The Impact of Computed Tomographic Screening for Lung Cancer on the Thoracic Surgery Workforce

Janet P. Edwards, MD, MPH, Indraneel Datta, MD, MSc (HEPM), John Douglas Hunt, PhD, Kevin Stefan, MSc, Chad G. Ball, MD, MSc, Elijah Dixon, MD, MSc (Epi), and Sean C. Grondin, MD, MPH

Division of General Surgery and Department of Civil Engineering, University of Calgary; HBA Specto Inc, and Division of Thoracic Surgery, University of Calgary, Calgary, Alberta, Canada

Background. This study aimed to predict variation in the thoracic surgery workforce requirements with the introduction of a national chest computed tomographic (CT) screening program for individuals at high risk of lung cancer.

Methods. Using Canadian census microdata and the Canadian Community Health Survey, a microsimulation model representing the national population was developed. The demand component simulates the incidence of lung cancer, whereas the supply component simulates the number of practicing thoracic surgeons. A national CT screening program in high-risk individuals (>30 pack-year history of smoking; age, 55–74 years) was introduced into the model to predict changes in the number of operable lung cancers per thoracic surgeon.

Results. From 2013 to 2040, the Canadian population increased from 34 to 43 million. The number eligible for screening varies from 1,112,800 (2013) to 513,200 (2040), peaking at 1,147,700 (2017). Comparing CT screening with chest radiography, overall lung cancer diagnoses increase 7.3% by 2040, with stage 1A increasing by 15.6% and stage IV decreasing by 7.5%. The rate of operable early lung cancers per thoracic surgeon increases by 24.2% (2020), 19.8% (2030), and 16% (2040), with CT screening relative to the baseline increase seen with chest radiography.

Conclusions. With the implementation of a CT screening program there will be an increase in operable lung cancers, resulting in increased surgical volume. A national strategy for the thoracic surgery workforce is necessary to ensure that an appropriate number of surgeons are being trained to meet the future needs of the national population.

Lung cancer is the largest contributor to cancer mortality worldwide [1, 2]. Overall 5-year survival for lung cancer is 15%, in part because of late stage at presentation [1]. Computed tomographic (CT) screening has been investigated as a method to improve early diagnosis and subsequent survival from lung cancer [3–6]. The National Lung Screening Trial demonstrated an increased rate of lung cancer diagnosis and a 20% reduction in mortality with the implementation of a CT screening program for high-risk individuals (age, 55–74 years; >30 pack-year history of smoking) [5].

To date, there are no studies examining the potential impact of CT screening on the future incidence and stage distribution of lung cancer or on the operative caseload of thoracic surgeons. The objective of this study was to forecast changes in lung cancer incidence and stage distribution, using a novel microsimulation model, and to examine the impact of these changes on the thoracic surgery workforce.

Microsimulation models use person-level data to simulate and draw conclusions about large representative populations, in contrast to aggregate models whose input variables already represent the collective.

Material and Methods

A microsimulation model was used to assess variation in demand for thoracic surgeons with the introduction of CT screening of individuals at high risk for lung cancer.

Modeling Supply

The supply component of the model simulated the career of thoracic surgeons from completion of training to retirement. The current supply of thoracic surgeons was determined using the Canadian Thoracic Manpower and Education survey conducted in 2009, which provided data on the demographics, training history, practice characteristics, and estimated retirement age of thoracic surgeons in Canada [7]. The number of thoracic surgeons entering the workforce was calculated based on the number of Royal College of Physicians and Surgeons accredited programs in Canada (n = 8), with a range of 4 to 8 graduates produced per year. A typical 7-year length of training was assumed, including 5 years of general surgery...
and 2 years of thoracic surgery training with 0% attrition and 0% emigration probabilities once admitted.

The model was advanced in 1-year cycles with the future year’s projections based on present-day supply, clinical volume, retirement estimates, and the number of new surgeons entering the workforce.

**Modeling Demand**

Lung cancer is the largest contributor to the thoracic surgical operative caseload in Canada (61.5%), with esophageal malignancy being the next most common (12.3%) [7]. Consequently, the demand model was built using lung cancer as a surrogate of overall demand for thoracic surgeons.

