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Current Trend of Robotic Thoracic and Cardiovascular Surgeries in Korea: Analysis of Seven-Year National Data

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Background: Robotic surgery is an alternative to minimally invasive surgery. The aim of this study was to report on current trends in robotic thoracic and cardiovascular surgical techniques in Korea. ***Methods:*** Data from the National Evidence-based Healthcare Collaborating Agency (NECA) between January 2006 and June 2012 were used in this study, including a total of 932 cases of robotic surgeries reported to NECA. The annual trends in the case volume, indications for robotic surgery, and distribution by hospitals and surgeons were analyzed in this study. ***Results:*** Of the 932 cases, 591 (63%) were thoracic operations and 340 (37%) were cardiac operations. The case number increased explosively in 2007 and 2008. However, the rate of increase regained a steady state after 2011. The main indications for robotic thoracic surgery were pulmonary disease (n=271, 46%), esophageal disease (n=199, 34%), and mediastinal disease (n=117, 20%). The main indications for robotic cardiac surgery were valvular heart disease (n=228, 67%), atrial septal defect (n=79, 23%), and cardiac myxoma (n=27, 8%). Robotic thoracic and cardiovascular surgeries were performed in 19 hospitals. Three large volume hospitals performed 94% of the case volume of robotic cardiac surgery and 74% of robotic thoracic surgery. Centralization of robotic operation was significantly ($p<0.0001$) more common in cardiac surgery than in thoracic surgery. A total of 39 surgeons performed robotic surgeries. However, only 27% of cardiac surgeons and 23% of thoracic surgeons performed more than 10 cases of robotic surgery. ***Conclusion:*** Trend analysis of robotic and cardiovascular operations demonstrated a gradual increase in the surgical volume in Korea. Meanwhile, centralization of surgical cases toward specific surgeons in specific hospitals was observed.

Key words: 1. Robotics
2. Cardiac surgery
3. Thoracic surgery

INTRODUCTION

Minimally invasive thoracic and cardiovascular operations have become increasingly common. The well-documented advantages of minimally invasive surgery include less postoperative pain, lower complication rates, and early recovery [1-4].

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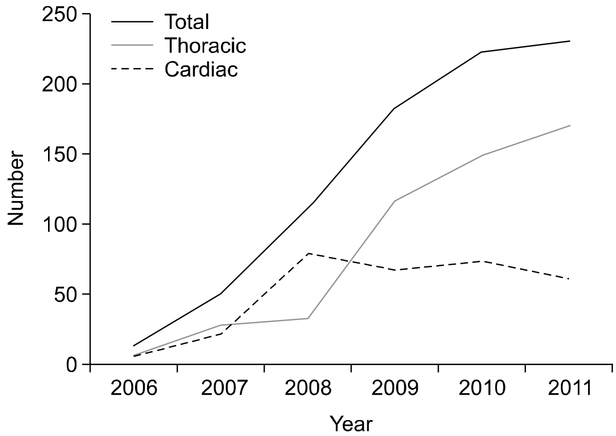

Fig. 1. Annual trend of robotic thoracic and cardiovascular surgery. In the early period, explosive increase of robotic surgery was observed. The rate of increase reached to steady state after 2010.

The recent development of robotic surgical technology has made robotic surgery another minimally invasive surgical option. A high-quality video system, three-dimensional view, free articulation of the robotic arms, motion scaling, and tremor filtering are specific features of the da Vinci robot system (Intuitive Surgical Inc., Sunnyvale, CA, USA) that can enhance the feasibility and improve the overall outcomes of minimally invasive surgery. Clinical studies on robotic surgery published in Korea have demonstrated that robotic surgery is more feasible and reliable than open thoracic or cardiovascular surgery [5-7]. However, it remains unclear how many robotic operations have been performed. The main indications for robotic surgery in Korea have not been established, and it is not known whether robots are being increasingly utilized in surgery in Korea. Therefore, the aim of this study was to identify overall trends in the occurrence of robotic thoracic and cardiovascular surgery in Korea by analyzing national data on robotic surgery collected by the National Evidence-Based Healthcare Collaborating Agency (NECA).

