Optimizing Personalized Lung Cancer Screening Policies:
A Markov Chain Approach to Cost-Effectiveness Analysis for Patients with Lung Nodules

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Background

The incidence and mortality rates of lung cancer globally, including in China [1], are alarmingly high, with late-stage diagnoses resulting in a dismal five-year survival rate of 17.4% [2]. Early detection through screening is crucial, enabling timely intervention, particularly through definitive surgery, leading to significantly improved treatment outcomes [3]. This approach offers substantial benefits, including reduced mortality rates and enhanced quality of life. Furthermore, early detection alleviates disease-related symptoms, as many cases are asymptomatic initially [4]. Patients diagnosed early also have a higher likelihood of survival post-resection compared to those diagnosed at advanced stages [5]. Screening programs not only decrease the prevalence of advanced lung cancer but also mitigate treatment-related morbidity [6]. Moreover, screening initiatives can prompt lifestyle changes and smoking cessation [7], bolstering overall public health.

Utilizing low-dose CT scans (LDCT) for screening enables the identification of pulmonary nodules, offering a critical window for early diagnosis and intervention before symptomatic manifestation. However, lung cancer screening also presents potential risks, including false-negative and false-positive results, radiation exposure, overdiagnosis from incidental findings, ineffective detection of invasive disease, anxiety, and financial costs [8]. Therefore, it is crucial for lung cancer screening programs to carefully balance these potential risks against the benefits and choose the appropriate timing for intervention.

Despite the importance of such programs, there is currently no unified standard for lung cancer screening, leading to variations in guidelines among different medical and health institutions [9-12]. These variations extend to recommended ages for initiating and concluding screening. Consequently, within the clinical community, opinions diverge on the optimal lung cancer screening policies. While physicians are generally aware of existing guidelines, specific screening recommendations can vary significantly.

Objectives

We aim to identify the most cost-effective screening strategy for our patient population by evaluating the cost and effectiveness of various guidelines. Thus, we offer insights for resource allocation, patient-centric care, and informing evidence-based clinical practice.

Background C'td

	Solid	Partially Solid	Non-Solid
Chinese Preventive Medicine Association (CPMA)	<= 6 mm 6 – 15 mm > 15 mm		<= 8 mm 8 – 15 mm > 15 mm
National Comprehensive Cancer Network (NCCN)	<= 6 mm 6 – 8 mm 8 – 15 mm > 15 mm	< 6 mm Solid < 6 mm Solid 6 – 8 mm Solid >= 8 mm	< 20 mm >= 20 mm
American College of Radiology (ACR)	The same as above		< 30 mm >= 30 mm
American Association for Thoracic Surgery (AATS)	<= 4 mm 4 – 6 mm 6 – 8 mm > 8 mm	< 5 mm 5 – 10 mm > 10 mm	

3-Month Follow-up
6-Month Follow-up
12-Month Follow-up
PET-CT/ Biopsy

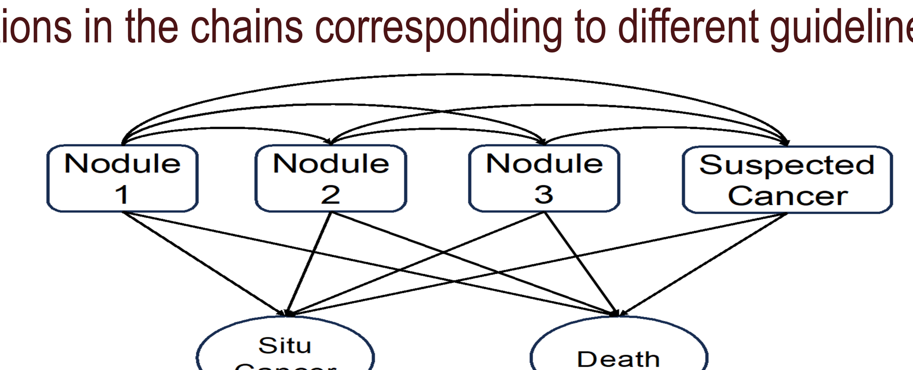
This table illustrates the differences in recommended interventions for solitary nodules from various institutes.

