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Comparative Effectiveness of Lung Cancer Screening Strategies:

An Analysis of the Veterans Health Administration Experience

A dissertation submitted in partial satisfaction of the requirements for the degree Doctor of Philosophy in Health Policy and Management

by

Lawrence Nathaniel Philip Benjamin

2024

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ABSTRACT OF THE DISSERTATION

Comparative Effectiveness of Lung Cancer Screening Strategies:

An Analysis of the Veterans Health Administration Experience

by

Lawrence Nathaniel Philip Benjamin

Doctor of Philosophy in Health Policy & Management

University of California, Los Angeles, 2024

Professor Carol Mangione, Chair

Lung cancer is the leading cause of cancer-related death. Lung cancer screening (LCS), with an annual computed tomography (CT) scan for at-risk smokers, can save lives by diagnosing and treating cancer early. Yet lung cancer screening rates have unfortunately been woefully low to date, with additional racial/ethnic disparities in screening rates. Centralization, or the use of dedicated lung cancer screening staff and electronic medical record infrastructure for tracking screening, is a promising intervention that in small trials has been associated with increasing lung cancer screening rates potentially by unburdening the primary care physicians who typically would be responsible for screening their patients. This dissertation investigated the association of lung cancer screening program centralization on lung cancer screening rates through descriptive analysis and retrospective, mixed methods analysis of Veterans Health Administration electronic medical record data and program surveys on centralization status. In a descriptive analysis of our dataset, we found that a significant proportion of veterans are eligible for lung cancer screening, with greater than 1 million veterans meeting current eligibility criteria. We found that centralization was associated with increased likelihood of receiving appropriate and timely follow up after initial screening. Furthermore, our analysis suggests that

hybrid centralized programs, where primary care physicians (PCPs) co-manage screening with lung cancer screening centralized staff, were associated with the highest odds of receiving appropriate and timely follow up. In a subset of Black and White Veterans, our findings suggest hybrid centralized programs were associated with higher odds of Black Veterans entering screening. However, centralization was not associated with improved Black/White disparities in receiving appropriate and timely follow up. We postulate hybrid programs may be best matching PCP-patient rapport and trust with support for overburdened PCPs through centralized staff. Understanding the results of the current study can provide valuable insights for healthcare systems and policy makers by highlighting the most effective screening strategies, addressing ongoing racial disparities. and informing the design of program interventions that can further optimize screening rates while supporting health providers and patients.

The dissertation of Lawrence Nathaniel Philip Benjamin is approved.

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Chapter 1: Background

Burden of Lung Cancer

Lung cancer is the second most common cancer in men and women, and notably the leading cause of cancer-related death[1]. Lung cancer is the third most prevalent cancer by annual incidence, but is overwhelmingly the most deadly, accounting for around 25% of all cancer-related deaths. More people die of lung cancer annually than breast, colon, and prostate cancers combined[1]. Men have higher rates of developing lung cancer than women[2]. The disease has classically been associated with tobacco use leading to around 90% of lung cancer cases, but is also associated with radon exposure, indoor and outdoor air pollution, occupational exposure, radiation exposure, and hereditary susceptibility[3]. There have been recent advances in lung cancer treatments such as immunotherapy that are more effective, with fewer side effects than previous forms of chemotherapy. Despite these advances, lung cancer survival remains low, with an estimated 1 year survival of only ~ 25% in the 1990s and ~ 35% in the 2010's [reviewed in 4]. Additionally, many patients present with advanced disease which often is not curable, imposing additional physical and emotional distress on patients.

Treatment for lung cancer includes surgery (which if performed at an early enough stage can be curative), radiation, or systemic medical therapies[4]. Notably, lung cancer survival is significantly improved when diagnosed and treated early, while the cancer remains at a localized stage. Survival rates near 60% when lung cancer is diagnosed and treated at an early stage compared to only around 6% in distant/advanced stages[5]. Given improved survival in lung cancer when caught at earlier stages, lung cancer screening has been proposed to diagnose lung cancer at an earlier, and hopefully more treatable, stage. To date, lung cancer screening has primarily focused on high-risk current and former smokers, though research has considered screening in other groups like patient's with HIV or radon exposure[6,7].

Data Supporting Lung Cancer Screening

Two large randomized controlled trials (RCTs) form the backbone of data supporting Lung Cancer Screening. The National Lung Screening Trial (NLST), published in 2011, is the largest US based lung cancer screening trial showing the efficacy of lung cancer screening. The 3 year trial used annual low-dose computed tomography (LDCT) scans and enrolled 53,454 enrollees. Participants in the NLST were individuals between 55 and 74 years of age who had smoked at least 30 pack-years, if former smokers, had quit within the previous 15 years, and didn't have signs or symptoms concerning for active lung cancer. The trial demonstrated a 20% reduction in cancer mortality and a 6.7% reduction in all-cause mortality with screening [8]. Notably, the trial had high retention, with ~ 90% of individuals remaining in screening through the end of the trial. A second large RCT, the Netherlands-Leuvens Longkanker Screenings Onderzoek (NELSON) trial, was performed in Europe and published in 2020. The NELSON trial screened at sequentially 1 year, then 2 year, then 2.5 year intervals and enrolled 15,792 enrollees. In contrast to the NLST, participants included individuals age 50-75 who had smoked > 15 cigarettes a day for > 25 years, or > 10 cigarettes a day for > 30 years. Participants had to be current smokers or have quit in ≤ 10 years. The NELSON trial demonstrated around a 24% reduction in lung cancer mortality at 10 years of follow-up in the screening group compared to the control group [9]. Additionally, following the publication of the NLST and NELSON trials, the Cancer Intervention and Surveillance Network (CISNET) performed post-hoc modeling to analyze the efficacy of various lung cancer screening strategies. This modeling yielded that annual screening with LDCT yielded better benefit than biennial screening[10].

The efficacy of lung cancer screening also compares favorably to other forms of commonly recommended cancer screening. The number needed to screen to save one life for LCS is around 255, compared to 350 for mammography and around 455 for colonoscopy for colorectal cancer screening[11–13]. Lung cancer screening is also thought to be cost effective, with an incremental cost-effectiveness ratio ranging from $49,200 to $96,700[14].

United States Initial Recommendations for Lung Cancer Screening

Given the significantly improved morbidity and mortality of lung cancer treatment if it is caught at an earlier, localized stage, there have been significant efforts to promote lung cancer screening for high-risk patients. In the United States, the most widely cited recommendation is that of the United States Preventive Services Task Force (USPSTF). In 2013, the USPSTF released its first recommendation in support of lung cancer screening (Grade B, meaning there is high certainty that the net benefit is moderate or there is moderate certainty that the net benefit is moderate to substantial). Screening with a low dose CT scan annually was recommended for individuals from 55-80 years old who were current or former smokers who had quit within the last 15 years and who had smoked the equivalent of at least 1 pack per day for 30 years over their lifetime (also referred to as 30 “pack-years”)[15]. Following this recommendation, the Centers for Medicare & Medicaid Services (CMS) announced it would cover Lung Cancer Screening for individuals aged 55-77 years of age with at least 30 pack-years[16]. There were, however, a number of requirements imposed for LCS performance. For screening to be covered by CMS, providers had to document that the patient was eligible, and that there had been a shared decision-making conversation with the patient including the use of one or more published decision aids. There were specific requirements for which MDs or non-MD practitioners could perform these conversations. There must also be documentation of counseling on the importance of adherence to annual screening and counseling on smoking cessation. There additionally were requirements that the reading radiologist be board certified and undergo continuing medical education. Finally, radiology facilities had to be certified by CMS. In 2022, in response to feedback from providers and patients, CMS relaxed some of these requirements, removing the restriction that the patient counseling must be furnished by a physician or non-physician practitioner, and expanding the eligible population of radiologists and facilities that could perform screening [16].

Poor Initial Penetration of Lung Cancer Screening

Following the USPSTF's recommendation for lung cancer screening in high-risk smokers, there is significant evidence that screening rates remained quite low. Estimated rates of eligible individuals who actually underwent screening in the 5 years following this USPSTF recommendation ranged from 4.1% to 17.7% [17–19]. In California, rates are estimated to be quite low, with only around 1% of those eligible undergoing screening, ranking the state last in the nation for adherence to this recommendation[20]. Furthermore, adherence rates are also quite low, measured by those who remained eligible for follow up annual LDCT scans and actually had subsequent scans at least annually. Of those screened, it is estimated that only around 20% of patients receive appropriate and timely follow-up screening studies after their first screening CT [21]. Poor adherence to follow up care will likely lead to much lower efficacy of screening programs in the real world compared to the mortality benefit seen in the original RCTs, which had follow-up adherence rates as high as 90%[8]. Notably, more than half of the incident cases of lung cancer in the NLST were detected *after* the first year of screening, on one of the subsequent annual LDCT scans, showing the paramount importance of long-term adherence to program performance. This was demonstrated in a recent report of more than a million individuals screened in the American College of Radiology's Screening registry, where adherence to follow-up scans remained low (22.3%), Hispanic and Black race was associated with poorer adherence, and the overall lung cancer detection rate was subsequently lower than expected[22].

Racial Disparities in Lung Cancer and Lung Cancer Screening

African American/Black individuals suffer the highest age-adjusted lung cancer incidence and the highest death rate of any racial/ethnic group[23]. African American/Black men in particular have the highest lung cancer mortality of any group in the United States, often at lower smoking intensity and younger age than other groups [24,25]. Compounding this disparity, a recent systematic review of LCS data demonstrated that African Americans are screened at lower rates

than their White counterparts[26]. However, once referred for LCS, African Americans participate at similar rates as their White counterparts[27], which suggests that barriers to access or provider variability in referral may contribute to this disparity in rates of screening by racial group. Beyond the previously cited Black/White disparities in lung cancer incidence and mortality, increasing interest has focused on the direct role systemic racism has played as a barrier to cancer screening. For example, manifestations of structural racism including poverty and residential segregation were shown in a recent study to be associated with most of the racial disparities in access to prostate cancer diagnostic imaging[28,29]. These persistent disparities have received significant focus for research and innovation, and were highlighted as an area of focus by President Biden's reignition of the Cancer Moonshot to combat cancer[30].

Expansion of LCS eligibility by USPSTF

The USPSTF updated its recommendations for LCS in 2021. Based on data from new clinical trials and an updated modeling study, USPSTF screening eligibility was expanded to those aged 50-80 years who were current or former smokers who had quit within the last 15 years and who had smoked the equivalent of 20 pack-years[31]. The impact of these recently expanded lung cancer screening eligibility criteria on overall lung cancer screening rates is yet to be seen. Given the low rates of screening previously reported, the expansion in eligibility may continue to be challenging for the current LCS structures to accommodate. It is estimated that the new criteria will roughly double the eligible population for screening[10]. It is also estimated that these expanded eligibility criteria will increase screening sensitivity in African Americans, Hispanics, and women, groups that historically had higher incidence of lung cancer with lower smoking intensity but poor rates of screening[10,32,33].

Ongoing Barriers to LCS

Multiple potential barriers may explain why lung cancer screening has had such poor uptake. A 2018 national survey of primary care physicians found that only 50% reported

believing there was significant evidence supporting LDCT for lung cancer screening, and most primary care physicians reported variable insurance coverage for CT scans and cumbersome prior authorization procedures as significant barriers [34]. Additionally, the American Thoracic Society, a large and influential professional organization, published a 2020 position statement on what the society identified as the largest drivers of ongoing disparities in access and uptake of lung cancer screening[35]. Key barriers identified included implicit bias amongst physicians, stigma around smoking, lack of health insurance coverage, significant geographic disparities in distance to the nearest lung cancer screening facilities (noted most profoundly often in rural locations), and poorly designed shared decision making tools for those with low health literacy and numeracy. Inadequate time to perform required shared decision making and smoking history assessment and counseling have also been identified as potential barriers[36].

Potential Impact of Social Determinants of Health on LCS

It has been long recognized that numerous social and demographic factors can significantly impact health outcomes broadly beyond lung cancer screening. Defined by the World Health Organization as "the conditions in which people are born, grow, live, work and age," social determinants of health have been increasingly recognized as impacting individual healthcare decision making, resources for seeking healthcare, and overall health outcomes[37].

There have been multiple proposed indices to quantify these social determinants and compare their impact region by region. One of the most widely cited is the Area Deprivation Index published by Amy Kind et al. at the University of Wisconsin-Madison. It provides a ranking, down to the level of census block group, for the relative socioeconomic disadvantage in a region incorporating data from the Health Resources and Services Administration and the American Community Survey [38]. As a publicly available, free metric that can be easily accessed through an online interactive map or downloadable file, it is a powerful tool for researchers to compare the relative socioeconomic disadvantage from region to region[39].

Impact of LCS Program Organizational Structure on LCS performance

Multiple strategies have been proposed for improving the performance of lung cancer screening programs including risk prediction calculators[40] and utilization of biomarkers[41]. However, many of these strategies are cost/labor intensive and may, given their complexity, lead to additional barriers to implementation of LCS which already suffers from low rates of uptake. Additionally, modeling studies suggest that risk prediction calculators, though associated with more benefits like being more cost-effective[40,42], were also associated with more over-diagnosis of early stage, slow growing cancers that would not have become clinically apparent/threatening if the person had not been screened [10]. This overdiagnosis can lead to unnecessary anxiety, distress, or invasive diagnostic procedures which themselves can be associated with risks/complications. Additionally, false positives can lead to invasive procedures for nodules that ultimately are found not to be cancer. There are also many significant, incidental findings unrelated to lung cancer that are found on these scans and likely require dedicated follow up, which may lead to additional diagnostic procedures and anxiety[43].

There is a small body of studies that look to the specific organizational structure of lung cancer screening programs and its impact on LCS uptake and adherence[44–46]. One organizational strategy referred to commonly as “centralization” has recently demonstrated promise due to higher screening rates relative to those previously reported. Centralized screening programs commonly employ electronic medical record (EMR) reminders, program coordinators, performance metrics integrated into the EMR, dedicated tumor review boards, and dedicated staff to assist in counseling and enrolling in lung cancer screening and performing follow up[45]. The findings by Kim et al., Núñez & Triplette, and Smith et al. suggest that centralized programs may have an advantage of greater uptake and adherence. Additionally, there is a suggestion that centralized programs may perform better in racial groups historically marginalized from LCS[26,46]. There is likely a minimum threshold of LCS volume to justify the

resources needed to centralize a lung cancer screening program. Therefore, these programs tend to be found LCS programs that serve a larger number of eligible patients, often in urban settings, and are less commonly found in rural settings.

However, there remains significant ambiguity and lack of consensus as to what specifically centralization means when implemented at various institutions, and reported in the literature. Authors Nunez & Triplette highlighted this problematic definitional question in a recent article[45]. In their article, they note that there is significant heterogeneity in what specific elements various lung cancer screening programs have implemented in their efforts to centralize, and therefore it remains unclear which specific elements of program centralization have the biggest impact on improved LCS program performance. Additionally, there is a lack of consensus on how these program elements may impact historically disadvantaged racial/ethnic groups. Exhibit 1 provides a general framework of the multiple potential elements of a centralized lung cancer screening program. Various programs may have implemented all, none, or some of these practices into their screening programs.

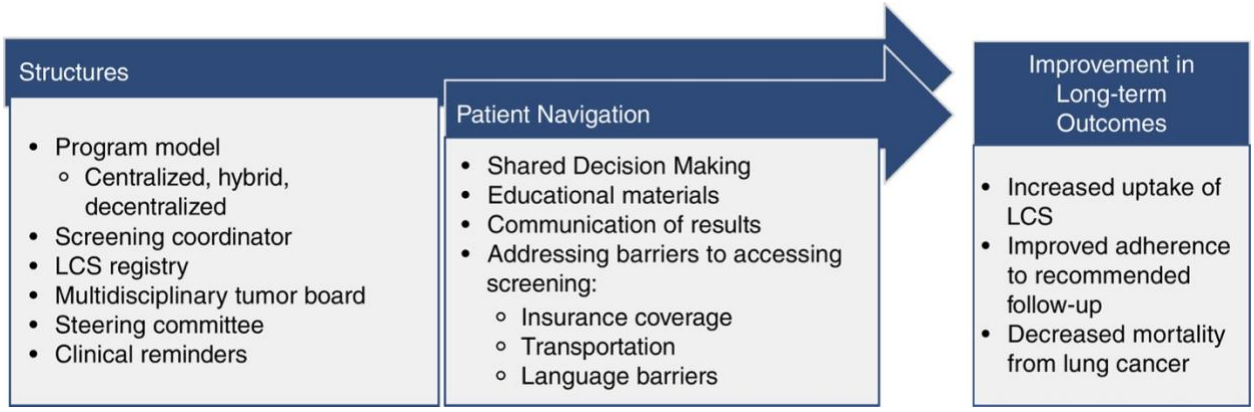

Exhibit 1: Elements of a Centralized LCS Program. Reprint from Nunez et al.45

Chapter 2: Conceptual Model

The Multi-Level Health Outcomes (MHOF) theoretical perspective to interventions and implementations developed by the Bastani et al. group provides an ideal initial framework to contextualize the interaction of an intervention like centralization both with upstream patient and healthcare system factors and downstream screening outcomes[47,48]. The MHOF model highlights the multiple steps between an implementation project leading to the desired downstream health outcome.