METHODS

1) Data collection

This study was approved by the institutional review board of Seoul National University Hospital (IRB No. 1403-096-566). National data on robotic operations were collected by the NECA. In 2012, the Ministry of Health and Welfare requested robotic surgery data from all hospitals in Korea in order to assess the policy question of the safety of robotic surgery. All hospitals where robot operations were performed submitted data to the Ministry of Health and Welfare. The data collected contained information about all cases of robotic surgery in Korea, and the NECA analyzed the data. The final analysis regarding the safety of robotic surgery in Korea was reported to the National Congress and released to the media. Of the data collected in 2012, we selected data on operations that were identified as having been performed in the Department of Thoracic and Cardiovascular Surgery of any institution. A total of 932 cases of robotic surgery between January 2006 and June 2012 were included in our study. In order to protect the private information of patients and hospitals, the identifiers of patients, hospitals, and surgeons were blinded to the authors. In order to prevent biased comparison between hospitals, outcome variables, including mortality, morbidity, and length of hospital stay, were not provided to the authors. The data analyzed in this study included gender, age, diagnosis, operation name, operation date, blinded hospital labels, and blinded surgeon labels. Therefore, the analysis was limited to annual trends in the frequency of robotic thoracic and cardiovascular surgery.

2) Statistical methods

The chi-square test or Fisher's exact test was used to compare categorical variables. All statistical tests were two-sided. IBM SPSS software ver. 21.0 (IBM Co., Armonk, NY, USA) was used for all statistical analysis. All p-values <0.05 were considered to indicate statistical significance.

RESULTS

1) Overall trends

The overall trend in the occurrence of robotic thoracic and cardiac surgery is shown in Fig. 1. In the early period of robotic surgery, few robotic thoracic and cardiac operations were performed in Korea. In 2006, only 13 thoracic and cardiac robotic operations were performed. The indications for robotic surgery in 2006 were: esophageal disease (n=5), valvular heart disease (n=4), mediastinal disease (n=2), and atrial septal defects (n=2). The number of annual cases increased to

Table 1. Growth rate of robotic surgery compared to the previous year

Year	Total (%)	Thoracic (%)	Cardiac (%)
2007	284	300	266
2008	124	17	259
2009	64	254	−15
2010	21	27	10
2011	3	14	−17

Table 2. Indications for robotic thoracic surgery

Diagnosis	No. (%)
Lung cancer	261 (44.2)
Pulmonary metastasis	4 (0.7)
Bronchiectasis	3 (0.5)
Benign pulmonary nodule	2 (0.3)
Congenital lobar emphysema	1 (0.2)
Esophagus	
Esophageal cancer	173 (29.3)
Benign esophageal tumor	15 (2.5)
Achalasia	8 (1.4)
Esophageal diverticulum	2 (0.3)
Gastroesophageal reflux disease	1 (0.2)
Mediastinum	
Mediastinal tumor	76 (12.9)
Thymoma	38 (6.4)
Myasthenia gravis	3 (0.5)
Others	
Chest wall tumor	1 (0.2)
Diaphragm palsy	1 (0.2)
Empyema	1 (0.2)
Tracheoesophageal fistula	1 (0.2)
Total	591 (100.0)

231 in 2011. Of the 932 total cases that were performed over this interval, 591 (63%) were robotic thoracic operations and 340 (37%) were robotic cardiac operations. In 2007 and 2008, the number of robotic operations increased explosively, with an annual rate of increase of 284% in 2007. However, the rate of increase then sharply decreased, dropping to 3% in 2011 (Table 1).

2) Robotic thoracic surgery

The indications for robotic thoracic surgery are summarized in Table 2. Three main indications were found for thoracic robotic surgery: pulmonary disease (n=271, 46%), esophageal disease (n=199, 34%), and mediastinal disease (n=117, 20%).

Table 3. Indications for robotic cardiac surgery

Diagnosis	No. (%)
Valvular heart disease	
MR	167 (49.1)
MR with Af	32 (9.4)
MR with TR	9 (2.6)
TR	8 (2.4)
MR with TR and Af	5 (1.5)
Mitral stenosis	1 (0.3)
Atrial septal defect	79 (23.2)
Cardiac myxoma	27 (7.9)
Ischemic heart disease	8 (2.4)
Infective endocarditis	3 (0.9)
Abdominal aortic aneurysm	1 (0.3)
Total	340 (100.0)

MR, mitral regurgitation; Af, atrial fibrillation; TR, tricuspid regurgitation.

