has a half-life of three minutes. If the correct artery is occluded, the lung will turn green but the segment of interest. At this time, the intersegmental plane can be confirmed and marked before stapling[10,11].

In this study, we used the traditional pulmonary insufflation method in most cases, due to unavailability of indocyanine. When available, we used the indocyanine method as described above, with peripheral venous injection of 3mg/kg of the substance after segmental artery identification and occlusion (Figure 2).

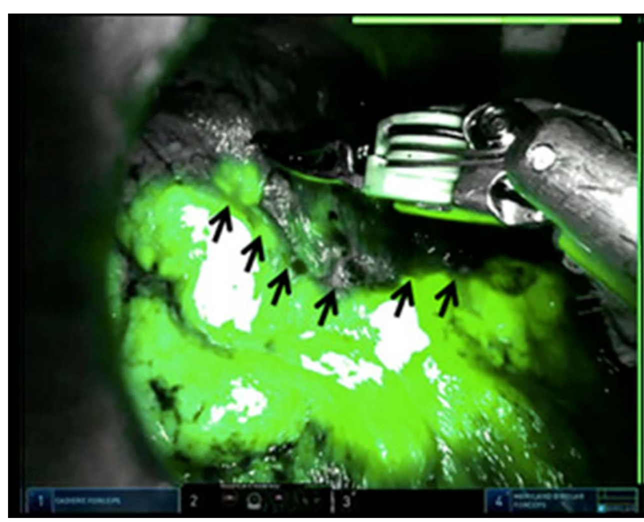

Figure 2. *View to intersegmentar plane (arrows) after intravenous injection of indocyanine green.*

Data collection and statistical analysis

This study was based on data from our database regarding demographics, diagnosis, type of segmentectomy, operative time, ICU referral, thoracic drainage time, length of hospital stay, histology and morbi-mortality of patients undergoing robotic segmentectomy. We expressed categorical variables as absolute numbers and percentages. We expressed continuous, normally distributed variables as mean and standard variation, and the ones with asymmetric distribution, as median and interquartile range.

RESULTS

In the evaluation period, 49 patients, including 33 women, underwent robotic segmentectomy. Table 1 describes the characteristics of patients and the distribution of the performed segmentectomies, histology and pathological staging for primary lung cancer. The most carried out procedure was the segmentectomy of the upper segments (S6) of the right lower lobe (RLL) and of the left lower lobe (LLL) (n=11, 22.4%), followed by trisegmentectomy (S1/S2/S3) of the left upper lobe (LUL) (n=9, 18, 3.0%) and the segmentectomy of the posterior segment

Table 1. *Characteristics of patients and distribution of performed segmentectomies, histology and pathology staging for lung cancer.*

Variables	Patients (N=49)
Age, mean (SD)	66 (9.6)
Female gender, n (%)	33 (67.3)
BMI*, median (range)	25.8 (21.4-31.6)
Smoking history, n (%)	24 (48.9)
Comorbidities, n (%)	
Hypertension	26 (53.06)
Diabetes *mellitus*	5 (10.2)
Congestive heart failure	3 (6.1)
Chronic kidney disease	2 (4.0)
Liver failure	1 (2.0)
Chronic obstructive pulmonary disease	7 (14.2)
Segmentectomy types	
Left upper lobe	
Lingulectomy (S4/S5)	1
Lingulectomy (S4)	1
Trisegmentectomy (S1/S2/S3)	9
Apicoposterior segment (S1/S2)	1
Left lower lobe	
Upper segment (S6)	4
Basal segments (S8/S9/S10)	3
Anterior segment (S8)	2

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Variables	Patients (N=49)
Right upper lobe	
Apical segment (S1)	4
Posterior segment (S2)	8
Anterior segment (S3)	2
Apicoposterior segment (S1/S2)	1
Right lower lobe	
Upper segment (S6)	6
Basal segments (S7/S8/S9/S10)	4
Anterior + medial segments (S7/S8)	1
Histological type of primary lung neoplasms	N=34
In situ adenocarcinoma	10
Minimally invasive adenocarcinoma	5
Predominantly lepidic adenocarcinoma	3
Predominantly papillary adenocarcinoma	1
Predominantly acinar adenocarcinoma	9
Invasive mucinous adenocarcinoma	2
Signet ring cell adenocarcinoma	1
Carcinoid	2
Mucinous/non-mucinous mixed adenocarcinoma	1
Pulmonary metastases	N=11
Kidney (clear cell carcinoma)	2
Colon (adenocarcinoma)	4
Rectum (adenocarcinoma)	1
Uterus (rhabdomyosarcoma)	1
Nasal sinus (rhabdomyosarcoma)	1
Pancreas (adenocarcinoma)	1
Skin (melanoma)	1
Benign nodules	N=4
Hypersensitivity pneumonitis	1
Pulmonary sequestration	1
Fibroinflammatory injury	2
Nodule size (primary lung cancer), mm, mean (SD)	12.4 (3.6)
Nodule size (lung metastases), mm, mean (SD)	17.5 (14.9)
Final pathological staging (primary lung cancer)	
Tis N0M0	9
T1a N0M0	12
T1b N0M0	8
T2a N0M0	1
T3 N0M0	1
Number of resected lymph nodes (for primary lung cancer), median (range)	6 (0-19)
Number of resected lymph node chains (for primary lung cancer), median (range)	5 (0-9)