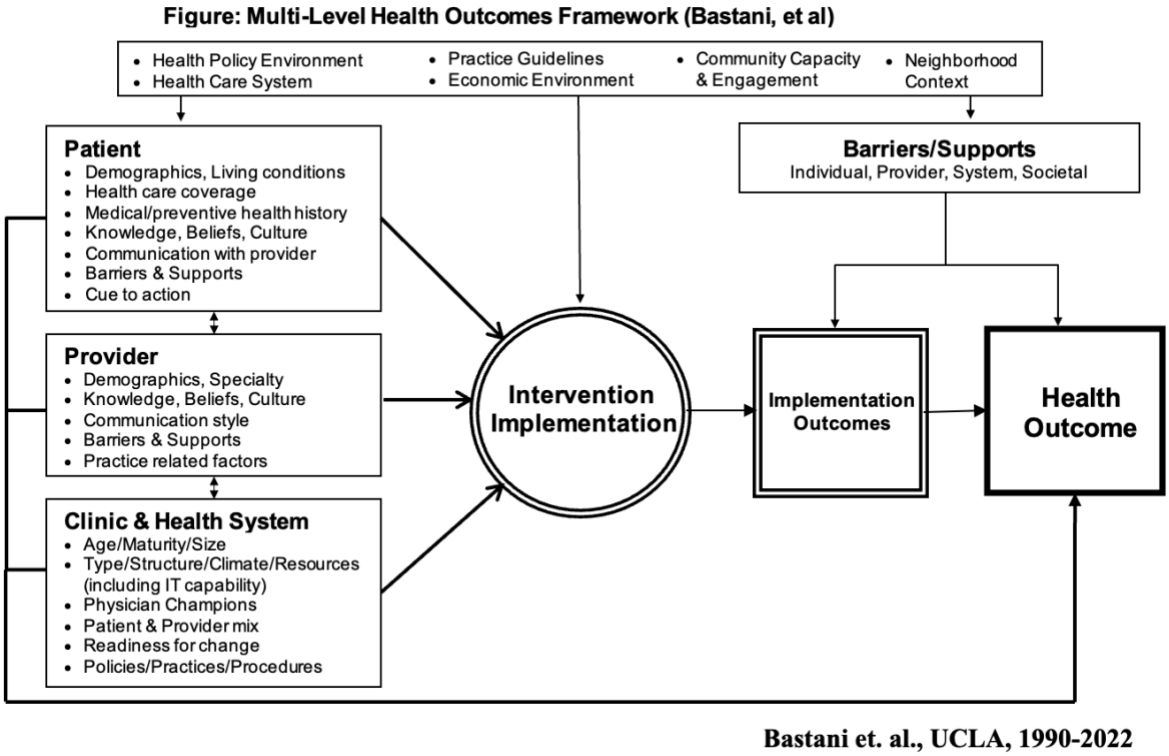

Exhibit 2: The Multi-Level Health Outcomes Framework (MHOF), developed by Bastani et al.

Notably, the Bastani et al. framework highlights 3 major categorical factors that feed into an intervention: the patient, the provider, and the health system. In this context, it can be seen that centralization of lung cancer screening programs intervenes at each of these levels. Centralization standardizes variability in providers and healthcare systems to control as many factors as possible around knowledge, communication, support, and identifying clear program

policies and champions. It additionally can bring extra resources to assist patients in overcoming barriers to communication and knowledge by standardizing shared decision making, and can support patients to overcome barriers through transportation and other coordination of care resources.

I propose that centralization may target two large barriers facing providers: time constraints and provider variability. Turning to the example of required shared-decision making, CMS mandated shared decision making be performed in order for lung cancer screening reimbursement[16]. Shared decision making is intended to address patient cognitive and psychological variables, and evidence supports patient reported improvements in knowledge and consistency between patient choices and their values[49]. However, the additional time required of primary care physicians (who historically have performed the majority of this counseling) to perform thoughtful and detailed shared decision making has been cited as a potential barrier to implementation[36]. In fact, it is estimated that the average primary care physician would need in excess of 26 hours per day to implement all the evidence-based guidelines for preventive, chronic disease, and acute care needs for an average panel in the U.S.[50] These time constraints on primary care physicians create an opportunity for centralized lung cancer screening programs staffed by trained allied health professionals to unburden the primary care physician from some or all of this time to perform shared decision making, smoking cessation counseling, screening, and follow-up.

Additionally, there may be significant provider variability not only in knowledge of current recommendations for screening but also in how often they offer screening and to whom. The USPSTF's eligibility criteria are more complex, requiring both age, pack-year, and quit date criteria beyond more straightforward criteria for other forms of cancer screening. Subsequently, providers may be unaware of these recommendations. Providers may also have potential biases which may lead to their recommending screening differently to different patients.

Although centralized programs may not completely remove biases, they standardize the approach to screening by employing a highly trained, dedicated group of providers.

Conversely, the decentralized model may itself carry advantages for some patients and providers. Given the significant biases and stigma around smoking and smoking-related disease, the therapeutic alliance of primary care physicians may be invaluable to nuanced shared-decision making conversations. Understanding these nuances is not possible from chart review alone, and likely require future studies that may focus more on qualitative assessments or specific interventions designed to impact these factors. However, comparison of LCS organizational strategies and improvement may at least hint at potential differences and generate hypotheses for future work. For example, if PCPs therapeutic alliance is key to increasing acceptance of LCS but time constraints still be an important factor, a hybrid model may excel at combining the benefits of PCP rapport and trust with patients with the support for the administrative burden of coordinating screening.

The current study seeks to investigate how system factors including organizational structure interact with patient factors like sociodemographic status. Additionally, this study seeks to pair information on the implementation of centralization with key patient and healthcare system factors to address if this intervention effectively improves LCS uptake and adherence equitably in all patients, leveraging available longitudinal data. Figure 1 presents the proposed project-specific conceptual model for the current study. It adapts elements of the Bastani et al. model while highlighting specific factors that may be most relevant to LCS. Notably, not all these patient, provider, and health system elements are measurable with the current dataset. Factors that are likely important but challenging to objectively measure in the current proposed project are included in parentheses. On the left are highlighted the contributory patient, system, and provider factors that may impact the effectiveness of the implementation of a lung cancer screening program. These all bidirectionally interact with the implementation of the LCS program's organizational structure, which may range from centralized to more decentralized

models. Certain patient, provider, and system level factors may be more associated with centralization, and centralization in turn may be more effective in certain patient populations, health systems, and for certain providers. This will in turn lead to varying rates of LCS uptake and adherence, the measurable outcome for the current study. Uptake and adherence are in turn upstream indicators of the proposed downstream (but unmeasured health outcome in the current study) of lung cancer morbidity and mortality. Studying the impact of an implementation like centralization can likely provide critical insights into the most effective strategies to increase lung cancer screening rates, and in turn improve lung cancer morbidity and mortality.

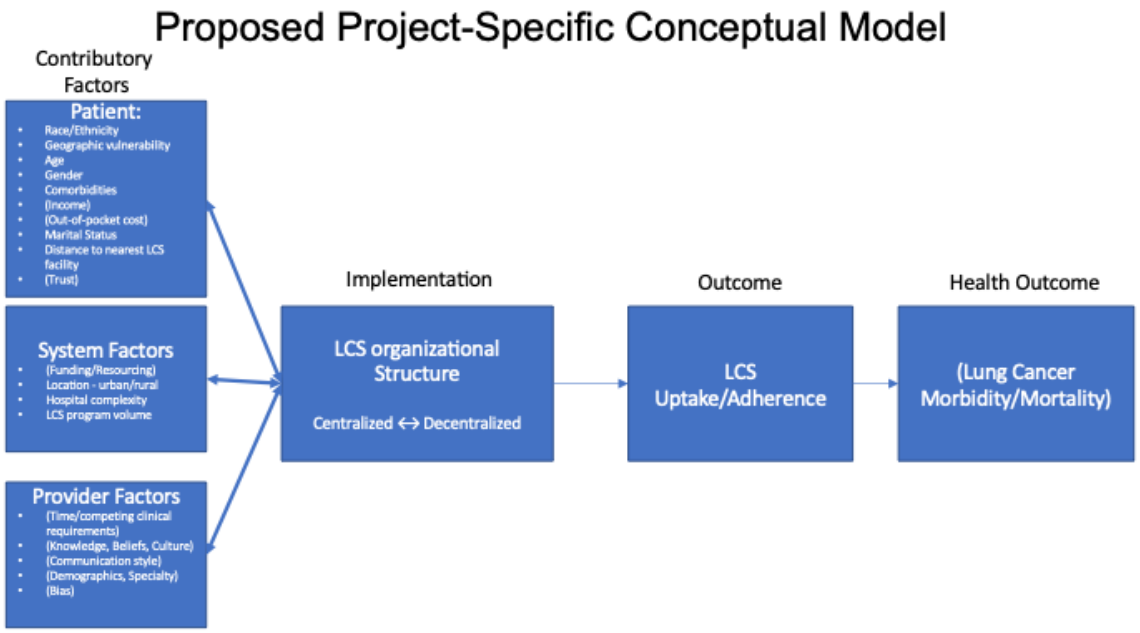

Figure 1: Proposed Project Specific Conceptual Model.
Contributory Patient, System, and Provider level factors are listed on the left, followed by the implementation studied (LCS centralization) and followed by the study outcome (LCS Uptake/Adherence), an intermediate outcome that should correlate with the ultimate health outcome of lung cancer morbidity & mortality

Chapter 3: Data Source and Overarching Methods

Study Population

The current study leveraged data on lung cancer screening rates abstracted from the Veterans Health Administration (VHA) Healthcare System. There are a number of advantages to the use of VHA data. Given their Veteran benefits, the VHA healthcare system represents as close to a universal coverage network as can be found in the United States, where patients, dependent on the presence of military service-connected conditions or on low income eligibility, can access care with little to sometimes no out of pocket costs. Moreover, the VHA serves a population of many Veterans who represent some of the highest-risk groups for lung cancer development. Many of the Veterans of Vietnam or Gulf wars are men in the age range eligible for screening. Furthermore, many are current or former smokers (and many began smoking when in the service and so have extensive smoking histories). Notably, around 30% of Veterans are current tobacco product users [51]. Around 36% of the Veteran population are ages 50-69 years old, and around 13% are Black/African American[52]. Moreover, those who enter military service are more racially and ethnically diverse than those who do not, enriching the diversity of the patient population served by the VHA[53]. Furthermore, many Veterans have a wide range of socioeconomic backgrounds and suffer high rates of concurrent diagnoses that historically have been significant barriers to healthcare utilization such as substance use, chronic mental illness, social isolation, or individuals experiencing homelessness[54].

The VA primarily utilizes a national electronic health record (EMR) system called the Computerized Patient Record System (CPRS). Data from this EMR is housed in a central data repository called the Corporate Data Warehouse (CDW). The CDW datasets can be utilized in the creation of large, comprehensive, longitudinal demographic, health, utilization, and outcome data following the patient from initial recommendation and throughout necessary follow up. At times, Veterans may need to seek care outside of the VHA if the VHA doesn't offer a service,

that service cannot be performed in a timely manner, or the distance to the service is burdensome for the Veteran. The VHA offers these Veterans VHA-paid care in the community (called "VA Community Care") through a network of contracted providers. The VA Informatics and Computing Infrastructure (VINCI) provisions data for researchers, including linked databases for claims related for VA community care and merged datasets with Medicare claims data for researchers to additionally capture data for Veterans who may seek care outside the VHA paid for by their Medicare benefits.

Additionally, the VHA is the largest nationally integrated delivery system in the US, and therefore provides a rich network to study the impacts of variations in care with sufficient sample size. The VHA is a leader in protocols and centralized approaches for care delivery, and many programs designed to improve quality of care have been developed at the VHA and translated to both managed care and fee-for-service settings in the U.S. The VHA also serves a complex patient population, many of whom suffer from multiple medical comorbidities, and face a range of socioeconomic barriers to accessing care. Despite the near universal coverage that VA benefits afford for health coverage, Veterans potentially may still face cost-sharing in the forms of varying co-payment or additional financial burdens like cost for transportation. Given the complexity and diversity of the population served by the VHA, VHA-based research has generalizable lessons for a wide range of practice settings who care for the most vulnerable patients. There is also a precedent for EMR-based implementation projects across the VHA having success, and for the VHA more broadly outperforming comparators like commercial managed care[55]. Therefore, there is robust generalizability and valuable insights that a VHA based observational study could still provide to the wider healthcare system, despite differences in care delivery across these systems.

Current State of Lung Cancer Screening in the VHA

The VHA divides the U.S. into 18 Veterans Integrated Service Networks (VISNs). The VISNs are regional systems of care organized to coordinate the local health needs of Veterans

in their region, and is comprised of about 6-8 different VA Medical Centers (VAMCs) per VISN. There are around 170 total VAMCs across the VHA national healthcare system. They are organized into 144 stations, with some stations having 2 VAMCs organized into a single integrated station with a unifying station identifier. Additionally, there are substation identifiers for the geographically distinct sites of care within each healthcare system, e.g. community-based outpatient clinics.

Following the NLST and the USPSTF's 2013 recommendation for LCS, a pilot study called the Lung Cancer Screening Demonstration Project (LCSDP) was performed across 8 VISNs to evaluate implementation of lung cancer screening through a more centralized approach[56]. Each VISN selected a representative VAMC (8 total) from a pool of volunteer facilities. These 8 VAMCs were all academic tertiary care facilities and spanned multiple regions across the United States. These facilities participating were: New York Harbor VA Healthcare System, New York, NY (VISN 3); Durham VA Medical Center, Durham, NC (VISN 6); Ralph H. Johnson VA Medical Center, Charleston, SC (VISN 7); Cincinnati VA Medical Center, Cincinnati, OH (VISN 10), VA Ann Arbor Healthcare System, Ann Arbor, MI (VISN 11); VA Portland Health Care System, Portland, OR (VISN 20); San Francisco VA Health Care System, San Francisco, CA (VISN 21); and Minneapolis VA Health Care System, Minneapolis, MN (VISN 23). Each site received three years of funding for a coordinator and a database to confirm patient eligibility, nodule tracking, diagnostic workup, management of incidental findings, and reminders for annual repeat imaging. Coordinators also conducted shared decision making conversations and provided decision aids to help Veterans understand the benefits and risks of screening.

The findings of the VA Lung Cancer Screening Demonstration Project were published in 2020. Tanner et al. reported an adherence rate of around 82% at the first year, and 65% at year 2, and roughly 2,103 patients were screened[57]. There was also significant variability observed in site-specific screening rates, with adherence rates ranging from 94% to 63% after 1

year. In this pilot study, there was notably similar rates of uptake and adherence for black and white Veterans, and driving time was not associated with lower rates of adherence.

The findings of the study were rather impressive when compared to estimates of LCS rates across the VHA. Broader estimates of LCS utilization across the largely decentralized LCS programs across the VA show much lower rates of utilization of only about 21 per 1000 eligible Veterans, or around 2%[58]. Other forms of cancer care within the VHA do demonstrate racial disparities in uptake especially among African Americans, as has been shown for colorectal cancer screening[59]. Notably, the LCSDP did not have a comparator/control group, and so it remains unclear the broader secular trends in LCS rates at similar facilities over this time period. An analysis of Medicare and VA data from ~28,000 Veterans who received lung cancer screening across the VA from 2015-2019 found that black Veterans, Veterans with mental health disorders, Veterans who lived further away from a VAMC, and Veterans with lower income were more likely to have delayed or absent follow up[60]. In that same analysis, Veterans with more concerning findings on their screening studies, or those at high-volume (screening >1000 Veterans per facility) or academic centers were more likely to have timely follow up either after an abnormal screening scan or for their annual screening study.

Following the lung cancer demonstration project, Lewis et al. investigated the association of health care system funding with lung cancer screening implementation, probing the impact that the funding and administrative assistance associated with the research study provided. They found that there was significantly higher screening and adherence during the study period, and that these gains were not maintained after the funding/support from the demonstration project concluded [61].

The Lung Precision Oncology Program

The VA's Lung Precision Oncology Program (LPOP) is a nationally coordinated research and clinical consortium that can provide funding and administrative support to enhance efforts to proactively address and treat lung cancer. LPOP spans 23 central "hub" sites, with numerous

associated “spoke” sites across the United States its territories. These 23 “hub” sites were selected to serve as hubs to coordinate & disseminate cutting-edge best practices for cancer screening, genetic testing, and participation in clinical trials. These “hubs” in turn were tasked with disseminating these opportunities to their geographically surrounding “spoke” sites, supporting the goal that all Veterans, regardless of where they live, would have access to cutting-edge cancer care. LPOP has a number of established administrative resources in addition to opportunities for collaboration with leading researchers in the field. LPOP organizes monthly nationwide virtual meetings to share research opportunities, findings, and general information about the program, and additionally hosts a number of sub committees focused on multiple aspects of lung cancer care including screening. These resources bolster the generation and feedback on proposed research studies, ease of Institutional Review Board (IRB) submissions, and increase the network of collaboratively available datasets.

Following the impressive results from the LCSDP, the VHA supported stations moving towards centralization of their LCS programs concurrently with LPOP backing. Included in the funding within LPOP was increased funding across the 23 hub sites specifically supporting implementing centralization, including hiring program coordinators and establishing electronic tracking systems. LPOP additionally fostered collaboration and administrative support between programs applying to and initiating centralized LCS programs. The National Center for Lung Cancer Screening (NCLCS) developed a standardized workflow for training program staff and initiating a centralized LCS program. This included educational materials both for program staff and for patients, a set of EMR tools to track smoking rates, eligibility for LCS, and an electronic registry to track referrals to LCS follow patients in subsequent follow up. LPOP promoted the utilization of the NCLCS LCS platform for stations that were initiating their own LCS platforms. Concurrently with the roll out of the LPOP, the NCLCS also conducted electronic organizational surveys across many of the 144 VHA stations nationwide to assess and assist stations as they considered and then implemented centralized screening programs. As of 2023, approximately

90 of the 144 stations have reported some information on their program characteristics to the NCLCS. The NCLCS is developing a dashboard for review of this information more broadly across the VA, as well as tracking general screening rates. Based on this survey data, it does appear a broader number of sites began implementing centralized lung cancer screening in the years after the completion of the LCSDP. There was a significant increase in the number of programs that centralized beginning in 2021.