Lung cancer, esophageal cancer, and mediastinal tumors were the most common indications for thoracic robotic surgery (Table 2). Only a very small number of robotic operations were performed for diseases of the chest wall, pleura, diaphragm, and airway. It was found that the number of lung cancer and esophageal cancer operations increased even after 2009. However, the frequency of mediastinal tumor operations has remained essentially the same since 2009.

3) Robotic cardiac surgery

The indications for cardiac surgery are summarized in Table 3. Three major indications were found for robotic cardiac surgery: valvular heart disease (n=228, 67%), atrial septal defects (n=79, 23%), and cardiac myxoma (n=27, 8%). Mitral valve surgery was the most common general indication in the category of valvular heart disease, and the most common specific indication was mitral regurgitation without atrial fibrillation (n=167, 49%). Robotic operations for ischemic heart disease were only performed in eight patients (2%). The case volume of robotic cardiac operations has remained steady since 2008.

4) Per-hospital analysis

The case volumes of robotic surgery in each hospital are shown in Fig. 2. Robotic operations were performed in 19 hospitals. Robotic thoracic operations were performed in 16

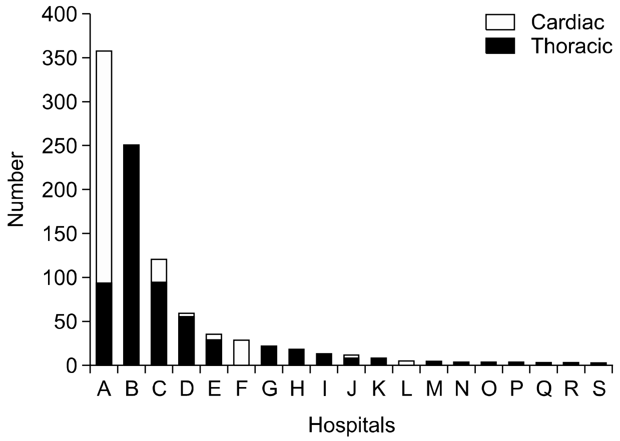

Fig. 2. Robotic surgery case volumes according to hospitals.

hospitals, and robotic cardiac operations were performed in 11 hospitals. The majority of the robotic operations (94% of cardiac operations and 74% of thoracic operations) were performed in three major hospitals. The degree of centralization of cardiac surgery was significantly ($p<0.0001$) higher than that of thoracic surgery. Eight hospitals (50%) performed more than 10 robotic thoracic operations. In comparison, only three hospitals (27%) performed more than 10 cases of robotic cardiac operations.

5) Per-surgeon analysis

One hospital did not submit data about the surgeons who performed robotic operations. Therefore, data about the surgeons were analyzed for 18 hospitals. A total of 39 surgeons performed robotic operations, including 26 thoracic surgeons and 13 cardiac surgeons. Seven surgeons (27%) performed more than 10 robotic thoracic operations, whereas three surgeons (23%) performed more than 10 robotic cardiac operations. Eleven hospitals (61%) had more than two surgeons who performed robotic surgery. Seven hospitals (39%) had only one surgeon who performed robotic surgery.

DISCUSSION

This is the first study to report annual trends in robotic thoracic and cardiovascular surgery in Korea. The analysis was performed using the NEHA database of information submitted by hospitals. Of a total of 932 cases, 63% were robotic thoracic surgery and 37% were robotic cardiac surgery. The annual volume of robotic surgery has continuously increased. However, the rate of increase is now lower than it was immediately after being introduced. We evaluated the centralization of cases, and found that robotic cardiac surgery was significantly more centralized than robotic thoracic surgery.

Robotic surgery has technological advantages over conventional thoracoscopic surgery. High-quality imaging with ×10 magnification and three-dimensional vision are the most important advantages. High-quality imaging is very important for minimally invasive surgery, especially when the target tissue or organs have a complex structure or when a complicated operation is required. Furthermore, complete resection of a tumor can be achieved by clearly delineating tumor tissue and normal tissue. Another significant advantage is the free articulation of the robotic arm, which enables a surgeon to perform difficult procedures more easily than in thoracoscopic surgery. Free articulation is useful when dissecting lymphatic tissues, performing complex valvular reconstruction, and when repairing organs or tissues. Theoretically, robotic surgery has many technological advantages. However, robotic surgery is not performed as frequently as might be expected for thoracic and cardiovascular disease because the advantages of robotic procedures have not been well established for thoracic and cardiac operations.