**Base Population.** Two sets of microdata were used to create the base population. Canadian census public use microdata files provide anonymous individual data sets with 123 variables, including income, educational status, and geographic location [8]. These records were used in a combinatorial optimization population synthesis procedure to replicate the entire 2006 population of Canada by age, sex, and census division [9].

The Canadian Community Health Survey is a cross-sectional survey providing data on health status and health care determinants and use, allowing for regional evaluation of smoking rates [10]. This was used to assign a smoking history (current, former, never, pack-years, quit time) to each member of the base population, controlling for age, sex, and location.

**Dynamic Model**

In the microsimulation, the population was advanced using 1-year time steps, with typical demographic processes occurring as well as detailed models of the dynamics involved with smoking and lung cancer, as described further on.

The demographic components included fertility, mortality, immigration, and emigration [11]. Mortality and infant mortality were adjusted based on sex, age, and provincial differences as well as on non–lung cancer-related death [11-13].

Smoking models included simulations of starting and quitting smoking based on Canadian Community Health Survey data [10]. The decision to start used a series of binary logit models considering age, sex, location, and francophone/immigrant status. The quitting model considered age, sex, and smoking intensity [11, 13].

The smoking history of each individual was a key input to the lung cancer model, which considered age, smoking status/duration/intensity, quit time, and other health factors (such as body mass index, ethnicity, education, past history of lung disease/emphysema, and chest imaging results) [14, 15]. Early or late lung cancer stage assignment was based on smoking history [16]. The base scenario of screening by chest radiography was phased in from 2014 to 2016 for individuals at high risk of lung cancer (> 30 pack-years history of smoking; aged 55–74 years). The stage distribution of lung cancers identified through chest radiography and the adherence rate of 93% were determined from the National Lung Screening Trial [5].

A national CT screening program was then introduced into the model, phased in from 2014 to 2016, for the same population to predict changes in the number of operable lung cancers per surgeon compared with screening with chest radiography. The stage distribution of lung cancers identified through CT screening and the adherence rate of 95% was again extracted from the National Lung Screening Trial [5].

The model was run using Python 2.7 (Python Software Foundation) code from 2006 to 2049. A 100% sample representing the entire population was used—31.8 million individuals (2006) growing to 46.0 million (2049).

The absolute incidence of operable lung cancers per year was extracted for chest radiography and CT screening. This was done separately according to 2 definitions of “operable”—first for stages I and II and second for stages I, II, and IIIA—because there is some controversy regarding the resectability of stage IIIA cancers.

The incidence of operable lung cancers per surgeon per year was determined according to the 2 definitions of operability. Incidence of operable cancer per surgeon was calculated by combining results for absolute incidence of operable lung cancer per year with those of the supply component of the model, assuming a typical graduation rate of 6 thoracic surgeons per year. Finally, we determined the incidence of operable lung cancer per surgeon in the setting of CT screening, with variation from 4 to 8 new surgeons per year.

**Variability**

To determine the degree of variability in the microsimulation process, 50 runs of the demand simulation and 1,000 runs of the supply simulation were performed. The standard deviation of the mean of the projections for supply and demand was calculated.

**Results**

The demand component of the model forecast an increase in the Canadian population from 31,769,000 (2006) to 46,042,000 (2049). The number at high risk for lung cancer and thus eligible for CT screening (> 30 pack-years of current or former smoking; aged 55–74 years) increased from 1,118,000 (2014) to 1,147,700 (2017) and then declined to 1,068,200 (2020), 835,800 (2030), 513,200 (2040), and 446,000 (2049). Screening with chest radiography was applied in 2014 to demonstrate lung cancer incidence and stage distribution in the absence of CT screening. With chest radiography, overall lung cancer diagnoses in this high-risk group will increase from 23,529 (2010) to 32,196 (2030) and then decline to 28,585 (2040) (Table 1).