Database Construction

Identification of Lung Cancer Screening Scans:

The study database was constructed via the VA national Corporate Data Warehouse (CDW) with data pulls for the 144 lung cancer screening stations across the national VA Healthcare System. With a nationwide dataset, reliably identifying CT scans as likely performed for lung cancer screening required a series of inclusion and exclusion criteria that was further refined by the study team. Broadly, initial low dose CT scans for lung cancer screening are grouped under the CPT code S8032 (retired on Oct 1, 2016), G0297 (retired Jan 1, 2021), and 71271 for the initial screening scan. These CPT codes are highly specific for LDCT for screening, but are unlikely to be sufficiently sensitive to capture all screening, as initial or subsequent follow up CT scans may be coded to different CPT codes. Additionally, some stations may perform CT scans for lung cancer screening but code them under more generic CPT codes for regular or low dose CT scans of the chest.

Additionally, scans for LCS commonly are coded by the reading radiologist with a Lung-RADS score to standardize interpretation of a radiology study and communicating recommended follow up. The American College of Radiology publishes guidelines for how to score CT Scan findings for lung cancer screening using the Lung-RADS category system. These were initially proposed in April 2014 and began adoption in 2015. The initial Lung-RADS categories are shown in exhibit 3 for reference. Conventionally, most scans for LCS should

have an associated Lung-RADS score attributed by the radiologist in order to guide the next steps in management based on whether a screening scan is considered positive or negative. However, it is possible that some radiologists reading scans across the VA may be unfamiliar with Lung-RADS scores and may not appropriately code scans to their appropriate diagnostic score. Nevertheless, Lung-RADS scores are highly specific to lung cancer screening, and therefore provide a robust means of identifying scans that may have heterogeneous CPT and radiology codes as scans likely for LCS.

Lung-RADS™ Version 1.0 Assessment Categories Release date: April 28, 2014

Category	Category Descriptor	Category	Findings	Management	Probability of Malignancy	Estimated Population Prevalence
Incomplete	0	0	prior chest CT examination(s) being awaited or comparison	Additional lung cancer screening CT images and/or comparison to prior chest CT examinations needed	n/a	1%
Negative	No nodule, and definitely benign nodules	1	nodule(s) with specific calcifications, complete, central, popcorn, concentric, fine, or soft tissue attenuation nodules	Continue annual screening with LDCT in 12 months	<1%	90%
Benign Appearance or Behavior	Nodule(s) with very low likelihood of becoming a clinically active cancer due to size or lack of growth	2	solid nodule(s): —new <4 mm —stable <4 mm part-solid nodule(s): —<4 mm total solid diameter on baseline screening non-solid nodule(s) (GGN): —<20 mm —≥20 mm and unchanged or slowly growing			
			category 3 or 4 nodules unchanged for 3–5 months			
Probably Benign	Probably benign finding(s) - Short-term follow-up suggested; or Includes nodules with true low likelihood of becoming a clinically active cancer	3	solid nodule(s): —1 to <6 mm at baseline OR —new <6 mm in diameter part-solid nodule(s) —<6 mm total diameter with solid component <6 mm OR non-solid nodule(s) (GGN) ≥20 mm on baseline CT or new	6 month LDCT	1-2%	5%
Suspicious	Finding for which additional diagnostic testing and/or tissue sampling is recommended	4A	solid nodule(s): —≥6 to <15 mm at baseline OR —growing <6 mm OR —new ≥4 to <6 mm part-solid nodule(s): —≥6 mm with solid component ≥4 mm to <6 mm OR —with new or growing <4 mm solid component endobronchial nodule	3 month LDCT, PET/CT may be used when there is a ≥6 mm solid component	5-15%	2%
		4B	solid nodule(s) —≥15 mm OR —new or growing and ≥6 mm part-solid nodule(s) with: —a solid component ≥6 mm OR —an new or growing ≥4 mm solid component	chest CT with or without contrast, PET/CT and/or tissue sampling depending on the probability of malignancy and comorbidities. PET/CT may be used when there is a ≥8 mm solid component.	> 15%	2%
		4X	Category 3 or 4 nodules with additional feature(s) or imaging findings that increase the suspicion of malignancy			
Other	Clinically Significant or Potentially Clinically Significant Findings (non-lung cancer)	S	modifier: 0 may be added to category 0 coding	As appropriate to other specific finding	n/a	10%
Prior Lung Cancer	any prior diagnosis of lung cancer when returning to screening	C	modifier: 0 may be added to category 0 coding	0	-	-
Modifier for patients with a history of lung cancer						

IMPORTANT NOTES FOR USE:

1) Negative screen does not mean that an individual does not have lung cancer

2) Size: nodules should be measured on lung windows and reported as the average diameter rounded to the nearest whole number; for round nodules only a single diameter measurement is necessary

3) Size Thresholds: apply to nodules at first detection, and that grow and reach a higher size category

4) Growth: an increase in size of ≥ 1.5 mm

5) Exam Category: each exam should be coded (1-4 based on the nodule(s)) with the highest degree of suspicion

6) Exam Modifiers: S and C modifiers may be added to the 0-4 category

7) Lung Cancer Diagnosis: Once a patient is diagnosed with lung cancer, further management (including additional imaging such as PET/CT) may be performed for purposes of lung cancer staging; this is no longer screening

8) Practice audit definitions: a negative screen is defined as category 1 and 2; a positive screen is defined as categories 3 and 4

9) Category 4B Management: this is predicated on the probability of malignancy based on patient evaluation, patient predetermined risk of malignancy; radiologists are encouraged to use the McWilliams et al assessment tool when making recommendations

10) Category 4X: nodules with additional imaging findings that increase the suspicion of lung cancer, such as spiculation, GGN that doubles in size in 1 year, enlarged lymph nodes etc

11) Nodules with features of an intrapulmonary lymph node should be managed by mean diameter and the 0-4 numerical category classification

12) Category 3 and 4A: nodules that are unchanged on interval CT should be coded as category 2, and individuals returned to screening in 12 months

13) LDCT: low dose chest CT

Link to McWilliams Lung Cancer Risk Calculator

Upon request from the authors at: http://www.brocku.ca/lung-cancer-risk-calculator

At UptoDate: http://www.uptodate.com/contents/calculator-solitary-pulmonary-nodule-malignancy-risk-brock-university-cancer-prediction-equation

Exhibit 3: American College of Radiology (ACR) Lung Imaging Reporting and Data System (Lung-RADS) categories
First published in 2014[62]*.*

Given Lung-RADS adoption in 2015, our team restricted data to FY2016-FY2021, which ranges from October 1, 2015 through September 30th, 2021. These dates were selected to maximize the timeframe in which Lung-RADS was utilized following the initial USPSTF LCS recommendation in 2013 and before its updated recommendations were implemented in late 2021.

Incorporating input from prior algorithms published for identifying like LCS scans in VA data[60,63], we used the following inclusion criteria to identify screening scans as likely LCS scans:

1. A Lung-RADS diagnostic code associated with the CT scan
2. A CPT code of G0297, S8032, or 71271
3. The CT scan had a status as "completed"

Based on initial exploratory analysis of the dataset that demonstrated CT scans that were unlikely to be LCS being likely erroneously coded with Lung-RADS diagnostic codes, we further refined our pool of scans by excluding studies that did not have a radiology procedure name found in the exhibit 4 below. This list was manually identified by the research PI as a procedure name that could likely be associated with a LCS CT scan from the broader list of CT scans identified using the inclusion criteria above. This methodology of utilizing specific radiology procedure names to further refine scans as likely for LCS has been utilized by other VA researchers [60,63]. Given that the list of procedure names associated with scans in the CDW is constantly updating as different sites may either generate new procedure names unique to that site or as procedure names are retired (often denoted by leading x's or z's), the creation of this procedure list is unique to the current study based on the procedure names identified at the times of data pulls. All data queries to the CDW to identify LCS scans were performed from November 2023 through May 2024.

CT LOW DOSE LUNG SCREENING	LDCT LCS 3 OR 6 MONTH FOLLOW UP
LDCT CHEST-SCREEN	LDCT LCS 6 MONTH FOLLOW UP
LDCT LCS 1,3, OR 6 MONTH FOLLOW UP	LDCT LCS COMM CARE 1,3,OR 6 MONTH
LOW DOSE CT LUNG SCREENING	LDCT LCS COMMUNITY CARE
*CT LUNG	LDCT LCS1, 3 OR 6 MONTH FOLLOW UP
*CT LUNG CANCER FOLLOW UP 3 OR 6 MONTHS	LDCT LOW DOSE CANCER SCREENING
*CT LUNG CANCER SCREENING	LDCT LUNG CA 3-6 MO F/U
*LDCT LUNG CANCER SCREENING	LDCT LUNG CA 3-6 MONTH F/U
.LDCT LUNG CANCER SCREENING 1, 3, OR 6 MONTH	LDCT LUNG CA SCREEN 3 OR 6 MTH F/U
[CT THORAX W/O CONT]	LDCT LUNG CA SCREENING
[LOW DOSE CT LUNG SCREENING]	LDCT LUNG CA SCREENING 71271
C LUG CANCER SCREENING	LDCT LUNG CA SCRN
CAT SCAN THORAX	LDCT LUNG CANCER SCEENING
CT - THORAX	LDCT LUNG CANCER SCREENING
CT THORAX W/O IV CONTRAST	LDCT LUNG CANCER SCREENING'
CT (LDCT-CHEST) SCREENING	LDCT LUNG CANCER- SCREENING
CT ANNUAL LOW DOSE FOR LUNG CANCER SCREENING	LDCT LUNG CANCER SCREENING (G0297)
CT CANCER SCREENING LOW DOSE CHEST W/O	LDCT LUNG CANCER SCREENING (P)
CT CHEST (LUNG CANCER SCREENING - WO/CONT., LOW DO	LDCT LUNG CANCER SCREENING 1, 3 OR 6 MONTH
CT CHEST (THORAX) HIGH RESOLUTION	LDCT LUNG CANCER SCREENING 1, 3 OR 6 MONTH FOLLOW
CT CHEST (THORAX) W/O CONTRAST	LDCT LUNG CANCER SCREENING 1, 3, OR 6 MONTH
CT CHEST LUNG CA SCREENING	LDCT LUNG CANCER SCREENING 1,3 OR 6 MONTH
CT CHEST LUNG CA SCRN WO CONTRAST	LDCT LUNG CANCER SCREENING 1,3 OR 6 MONTH FOLLOW U
CT CHEST LUNG CANCER SCREENING	LDCT LUNG CANCER SCREENING 1,3 OR 6 MONTHS
CT CHEST THORAX W/O CONT	LDCT LUNG CANCER SCREENING 1,3, OR 6 MONTH
CT CHEST W/O CONT (LOW DOSE-LUNG CANCER SCREENING)	LDCT LUNG CANCER SCREENING 2020
CT CHEST,LUNG SCREENING LOW DOSE	LDCT LUNG CANCER SCREENING FOLLOW UP
CT CHEST/THORAX W/O CONTRAST	LDCT LUNG CANCER SCREENING INACTIVE
CT CHEST/THORAX WO CONTRAST-DIAGNOSTIC	LDCT LUNG CANCER SCREENING-OUTSIDE

CT CHEST-LUNG CANCER SCREENING	LDCT LUNG CANCER SEREENING 1, 3 OR 6 MONTH
CT HIGH RESOLUTION THORAX (2)	LDCT NON-LUNG CANCER SCREENING
CT LDCT LUNG CA SCREEN	LDCT NON-SCREENING
CT LOW DOSE LUNG / CHEST	LDCT OTHER
CT LOW DOSE LUNG CANCER SCREENING	LDCT SCREENING
CT LOW DOSE LUNG CANCER SCREENING LDCT	LDCT SCREENING 1,3 OR 6 MONTH
CT LOW DOSE LUNG SCREENING	LDCT SCREENING,W/O CONTRAST
CT LOW DOSE LUNG SCREENING (D)	LDCT WHOLE BODY MULTIPLE MYELOMA (PARENT)
CT LOW DOSE LUNG SCREENING 2021	LDCT(LOW DOSE CHEST CT)
CT LOW DOSE LUNG SCREENING STUDY	LDCT(LUNG CANCER SCREENING)G0297
CT LOW DOSE LUNG SCREENING, S8032	LDCT, COMMUNITY CARE LUNG CA SCREENING, W/O CONTRA
CT LOW DOSE THORAX W/O	LDCT, LUNG CANCER SCREENING
CT LUNG & MEDIASTINUM (P)	LO DOSE CT LUNG CANCER SCREENING
CT LUNG CA SCREENING	LOW DOSE CT LUNG CANCER SCREENING
CT LUNG CA SCREENING LOW DOSE	LOW DOSE CT LUNG SCREENING
CT LUNG CA SCREENING LOW DOSE (+)	LOW DOSE CT SCAN LUNG CANCER SCREENING
CT LUNG CANCER SCREEN WO C LOW DOSE [G0297]	LOW DOSE LUNG CANCER SCREENING
CT LUNG CANCER SCREENING	LOW DOSE LUNG CT
CT LUNG CANCER SCREENING - LOW DOSE	LOW DOSE LUNG CT
CT LUNG CANCER SCREENING 71271	LOW DOSE LUNG SCREENING
CT LUNG LOW DOSE SCREENING	LUNG CA SCREENING
CT LUNG NODULE > 1CM. (P)	LUNG CA SCREENING 3 OR 6 MONTH F/U
CT LUNG NODULE FOLLOW UP	LUNG CANCER DIAGNOSIS (P)
CT LUNG SCREENING	LUNG CANCER SCREENING
CT LUNG SCREENING LOW DOSE	LUNG CANCER SCREENING (LDCT)
CT LUNG W/O CONTRAST	LUNG CANCER SCREENING 3 OR 6 MONTH FOLLOW UP
CT THOLDCT LUNG CANCER SCREENINGAX LOW DOSE W/O CO	LUNG CANCER SCREENING ANNUAL
CT THORAX	LUNG CANCER SCREENING INITIAL AND ANNUAL
CT THORAX (P)	LUNG CANCER SCREENING LDCT
CT THORAX (W CONT)	LUNG CANCER, NON-SMALL CELL, DIAGNOSIS
CT THORAX (W&WO CONT)	LUNG DIFFERENTIAL FOR CA LUNG

CT THORAX DIAGNOSTIC W/O CONT	NM CT CHEST LUNG CANCER SCREENING
CT THORAX DIAGNOSTIC W/O CONTRAST	NM CT THORAX W/O CONT
CT THORAX FOLLOW UP LOW DOSE	NM CT THORAX W/O CONTRAST
CT THORAX HIGH RESOLUTION (HRCT)	NM CT THORAX W/O DYE
CT THORAX HIGH RESOLUTION W/O CONTRAST	NON VA CT LUNG CANCER SCREENING
CT THORAX HIGH-RES WITHOUT CONTRAST (D)	NON VA LDCT LCS 1,3 OR 6 MONTH FU
CT THORAX HIRES W/O CONT	NON VA LDCT LUNG CANCER SCREENING
CT THORAX HI-RESOLUTION W/O	NON-VA CT LOW DOSE CT (FOR LUNG CANCER SCREENING)
CT THORAX LOW DOSE	NON-VA LDCT (FOR LUNG CANCER SCREENING)
CT THORAX LOW DOSE (71250)	NON-VA OS LDCT FOR SCREENING
CT THORAX LOW DOSE *	OLD CT THORAX LOW DOSE SCREENING CT SCAN
CT THORAX LOW DOSE FOR LUNG CA SCREENING W/O CONT	OLD LCDT LUNG CANCER SCREENING CT THORAX WO CONTRA
CT THORAX LOW DOSE FOR LUNG CANCER SCREENING	OLD LDCT LUNG CANCER SCREEN 6 MO
CT THORAX LOW DOSE SCREENING	OLD LDCT LUNG CANCER SCREEN 9 MO
CT THORAX LOW DOSE SCREENING CT SCAN	OLD LDCT LUNG CANCER SCREENING
CT THORAX LOW DOSE WITHOUT CONTRAST	OUTSIDE LDCT LUNG CANCER SCREENING
CT THORAX LUNG CANCER SCR C-	PULMONARY CLINIC LDCT
CT THORAX LUNG CANCER SCREENING 71271	PULMONARY LDCT 3 OR 6 MONTH F/U, 71250
CT THORAX W/ (3D)	THORAX (W/O IV CONT) CT
CT THORAX W/O	THORAX CT W/O
CT THORAX W/O (3D)	THORAX W/O CONTRAST
CT THORAX W/O CONT	THORAX W/O CONTRAST (CT)
CT THORAX W/O CONT (HIGH RES)	XCT CHEST/THORAX W/O CONT DUP
CT THORAX W/O CONT (P)	XCT CHEST/THORAX WO (HI-RES)
CT THORAX W/O CONT **SUBMIT TO CT**	XCT LUNG CANCER SCREEN WRONG CPT
CT THORAX W/O CONT [71250,74176]	XOLD LDCT
CT THORAX W/O CONT [71250]	XOLD LUNG SCREENING ORDER
CT THORAX W/O CONT HIGH RES	XXCT LOW DOSE LUNG SCREENING
CT THORAX W/O CONT HIGH RESOLUTION	XXLDCT FOR LUNG CANCER SCREENING