Data

We use historical CT data from a cohort comprising 2,139 patients with pulmonary nodules who underwent biopsy diagnosis between December 2018 and June 2022. All participants had biopsy-confirmed pulmonary nodules. The age range of the patients in our cohort spanned from 50 to 80 years old. CT scans were conducted spontaneously by the patients, without any specific requirements or restrictions. Patients suspected of having lung cancer were referred for biopsy diagnostic procedures. Upon confirmation of lung cancer diagnosis, patients underwent treatment and were subsequently excluded from our study. Demographic data were collected at the initiation of the examination, with detailed medical histories documented, including analysis of prevalent diseases. Radiological information, such as lung masses and nodule sizes, was recorded during each CT scan, along with assessment of tumor metastasis.

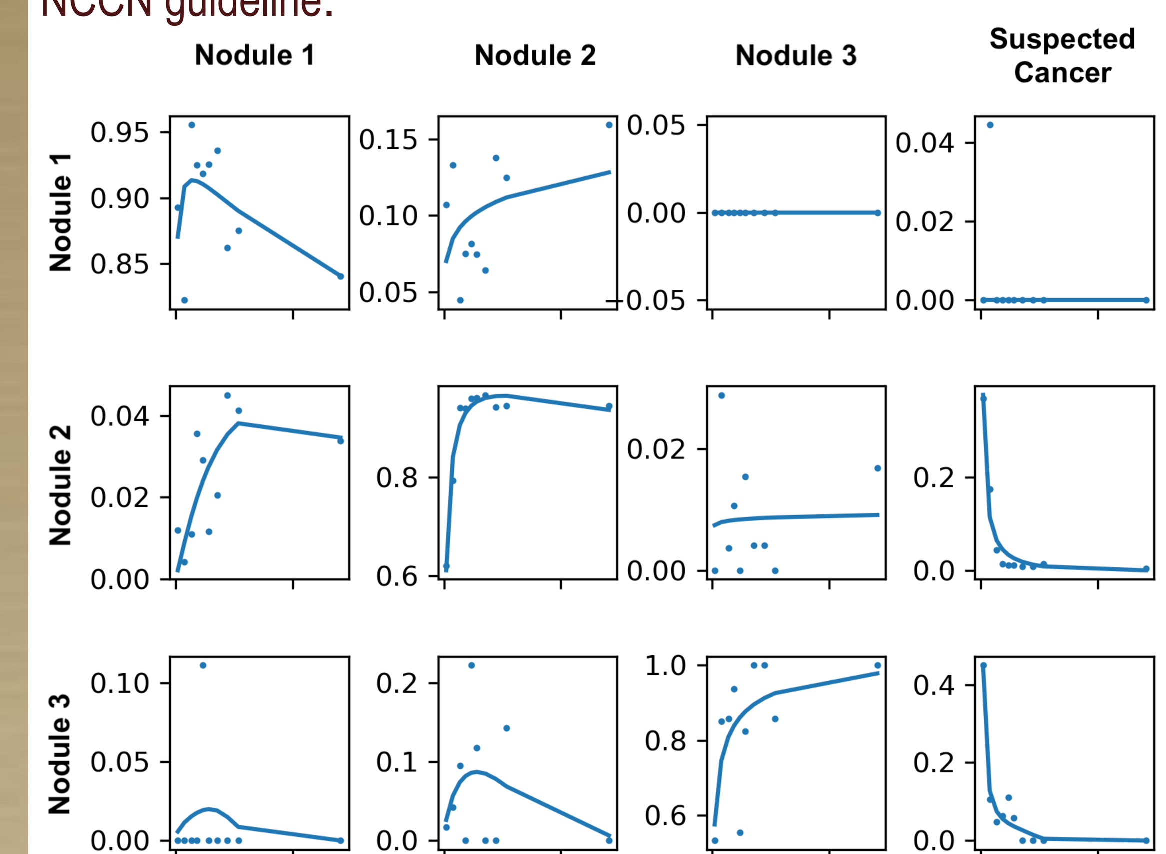
Methodology

To calibrate the cost and Quality-Adjusted Life Years (QALY) per patient, we employ Markov chain modeling [13] to delineate the stages at which different interventions are recommended, with variations in the chains corresponding to different guidelines.