Predicted rates of uptake and adherence to CT screening guidelines translate into 369,700 CT scans (2014), increasing to a high of 1,039,200 (2017) and decreasing with time to 965,000 (2020), 755,800 (2030), 464,000 (2040), and 403,300 (2049). With CT screening, the incidence of lung cancer diagnoses is projected to increase to 30,415 (2020) and
again to 34,189 (2030) and then decline to 30,681 (2040) (Table 1). When compared with chest radiography, there is an overall increase in lung cancer diagnoses with CT for any given year, namely, 7.8% (2020), 6.2% (2030), and 7.3% (2040). The proportion of early-stage lung cancer diagnoses is higher with CT screening than with chest radiography, with stage IA representing 27.1% of all lung cancers diagnosed with CT in 2020 compared with 21.3% for chest radiography. This is a 27.2% relative increase in stage IA diagnoses. For the same period, stage IB diagnosis increases by 2% and stage II diagnosis remains stable. Coincidently, stage IV cancer will decrease as a percentage of overall lung cancers diagnosed by CT compared with chest radiography, representing 31.3% of all lung cancers diagnosed by CT in 2020 compared with 35.9% with chest radiography. This is a 14.7% relative decrease in stage IV cancer diagnoses. For the same period, stage IIIB lung cancer diagnoses decrease by 5.6% with CT screening. Fig 1 shows the absolute incidence of operable lung cancer per year according to screening methodology. Fig 1A defines “operable” as stages I/II lung cancers. Fig 1B also includes stage IIIA.

For both definitions of operable lung cancer, the incidence is higher in the CT group. Fig 2 presents the incidence of operable lung cancer per surgeon according to screening methodology assuming a typical 6 new thoracic surgeons per year. Fig 2A defines “operable” as stages I/II. Fig 2B also includes stage IIIA. For both screening modalities and both definitions of operability, the number of operable cancers per surgeon peaks in 2030. When considering only stages I/II, the incidence of operable lung cancer per year reaches 91 cases per surgeon in the CT group compared with 76 cases in the chest radiography group. When including stage IIIA, the incidence of operable lung cancer per year reaches 114 cases per surgeon (CT) compared with 99 (chest radiography).

Figure 3 shows the incidence of operable lung cancer per surgeon in the setting of CT screening, with variation demonstrated according to the number of new thoracic surgery graduates per year. Figure 3A represents stage I/II lung cancers; Fig 3B also includes stage IIIA. With a decrease to 4 graduates per year, the number of operable cancers peaks in 2030 at 130 when only stages I/II are considered operable or 163 when stage IIIA is included. Increasing to 8 trainees per year leads to a lower peak of operable lung cancers per surgeon of 71 (stages I–II) or 88 (stages I–IIIA).

The standard deviation in the results of the 50 runs of the demand simulation was 1.5% to 2.5% of the mean of the projection for the results presented in this article. Because of the small number of surgeons in the supply simulation, the microsimulation variation is high on any individual run; to counter this, the results of 20 simulations were averaged. These averaged results over 1,000 runs have a standard deviation in the range of 1.5% to 1.8% of the mean of the projection.

Comment

The purpose of this study was to assess the impact of a CT screening program on the thoracic surgery workforce.
using a novel microsimulation. To our knowledge, this is the first model created to predict variation in the thoracic surgery workforce needs in the setting of CT screening. Although our model is novel in this setting, such techniques have been developed and validated in other areas, including medical (ie, obesity rates, transmission of infectious diseases, impact of screening programs) and nonmedical (ie, prediction of traffic patterns) applications.

Based on our model, the overall incidence of lung cancer will rise until the year 2030 and then plateau and decline. This lags behind a predicted decrease in the proportion of smokers in the population with time. With CT screening, there will be an even greater increase in lung cancer diagnoses. This differential increase compared with chest radiography screening will be maintained as the overall rates of lung cancer start to decline. The implementation of CT screening will lead to a change in stage at presentation of lung cancer, tending toward earlier stages and potentially resectable cancers. When lung cancer incidence in the setting of CT screening is modeled along with predicted variation in the surgical workforce, we see that the rate of operable lung cancers per surgeon will increase until the year 2030 before starting to decline. This is over and above the increase in caseload per surgeon predicted in the base scenario of chest radiography. Finally, we modeled the incidence of operable lung cancers per surgeon with variation according to the number of new thoracic surgeons per year. Even a single additional trainee per year can noticeably change the number of operable lung cancers per surgeon in the future.