CT THORAX W/O CONTRAST	XXLDCT LUNG CANCER SCREEN WO
CT THORAX W/O CONTRAST (HIGH-RESOLUTION)	XXXLDCT LUNG CANCER SCREENING..
CT THORAX W/O CONTRAST (LOW DOSE)	ZCT THORAX DIAGNOSTIC W/O CONTRAST
CT THORAX W/O CONTRAST, LOW DOSE FOR CANCER SCREEN	ZCT THORAX W/O CONT (HIGH RESOLUTION)
CT THORAX W/O DYE	ZCT THORAX WO CONTRAST (HIGH RESOLUTION)
CT THORAX W/O IV CONT.	Z-IMPORTED CT THORAX
CT THORAX W/O LOW DOSE	Z-IMPORTED LDCT LUNG CANCER SCREENING
CT THORAX W/WO CONTRAST	ZLDCT LUNG CANCER SCREENING
CT THORAX W/WO IV	ZLDCT LUNG CANCER SCREENING 1, 3, OR 6 MONTH
CT THORAX WITHOUT	ZLOW DOSE CT LUNG SCREENING
CT THORAX WITHOUT - LOW DOSE	ZLUNG CANCER SCREENING LDCT
CT THORAX WITHOUT CONT	ZZ CT CHEST BASELINE LUNG CANCER SCREENING
CT THORAX WITHOUT CONTRAST	ZZ CT THORAX LUNG CANCER SCR C-
CT THORAX WITHOUT CONTRAST (D)	ZZ CT THORAX W/O CONT
CT THORAX WO	ZZ CT THORAX W/O CONT MU
CT THORAX WO CONTR (HIGH RESOLUTION)	ZZ CT THORAX W/O CONT - MU
CT THORAX WO CONTRAST	ZZ LDCT CHEST
CT THORAX(DIAGNOSTIC)W/O CONT	ZZ LDCT LUNG CANCER SCREEN 3-6 WKS
CT THORAX, DIAGNOSTIC W/O CONT	ZZ LOW DOSE CT LUNG SCREENING
CT THORAX, DIAGNOSTIC W/O CONTRAST	ZZANNUAL LUNG CANCER SCREEN FOLLOW-UP
CT THORAX, LOW DOSE FOR LUNG CANCER SCREENING, W/O	ZZCT LDCT
CT THORAX, W/O CONTRAST	ZZCT LUNG CA SCREENING
CT THORAX,HIGH RES	ZZCT LUNG CANCER SCREENING
CT THORAX-HIGH RESOLUTION	ZZCT THORAX HIGH RES
CT THORAX-SCREENING	ZZCT THORAX W/O CONT
CT* THORAX LOW DOSE SCREENING CT SCAN	ZZCT THORAX W/O CONTRAST
CT, LUNG SCREENING	ZZCT* LOW DOSE LUNG SCREENING
CT, THORAX LOW DOSE FOR LUNG SCREENING, WITHOUT CO	ZZLDCT LCS 3 OR 6 MONTH FOLLOW UP
CT, THORAX WITHOUT CONTRAST LIMITED	ZZLDCT LUNG CANCER SCREENING
DIAGNOSTIC CT FOR LUNG CANCER SCREENING W/O CONTRA	ZZLDCT LUNG SCREENING

DIAGNOSTIC CT LUNG CANCER SCREEN W/CONT	ZZLOW DOSE CT LUNG SCREENING
FEE-BASIS CT THORAX	ZZLOW DOSE CT LUNG SCREENING (DISCONTINUED)
FEE-BASIS CT THORAX W/CONT	ZZTHORAX CT W/O CONT
FEE-BASIS CT THORAX W/O CONTRAST	ZZXZ CT LOW DOSE LUNG SCREENING
FEE-BASIS LDCT LCS 1, 3 OR 6 MONTH FOLLOW UP	ZZZLDCT LCS 1, 3, OR 6 MONTH FOLLOW UP
FEE-BASIS LDCT LUNG CANCER SCREENING	ZZZLDCT LUNG CANCER SCREENING
IN HOUSE LDCT LUNG CANCER SCREENING	ZZZLDCT LUNG CANCER SCREENING 1,3,OR 6 MONTH
IN HOUSE LDCT LUNG CANCER SCREENING 1, 3, OR 6 MON	ZZZZCT LOW DOSE THORAX W/O
INACTIVE LDCT LUNG CANCER SCREENING INACTIVE	ZZZZLDCT LUNG CANCER SCREENING
LCDT LUNG CANCER SCREENING	ZZZZLOW DOSE CT LUNG SCREENING
LCDT LUNG CANCER SCREENING 1,3 OR 6 MONTH FOLLOW U	ZZZZZLDCT LUNG CANCER SCREENING
LCT THORAX WITHOUT CONTRAST	LDCT FOR LCS 3 OR 6 MONTH FOLLOW UP
LDCT	LDCT FOR LUNG CA SCREEN
LDCT (LOW DOSE CT) FOR LUNG CANCER SCREENING	LDCT FOR LUNG CANCER SCREENING
LDCT 1,3 OR 6 MONTH FOLLOW UP	LDCT LCS 1 YEAR FOLLOW UP
LDCT CHEST	LDCT LCS 1, 3 OR 6 MONTH FOLLOW UP
LDCT CHEST (71250-FOLLOW UP)	LDCT LCS 1,3 OR 6 MONTH FOLLOW UP
LDCT CHEST (71250-SCREEN)	LDCT LCS 1,3, OR 6 MONTH FOLLOW UP
LDCT COM CARE LCS 1, 3 OR 6 MONTH FOLLOW UP	LDCT LCS 12 MONTH FOLLOW UP
LDCT COM CARE LUNG CANCER SCREENING	LDCT LCS 3 MONTH FOLLOW UP
LDCT LCS 3 OR 6 MONTH F/U	

Exhibit 4: Radiology procedure names for CT scans likely performed for LCS

Procedure names identified by research team as likely associated with lung cancer screening based on attributed radiology procedure name in the VA Corporate Data Warehouse EMR. Procedure names which have been retired are frequently marked with a preceding single or string of the letters X or Z.

The NCLCS has disseminated a proposed algorithm for defining adherence for patients within lung cancer screening programs, with both “target” goals for adherence with more stringent time targets for follow up, and a “minimum” range with more lenient benchmarks for

adherence. An outline of these adherence targets is shown in exhibit 5, adapted from internal NCLCS documents.

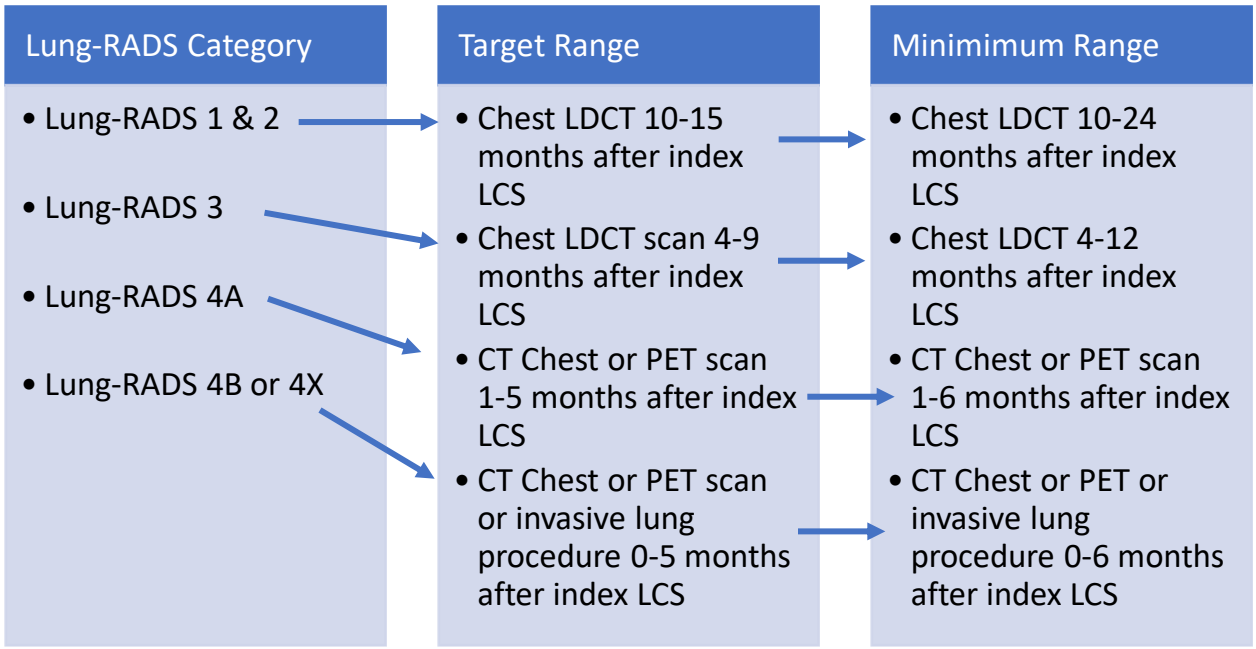

Exhibit 5: Definitions of adherence for LCS based on Lung-RADS category
Recommendations defined by the VA National Center for Lung Cancer Screening. Adapted from unpublished internal documents.

These target dates for follow up are based on literature previously published by Dr. Renda Weiner's group, and echoes previously published targets for adherence like those used for the NLST. These adherence definitions are similar to that used for the NLST – individuals with either a normal baseline CT Scan (Lung-RADS 1), benign appearing nodules on baseline scan (Lung-RADS 2), or incomplete scan (Lung-RADS 0), who had a follow up scan up to 2 months before and up to 3 months after the yearly due date (i.e. within 15 total months of initial scan[8]). Evaluating programs adherence based on the definitions of NLST is valuable, as realizing the mortality benefit seen in the NLST likely requires similarly high (~90%) adherence levels as were seen in the NLST. The VA's NCLCS expanded these NLST definitions to define target and minimum adherence ranges based on the initial LungRADS category as outlined in Exhibit 5 above. These same definitions were adopted for the current study.

LCS scans/procedures were linked to patient ICN number, a nationwide, unique patient identifier that can identify a patient regardless of which VA facility is utilized, minimizing the risk that patients would be lost to follow up simply by moving facilities. Additional individual demographic variables collected for each Veteran included age at the time of scan/procedure, gender, race, ethnicity, ADI, smoking status, comorbid conditions, and address. All analysis was based on retrospective data analysis, and there was not any interaction directly with patients or direct interventions involving patients.

Smoking rates in the study population were estimated based on available structured data elements collected as part of the NCLCS LCS platform. These structured data elements, called health factors, collected detailed information on whether a Veteran was a current, former, or never smoker. It also collected detailed information of the packs/day smoked, if the patient quit in < or >/=15 years ago, and the total number of years smoked and the quit year. Detailed methodology on the creation and interpretation of smoking data is outlined in Chapter 4: Manuscript 1 of this dissertation.

Station Level Data:

There is likely significant variability in the size and resourcing of various stations and the patient mix seen, which could introduce potential sources of bias. To provide metrics for controlling for this variability, the VA has assigned each station a complexity level to indicate a facilities relative patient risk, academic affiliation, and resourcing. A summary of the VA complexity level is provided in exhibit 6 below. Additionally, the case mix and access of Veterans at a given facility will likely also vary significantly with the rurality of the station itself. We will therefore obtain station location attribution of the stations rurality based on the USDA's Rural-Urban Commuting Area (RUCA) codes. For the purposes of the current study, all patient data was associated and coded to a single parent station, including care that may have been received at Community-Based Outpatient Clinics (CBOCs).

Summary of VHA Facility Complexity Model

The complexity model presented divides VHA facilities into five levels (not including excluded). The following table lists the number of VHA Facilities by Complexity Level:

Complexity Level	Number of VHA Facilities
1a	39
1b	21
1c	25
2	24
3	31
Excluded	1
Total	141

The numbering of the levels corresponds to the three Senior Executive Review Program (SES) pay bands adopted by VA. The model produces complexity levels as follows:

Complexity Level 1 – High Complexity

High patient risk

High levels of teaching and/or research

High number of Veterans Equitable Resource Allocation (VERA) Pro-Rated Persons

Divided into three sub-levels: 1a, 1b, and 1c.

Complexity Level 1a

Largest levels of volume, patient risk, teaching and research

Largest number and breadth of physician specialists.

Level 1a facilities contain level 5 Intensive Care Unit (ICU) units. [1]

Complexity Level 1b

Very large levels of volume, patient risk, teaching and research

Level 1b facilities contain level 4 and 5 ICU units. [1]

Complexity Level 1c

Large levels of volume, patient risk, teaching and research

Level 1c facilities contain level 4 ICU units. [1]

Complexity Level 2 – Medium Complexity

Medium number of VERA Pro-Rated Persons

Medium levels of teaching/research activity

Medium patient risk

Some teaching and/or research

Level 2 facilities contain level 3 and 4 ICU units

Complexity Level 3 – Low Complexity

Low levels of patient complexity

Smallest level in terms of volume

Little or no teaching/research

Lowest number of physician specialists per pro-rated person

Level 3 facilities contain level 1 and 2 ICU units.

[1] The score of 5 represents the most complex ICU level rated 1 in healthcare analysis and information group.

Exhibit 6: VA site facility complexity model outlining the criteria related to a VA stations attributed complexity level
Reproduced from online materials [64].

Qualitative Survey Data on LCS screening programs

In order to capture the variability in LCS practices related to centralization, our study leveraged available qualitative organizational survey data. The National Center for Lung Cancer Screening (NCLCS) led by Christopher Slatore, MD (a key advisor for the current project) performed electronic surveys for organizational structure across a range of lung cancer screening programs across the VA. 73 stations responded reporting information ranging from the overall screening program structure (categorized into decentralized, hybrid, or consult, i.e. fully centralized), when various program elements were initiated, and other basic information on who is responsible within the program. Survey responses were collected on a rolling basis through the end of 2023. Exhibit 7 below outlines the list of electronic survey questions administered by the NCLCS. To improve the data capture of VA station LCS practices across

the VA related to centralization, we additionally pulled data from a different qualitative organizational survey administered by Núñez et al [65]. Questions utilized by the Núñez research group are reproduced in exhibit 8. The Nunez survey was conducted between August and December 2021. 64 stations responded to the Núñez group survey. 42 stations overlapped between the NCLCS and Núñez surveys, and the Núñez survey provided information on an additional 22 stations not included in the NCLCS survey dataset. The combined survey data subsequently provided information on 95 total stations.

Number	Question
Question 1	01) When did this Station hire its first Coordinator?
Question 2	02) What is the LCS Coordinator FTE at this Station?
Question 3	03) When did this Station assemble an Oversight Board and assign relevant roles?
Question 3.1	04) Who participates in the Oversight Board?
Question 4	05) Which specialties make up this Station's Nodule/LungRADS Review Board?
Question 5	06) How often do the LCS Nodule/LungRADS Review Boards specialties meet?
Question 6	07) Which type of Clinical Model has this Station chosen?
Question 7	08) When did this Station create its SOP?
Question 8	09) When was the Clinical Restructuring Request submitted to Local Administration?
Question 9	10) When was the Clinical Restructuring Request submitted to the VISN?
Question 10	11) When was the Clinical Restructuring Request approved by the VHA?
Question 12	12) Were Lung RADS Diagnostic Codes/LCS-specific Orders installed and CPT Codes updated?
Question 13	13) When was the LCSP 60-Day Audit completed?
Question 14	14) Did this Station receive HIMS approval for Clinical Reminders, Note Titles, and a New Clinic?
Question 15	15) When did this Station install and configure LCSP Clinical Reminders and Coordinator Templates?
Question 16	16) Were Initial Reminder, Repeat Reminder, and Coordinator Templates checked against the Clinical Reminder Install Checklist, properly installed according to the Station's chosen Clinical Model, and mapped to Orders/Consults?
Question 17	17) How does this Station assess patients for LCS eligibility?
Question 18	18) How does this Station facilitate offering LCS to eligible patients?
Question 19	19) How does this Station track adherence to LDCT follow-up guidelines?

Question 20	20) When was LCSP Test Data validated?
Question 21	21) When did this Station train and educate its first group of Primary Care Clinical Staff?
Question 22	22) When did this Station provide its first ever LDCT to a Patient?
Question 23	23) When were EHR Reminders first initiated to prompt PCPs to offer/order LDCTs?
Question 24	24) When were EHR Reminders expanded to prompt approximately 50% of PCPs to offer/order LDCTs?
Question 25	25) When were EHR Reminders expanded to prompt at least 90% of PCPs to offer/order LDCTs?
Question 26	26) Does this Station's LCS Program track Veterans who undergo LCS in the Community?
Question 27	27) Does this Station offer patients an effective, evidence-based Smoking Cessation Program?
Question 28	28) What criteria does this Station use to determine eligibility for lung cancer screening?
Question 29	29) Which patient education materials does this Station use to promote shared decision making?
Question 30	30) Does this Station have access to a Nodule/LungRADS Review Board or a Tumor Board with expertise in lung cancer treatment?
Question 31	31) Where is the Nodule/LungRADS Review Board held?
Question 32	32) Where is the Tumor Board held?
Question 33	Comment Area

Exhibit 7: List of electronic survey questions administered by the NCLCS
Administered by NCLCS to VA lung cancer screening programs. Adapted from internal, unpublished documents

Appendix Table 4.* Survey for VA lung cancer screening (LCS) programs identifying current structures and processes employed and barriers to optimizing adherence to LCS

