Review Article on Robotic Surgery

Robotic lung cancer surgery: review of experience and costs

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Abstract: Use of robot-assisted techniques is growing fast in several surgical disciplines, now including thoracic surgery. The paper reviews experience of robotic surgery to resect lung cancer and in particular analyzes data on the costs of these procedures in comparison to open surgery and video-assisted thoracoscopic surgery (VATS). Retrospective studies published over 14 years show that robotic surgery for lung cancer has the advantages of minimally invasive surgery for patients, and some advantages over VATS for the surgeon. Limited data indicate that oncological outcomes are comparable with those of VATS and open surgery, while lymph node dissection may be more radical. Other studies indicate that robotic surgery for lung cancer offers no advantages either in terms of costs or outcomes. The high costs of purchase, maintenance and consumables are a concern and continue to limit uptake of robot systems in thoracic surgery. Most studies—but not all—indicate that robotic surgery for lung cancer is more expensive than VATS and open surgery. However limited data also indicate that hospitals can make a profit from robotic thoracic surgery, as costs seem to be lower than reimbursements from paying bodies. Nevertheless robotic thoracic surgery is still too expensive for many public hospitals, particularly in low income countries. Entry of new surgical robot manufacturers onto the market will bring much-needed competition that may also lead to cost reduction.

Keywords: Robotic thoracic surgery; costs; lung cancer; lung lobectomy; video-assisted thoracoscopic surgery (VATS); open surgery

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Introduction

Robot-assisted surgery for lung cancer was introduced in 2002 (1,2). After a slow start, use of a robot to perform lobectomy and other pulmonary excisions has increased rapidly from 2009. According to a study on non-academic hospitals in the United States, based on the database of the Agency for Health Care Research and Quality, in 2009, 66% of lobectomies were performed by thoracotomy, 33% by video-assisted thoracoscopic surgery (VATS), and only 1% by robot-assisted surgery, while by 2013, robotic resections had risen to 11% of the total (3). An analysis of the US Nationwide Inpatient Sample database (4) found a rapid increase in the number robotic lobectomies performed between 2008 and 2011, and also of the number of centers offering robotic lung surgery.

Several studies indicate that robotic surgery for lung resection is safe, and is associated with similar oncological outcomes to VATS and open surgery (5-8). Furthermore robot-assisted lung surgery offers several advantages to the surgeon summarized as improved vision and more precise and comfortable instrument manipulation (9,10).

Principal limitations to the wide adoption of robotic thoracic surgery are perceived as high capital and running costs of the robot instruments (11,12). Furthermore it would seem that use of robotic surgery in general has not improved patient outcomes as dramatically as the first wave of minimally invasive surgery did (13,14), so it is important to provide a balanced assessment the advantages and disadvantages of robot-assisted surgery for lung resection. In this article we make an attempt to do this, first by reviewing published experience of robotic surgery for lung cancer, then by evaluating data on the costs of robotic thoracic surgery in comparison to open and video-assisted approaches. Finally we assess prospects for cost reduction in the near future.

The da Vinci surgical system

At present the only manufacturer of robotic surgery equipment is Intuitive Surgical Inc. CA, USA. Intuitive's line of da Vinci Surgical robots is sold worldwide directly by the company or by agents such as AB Medica, SpA (in Italy). Intuitive Surgical aimed to establish da Vinci surgical systems as standard for complex surgical procedures in four main areas: urology, gynecology, cardiothoracic surgery and general surgery. Part of its approach consists of recruiting leading surgeons in these areas and encouraging them to communicate their experience with robotic techniques to their peers to thereby introduce surgeons, hospitals and patients to the advantages of minimally-invasive surgery performed robotically. It is also evident however that there is widespread direct-to-consumer advertising, and patients are increasingly requesting robotic surgery, with little knowledge of whether it is indicated for their particular condition (14).

Although some centers enjoy discounts, a new da Vinci robotic system generally costs around 2 million US$ ranging from 1$ to 2.5$ million for each unit (15). Maintenance costs are around 10% of the initial capital outlay per year (15). The cost of "consumables" which includes the instruments attached to the robotic arms is also high, mainly because the instruments can be sterilized and reused only a limited number of times, as specified by the company, irrespective of their duration of use in a given operation. Finally, depreciation costs are also significant.

The costs of training the surgeon and the surgical team also need to be considered. Several authorities (16-19) consider that the trainee surgeon should first gain familiarity on a simulator and then progress to a dual console so as to gain proficiency at switching the arms, using the endowrist instruments and suturing. A simulator costs 35,000–158,000 US$ (20) and is typically sold with the machine, as with the latest XI system robots. A second console increases the cost to around 3 million US$ (21) but makes it possible for the trainee to be tutored in real time by an expert robotic surgeon. Some hospitals purchase a da Vinci robot as a strategic choice unrelated to current cost, with the aim of stimulating clinical research, increasing publications, and enhancing their attractiveness to both patients and young surgeons. The purchase often follows an evaluation of the advantages and disadvantages of the robot system, but costs may be a non-critical aspect of this evaluation (22).