One of the main strengths of this study is the use of a large cohort of individual data to simulate supply and demand. This model was a “full run,” using 100% of the national population instead of a sample, which is often used for tractability. Our approach attempts to produce an accurate assessment of the supply of thoracic surgeons by using key factors such as surgeon demographics and retirement estimates from a recent national survey.
information such as varying smoking rates and immigration on the incidence of lung cancer. By selecting these detailed data to build the model, we attempted to minimize error and generate precise estimates of lung cancer incidence and workforce requirements. We quantified the variability in our model projections by performing numerous runs and determining the standard deviation of the results. The results of each component had a standard deviation of less than 3%. Because there are path dependency effects in the simulation, such as a person who has lung cancer in 2025 being unavailable to get lung cancer in later years, the variation is lowest at the beginning of the run and increases with time. We also validated our model by comparing our forecasted change in lung cancer incidence against Canadian cancer statistics, which showed a 13.0% increase from 2006 to 2013 [20, 21].

Our model may be limited by assumptions made in its construction. It uses lung cancer as a surrogate marker for overall demand. According to recent data, malignant disease of the lung accounts for 61.5% of an average thoracic surgeon’s operative practice. Lung cancer was considered a reasonable surrogate because the next largest contributor was malignant esophageal disease at 12.3% [7]. The supply model assumed no immigration or emigration. Because small variation in the number of trainees translates into wide variation in caseload per surgeon, immigration or emigration could have an important impact on our results, although recent data indicate that fewer than 3% of Canadian thoracic surgeons are planning to move from their present location [7].

Despite these limitations, our novel microsimulation provides insight into how CT screening will impact the thoracic surgery workforce and interact with variation in the number of new surgeons. We demonstrated that CT screening will lead to an overall increase in lung cancer diagnoses, with a trend toward more cancers being diagnosed at early stages. Should the thoracic surgery workforce remain relatively constant, the operative caseload per surgeon would increase. Depending on the ability of surgeons to access operating room time and take on this extra work in addition to their current multifaceted practices, this may point to the need for an increased numbers of thoracic surgeons.

To explore this supposition, we examined how variation in the number of practicing thoracic surgeons interacts with changes in lung cancer incidence and stage distribution. This model considers important factors such as demographics and predicted retirement age (7). Assuming a typical graduation rate, the incidence of operable lung cancers per surgeon increases in the base scenario of chest radiography until the year 2030 before starting to decline. With CT screening, a similar but exaggerated trend is seen with even higher numbers of operative cases per surgeon for any given year. With variation in the number of new surgeons entering the workforce incorporated into the CT screening, a more accurate comparator may have no screening of any kind because until recently there was no guideline suggesting that high-risk individuals be screened for lung cancer by any means. We used chest radiography to maintain consistency with previous studies and to obtain the detailed stage breakdown for lung cancers at presentation that we required [5]. In using chest radiography as a control, our results may underestimate the increase in lung cancer diagnoses that CT screening will produce as well as the relative increases in early-stage lung cancers. In addition, diagnostic uncertainty will likely lead to the removal of a significant number of benign lesions, further increasing surgical caseload.

Our model may be limited by assumptions made in its construction. It uses lung cancer as a surrogate marker for overall demand. According to recent data, malignant disease of the lung accounts for 61.5% of an average thoracic surgeon’s operative practice. Lung cancer was considered a reasonable surrogate because the next largest contributor was malignant esophageal disease at 12.3% [7]. The supply model assumed no immigration or emigration. Because small variation in the number of trainees translates into wide variation in caseload per surgeon, immigration or emigration could have an important impact on our results, although recent data indicate that fewer than 3% of Canadian thoracic surgeons are planning to move from their present location [7].

Despite these limitations, our novel microsimulation provides insight into how CT screening will impact the thoracic surgery workforce and interact with variation in the number of new surgeons. We demonstrated that CT screening will lead to an overall increase in lung cancer diagnoses, with a trend toward more cancers being diagnosed at early stages. Should the thoracic surgery workforce remain relatively constant, the operative caseload per surgeon would increase. Depending on the ability of surgeons to access operating room time and take on this extra work in addition to their current multifaceted practices, this may point to the need for an increased numbers of thoracic surgeons.