Question	Response	Domain
Program Structures		
At which VA facility are you primarily involved in lung cancer screening (LCS)?	(Free Text)	
What is your role within the LCS program?	Screening coordinator Primary Care Provider (PCP) Pulmonologist Radiologist Oncologist Thoracic Surgeon Other: (Please specify)	
What is your role in Lung Precision Oncology Program (LPOP)?. LPOP is a new cooperative studies program focused on increasing Veteran access to lung cancer screening and ensuring those diagnosed with lung cancer undergo appropriate molecular testing to allow for personalized treatment.	Hub – if a Hub site, please identify which spoke sites are within your LPOP infrastructure. Spoke	Program Model
How many CT scanners are available to perform LCS at the main site?	Please specify number:	Program Services
How many Community-based outpatient clinics (CBOCs) is your primary facility affiliated with?	Please specify number:	Program Model
How many CBOCs have CT scanners?	Please specify number:	Program Services
Do you have an active lung cancer screening (LCS) program at your site?	Yes No	Program Model
If yes, approximately in what month and year did you start screening?	Please specify month and date:	Program Model
What department oversees LCS?	Pulmonary Radiology Oncology Primary Care Thoracic Surgery Other:	Program Model
Do you use a screening coordinator? A screening coordinator is a clinician responsible for communicating with patients and referring providers, as well as coordinating follow-up testing.	Yes No	Key Stakeholders & Personnel
If so, what is the role of the screening coordinator? (select all that apply)	Conducts shared decision making with Veterans Orders CT Chest Contacts patient with results Schedules follow-up evaluation Contacts Veterans for annual screening	Key Stakeholders & Personnel

effective tools for the LCS program.		
Which members make up the steering committee? (Select all that apply)	Radiologist Medical oncologist Radiation oncologist Thoracic surgeon Palliative care provider Psychologist/Psychiatrist specializing in cancer Advanced Practice Providers (NPs, PAs) screening coordinator Pulmonologist **Representative(s) from:** Hospital leadership Community organizers Employer coalitions Local Non-profit or diversity organizations Other:_____	Key Stakeholders & Personnel
How does your site typically offer lung cancer screening with low-dose computed tomography (LDCT)?	Patients are referred to a dedicated lung cancer screening program that handles all subsequent care (i.e. program coordinates a bundle of services including imaging, tissue biopsy, diagnosis, and possibly other services) (Centralized model) Primary Care Providers (PCPs) order LDCT and are responsible for tracking the results and coordinating follow-up (Decentralized model) Workload is shared by PCP and dedicated LCS staff (ex: PCP orders LDCT and is responsible for coordinating low-risk follow-up but a LCS committee reviews and assists with intermediate or high-risk findings (Hybrid Model) Other, if none of the above: _____	Program Model
Are you using the Lung-RADS reporting system? Lung-RADS refers to the American College of Radiology's Lung CT Screening Reporting & Data System, which standardizes reporting of LCS results by categorizing findings according to risk and including a recommendation for follow-up testing	Yes No	Radiology Tools
If no to above, what standardized reporting system do you use?	National Comprehensive Cancer Network (NCCN) Fleischner Society Other: _____ None	Radiology Tools
Does radiology use volumetric software for assessment of pulmonary nodules found on LCS?	Yes No	Radiology Tools
Does radiology use a computer aided detection (CAD) nodule software to interpret LCS?	Yes No	Radiology Tools
Do you have a lung cancer screening registry/tracking tool?and if yes, which one do you use?	VISN23 CCTS VAPALS-ELCAP Commercial: (please specify) Other: (please specify) No	Registry Tools
If yes, does your program include CBOCs in the registry in addition to your facility?	Yes No	Registry Tools

Do you have a multidisciplinary tumor or nodule board	Yes No	Key Stakeholders & Personnel
Please indicate if you have the following types of providers available at your facility (on-site) to participate in the evaluation and care of patients with known or suspected lung cancer (select all that apply):	Dedicated chest (thoracic) radiologist Radiologists trained in reading chest CTs Interventional radiologist (for transthoracic biopsy) Medical oncologist Radiation oncologist Thoracic surgeon Palliative care provider Psychologist/Psychiatrist specializing in cancer Pulmonologist	Key Stakeholders & Personnel
Are the following procedures available to patients on-site? (select all that apply)	Transthoracic needle lung biopsy Flexible Bronchoscopy Advanced Bronchoscopy (check all that apply) Bronchoscopy with endobronchial ultrasound (EBUS) Bronchoscopy with navigation technology Robotic Bronchoscopy Rigid Bronchoscopy Mediastinoscopy Surgical lung biopsy via thoracotomy Surgical lung biopsy via Video-assisted thoracoscopic surgery (VATS) Surgical lung biopsy via robotic surgery Stereotactic Body Radiation Therapy (SBRT)	Program Services
Are the following radiology services available to patients onsite? (select all that apply)	CT Chest PET/CT Brain MRI Interventional Radiology for biopsy procedures	Program Services
Does your facility offer an on-site smoking cessation program as part of LCS? (not including national VA programs or treatment by primary care)? This could include classes, pharmacist clinics, or other models.	Yes No	Program Services
Who provides smoking cessation treatment at your site? (select all that apply)	Screening coordinator Smoking cessation specialist Pharmacist Psychologist or Psychiatrist PCP Other: (please specify)	Program Services
How is tobacco cessation addressed in the LCS process?	By individual PCP discretion By PCP via systematic referral to tobacco treatment (Ask-Advise-Connect) By the Screening coordinator at the time of enrollment (evaluates and treats). By Screening coordinator via systematic referral (Ask-advise-connect). Other: _____	Program Services
Is tobacco use and tobacco treatment tracked by the lung cancer screening program?	Yes No	Program Services
Does your LCS program have a steering committee? A steering committee is a multi-disciplinary governance committee with goal of ensuring that the interests and expertise of the key stakeholders are represented and for members to identify	Yes No	Key Stakeholders & Personnel

Does your site use a notification process (e.g. phone calls or letters) to notify patients about: (Check all that apply)	Recruit eligible Veterans by providing informational brochure/letter Reminder for eligible Veterans who agree to screen but have not scheduled their LCS Reminder for annual/repeat LDCT testing We do not notify patients that they are due for LDCT screening	Communication of results
How are LCS and evaluations for potential lung cancer that are obtained outside of the VA system tracked?	Screening coordinator tracks and documents PCP tracks and documents Not tracked or documented Other:	Coordinating VA and private care
Addressing Barriers Experienced by Vulnerable Populations		
Please rate the importance of each item as it relates to **implementing** lung cancer screening at your site: Options: - Not at all important - Somewhat important - Very important - Absolutely essential	Availability of a screening registry Availability of screening coordinator Availability of patient navigator Supportive leadership Available champion with dedicated time (i.e. a defined leader that can act as a program advocate and liason for the program) Presence of multi-disciplinary lung cancer team Adequate CT scan availability Adequate interpreting radiologist support Access to advanced bronchoscopic techniques Lack of insurance barriers (e.g. prior authorization) to obtaining screening Process to refer certain patient populations (e.g. patients with mental health co-morbidities) Services for non-English speakers Transportation solutions for patients Cost of obtaining screening exam PCP buy-in Veteran's level of interest Sufficient staff/personnel Sufficient infrastructure	Implementing and maintaining LCS
Please rate the importance of each item as it relates to **maintaining** lung cancer screening at your site: Options: - Not at all important - Somewhat important - Very important - Absolutely essential	Availability of a screening registry Availability of screening coordinator Availability of patient navigator Supportive leadership Available champion with dedicated time (i.e. a defined leader that can act as a program advocate and liason for the program) Presence of multi-disciplinary lung cancer team Adequate CT scan availability Adequate interpreting radiologist support Access to advanced bronchoscopic techniques Lack of insurance barriers (e.g. prior authorization) to obtaining screening Process to refer certain patient populations (e.g. patients with mental health co-morbidities) Services for non-English speakers Transportation solutions for patients Cost of obtaining screening exam PCP buy-in Veteran's level of interest Sufficient staff/personnel	Implementing and maintaining LCS

Do you have a registry for incidentally-detected nodules?	Yes, it is the same as the one for screen-detected nodules Yes, it is different from the one for screen-detected nodules. Please specify: Yes, and we do not have one for screen-detected nodules No	Registry Tools
Program Processes		
Does your site use any of the following guidelines for eligibility criteria for lung cancer screening with LDCT? (Check all that apply)	Centers for Medicare and Medicaid Services (CMS) American Cancer Society (ACS) US Preventive Services Task Force (USPSTF) American Lung Association (ALA) American College of Radiology (ACR) Risk-based assessment using predictive models (e.g. PLCO-M2012), specify: _____ Other, specify:_____ None	Identifying patients and screening
Do you use a reminder for identifying patients with the appropriate cigarette smoking history?	Yes, an electronic medical record (EMR) reminder Yes, other. Please specify: No	Identifying patients and screening
Does your site provide guidance on assessing Veterans that may not benefit from LCS (e.g. Veterans with limited life expectancy)	Yes, specify: No	Identifying patients and screening
Does your site provide a Shared Decision Making (SDM) aid?	Yes, specify: No	Shared Decision Making
Do you provide an individual risk calculation for explaining lung cancer risk to the Veteran?	Yes, it is required to use one Yes, it is optional to use one No If yes, please specify which risk calculator is used: _____	Shared Decision Making
Does your site use any supplemental patient educational materials? (Check all that apply)	Informational brochure (shared decision aid) Website Audio or video presentation We do not use any supplemental educational material Other:	Shared Decision Making
After patients receive lung cancer screening with LDCT, who typically communicates the findings to the patient? (select all that apply)	The primary care provider The referral screening program Other, please specify:	Communication of results
How does your site communicate LCS results for low-risk findings (e.g. Lung-RADS 1&2)?	Telephone Call Letter sent to home Both letter and phone call Other, please specify:	Communication of results
How does your site communicate LCS results for high-risk findings (e.g. Lung-RADS 3&4)?	Telephone Call Letter sent to home Both letter and phone call Other, please specify:	Communication of results

	Sufficient infrastructure	
How have you identified ways that LCS can be tailored to meet the needs of the local community? (select all that apply)	Feedback from patients Feedback from providers Feedback from other stakeholders Feedback from leadership Meetings with other implementers Quality assurance checks Other: _____ None of the above	Implementing and maintaining LCS
Does your LCS program use a patient navigator? Patient navigators are team members that may be culturally or linguistically equipped to assist patients from diverse backgrounds overcome barriers to care, and can assist with other populations as well.	Yes, we use a patient navigator for certain patient populations, please specify: _____ Yes, we use a patient navigator for all patients. No	Racial / ethnic disparities
If yes, please specify any background or special training that the patient navigator has that helps outreach with the local community:		Racial / ethnic disparities
Does your LCS program or VA facility facilitate transportation for Veterans that live in rural communities?	Yes, please specify: No	Geographic Barriers
Does your LCS program have any special considerations regarding LCS for Veterans with mental health disorders?	Yes, specify_ No	Mental Health Barriers
Does your LCS program perform any outreach with psychiatry clinic on how to best conduct LCS uptake and follow-up with patients who have mental health disorders?	Yes, specify_ No	Mental Health Barriers
Are there any other barriers or facilitators to LCS that you think could help improve adherence in your local community?	Open-ended free text field	Novel local solutions

* The survey was designed based on the Donabedian model. The initial draft of the survey was developed by ERN with guidance from CGS and RSW. Then the rest of the authorship team (e.g. pulmonologists, radiologist, screening program director) evaluated the draft survey on purpose, format, content, and face validity. The survey was iteratively revised in response.

Exhibit 8: List of electronic survey questions administered by Núñez et al. adapted from supplemental materials prior publication [65].

Survey responses ranged from free text to more discrete toggle check list or binary responses. Study PI Lawrence Benjamin and Eduardo Nunez independently abstracted the combined available survey data by independently coding responses from both surveys into discrete binary, categorical, or date responses. For stations with survey data from only one of the survey sources (NCLCS or Núñez et al), the survey with data present was used as the sole source for coding. For surveys with data from both survey sources, responses were compared, and any conflicting responses were resolved by presuming the most recent survey response was assumed to be base truth for the purposes of this study (typically the NCLCS survey given its administration following the Núñez survey). Drs. Benjamin and Núñez then compared discrepancies in coding and performed tie breaks by coding any question non-response or

partial response as missing, and coding any discrepancies between coders by re-review of primary survey response and subsequent consensus between coders on intent.

Missingness in survey responses ranged from ~ 4 to 75% on some survey questions. Any question with > 50% missingness was dropped from any further analysis. To create a more ordinal measure of centralization and include as much survey information as to be abstracted without having to drop stations with missingness on individual questions, a composite measure of centralization was created by summing binary indicator dummy variables for the categories of if a station reported having any of 7 discrete elements of centralization: a LCS coordinator, Oversight board, LCS Registry, EHR reminders, Coordinator assistance with SDM, LCS Tumor Board, and whether centralized LCS staff performed tracking of scans performed in the community (CITC). If a study reported that only Primary care physicians sporadically were responsible for tracking CITC scans, this was coded as 0, given PI familiarity of clinical practices and presumption that this was the expected standard of care in decentralized programs. We then explored the distribution in responses and created logical cut-points based on clustering noted in the data that roughly correlated with program reported centralization practices. These logical cut points were as follows: a score of 0-3 was categorized as decentralized, 4/5 as low centralization, and 6/7 as high centralization. For the 4 indicator variables for subsequent model building (LCS coordinator, EHR registry, EHR reminders, and LCS coordinator SDM support), missingness ranged from ~4-40%.

Inclusion/Exclusion Criteria

The current study cohort was provisioned by the VA Informatics and Computing Infrastructure (VINCI) group and was restricted to Veterans who were aged 55-80 who had at least 1 outpatient visit from January 1, 2013 to December 31, 2021. This time interval is selected as it encompasses the first major USPSTF recommendation for lung cancer screening before the guidelines were updated, and allows for consistent inclusion definitions for those

eligible for lung cancer screening, while also utilizing consistent ICD-9 and ICD-10 coding nomenclature. The definition of eligibility for Lung Cancer Screening mirrored those of the USPSTF recommendations. Based on the 2013 definitions, eligibility was defined as individuals age 55-80 who are current and former smokers with at least 30 pack-years of smoking history who were current smokers or quit <= 15 years ago. A second cohort was additionally provisioned by VINCI to include all Veterans who were aged 50-80 who had at least 1 outpatient visit from January 1, 2013 to December 31, 2021. This second broader cohort was utilized to study trends in eligibility based on more recent recommendations like the 2021 USPSTF recommendations and 2023 ACS recommendations. Please see Chapter 4 for further details. As previously reviewed, the LungRADS criteria for categorizing LCS findings were initially published in 2014 and gradually adopted beginning in 2015. As LungRADS criteria were critical to identifying LCS scans for the current study, the study period was further narrowed to the first quarter of FY 2016 through the fourth quarter of FY 2021 given the limitations in reliably identifying scans for LCS prior to 2015 without appropriate LungRADS scores.

LCS uptake was defined as the number of unique, new Veterans receiving their first CT scan for lung cancer screening. This count was then normalized to an estimate of the total eligible smokers unique to each station. Detailed descriptions of the methods to identify unique Veterans, CT scans as likely performed for LCS, and estimates of the eligible population will be discussed in the manuscript specific methods sections in later chapters. The interval for assessing uptake rates was defined as the station-quarter, or the quarterly count of new Veterans entering screening at each station. Adherence was defined via the definitions previously described in Exhibit 5. Following initial analysis restricted to the target, additional analysis was performed with more lax minimum definitions of adherence (i.e. follow up scan within 24 months of initial screen) to explore differences in follow-up that still occurs but is delayed. Adherence was defined with a similar definition of that used for the NLST – individuals with either a normal baseline CT Scan (Lung-RADS 1), benign appearing nodules on baseline

scan (Lung-RADS 2), or incomplete scan (Lung-RADS 0), who had a follow up scan up to 2 months before and up to 3 months after the yearly due date (i.e. within 15 total months of initial scan[8]). Evaluating programs adherence based on the definitions of NLST is valuable, as realizing the mortality benefit seen in the NLST likely requires similarly high (~90%) adherence levels as were seen in the NLST. The VA's NCLCS expanded these NLST definitions to define target and minimum adherence ranges based on the initial LungRADS category as outlined in Exhibit 5 above. These same definitions were adopted for the current study.

Data Parameters

Exhibit 9 outlines the key data parameters planned for proposed analysis.

Parameter	Variable	Notes
Main Outcomes		
	LCS Uptake (LDCT performed)	Defined by the station-quarter, calculated to be = (total CT scans performed at station by quarter)/(estimate of screen eligible population at that station)
	LCS Adherence	Calculation based on Exhibit 5 above, with adherence based on target range and minimum range. Adherence based on first occurrence of entering screening and subsequent first timepoint for expected follow up based on LungRADS score.
Main Regressor		
	Centralization	Created 2 measures of centralization. The first was a categorical variable with three levels: decentralized, hybrid, and centralized based on station response. Additionally, an ordinal metric was created by tally of elements of centralization reported and then recoding to a 3 level categorical variable, with 0-3 coded as decentralized, 4/5 as low centralization, and 6/7 as high centralization.
	Race Interaction	Interaction Term utilized for manuscript 2 to investigate impact of race/ethnicity, focus on Black/White differences
Individual Patient Level Covariates		

Parameter	Variable	Notes
	Race/Ethnicity	Categorical
	Age	Raw and categorical, binned to 55-64, 65-74, 75-80
	Sex	Categorical
	Smoking Status	Binary, Current vs Former
	Comorbidity	Elixhauser Comorbidity Index calculated for individual patients
	Comorbid Mental Illness	Composite variable for diagnoses for Depression, post-traumatic stress disorder, and Schizophrenia. See exhibit 10 for diagnostic code definitions
	Comorbid Substance Use Disorder	Indicator variable for diagnosis of Substance Use Disorder. See exhibit 10 for diagnostic definitions.
	NADI	National ADI ranging from 0-100, recoded to be dichotomized to >/= 85 (the highest disadvantage) vs < 85
	SADI	State Area Deprivation Index, decile, recoded to be dichotomized to >/= 9th decile (the highest disadvantage) vs </= 8th decile
	Marital Status	Categorical variable
	Lung-RADS score of LDCT	Categorical
	Urban/Rural/Insular/Highly Rural (URIH)	Categorical
	Distance to facility	Continuous
	Priority Group	Categorical, surrogate for out-of-pocket cost
Station level covariates		
	Facility Rurality (URIH)	Categorical
	Facility complexity	Categorical
	LCS_Model_NCLCS	Categorical (centralized vs hybrid vs decentralized), from qualitative survey
	Date_LCS_Coord	Date, time varying exposure for LCS coordinator, from qualitative survey
	LCS_Coord	Binary, from qualitative survey, whether station has an LCS coordinator
	LCS_Oversight	Binary, whether station has an oversight board, from qualitative survey
	Date_LCS_Oversight	Date, time varying exposure for having an oversight board, for qualitative survey
	LCS_Registry	Binary, whether there is registry tracking, from qualitative survey
	Date_LCS_EHR_Install	Date, time varying exposure, from qualitative survey
	LCS_EHR_Reminders	Binary, for if station has EMR reminders, from qualitative survey

Parameter	Variable	Notes
	Date_LCS_EHR_Reminder_initiate	Date, time varying exposure, for when first initiated EHR reminder
	Date_LCS_EHR_Reminder_50	Date, time varying exposure, from which EHR reminders expanded to 50% of station clinical sites
	Date_LCS_EHR_Reminder_90 LCS_Program_Initiate_Nunez	Date, time varying exposure, for when EHR reminders expanded to 90% of station clinical sites
	LCS_First_Scan	Date estimate of first LCS scan performed, from qualitative survey
	LCS_Smoke_Cess	Binary, whether station has on site smoking cessation, from qualitative survey
	LCS_Coord_SDM_Support_Nunez	Binary, whether station has shared decision making support from coordinator, from qualitative survey
	LCS_Tumor/Nodule_Board	Binary, whether station has a tumor/nodule board, from qualitative survey
	LCS_Patient_Navigator	Binary, whether station has patient navigators, from qualitative survey
	LCS_Transportation_assist	Binary, whether station has transportation assistance for Veterans, from qualitative survey
Random effect parameters		
	Random intercepts	
	Station ID	Allows for different stations to have difference LCS “starting points”
	Random slopes	
	Station ID	Account for varying LCS throughput, potential “throttling” or congestion with growth.