In Italy, as in most European countries, hospitals are reimbursed for admissions, treatments and surgical procedures by the Italian Health Service at fixed rates determined by a modified DRG system. Additional remuneration is not provided for robotic procedures except for robotic prostatectomies.

Literature review on robotic surgery for lung cancer

Following initial experience (1,2) Park *et al.* (23) reported on 34 patients undergoing robotic lobectomies with two thoracoscopic ports and a 4-cm utility incision. Conversion was performed in 4/34 (12%) patients, and all received an R0 resection. Operative mortality was 0%, median length of stay was 4.5 days (range, 2–14 days) with median operating time 218 minutes (range, 155–350 minutes). The authors concluded that robot assistance for video-assisted thoracic surgical lobectomy was feasible and safe. Veronesi *et al.* reported on the feasibility and safety of four-arm robotic lung lobectomy in 2009 (7). Fifty-four lung cancer patients treated by robotic lung lobectomy were compared with 54 patients who received open surgery. These experiences indicated that robotic lobectomy with lymph node dissection was practicable, safe, and associated with shorter postoperative stay than open surgery with similar number of lymph nodes removed. In 2012 a multi-institution group (24) presented technical aspects and initial results of robotic anatomic segmentectomies using the four-arm technique described by Veronesi *et al.* (7). Outcomes were comparable with those obtained by open surgery and VATS; however the authors noted that precise radical dissection of mediastinal and hilar lymph nodes was easier by the robotic approach than with VATS.

In 2011, Dylewski *et al.* (25) reported on 200 robotic lung resections performed using their approach involving chest cavity insufflation with CO2. Perioperative results were good with mean postoperative stay of 3 days, mean duration of surgery 90 minutes, 2% 60-day mortality and 26% morbidity. Also in in 2011, Cerfolio *et al.* (26) published their experience on a consecutive series of 107 four-arm robotic lobectomies, in comparison to 318 lobectomies performed by open surgery. The robotic group had better quality of life, shorter hospital stay, and lower mortality and morbidity than the thoracotomy group. In 2012 Louie *et al.* (3) published a case-control analysis of consecutive anatomic lung resections performed by robotic surgery or VATS. Surgical and postoperative outcomes were similar in both groups, but patients who received robotic surgery had significantly shorter duration of narcotic use and earlier return to normal activities than patients who received VATS.

Data on oncological outcomes with robotic surgery are limited. A multi-institute retrospective evaluation of over 300 robotic lobectomies (8), performed on mainly stage I patients with non-small cell lung cancer, indicated long-term stage-specific survival that was acceptable and consistent with prior results for VATS and thoracotomy.

Rate of nodal upstaging has been used a surrogate for completeness of nodal evaluation and quality of surgery. In one study (27) it was found that rate of nodal upstaging for robotic resection was greater than for VATS and similar to that for thoracotomy, however the authors noted that a larger series of matched open, VATS and robotic patients was necessary to confirm their finding. In comparative studies by Veronesi *et al.* (7) and Cerfolio *et al.* (26) the median numbers of lymph nodes removed by robotic and open procedures were closely similar, suggesting that robotic resection achieves similar oncological radicality to that achieved by thoracotomy. In their 2016 study, Louie *et al.* compared outcomes between robotic surgery and VATS in non-small cell lung cancer cases archived in the US Society of Thoracic Surgeons database. The found that, while operating times were significantly longer in robotic cases, all postoperative outcomes were similar, including complications, 30-day mortality, and nodal upstaging, indicating substantial equivalence between robotic surgery and VATS (3).

Notwithstanding these encouraging findings more long-term comparisons of outcomes in lung cancer patients treated by robotic and VATS approaches are required.

Costs of robotic surgery for lung cancer

The main argument against robotic thoracic surgery is greater costs in comparison to VATS. Several papers have analyzed costs, but results have been conflicting. Park *et al.* (28) analyzed lobectomies performed in 267 cases by open surgery, 87 cases by VATS, and by cases 12 by robot-assisted procedure. They found that operating times were similar for each group, and length of postoperative stay was shorter for VATS and robotic surgery (4 days) compared to open surgery (6 days). However robotic surgery cost US$ 3,981 more than VATS per operation, mainly due to the costs of robotic disposables and drapes. Importantly, however, robotic surgery was estimated to cost US$ 3,988 less than open surgery. This analysis did not consider depreciation of the robot instrument but did cite a theoretical cost analysis, which, assuming a 7-year life-span of the robot and 300 operations per year, estimated an additional cost of US$ 857 per robotic patient. When this depreciation cost was added to the original estimate of Park *et al.* (28) robotic surgery was still cheaper than open surgery.