To explore this supposition, we examined how variation in the number of practicing thoracic surgeons interacts with changes in lung cancer incidence and stage distribution. This model considers important factors such as demographics and predicted retirement age (7). Assuming a typical graduation rate, the incidence of operable lung cancers per surgeon increases in the base scenario of chest radiography until the year 2030 before starting to decline. With CT screening, a similar but exaggerated trend is seen with even higher numbers of operative cases per surgeon for any given year. With variation in the number of new surgeons entering the workforce incorporated into the CT screening, a more accurate comparator may have no screening of any kind because until recently there was no guideline suggesting that high-risk individuals be screened for lung cancer by any means. We used chest radiography to maintain consistency with previous studies and to obtain the detailed stage breakdown for lung cancers at presentation that we required [5]. In using chest radiography as a control, our results may underestimate the increase in lung cancer diagnoses that CT screening will produce as well as the relative increases in early-stage lung cancers. In addition, diagnostic uncertainty will likely lead to the removal of a significant number of benign lesions, further increasing surgical caseload.

Our model may be limited by assumptions made in its construction. It uses lung cancer as a surrogate marker for overall demand. According to recent data, malignant disease of the lung accounts for 61.5% of an average thoracic surgeon’s operative practice. Lung cancer was considered a reasonable surrogate because the next largest contributor was malignant esophageal disease at 12.3% [7]. The supply model assumed no immigration or emigration. Because small variation in the number of trainees translates into wide variation in caseload per surgeon, immigration or emigration could have an important impact on our results, although recent data indicate that fewer than 3% of Canadian thoracic surgeons are planning to move from their present location [7].

Despite these limitations, our novel microsimulation provides insight into how CT screening will impact the thoracic surgery workforce and interact with variation in the number of new surgeons. We demonstrated that CT screening will lead to an overall increase in lung cancer diagnoses, with a trend toward more cancers being diagnosed at early stages. Should the thoracic surgery workforce remain relatively constant, the operative caseload per surgeon would increase. Depending on the ability of surgeons to access operating room time and take on this extra work in addition to their current multifaceted practices, this may point to the need for an increased numbers of thoracic surgeons.

To explore this supposition, we examined how variation in the number of practicing thoracic surgeons interacts with changes in lung cancer incidence and stage distribution. This model considers important factors such as demographics and predicted retirement age (7). Assuming a typical graduation rate, the incidence of operable lung cancers per surgeon increases in the base scenario of chest radiography until the year 2030 before starting to decline. With CT screening, a similar but exaggerated trend is seen with even higher numbers of operative cases per surgeon for any given year. With variation in the number of new surgeons entering the workforce incorporated into the CT
screening model, we see that even small variation in the number of trainees per year has an important impact on the incidence of operable lung cancers per surgeon.

This model forecasts that the operative caseload for thoracic surgeons will increase, a favorable finding for the future of the specialty. If the current number of trainees is maintained, we foresee no oversupply of thoracic surgeons. On the contrary, with the current number of trainees entering the workforce per year, there will still be an increase in the number of cases of operable lung cancer per surgeon until the year 2030. We suggest that any decrease in the number of trainees per year may lead to an important increase in the caseload per surgeon. The impact of new treatment modalities, such as stereotactic radiotherapy, on workforce planning remains uncertain and will be addressed in further modeling efforts, as will the cost of a national CT screening program for lung cancer.

In conclusion, our model predicts that with the implementation of a national CT screening program for individuals at high risk of lung cancer, the incidence of operable lung cancer will increase both overall and relative to the supply of thoracic surgeons in Canada until the year 2030. Even small fluctuations in the number of thoracic surgery trainees will dramatically change the number of operable lung cancers per surgeon. These findings underscore the importance of a national policy regarding CT screening as well as regulation of thoracic surgery training positions.

Editorial assistance was provided by Ms Catherine MacPherson and Dr Ray Miksa.

The authors received funding from the Canadian Association of Thoracic Surgeons Research Development Fund.

References