** BMI: body mass index.*

(S2) of the right upper lobe (RUL) (n=8, 16.3%). Most patients had NSCLC (n=34, 69.3%), followed by metastatic disease (n=11, 22.4%) and benign diseases (n=4, 8.1%). Among patients with NSCLC, the main histological types were *in situ* (n=10, 29.4%) and acinar (n=9, 26.4%) adenocarcinomas. Mean nodule size was 12mm for NSCLC and 17.5mm for metastatic disease. There was no case of microscopically compromised margins.

Table 2 describes the outcomes. There was no conversion to open surgery or VATS, nor conversion to lobectomy. The median operative time was 160 minutes, and the console time was 117 minutes. One patient had an intraoperative complication, with cardiopulmonary arrest after an anaphylactic reaction that occurred at the end of the procedure, after removal of the pathological specimen. This patient recovered very well and was discharged on the fifth postoperative day.

The median length of hospital stay was three days. Postoperative complications occurred in nine patients (18.3%). Of these, four (8.1%) had prolonged hospitalization (>7 days) due to persistent air leak and two (4%) due to abdominal complications not related to the surgical technique. As for the abdominal complications, one patient presented Olgilvie syndrome, receiving conservative treatment displaying good evolution. The other patient had acute abdomen secondary to perforated acute diverticulitis, and underwent emergency colectomy, also with good clinical outcome. One patient (2%) had pneumonia. Three patients (6.1%) were discharged with the chest tube (Table 2).

DISCUSSION

In the past, anatomical pulmonary segmentectomy was performed mainly for benign diseases, such as bronchiectasis and infectious lesions[12,13]. The role of this procedure for the treatment of NSCLC at an early stage has been questioned, as the single randomized clinical trial that compared lobectomy with limited resection, carried out in 1995, suggested an increased risk of local recurrence in patients undergoing the latter. However, that study has been criticized for including wedge resections and anatomic segmentectomies in the same study branch[14].

Table 2. *Outcomes.*

Variable	Patients (N=49)
Conversion to thoracoscopy, thoracotomy or lobectomy	0
Operative time in minutes, median (range)	160 (60-313)
Console time in minutes, median (Range)	117 (27-279)
Pleural drainage time in days, median (range)	2 (1-15)
Length of hospital stay in days, median (range)	3 (1-30)
Postoperative complications	
Atelectasis	1
Pneumonia	1
Prolonged air fistula	4
Pneumothorax	2
Pseudo-obstruction of the colon (Ogilvie's syndrome)	1
Perforated acute abdomen (secondary to diverticulitis)	1
Atrial fibrillation	2
Intraoperative complications	
Anaphylactic reaction with cardiopulmonary arrest	1

Since then, some retrospective studies have sought to establish the efficacy of segmentectomy in NSCLC stage I with 2cm or less, demonstrating better preservation of pulmonary function, without decreased survival when compared with lobectomy[4,15,16]. The Cancer and Leukemia Group B140503 study is currently investigating the efficacy of segmentectomy compared with lobectomy as for overall survival[17].

Currently, with the technological advances in the field of radiology and the advent of lung cancer screening programs, a higher incidence of early-stage NSCLC is being observed. In this scenario, the minimally invasive segmentectomy is gaining more attention.

Performing a true anatomical segmentectomy requires a thorough knowledge of the pulmonary anatomy and a good tomographic study of the location of the nodule in the lobe, ideally with reconstruction tomography. The use of minimally invasive technique, as we have described, has a disadvantage of not allowing digital palpation of the nodule. On the other hand, many ground-glass opacities would not be easily located by digital palpation, even through a minor accessory incision. For this reason, the nodule must have a favorable location in the lung segment for the resection margins to be safe. In thoracoscopic procedures, we can use intraoperative fluoroscopy to locate radiopaque markers previously inserted in the nodule by tomographic guidance, thus ensuring adequate resection margins. Unfortunately, the positioning of the radioscopic arc is not possible due to the robotic arms. In this situation, frozen section analysis of surgical margins is mandatory. Electromagnetic navigation bronchoscopy-directed pleural tattoo right before the procedure may facilitate localizing small nodules[18]. Cerfolio *et al*.[8] described the use of this procedure in 16 patients, with good results in 11 of them. Unfortunately, it is not yet available in Brazil.