Exhibit 9: Data parameters for dataset construction

Data for station level and individual characteristics was collated based on available CDW data from both the CDW including the Planning Systems Support Group (PSSG) geocoded enrollee files and the VA Space Table (VAST) data platforms. Given information for some covariates is only updated on a fiscal year quarterly basis, this was the minimum temporal resolution available for the current study. Patients were linked to their ICN number to ensure a consistent, unique identifier that would follow patients regardless of which VA station they sought care, especially given Veterans may utilize care at multiple stations throughout the study period. Using the STAPA parent station identifier, patients were mapped to a presumed home station via an algorithm that compared average primary care utilization during each fiscal year. Patients

were then assigned to a “home” parent station for lung cancer screening purposes based on the parent station with the highest utilization during the study period. The average number of Veterans who were aged 55-80 who utilized each parent station were calculated for each fiscal year in the study period (FY 16, FY 17, FY 18, FY 19, FY 20, and FY 21). These averages were used to calculate the estimated screen eligible patients at each parent station for each study year.

ICD-9 and ICD-10 diagnostic codes for comorbid mental illness (made from an aggregate of the diagnoses of depression, Post-traumatic stress disorder, schizophrenia), substance abuse, and follow up diagnostic studies and procedures were adapted from previously published definitions[60] from project partners and are displayed in the exhibit 10 below.

eTable 1. *ICD-9*, *ICD-10*, and *CPT* Codes for Lung Cancer Screening Analysis of Procedures

Procedure	ICD-9 procedure codes	ICD-10 procedure codes	CPT procedure codes
Transthoracic Needle Lung Biopsy	33.26	0W9C3ZX, 0WBC3ZX, 0B9C3ZX 0B9D3ZX 0B9F3ZX 0B9G3ZX 0B9H3ZX 0B9J3ZX 0B9K3ZX 0B9L3ZX 0B9M3ZX 0BBC3ZX 0BBD3ZX 0BBF3ZX 0BBG3ZX 0BBH3ZX 0BBJ3ZX 0BBK3ZX 0BBL3ZX 0BBM3ZX	32405
Lung surgery for pulmonary nodule including Open or thorascopic: wedge, segment, lobectomy, pneumonectomy	32.0, 32.01, 32.09, 32.1, 32.2, 32.20, 32.39, 32.3, 32.30, 32.39, 32.4, 32.41, 32.49, 32.5, 32.50, 32.59, 33.2, 33.20, 33.25, 33.28,	0BBC4ZX 0BBD4ZX 0BBF4ZX 0BBG4ZX 0BBH4ZX 0BBJ4ZX 0BBK4ZX 0BBL4ZX 0BBM4ZX 0BDC4ZX 0BDD4ZX 0BDF4ZX 0BDG4ZX 0BDH4ZX 0BDJ4ZX 0BDK4ZX 0BDL4ZX, 0BBM0ZZ 0BBM3ZZ 0BBM7ZZ 0BTK4ZZ 0BTL4ZZ 0BTM4ZZ 0BBK4ZZ, 0BBL4ZZ, 0B5K0ZZ 0B5K3ZZ 0B5K7ZZ 0B5L0ZZ 0B5L3ZZ 0B5L7ZZ 0B5M0ZZ 0B5M3ZZ 0B5M7ZZ 0BBK0ZZ 0BBK3ZZ 0BBK7ZZ 0BBL0ZZ 0BBL3ZZ 0BBL7ZZ 0BTG0ZZ 0BTJ0ZZ, 0BB77ZZ 0BB80ZZ0BB83ZZ 0BB87ZZ 0BB90ZZ 0BB93ZZ 0BB97ZZ 0BBB0ZZ 0BBB3ZZ 0BBB7ZZ 0BTC4ZZ 0BTD4ZZ 0BTF4ZZ 0BTG4ZZ 0BTJ4ZZ 0BTC0ZZ 0BTD0ZZ 0BTF0ZZ , B5B0ZZ 0B5B3ZZ 0B5B7ZZ 0BB30ZZ 0BB33ZZ 0BB37ZZ 0BB40ZZ 0BB43ZZ 0BB47ZZ 0BB50ZZ 0BB53ZZ 0BB57ZZ 0BB60ZZ 0BB63ZZ 0BB67ZZ 0BB70ZZ 0BB73ZZ, 0B540ZZ 0B543ZZ 0B547ZZ 0B550ZZ 0B553ZZ 0B557ZZ 0B560ZZ 0B563ZZ 0B567ZZ 0B570ZZ 0B573ZZ 0B577ZZ 0B580ZZ 0B583ZZ 0B587ZZ 0B590ZZ 0B593ZZ 0B597ZZ 0BTG0ZZ, 0BTG0ZZ, 0BTJ0ZZ, 0BTK0ZZ, 0BTK0ZZ, 0BTL0ZZ, 0BTM0ZZ, 0B9L0ZX 0B9M0ZX 0BBK0ZX 0BBL0ZX 0BBM0ZX 0BB10ZZ 07JL0ZZ 07JM0ZZ 0WJ90ZZ 0WJB0ZZ 0WJQ0ZZ, 0BTK0ZZ, 0BTL0ZZ, 0BTM0ZZ, 0BTC0ZZ 0BTD0ZZ, 0BTF0ZZ, 0B930ZX 0B940ZX 0B950ZX 0B960ZX 0B970ZX 0B980ZX 0B990ZX 0B9B0ZX 0BB30ZX 0BB40ZX 0BB50ZX 0BB60ZX 0BB70ZX 0BB80ZX 0BB90ZX 0BBB0ZX 0B9K0ZX 0BDM4ZX 0B9C4ZX 0B9D4ZX 0B9F4ZX 0B9G4ZX 0B9H4ZX 0B9J4ZX 0B9K4ZX 0B9L4ZX 0B9M4ZX, 0BT30ZZ 0BT34ZZ 0BT40ZZ 0BT44ZZ 0BT50ZZ 0BT54ZZ 0BT60ZZ 0BT64ZZ 0BT70ZZ 0BT74ZZ 0BT80ZZ 0BT84ZZ 0BT90ZZ 0BT94ZZ 0BTB0ZZ 0B530ZZ 0B533ZZ 0B537ZZ	31786, 32095, 32100, 32440, 32442, 32445, 32480, 32482, 32484, 32486, 32488, 32500-32501, 32503-32504, 32520, 32602, 32657, 32663
Mediastinoscopy	34.22, 34.26	0W9C3ZX, 0W9C4ZX, 07B70ZZ, 07BL0ZZ, 07T70ZZ, 0W9C0ZX,0WBC0ZX, 0WCC0ZZ, 0WBC3ZZ, 0WJQ0ZZ, 02BN0ZX, 0W9C0ZZ, 07B70ZZ, 07BL0ZZ, 07T70ZZ	32605-32606, 32662, 38746, 39000, 39010, 39220, 39400
Bronchoscopy	33.21-33.24, 33.27	0BJ08ZZ, 0BJ08ZZ, 0BJ18ZZ, 0BJK8ZZ, 0BJL8ZZ, 3E1F78Z, 3E1F88X, 3E1F88Z, 0BB28ZX, 0BB38ZX, 0BB48ZX, 0BB58ZX, 0BB68ZX, 0BB78ZX, 0BB88ZX, 0BB98ZX, 0BBB8ZX, 0BD28ZZ, 0BD38ZX, 0BD48ZX, 0BD58ZX, 0BD68ZX, 0BD78ZX, 0BD88ZX, 0BD98ZX, 0BDB8ZX, 0B918ZX, 0B928ZX, 0B938ZX, 0B948ZX, 0B958ZX, 0B968ZX, 0B978ZX, 0B988ZX, 0B998ZX, 0B9B8ZX, 0BC18ZZ, 0BC28ZZ, 0BC38ZZ, 0BC48ZZ, 0BC58ZZ, 0BC68ZZ, 0BC78ZZ, 0BC88ZZ, 0BC98ZZ, 0BCB8ZZ, 0BCC8ZZ, 0BCD8ZZ, 0BCG4ZZ, 0BCH4ZZ, 0BCJ4ZZ, 0BCN4ZZ	31615, 31620, 31622-31625, 31628-31633, 31635-31638, 31640-31641, 31643, 31645-31646, 31652-31654

Abbreviations: *ICD, International Classification of Diseases*; CPT, Current Procedural Terminology.

eTable 2. *ICD-9*, *ICD-10*, and *CPT* Codes for Lung Cancer Screening Analysis of Comorbidities

Comorbidities	ICD-9 codes	ICD-10 codes	ICD-9 procedures	ICD-10 procedures	CPT procedure codes
The next 2 variables are based on a single principal code from inpatient records (VA or Medicare) or primary code from Emergency room data anytime before or on the index date.					
Major Adverse Cardiac Event	410, 410.xx, 411.0, 411.1, 411.81, 411.89, 412, 412.xx, 427.5	I20.0, I21, I21.x, I21.xx, I22.x, I24.0, I24.1, I24.8, I24.9, I25.2, I46.9	36.01-36.07, 36.09-36.16, 36.19	0210.x, 02111.x, 0212.x, 0213.x, 0270.x, 0271.x, 0272.x, 0273.x	33510-33519, 33521-33523, 33533-33536, 33572, 92973-92975, 92977, 92980-92982, 92984, 92986, 92995, 92996
All other morbidity variables are based on 2+ days with codes (IP or OP, VA or Medicare) in the 731 days (2 years) before and including the index date, except as noted.					
COPD	491.xx, 492.xx, 496.xx	J40-J44.xx			
Congestive heart failure	428,428.xx,402.01,402.11,402.91,404.01,404.03, 404.11, 404.13, 404.91, 404.93	I50.x, I50.xx, I11.0, I13.0, I13.2			
Chronic kidney disease	250.4, 581-583.xx, 585-587.xx, 996.73, 996.81, V42.0, V45.1	E11.29, E10.29, E11.21, E10.21, N03.x, N04.x, N05.x, N07.x, N08.x, N17.x, N18.x, N19.x, N26.x, T82.8xxA, Z94.0, Z99.2, Z91.15			
HIV	042- 044.xx	B20, B17.1x, B17.8, B17.9, B18.2, B18.8, B18.9			
Dementia	290, 290.xx, 331.0-331.82, 331.9, 331.9x, 797	F01.5, F01.5x, F02.8, F02.8x, F03.9, F03.9x, G30.x, G31.x, G31.xx, R41.81			
Depression	296.2-296.3x, 300.4, 300.4x, 300.9, 300.9x, 301.12, 309.0, 309.0x, 309.1, 309.1x, 309.28, 311, 311.x	F32.x, F32.xx, F33.x, F33.xx, F34.1, F43.21, F43.23, F48.9			
Post-traumatic stress disorder	309.81	F43.10, F43.11, F43.12			
Schizophrenia	295, 295.xx	F20.x, F20.xx			
Substance Use Disorder	291, 291.xx, 292.0, 292.0x, 292.89, 292.9, 292.9x, 303, 303.xx, 304, 304.xx, 305, 305.0, 305.0x, 305.2-305.9x, 357.5, 425.5, 535.3, 571.0-571.3x, 760.71, 790.3, 977.3, 980.0, 980.9, E860-E860.1, E860.9, E947.3, V11.3, V79.1	F10-F16.xx, F18-F19.xx, F62.1, I42.6, K29.20, K29.21, K70.x, K70.xx, P04.3, Q86.0, R78.0, T50.991A, T51.0X1A, T51.0X2A, T51.0X3A,T51.0X4A, T51.91XA, T51.92XA, T51.93XA, T51.94XA, NOD.X, Z65.8, Z13.89			

Abbreviations: *ICD*, *International Classification of Diseases*; CPT, Current Procedural Terminology.

Exhibit 10: Study Utilized CPT and ICD codes,
Identify LCS procedures in addition to comorbidity CPT codes utilized by Nunez et al. [60]*, adapted from supplemental figures to the paper.*

Human Subjects and Data Protection

This study protocol was reviewed and approved by the institutional review board for the Greater Los Angeles Veterans Affairs Healthcare system. The study utilized best practices in data management and safeguarding in accordance with well-established VA data security procedures. All data with PHI/PII were stored on the VINCI platform; all other data were stored on the VINCI platform or the local GLA secure research server with access limited to the Principal Investigator research study staff who have been credentialed by VA GLA Research Service and are on the VA GLA IRB approved Study Staffing List. All study staff complete annual trainings on VA Privacy and Information Security Awareness, as well as Privacy and HIPAA requirements, and Human Subjects Protection training every three years. The research team had varying levels of access to the data by using research project folders that are part of the architecture of the VA GLA Research server and managed using VA Information

Technology Operations and Services (ITOPS) Shared Folder and File Exchange program (SFFX).

Access to data files was limited to the minimum number of individuals necessary to achieve the approved purpose. Access to the most sensitive data was highly restricted to only project PI and statisticians/data analysts. Any database linkages or crosswalk files were maintained in separate secure folders. Storage and transfer of any PII and PHI was done in accordance with applicable VA and VHA policies and directives, federal regulations, and applicable statutes including HIPAA. No project data was stored on desktop computer hard drives, laptops, thumb drives or any other mobile storage device. All data was securely stored until such time as they can be destroyed per the VHA Records Control Schedule 10-1, which currently requires that research files be retained for six years following the end of the fiscal year in which the study is closed. Throughout the study, the project team worked closely with the VA GLA Privacy Officer, Information Security Officers, and VA GLA Research staff to ensure that we were in compliance with all current data security regulations.

Aggregate, de-identified model output was stored on a secure, encrypted laptop and backed up onto a secure, password-protected file server. Qualitative survey data was previously obtained by project partners via previously published data protection best practices[65] and under the data protection permissions of the NCLCS, and furnished to our study team for the current study were stored and maintained in a similar fashion. All patient associated PHI was de-identified before analysis and publication, and only presented in aggregate format.

Research Objectives and Specific Aims

The VA's commitment to implementing centralized lung cancer screening programs across its national healthcare system presents a unique natural experiment to investigate the impact of various lung cancer screening program strategies. Additionally, there was variable implementation of screening in a spectrum of organizational structures. During the transitional

period, some programs remained decentralized throughout and LCS remained largely driven by ad hoc screening by primary care physicians. Some programs transitioned from decentralized programs to hybrid models, and have implemented some elements of centralization like coordinators or EMR tracking but may still leverage PCPs in the LCS program. And yet other programs transitioned from decentralized screening programs to fully centralized/"consult" model, where a primary care physician simply refers a patient to screening and the program staff take over completely. There is additionally variability even within how fully centralized and hybrid programs have been implemented.

As centralization is implemented across the VA, important questions can be probed leveraging real world data. Centralization does appear in initial research to lead to higher LCS uptake and adherence. Yet these prior research studies frequently only reported the experience of a single center or a small consortium of screening programs in the confines of a controlled research study. There additionally has yet to be a research study that reports on the experience using real-world data of a large, nationally integrated healthcare system like the VHA. Furthermore, is an opportunity for research studies to better control for unmeasured bias that could explain why institutions that centralized their programs have this improved performance. Additionally, what exact components of centralization are the most effective/necessary remains unclear. And finally, probing if these improvements in uptake and adherence remain *equitable* when assessed by patient race/ethnicity or social vulnerability remains vital. Answering these questions is the foundation of the specific aims of the proposed research project.

Research Specific Aims:

The preceding chapters have demonstrated the ongoing unacceptably low utilization of lung cancer screening and the excess morbidity and mortality incurred due to this poor utilization. Many potential barriers may contribute to this low utilization, ranging from patient, provider, and health system factors. How lung cancer screening is implemented shows initial

promise as a potential solution, leading to significantly improved rates of screening uptake, and maintenance with ongoing annual screening or timely follow up of positive screening exams. However, there remain extensive knowledge gaps in the current literature, including high quality real-world data, controlling for potential confounders and with appropriate comparator groups, that validates that centralization improves both uptake (i.e. new individuals entering screening) and adherence (i.e. timely follow up for positive findings or repeated screening for those who remain eligible). Furthermore, it is critical that these implementation strategies improve screening rates equitably, ensuring improved uptake and adherence in racial /ethnic minority populations and those facing significant social determinant of health barriers, two groups which historically have suffered higher morbidity and mortality from lung cancer and had lower screening rates.

It is against this backdrop that the current study proposes the following three specific aims.

- **Aim 1:** To describe the available structured smoking data collected for Veterans in the study cohort, and estimate the eligible population for lung cancer screening based on multiple proposed screening eligibility criteria
- **Aim 2:** To investigate if LCS uptake and adherence varies based on degree of LCS program centralization. To capture the spectrum of how LCS programs have implemented centralization ranging from decentralized to hybrid to fully centralized programs, we will investigate both self-reported and a new, project-generated ordinal scale of centralization based on which program elements are implemented by a program and when they were implemented. Subsequently, we seek to investigate the relative effectiveness of centralization elements by incorporating dummy variables representing components of centralization into our model.
- **Aim 3:** To investigate if race/ethnicity moderates LCS uptake and adherence in programs of differing degrees of centralization, with particular focus on Black/White

differences. This moderation analysis will center on inclusion of an interaction term into the model utilized in aim 2.