One of the largest single-surgeon experiences in robot-assisted surgery was reported in 2014 by Nasir *et al.* (9). Although these authors found that robot-assisted lobectomy for cancer offered outstanding results, excellent lymph-node removal and minimal morbidity and pain, costs were higher than for VATS.

Median total costs were US$ 15,440 per patient against a median Medicare reimbursement of US$ 18,937, so notwithstanding the higher cost, robotic surgery was profitable for the hospital.

A retrospective analysis by Dylewski *et al.* (29) of 176 robot-assisted lobectomies compared to 76 VATS lobectomies, found that the robot assisted approach was US$ 560 per case lower than VATS, with most of the cost-saving due to reduced length of hospital stay and lower overall nursing costs.

However other papers, particularly large database comparisons, indicate considerably greater costs for robotic thoracic surgery. An analysis by Swanson *et al.* (30) on 15,502 operations (96% VATS, 4% robotic) found that robot-assisted thoracic surgery was associated with higher hospital costs, longer operating times, and no improvement in adverse events. Considering only lobectomies in a matched-pair analysis, robotic surgery was about 15% more expensive than VATS (US$ 21,833 *vs.* US$ 18,080). The robot-assisted procedures were performed in 40 different hospitals, equating to <8 cases/center over the two-year study period. Thus most hospitals were performing too few robotic procedures to complete learning or to maintain proficiency. However this is likely to have has only a limited effect on costs (perhaps by increasing operating times or complications compared to operations performed by experienced surgeons).

Paul *et al.* (4) compared perioperative outcomes and costs for robot-assisted lobectomy with thoracoscopic lobectomy from 2008 and 2011 (2,478 robotic pulmonary lobectomies and 37,595 VATS lobectomies), finding that robot-assisted surgery had higher costs and more complications. The results of this study may also have been biased because a greater proportion of robot-assisted operations were performed in small-to-medium sized hospitals, in non-teaching hospitals, and those with moderate patient volume, explaining the greater proportion of complications and possibly also part of the increased costs.

Deen *et al.* (31) analyzed 184 consecutive patients with similar comorbidities who underwent lobectomy or segmentectomy (69 by thoracotomy, 57 by robot, and 58 by VATS). There were no differences in complication rate or length of hospital stay, but significantly different operation times. Furthermore overall costs, which included depreciation, differed significantly between the groups: VATS was the least expensive, and robotic surgery was the most expensive procedure. There were no significant differences in overall cost between thoracotomy and robotic surgery, but robotic surgery cost US$ 3,182 more than VATS ($P<0.001$) attributed to the cost of robot supplies and depreciation. The authors commented that operating times and robot consumables needed to reduce in order for robotic surgery to become competitive.

It is noteworthy that no cost analyses of robotic thoracic surgery have yet been published by European hospitals or surgeons. An analysis of conducted at our own hospital in Italy (submitted for publication) indicates that costs for robot-assisted surgery (lobectomy or segmentectomy for clinical stage I or II NSCLC) were higher than for both VATS and open surgery, but all operations are profitable since reimbursement from the Italian Health Service exceeded costs. Notably, robot-assisted surgery was associated with reduced duration of stay (both in hospital and in the intensive care unit), reduced postoperative examinations, and reduced use of painkillers and other drugs.

The two main robotic techniques for lung lobectomy may differ intrinsically in costs, but this has not been verified by comparative cost analyses. Dylewski *et al.* (25) use four accesses, but only three robotic arms thus sparing the cost of one instrument compared to the four accesses of Cerfolio *et al.* (26). The recent paper by Tchouta *et al.* (32) showed that those robotic lung lobectomies performed in high volume centers were associated with significantly shorter hospital stay and significantly lower mortality. It is reasonable that high volume can also contribute to cost reduction by standardization of patient preparation, robot docking and surgical procedures (9,17) as well as by reducing operating times, hospital stay and complications.

Robotic thoracic surgery—the future

The lack of randomized studies comparing outcomes in with those achieved by VATS or open surgery is a major concern. A recent randomized trial (33) showed that pain is reduced and quality of life is better in patients given VATS compared to open thoracotomy for early stage lung cancer. Similar data are sorely needed for robotic thoracic surgery. Our institute (Humanitas Research Hospital) has started a multicentred randomized trial (NCT02804893) comparing robotic surgery with VATS in lung cancer patients scheduled for lobectomy or sublobar resections. Three hundred patients will be recruited, and complications, conversions to open surgery, lymph node dissection, and quality of life will be assessed.

The future development robotic surgery in general is likely to be enhanced by the arrival of new surgical robots from new manufacturers. Medtronic and Johnson and Johnson (34) are developing surgical robots which will challenge Intuitive Surgical monopoly and hopefully drive costs down. Notwithstanding these problems we expect that use of robot-assisted surgery to perform thoracic surgery in general, and lung cancer resections in particular, will continue to increase.

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Footnote

Conflicts of Interest: G Veronesi is a consultant for ABI Medica SpA and Medtronic. And other authors have no conflicts of interest to declare.

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