When compared to thoracoscopy, the robotic system has some advantages that facilitate the anatomic segmentectomy. Whilst the instruments of the former are rigid, restricting maneuverability, the robotic arms and instruments allow higher degrees of movement, simulating the human arms' and wrists movements. In Addition, the robotic system allows three-dimensional view, which is superior to the two-dimensional visualization of thoracoscopy.

Some segments are more prone to resection due to their anatomical structure. In this study, the most performed procedure was the segmentectomy of the upper segment (S6) of the lower lobes, followed by LUL trisegmentectomy (S1/S2/S3). Since the LUL is the biggest lobe, we believe that it is important to spare pulmonary parenchyma with segmentectomy whenever possible. On the other hand, with the middle lobe, the smallest one, we usually opt for direct lobectomy.

In this study, we show our initial experience with robotic segmentectomy, describing our preferred portal positioning, operative technique, and results. As previously published[19], we prefer to use the three-arm robotic technique proposed by Ninan and Dylewski[20], with some adaptations. This technique has the advantage of being more economical, since it does not require the use of a third clamp, normally used in the four-arm technique proposed by Cerfolio *et al*.[21], which is extremely important in the Brazilian reality.

Our median surgical time was 160 minutes, which is longer than the 88 minutes reported by Cerfolio *et al*.[8] in the largest series of robotic segmentectomy in existence today, but is comparable to the operative time reported by other authors, such as Dylewski[22] (n=35, 180min), Pardolesi[23] (n=17, 189min), Yang[24] (n=35, 146min) and Demir[25] (n=34, 76±23min). The median length of hospital stay of three days was also compared to the cited works. The most common complication was air leak persistence (over five days). This is one of the main complications observed in pulmonary resection surgeries, being more common in patients with emphysema and pleural adhesions. In the literature[26], its incidence varies between 8% and 10%, agreeing with our findings.

This study presents some limitations. Due to the short follow-up period, we could not assess the recurrence and survival curves for primary lung cancer, which is an important issue when deciding between lobectomy and segmentectomy for NSCLC <2cm. In addition, this study is an experience of a small group of thoracic surgeons who started their robotic procedures two years ago and are still on their learning curve.

Our results suggest that a robotic approach to anatomic segmentectomy is safe and feasible. There was no conversion to lobectomy or open surgery, with variable operative time and short hospital stay. However, more studies are needed to compare the robotic segmentectomy with the open and thoracoscopic approaches, especially to analyze the long-term follow-up in terms of oncological efficacy. We believe that the robotic system will favor the anatomical segmentectomy in the near future, due to its technical advantages over the VATS procedures.

R E S U M O

Objetivo: *relatar nossa experiência inicial com a segmentectomia robótica, descrevendo a técnica operatória, a colocação preferencial dos portais, os resultados iniciais e desfechos.* **Métodos:** *dados clínicos de pacientes submetidos à segmentectomia robótica, entre janeiro de 2017 e dezembro de 2018, foram obtidos de um banco de dados prospectivo de cirurgia robótica. Todos os pacientes tinham câncer de pulmão, primário ou secundário, ou doenças benignas, e foram operados usando o sistema Da Vinci com a técnica de três portais mais uma incisão utilitária de 3cm. As estruturas hilares foram dissecadas individualmente e as ligaduras dos ramos arteriais e venosos, dos brônquios segmentares, assim como, a transecção do parênquima, realizadas com grampeadores endoscópicos. Dissecção sistemática dos linfonodos mediastinais foi realizada para os casos de câncer de pulmão não de pequenas células (CPNPC).* **Resultados:** *quarenta e nove pacientes, dos quais 33 mulheres, foram submetidos à segmentectomia robótica. A média de idade foi de 68 anos. A maioria dos pacientes tinha CPNPC (n=34), seguido de doença metastática (n=11) e doenças benignas (n=4). Não houve conversão para cirurgia aberta ou vídeo, ou conversão para lobectomia. A mediana do tempo operatório total foi de 160 minutos e do tempo de console foi de 117 minutos. Complicações pós-operatórias ocorreram em nove pacientes (18,3%), dos quais sete (14,2%) tiveram internação prolongada (>7 dias) devido à fístula aérea persistente (n=4; 8,1%) ou complicações abdominais (n=2; 4%).* **Conclusão:** *a segmentectomia robótica é um procedimento seguro e viável, oferecendo curto período de internação e baixa morbidade.*

Descritores: *Neoplasia de Pulmão. Procedimentos Cirúrgicos Robóticos. Cirurgia Torácica Videoassistida. Verde de Indocianina.*

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