The following chapters present 3 manuscripts reporting our research findings related to these 3 specific aims.

Chapter 4: Manuscript 1

Trends in the Lung Cancer Screening-Eligible Population of the Veterans Healthcare Administration

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Contributions:
(***To be finalized by authorship and added at time of publication***)

Data Sharing Statement: There are legal restrictions on access to data placed by the Department of Veterans Affairs (VA), including identifying data and sensitive information. The analytic datasets used for this study are not permitted to leave the VA firewall without an express Data Use Agreement.

Declarations:
None.

Conflicts of Interest:
None.

Abbreviations:
LCS: Lung Cancer Screening
USPSTF: United States Preventive Services Task Force
ACS: American Cancer Society
EMR: Electronic Medical Record
VHA: Veterans Health Administration
CT: Computed Tomography
ADI: Area Deprivation Index

Introduction:

The Veterans Healthcare Administration (VHA) is the largest, vertically-integrated health delivery system in the United States, serving over 9 million Veterans across 172 Medical Centers and 1,138 outpatient sites nationwide[66]. The Veterans the VHA serves are a population with considerably higher risk for developing lung cancer than on average for the US population. As of 2020, around 24% of Veterans were current smokers, and over 56% were former smokers[67]. And yet, in the years following the United States Preventive Services Task Force (USPSTF) initial lung cancer screening (LCS) recommendation in 2013, estimates of LCS rates in the VHA were unacceptably low: only around 2% of those eligible underwent screening[58]. LCS consists of an annual low-dose computed tomography (CT) scan for at risk smokers. Critical to ameliorating the underutilization of LCS is an accurate understanding of the Veteran population that would be eligible for screening. Eligibility for lung cancer screening is tied to

lifetime smoking exposure quantified in “pack-years”, defined as the number of cigarette packs an individual smoked multiplied by the number of years smoked[68]. Therefore, it is fundamental to accurately assess the precise cigarette packs smoked per day and years of smoking in the Veteran population. And yet, there remains a paucity of information on the exact quantity Veterans have smoked beyond basic survey information on those who are current or former smokers, with smoking status often limited just to the definition of smoking ≥ 100 cigarettes in one’s lifetime[51].

Previously, researchers have tried to estimate LCS eligibility by abstracting documentation of smoking rates in the medical record. Basic smoking status is coded into the VA’s Computerized Patient Record System (CPRS) using a number of health factors. There are an estimated 478 health factors relate to smoking status[69]. There is, however, imprecision in how these health factors are used. For example, tobacco use is often flagged, but it may be unclear if that tobacco use was specifically cigarettes. Additionally, these health factors historically have not allowed for precise assessment of smoking status to the precision of calculating pack-years smoked. Detailed smoking history may be contained in free text in the notes of medical providers. However, researchers have shown that smoking status is inconsistently and inaccurately documented in the medical record[70], and it may be too challenging for researchers to assess the quality of this data without prospectively surveying patients, extensive chart review, or complex natural language processing algorithms. Researchers have nevertheless attempted to leverage the data available. Gundle et al. compared chart abstraction with available structured data on smoking status and the diagnosis of COPD, but there were significant trade-offs in sensitivity or specificity depending on the data elements utilized[71]. Additionally, these studies again are often unable to abstract accurately pack-years to reliably capture the extent of smoking exposure across the population served by the VHA.

Alternatively, prior researchers have turned to large population-based survey data to probe smoking burden in the Veteran population. Tailor et al. reported using demographic information from census data from the American Community Survey to estimate the screening eligible population[17]. Additionally, Rustagi et al. utilized data from the Behavior Risk Factor Surveillance System (BRFSS) to estimated that ~17% of Veteran 55-79 were eligible for LCS based on survey responses taken from 28 states[72]. However, these surveys can commonly only determine who reports being a Veteran or having access to VHA services, but do not necessarily accurately reflect the individuals actually utilizing services in the VHA. Additionally, these surveys do not commonly report exact pack-years for individuals identified as current or former smokers.

Compounding the paucity of data on the burden of smoking exposure across the VHA is the changing landscape of LCS eligibility. The USPSTF made its first recommendation for LCS in 2013, recommending screening for individuals aged 55-80 years old who were current or former smokers who had quit within the last 15 years with a lifetime equivalent of 30 pack-years of smoking history[15]. In an attempt to expand eligibility to more equitably identify LCS risk especially in racial/ethnic groups and women who frequently developed lung cancer at lower smoking intensity, the USPSTF expanded LCS eligibility in 2021[68]. Eligibility now extends to individuals aged 50-80 years old who were current or former smokers who had quit within the last 15 years with a lifetime equivalent of 20 pack-years of smoking history. It has been estimated that the new criteria roughly doubled the eligible population for screening[10]. Furthermore, in 2023, the American Cancer Society (ACS) release recommendations mirroring the 2021 USPSTF age and pack year recommendation, but dropping the 15 years since quitting tobacco use stipulation[73]. It has yet to be described how these changing recommendations impact the LCS screen-eligible population in the VHA.

As the VHA implemented LCS across its nationwide network, the VA's National Center for Lung Cancer Screening (NCLCS) developed an electronic medical record (EMR)-based

platform called the Lung Cancer Screening Platform (LCSP) to assist stations in tracking LCS efforts. First introduced in 2021 and gradually implemented nationwide, this platform includes collecting and documenting structured smoking history from patients including exact packs per day smoked, smoking duration, and quit year for those who have quit smoking. Patients are assessed for smoking history typically in primary care clinics when presenting for routine care. This dashboard/platform has been adopted by over 100 stations across the VHA. These data allow for far more robust, accurate estimates of the screening eligible population than has been previously reported.

Objective:

The current study seeks to leverage structured smoking data from the VHA's EMR to describe sociodemographic trends and estimate the LCS screen eligible population across 2013 USPSTF, 2021 USPSTF, and 2023 ACS recommendations.

Methods

Study Population:

Data queries were performed from the central EMR data repository for the VHA called the Corporate Data Warehouse (CDW). The study period for study cohort identification from October 1, 2015 through September 30, 2021 which corresponded to the 2016 through 2021 fiscal years. All patients/Veterans included in analysis were linked to their unique Integration Control Number (ICN), which is consistent nationwide regardless of the facility/location of services rendered.

We identified two primary study populations. The first was our 2013 USPSTF cohort of all unique Veterans who were aged 55-80 at any point in the period from Oct 1, 2015 through September 30, 2021 who had utilized at least 1 outpatient visit at a VA station, regardless of smoking history. The second 2021 USPTF and 2023 ACS cohort was all unique Veterans who were aged 50-80 at any point in the period from Oct 1, 2015 through September 30, 2021 who

had utilized at least 1 outpatient visit at a VA station regardless of smoking history. To assess eligibility based on 2013 USPSTF eligibility criteria, we created an indicator variable for all Veterans aged 55-80 who were current or former smokers with ≥ 30 pack-years smoking history and a quite date, if applicable, ≤15 years to the time of assessment. To assess eligibility based on 2021 USPSTF eligibility criteria, we created an indicator variable for all Veterans aged 50-80 who were current or former smokers with ≥ 20 pack-years smoking history and a quite date, if applicable, ≤15 years to the time of assessment. To assess eligibility based on ACS eligibility criteria, we created an indicator variable for all Veterans aged 50-80 who were current or former smokers with ≥ 20 pack-years smoking history regardless of quit date. If a Veteran ever met eligibility via either USPSTF or ACS criteria during the study period, they were included in tabulations of total Veterans meeting eligibility criteria. We additionally tallied the ratio of those eligible for screening to the total number of individuals with available smoking data for each parent station.

Data was abstracted for each individual in the dataset to obtain their age, sex, race/ethnicity, National Area Deprivation Index (ADI), State ADI[38], Veteran priority group (a designation which determines a Veteran's out-of-pocket cost share for utilizing VHA services), marital status, rurality based on U.S. Department of Agriculture's Rural-Urban Commuting Area (RUCA) codes[74], and distance to nearest VA facility in miles. Due to small sample size, Veterans living in an insular/island rurality designation were dropped from the analysis. National ADI, which ranges from 1-100, and State ADI, which is reported in deciles, were dichotomized based on those who were in the most disadvantaged 15% and 20% of home addresses respectively. Additionally, Veterans were assigned to a designated "home" facility (commonly called a "parent station" in the VHA) by an algorithm that compared average primary care utilization during each fiscal year, and assigned Veterans to the facility of highest average utilization. Each station's complexity score, a metric used by the VHA to indicate a facilities relative size, patient risk, academic affiliation, and clinical services/resourcing[64,75], was also

pulled from VHA reports. Complexity score ranges from the highest score of 1a to the lowest of 3. International Classification of Diseases ICD-9 and ICD-10 diagnostic codes for comorbid mental illness (made from an aggregate of the diagnoses of depression, post-traumatic stress disorder (PTSD), and schizophrenia) and substance abuse were used to identify patient's holding these diagnoses. These diagnostic codes adapted from diagnostic codes published by prior researchers using VHA data[60]. The specific diagnoses queried are available in Supplemental eTable 1. Elixhauser Comorbidity Index was calculated for each patient as a surrogate for overall health status. All data queries were performed between January and July, 2024. Veterans were excluded if they were not between the ages of 50-80 during the study period, or if the medical record indicated they had died before the 2016 fiscal year.

Smoking Histories

Smoking history was abstracted from discrete data elements called "health factors" in the CDW. The health factors used in the current analysis were LCS CURRENT SMOKER, LCS FORMER SMOKER, LCS LIFETIME NON-SMOKER, LCS PACKS/DAY, LCS PT DECLINES/UNABLE TO GIVE PK YR HX, LCS QUIT SMOKING, LCS QUIT YEAR (ACTUAL), and LCS YEARS SMOKED. Only these health factors are adequate to calculate pack-year smoking histories for individuals in the dataset. Other smoking-related health factors available in the EMR were excluded from the current analysis. As a significant component of smoking history data was collected in 2021-2023, data for smoking history was collected based on all available data at the time of data query associated with each unique patient in the study cohort, even if that data was collected after September 30, 2021. Smoking history assessments were associated with the clinical encounter date when the history was reported. Using the date of the encounter for which smoking data was collected and available smoking data, the smoking data was extrapolated to what each Veteran's smoking history would have been, including pack-year smoking burden, for each year of the study period from 2015 through 2021. These annual pack-year estimates were used for analysis, assuming Veterans maintained constant smoking

history each year unless they reported quitting smoking at a later date in the study period. For Veterans who had multiple entries for smoking history over multiple encounters, we took the maximum smoking history based on pack-years reported during a single encounter to extrapolate annual smoking history estimates. If there was insufficient data reported during an encounter to fully assess smoking history, that encounter's data was considered missing and was dropped from analysis unless an alternative suitable smoking history was reported.

Veterans were associated with their likely parent station based on utilization to create station-specific LCS eligibility estimates. Station geographic location was utilized to create regional eligibility estimates based on CDC designation[76]. Stations with smoking history data on fewer than 1000 Veterans were dropped from station-specific estimate calculations as it was assumed that smoking history assessments at that station were too sporadic to be representative of the population served at that station. Additionally, some Veterans had documented smoking histories that appeared to be physically unlikely, like smoking 10-15 packs per day. Given investigator suspicion that these represented erroneous entries of total cigarettes smoked per day in lieu of packs per day, we divided any pack per day value > 5 by 20 (the number of cigarettes typically in a pack).

To generate estimates of the total nationwide LCS eligible population, we first generated an estimate of the total number of Veterans utilizing the VHA who were in the appropriate age range for screening were taken from published VA survey data[77] and the VHA Support Service Center Capital Assets (VSSC) database[78] by calculating the proportion of Veterans who were either 55-79 or 50-79 and multiplying that proportion by the total number of unique individuals utilizing VHA services nationwide in 2023. VHA population-based surveys only report proportions for Veterans in 5 year increments (e.g. 75-79), and therefore the nationwide number of Veterans who are exactly 80 years old in 2023 was unavailable for the current analysis and was therefore excluded from nationwide LCS population estimates. We then multiplied this

number (an estimate of all Veterans either 55-79 or 50-79 who utilized VHA services) by our estimated percent eligible for LCS based on available smoking data.

Results

Figure 1 presents a flow diagram of individuals included in the current analysis. A total of 5,492,740 unique Veterans were identified meeting our inclusion criteria who had utilized at least 1 outpatient visit during the study period. Of those, 1,422,573 had adequate smoking history data to calculate pack-year smoking exposure to be included in the current analysis.

As pack-year smoking histories were only available on a subset of the over 5 million unique Veterans meeting inclusion criteria in the study cohort, we sought to assess the generalizability of the Veterans identified with available pack-year smoking histories to the overall cohort. To that end, we compared the baseline demographics of all individuals with complete smoking data with the overall demographics of the broader study cohort of individuals age 50-80 and 55-80 during the study period. Table 1 presents the baseline characteristics of the overall study cohort compared to individuals with smoking history data. Overall, the cohort with smoking history data had higher proportions of comorbid mental illness and substance use disorder, lower proportions of individuals from addresses with the highest disadvantage by ADI, higher proportions of Veterans with lower out of pocket cost based on assigned priority group (a designation used by VHA to determine co-pays for accessing VHA services), higher proportions living in urban areas, and primarily received care at the most academically/clinically resourced facilities as measured by station complexity score.

Figure 2 presents the distribution of packs per day smoked and the years smoked reported by Veterans who indicated any lifetime smoking history. The plurality of Veterans reported smoking between 0.5 to 1.5 packs per day. The majority of smokers reported between

20 and 64 years of smoking history. We additionally saw 3 peaks of years smoked at around 30, 40, and 50 pack years.

From the approximately 1.4 million Veterans with available smoking data, a total of 293,796 individuals were identified who met 2013 USPSTF LCS eligibility criteria, 394,424 individuals met 2021 USPSTF criteria, and 395,976 met ACS eligibility criteria. Table 3 presents baseline characteristics of these three populations. Given the large sample size, all cohorts were statistically significantly distinct. Focusing on the most disparate characteristics, compared to the demographics of the overall cohort of individuals in the age range for screening who utilized outpatient services, the LCS eligible cohorts had higher proportions of non-Hispanic White Veterans, diagnoses of comorbid mental illness, and rates of divorced/separated/widowed individuals. Comparing the USPSTF 2013 LCS eligibility to the USPSTF 2021 and ACS eligibility criteria, the USPSTF 2021 and ACS populations had higher proportions of Black and Hispanic individuals who met eligibility criteria, and overall the percentage of Blacks meeting eligibility mirrored the proportion of Black individuals in the entire 50-80 cohort.

Table 3 presents estimates of LCS eligibility based on USPSTF and ACS eligibility criteria definition. Nationwide, 23.1% of Veterans aged 55-80 reported smoking histories that met 2013 USPSTF LCS eligibility during the study period. For individuals ages 50-80, 27.8% met 2021 USPSTF criterial and 27.9% met ACS criteria. There was noted regional variation in eligibility rates, with the lowest eligibility being seen in the North and West regions, and the highest in the Midwest and South. Using these national percentages meeting LCS eligibility and VHA reports of the total number of Veterans in the 55-80 and 50-80 age ranges who utilized VHA services in 2023, we estimated that the nationwide number of individuals eligible for 2013 USPSTF, 2021 USPST, and 2023 ACS criteria were 721,122 individuals, 1,035,880 individuals, and 1,039,967 individuals respectively. 2021 USPSTF eligibility criteria and 2023 ACS eligibility criteria therefore would the LCS eligible population by ~ 41% and 42% respectively over the 2013 USPSTF criteria in this patient population.

Discussion

We report the largest description of smoking patterns and LCS eligibility in the VHA using directly reporting smoking history to date. The current study is able to harness structured EMR data to conduct a more robust assessment of smoking rates and LCS eligibility than more limited medical note abstractions or utilization of survey data on selected samples. Notably, the data utilized for the current study is taken from those utilizing VHA services, and subsequently is likely more representative of the population currently served by the VHA than broader surveys which may only identify individuals as Veterans or having access to VHA benefits, but who may not actually utilize those services.

We found that approximately one fifth (23.1%) of Veterans 55-80 met 2013 USPSTF eligibility criteria. These estimates are notably higher than the previously estimated 17% of Veterans meeting 2013 USPSTF LCS eligibility criteria based on BRFSS survey data[72], and significantly higher than the ~ 11% of adults estimated to be LCS eligible nationwide using BRFSS and NHIS data[79]. There are a number of potential explanations for our findings. Survey data suggests that Veterans have higher smoking rates than the general population[67]. Additionally, smoking-related disease may lead to higher healthcare utilization, and subsequently higher representation in the population served by the VHA relative to Veterans more broadly. Therefore, estimates that rely on survey data of Veterans more broadly like BRFSS or NHIS may underestimate the LCS eligible population that is actually utilizing VHA services.

Furthermore, we found that more than one fourth of Veterans 50-80 met 2021 USPSTF and 2023 ACS eligibility criteria. We estimated that this would lead to over 1 million Veterans meeting current LCS eligibility criteria. The shift from 2013 to 2021 USPSTF criteria and then 2023 ACS criteria did not lead to a doubling in the eligible population as has previously been estimated in the general population[10], but this is likely due to the high smoking rates seen in Veterans leading to many already meeting the higher 30 pack-year smoking threshold of the

2013 recommendations. We similarly did not see a significant difference in estimated Veterans eligible by 2023 ACS criteria vs 2021 USPSTF criteria. We suspect this is due to many Veterans either still being current smokers or having recently quit, and subsequently there being significant overlap between the USPSTF and ACS eligible populations based on Veterans' smoking histories. We did see the proportion of Black Veterans meeting 2021 USPSTF eligibility criteria reaching parity with the proportion of Black Veterans in the overall cohort, suggesting that the expanded eligibility criteria appropriately take into account that Black males have a higher incidence of lung cancer at a younger age and with fewer pack years of smoking history[25]. However, the relative proportion of Hispanic Veterans meeting eligibility criteria across eligibility definitions remained lower than the proportion of Hispanic individuals in the broader cohort of individuals with smoking data. This may suggest that current eligibility definitions do not increase the proportional eligibility for Hispanic Veterans. Prior research before the 2021 USPSTF expansion of LCS eligibility did suggest disparities in eligibility and lung cancer risk within the Hispanic population[80]. It remains unclear if this may reflect gaps in the eligibility criteria themselves, or unique smoking behavioral differences among Hispanic Veterans.