In this study, the most common indication for robotic thoracic surgery was lung cancer. Robot-assisted pulmonary resection was the major indication in other studies [8]. Whether robotic pulmonary resection is superior to other surgical modalities is not clear. Robotic surgery is likely to share the advantages of thoracoscopic surgery, including less postoperative pain, earlier recovery, and lower complication rates than open surgery. However, the benefits of robotic surgery over thoracoscopic surgery are unclear. Kent et al. [8] reviewed the State Inpatient Database and reported a total of 430 robotic lobectomies. Their study found a significant increase in the case volume of robotic pulmonary resection, and the early outcomes include improved mortality, length of stay, and overall complication rates in the robotic lobectomy group compared to the open lobectomy group. However, they were not able to demonstrate the superiority of robotic lobectomy over thoracoscopic lobectomy. Swanson et al. [9] compared 335 robotic lobectomies to 3,818 thoracoscopic lobectomies and found no difference in the length of hospital stay or adverse events. One study did report better outcomes in the robotic surgery group. Farivar et al. [10] compared 181 robotic pulmonary resections with 4,612 thoracoscopic resections. A significant decrease in the length of stay was observed in the robotic surgery group, but the mortality and morbidity rates were not significantly lower. Therefore, the role of robotic pulmonary resection as an alternative to thoracoscopic surgery remains unclear.

Robotic esophageal surgery was the second indication that we identified for thoracic surgery. A small case series has been reported for robotic esophagectomy, but no large series or systematic review is currently available. Kim et al. [5] reported that robotic esophagectomy was a feasible operation with acceptable early outcomes. Of the 21 patients included in their study, none experienced respiratory complications or mortality. Comparative studies between robotic and thoracoscopic esophagectomy involving small case series [11,12] have reported comparable outcomes for robotic esophagectomy. A study conducted by Suda et al. [11] found that robotic surgery prevented vocal cord paralysis more effectively than thoracoscopic esophagectomy.

Mediastinal disease was another indication for robotic thoracic surgery. The superiority of robot-assisted surgery in the treatment of anterior mediastinal tumors has been established in several studies [7,13,14]. A shorter length of stay, less blood loss, and fewer complications than open sternotomy have been reported [7,13] Robotic thymectomy was also found to have better results regarding control of myasthenia gravis than thoracoscopic thymectomy [14]. In anterior mediastinal disease, better outcomes after robotic surgery have been repeatedly reported. However, no large series has yet been reported.

In this study, the most common indication for robotic cardiac surgery was valvular heart disease. Mitral valve repair has been established as the major indication for robot-assisted cardiac surgery in other studies [4]. However, it is not clear whether robotic mitral valve repair is superior to other surgical modalities. Robotic surgery is likely to share the advantages of minimally invasive approaches, such as less postoperative pain, early recovery, and lower complication rates than open surgery. However, controversy persists regarding whether robotic surgery is more advantageous than other minimally invasive surgical modalities. Mihaljevic et al. [15] reported the results of 473 robotic mitral valve repairs from several cohorts in large multispecialty academic medical centers. They found that the cost of care for robotically assisted operations exceeded that of alternative approaches (by 26.8%, 32.1%, and 20.7% for complete sternotomy, partial sternotomy, and anterolateral thoracotomy, respectively). Higher operative costs were partially offset by lower postoperative costs and earlier return to work. The net differences in the cost of robotic surgery compared to the three other modalities were 15.6%, 15.7%, and 14.8%, respectively. However, robotically assisted surgery can only be performed with a cost similar to that of conventional approaches in high-volume centers. Unfortunately, no report has assessed cost-effectiveness in Korea, and the results from the United States cannot directly be applied to the Korean medical system due to fundamental differences in medical costs and the insurance system. Woo and Nacke [16] reported that robotic surgery patients had a significant reduction in blood transfusions and length of stay compared to sternotomy patients. Folliguet et al. [17] reported that the only advantage of robotic surgery was a shorter hospital stay (7 days vs. 9 days, p=0.05).