Major Findings

Based on each guideline, we initially categorize patients into distinct stages, then calibrate the transition probabilities between these stages utilizing our clinical data. Subsequently, we forecast the transition probabilities over time employing statistical learning techniques. The following plots depict the estimated time-dependent transition probabilities under the NCCN guideline.

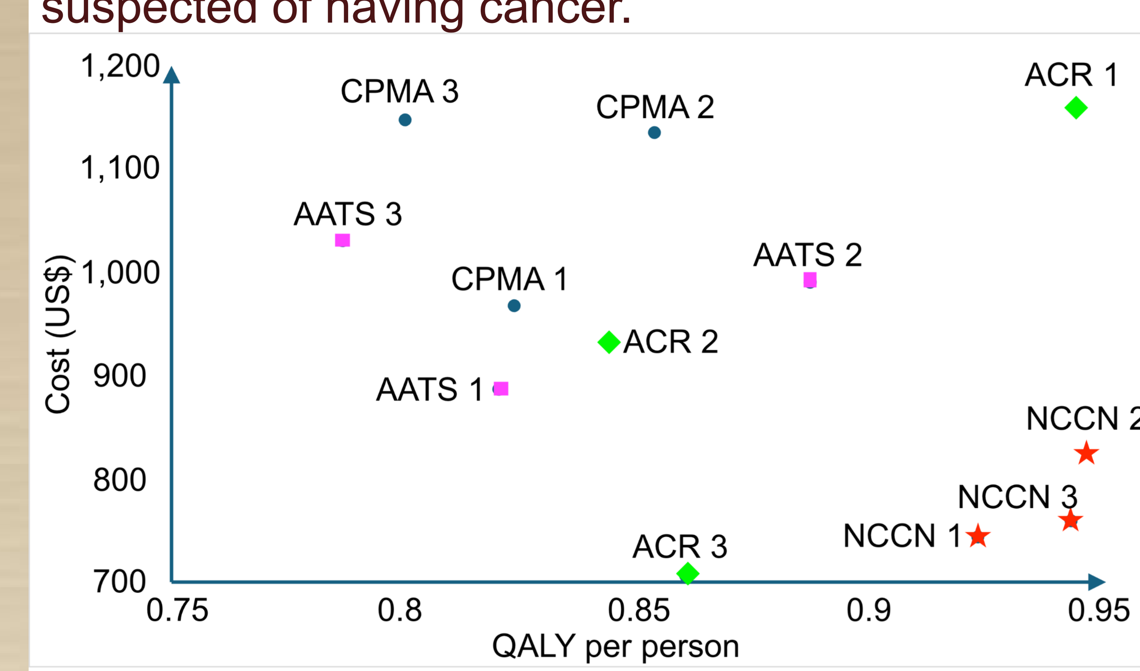


We evaluate the following strategies based on categorization criteria outlined by guidelines:

Strategy 1: Annual LDCT for patients with nodules, with biopsy for those suspected of having cancer.

Strategy 2: Biopsy for patients categorized as Nodule-3, with 6-month and 3-month LDCTs for those classified as Nodule-1 and Nodule-2.

Strategy 3: 12-month, 6-month, and 3-month LDCTs for patients categorized as Nodule-1, Nodule-2, and Nodule-3, respectively, with biopsy for those suspected of having cancer.



Conclusion: The NCCN guideline is the most cost-effective for the patient mix under study.

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The Presenter

Dr. Zhu's research focuses on improving effectiveness and efficiency in healthcare and service systems. She contributes to strategic, operational and technical policy-making by applying interdisciplinary approaches, including mathematics, analytics, statistics, operations management, and economics. Closely collaborating with physicians, health administration, and researchers, she is working on several projects related to maternity care, oncology, Emergency Departments, electric vehicles and shared transport. Dr. Zhu received her Ph.D. in Operations Management from McGill University, Canada in 2018; she has a M.Sc. in Mathematical and Computational Finance from University of Oxford, UK, and a B.Sc. in Mathematics from Nanjing University, China.

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