Repair for atrial septal defects was the second most common indication for robotic cardiac surgery. Kim et al. [6] reported that robotic atrial septal defect closure was a feasible operation with acceptable early outcomes. No instances of mortality or serious surgical complications were observed in the 50 patients included in their study. They concluded that, in selected patients, complete port access can be helpful for obtaining better cosmetic results with less musculoskeletal injury. No study has been carried out comparing robotic and thoracoscopic atrial septal defect closure.

Cardiac myxoma was another indication for robotic surgery. Gao et al. [18] reported that excellent results were obtained in the robotic excision of atrial myxomas in 19 patients. No operative deaths, strokes, or other complications occurred. No tumor recurrences or septal leakage was observed over the course of 18 months of follow-up [18]. However, the superiority of robot-assisted surgery over the conventional approach in treating myxoma has not been established.

Robot-assisted coronary artery bypass is a possible option for certain patients. Although some surgeons have reported some degree of experience with total endoscopic coronary bypass (TECAB), the complexity and the lack of long-term results after the procedure made it difficult to perform TECAB routinely [19,20].

In this study, we found that the case volume of robot-assisted surgery in Korea has increased over the study period. Although it is difficult to compare Korean data to data from other countries, analogous findings have been reported in other countries. Kent et al. [8] reported that the case volume of robot-assisted lung surgery in the United States increased from 0.2% to 3.4% between 2008 and 2010, while the case volume of thoracotomy decreased from 66% to 57%, representing a gradual increase in robotic surgery for major lung disease.

However, the rate of increase in the case volume showed the characteristic pattern of change for new surgical procedures, which involves early growth and a later slowdown. Although the reason for this phenomenon is unclear, one of the causes may be the small number of surgeons who performed robotic surgery. During the study period, the number of surgeons who performed robotic surgery did not increase significantly. There may be many reasons why many surgeons are reluctant to perform robotic surgery, such as lack of evidence, higher cost, and resistance to new technology. However, in this study, we were not able to determine which of the above considerations was the most important.

In this study, the annual case volume of robotic thoracic and cardiovascular surgery was found to have increased gradually. However, centralization in several centers was also observed. Centralization is an issue in the improvement of surgical outcomes. Hanneman et al. [21] reported that reductions in six-month and two-year postoperative mortality were associated with increased surgical volumes of esophagectomy. They found that the centralization of surgical esophagectomy was effectively established in the Netherlands. Centralization of robotic surgery has been documented for other diseases as well. Stitzenberg et al. [22] reported that both serial increases and decreases in prostatectomy volume were associated with robotic surgery. The volume increased in hospitals that obtained robots, but decreased in hospitals that never obtained a robot. This trend potentiates the centralization of surgical volume in high-volume centers, which results in an increased travel distance from the patient's home to the hospital. Anderson et al. [23] confirmed that the presence of a robot was associated with a higher prostatectomy volume. Whether the centralization is a result of active quality improvement interventions or patients' preferences for high-quality medical services is beyond the scope of this study. We believe that centralization to a small number of hospitals is a negative phenomenon, which may limit the spread of robotic surgery to other areas of the country.

Although the cost-benefit analysis of robotic surgery was not a main goal of this study, it is an important issue for understanding the situation regarding robotic surgery in Korea. In contrast to other surgical procedures that are reimbursed by the National Health Insurance Service in Korea, the surgical fee for robotic surgery is paid by the patients themselves. However, hospitals cannot charge for additional costs of surgical materials. In terms of cost-benefit analysis, robotic surgery is not an ideal surgical procedure for either patients or hospitals. Therefore, the advantages of robotic surgery should be confirmed by well-designed clinical studies and the additional cost of robotic surgery should be justified by clinical benefits for patients.

In this study, we reviewed national data on robotic thoracic and cardiovascular surgery. Although we could not evaluate the efficacy of robotic surgery in this study because the data did not contain outcome parameters, recent national trends in robotic surgery were identified. A gradual increase in the frequency of robotic thoracic and cardiovascular operations in Korea was identified. However, it was observed that cases of robotic surgery were centralized in specific hospitals and most frequently performed by a small number of surgeons.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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