Reaching the over million Veterans we estimate are eligible for LCS will represent no small task to the VHA, especially given reported initially low screening rates[58]. Our study found regional variation in eligibility that reflects well described higher smoking in the in the Midwest and South[81]. It has previously been reported that there is geographic variation in access to LCS facilities in the VHA, with the highest geographic access unfortunately often being in the regions with the lowest burden of LCS eligiblity[63]. The structured data harnessed by this study could be utilized by not only the VHA but also researchers to target the areas of highest smoking-related eligible populations.

The current study also highlights the high proportion of Veterans who suffer from concurrent mental health and substance use diagnoses. Veterans have high rates of mental health disorders like PTSD, depression, schizophrenia, and substance use disorder[82–84].

Additionally, smoking has been correlated with mental health disorders like PTSD in the Veteran population[85]. This comorbid illness provides potential opportunities and barriers to access for the LCS eligible population. Educating and leveraging providers who provide substance use or mental health treatment as an opportunity to discuss Veteran tobacco use and LCS eligibility could be an additional opportunity to reach Veterans who are LCS eligible. Yet it has been previously reported that lower proportions Veterans with comorbid mental illness or substance use received preventive services than their peers without those diagnoses[86]. Given high rates of comorbid mental illness and substance use in the LCS eligible population, reaching the LCS population and ensuring they receive timely and appropriate follow up likely will require accounting for this comorbid illness.

Limitations

Though we present one of the largest descriptions of the LCS eligible served by the VHA to date, the current study is not without limitations. Smoking history assessments are conducted during office visits, and only collects information for care received within the VHA. Therefore, there could be missingness not at random that correlates with healthcare access, as those Veterans who have the hardest difficulty accessing VHA services will be less likely to present to an outpatient visit to be asked for their smoking history. This is likely reflected by the ADI of those reporting smoking history and their home address rurality (with the majority of Veterans with available data coming from urban centers). We do believe this data is likely still representative of the Veterans who are currently utilizing VHA services, though it may not reflect the smoking behavior of the broader Veteran population at large or those who primarily seek care outside the VHA.

Our descriptive statistics presented in Table 1 do show that the population with available smoking information tended to be more urban, and to have sought care at larger, academically-associated facilities serving most complex patients. This likely in part reflects how the data is

collected. Structured smoking data required implementation of a specialized EMR-based platform for tracking lung cancer screening, and the facilities that self-selected to implement these platforms tend to be large, academically affiliated healthcare facilities located in urban centers. It has previously been reported that Veterans in rural settings have higher rates of smoking dependence than in urban settings[85]. Therefore, we may underestimate the LCS eligible population given the likely under-sampling of rural Veterans, and the overall proportion of eligible Veterans served by the VHA may be even higher. Rural Veterans also have some of the lowest geographic access to LCS[63], highlighting the need for future research to focus on bridging barriers to access for rural Veterans served by the VHA. Additionally, to create national LCS eligible estimates we relied on VHA published survey data that only reports population estimates in 5 year increments up to age 79. Therefore, our national LCS estimates may additionally be a slight underestimate due to exclusion of those aged exactly 80 in our proportions.

Conclusion:

The Veterans served by the VHA are some of the highest risk individuals for developing lung cancer. In order to ensure effective and equitable improvement in LCS to save lives, it is critical to understand the characteristics and magnitude of the population eligible for screening. The current study takes an important step towards utilizing some of the most robust structured data on smoking rates to describe the LCS eligible population served by the VHA. We intend to use these insights to further develop interventions to better reach the estimated over 1 million Veterans currently eligible for LCS.

Tables and Figures

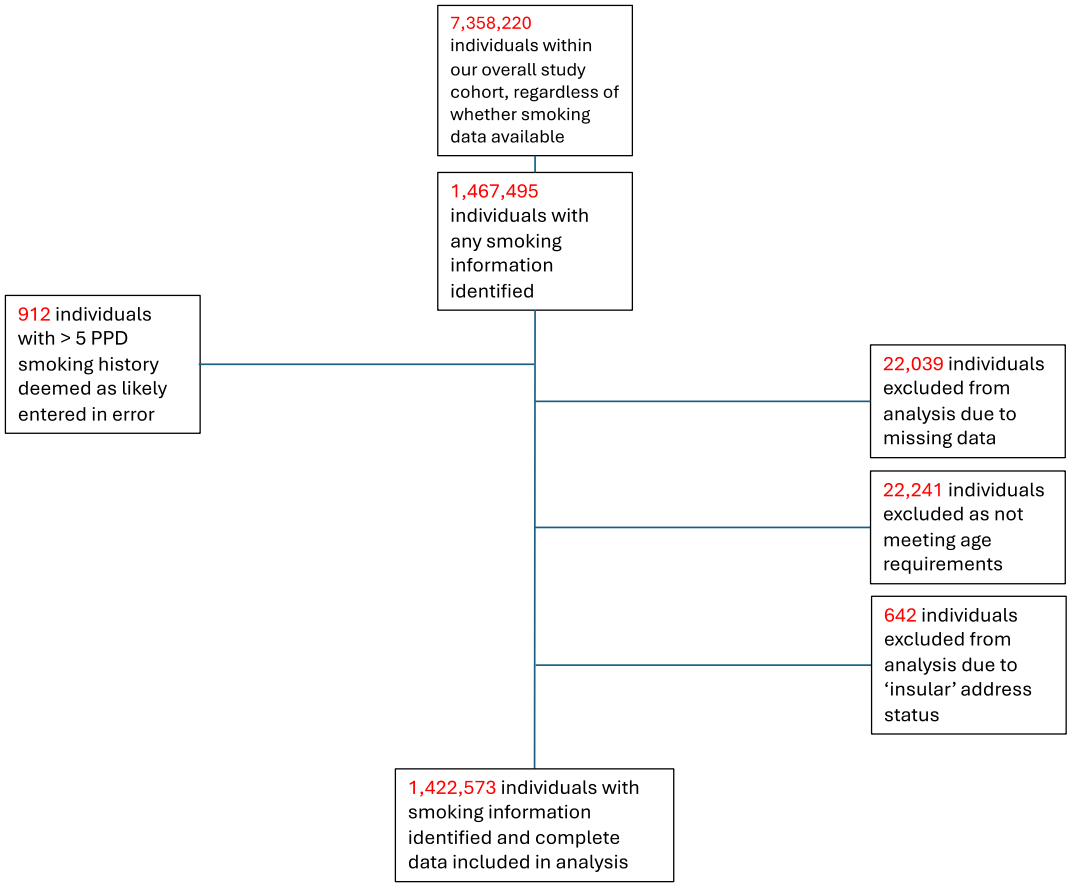

Figure 2: Flow diagram of Veterans included in the current analysis

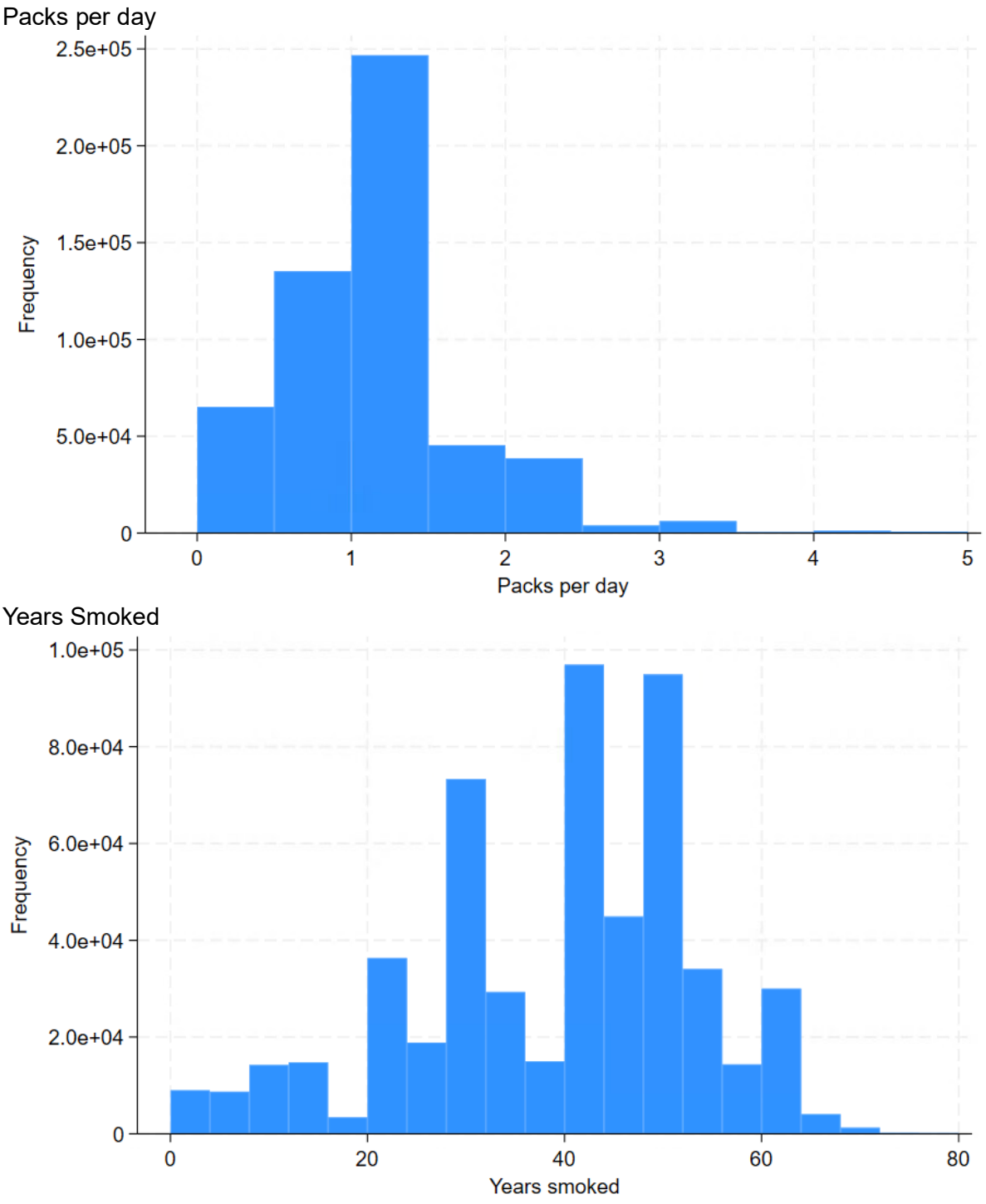

Figure 3: Histograms of smoking data for individuals who smoked

Variable	Entire Cohort 55-80, N=6,277,325	Entire Cohort 50-80, N= 6,907,611	All Individuals 50-80 with Pack-Year Smoking Histories, N= 1,422,573
Age (2016), mean, SD	66.7, 8.8	64.8, 10.2	62.7, 8.2
Sex, N (%)			
Male	5,898,777 (94%)	6,419,997 (92.9%)	1,332,536 (93.7%)
Female	378,545 (6%)	487,611 (7.1%)	90,037 (6.3%)
Ethnicity, N (%)			
White	4,158,620 (66.2%)	4,481,433 (64.9%)	986,500 (69.4%)
Black	917,438 (14.6%)	1,055,987 (15.3%)	227,990 (16%)
Asian	51,539 (0.8%)	61,842 (0.9%)	11,485 (0.8%)
Hispanic	292,474 (4.7%)	335,743 (4.8%)	60,376 (4.2%)
Other (AIAN, NHOPI, multi-race)	857,254 (13.7%)	972,606 (14.1%)	136,222 (9.6%)
Elixhauser Comorbidity, mean (SD)	3.1 (2.3)	3.1 (2.3)	3.0 (2.2)
Comorbid Mental Illness	2,817,477 (44.9%)	2,807,654 (40.7%)	698,805 (49.1%)
Comorbid Substance Use Disorder	2,517,355 (40.1%)	2,510,064 (36.3%)	660,745 (46.5%)
National ADI[1]			
Top 15% of Disadvantage	1,855,904 (29.6%)	2,026,069 (29.3%)	308,019 (21.7%)
Bottom 85%	4,421,421 (70.4%)	4,881,542 (70.7%)	1,114,554 (78.3%)
State ADI[1]			
Top 20% of Disadvantage	2,140,828 (34.1%)	2,331,171 (33.8%)	397,487 (27.9%)
Bottom 80%	4,136,497 (65.9%)	4,576,440 (66.2%)	1,025,086 (72.1%)
Veteran Priority Group[2]			
1	1,579,219 (25.1%)	1,830,284 (26.5%)	447,306 (31.4%)
2	377,413 (6%)	425,263 (6.2%)	99,102 (7%)
3	758,969 (12.1%)	833,154 (12.1%)	197,054 (13.8%)
4	129,690 (2.1%)	132,973 (1.9%)	27,178 (1.9%)
5	1,009,602 (16.1%)	1,062,949 (15.4%)	251,541 (17.7%)
6	273,234 (4.3%)	305,217 (4.4%)	71,255 (5%)
7	224,578 (3.6%)	238,235 (3.4%)	54,943 (3.9%)
8	989,362 (15.8%)	1,052,992 (15.2%)	180,910 (12.7%)
Missing	935,258 (14.9%)	1,026,544 (14.9%)	93,284 (6.6%)
Marital status (%)			
Single	547,139 (8.7%)	645,323 (9.3%)	151,885 (10.7%)
Married	3,655,091 (58.2%)	3,975,702 (57.6%)	793,141 (55.7%)
Divorced/Separated/Widowed	1,869,680 (29.8%)	2,027,325 (29.3%)	460,641 (32.4%)
Unknown	205,415 (3.3%)	259,261 (3.8%)	16,906 (1.2%)
Rurality (URH)[3]			
Urban	3,410,579 (54.3%)	3,786,916 (54.8%)	857,366 (60.3%)
Rural	1,696,245 (27%)	1,844,030 (26.7%)	417,946 (29.4%)
Highly Rural	229,848 (3.7%)	243,998 (3.5%)	53,229 (3.7%)
Missing	940,653 (15%)	1,032,667 (15%)	94,032 (6.6%)

Distance to nearest VA facility in miles, mean (SD)	15.7 (15.6)	15.6 (15.5)	15.3 (15)
Parent Facility Complexity Score[4]			
1a	2,702,027 (43%)	2,977,352 (43.1%)	695,027 (48.9%)
1b	1,406,623 (22.4%)	1,547,139 (22.4%)	390,435 (27.4%)
1c	845,061 (13.5%)	931,729 (13.5%)	179,250 (12.6%)
2	581,920 (9.3%)	639,424 (9.3%)	65,329 (4.6%)
3	665,550 (10.6%)	725,762 (10.5%)	80,771 (5.7%)
Excluded/Missing	76,144 (1.2%)	86,205 (1.2%)	11,761 (0.8%)

[1] Area Deprivation Index (ADI) is a ranking of neighborhoods by socioeconomic disadvantage at the state or national level and is reported by the Neighborhood Atlas published by the Kind et al. research group from the University of Wisconsin-Madison. National ADI is ranked 1-100, and State ADI is ranked in deciles 1-10.
[2] Priority Group is a designation given by the VHA to each Veteran utilizing services and determines a Veteran's out-of-pocket cost/copayments, ranging from Group 1 with little to no out-of-pocket cost to group 8 with the highest out-of-pocket cost.
[3] Address rurality is reported by the VHA for each Veteran's primary address based on Rural-Urban Commuting Area Code (RUCA) associated with a Veteran's primary address Census Tract.
[4] Parent Facility Complexity Score is a designation used by VHA as a general measure of a facilities size, patient complexity, available clinical services, and academic affiliation. It ranges from a maximum of 1a to 3.

Table 1: Baseline Demographics for Study Cohort with and without smoking data.
Abbreviations: N = number, SD = standard deviation, AIAN = American Indian and Alaska Native, NHOPI = Native Hawaiian, and Other Pacific Islander, ADI = Area Deprivation Index

Variable	Eligible for LCS (2013 USPSTF) N=293,796	Eligible for LCS (2021 USPSTF) N=394,424	Eligible for LCS (ACS) N=395,976	p-value, 1 vs 2, 1 vs 3
Age (2016), mean, STD	62.8, 6.8	61.3, 7.4	61.3, 7.4	
Sex, N (%)				<0.01, <0.01
Male	278,506 (94.8%)	369,894 (93.8%)	371,379 (93.8%)	
Female	15,290 (5.2%)	24,530 (6.2%)	24,597 (6.2%)	
Ethnicity, N (%)				<0.01, <0.01
White	219,850 (74.8%)	284,007 (72%)	285,174 (72%)	
Black	38,889 (13.2%)	61,199 (15.5%)	61,352 (15.5%)	
Asian	1,091 (0.4%)	1,880 (0.5%)	1,893 (0.5%)	
Hispanic	8,840 (3%)	13,281 (3.4%)	13,333 (3.4%)	
Other (AIAN, NHOPI, multi-race, unknown)	25,126 (8.6%)	34,057 (8.6%)	34,224 (8.6%)	
Max Pack-years, mean, STD	54.8, 25.9	47.7, 26	47.7, 26	<0.01, <0.01
Elixhauser Comorbidity, mean	3, 2.2	3, 2.2	3, 2.2	<0.01, <0.01
Comorbid Mental Illness	177,013 (60.3%)	220,642 (55.9%)	221,433 (55.9%)	<0.01, <0.01
Comorbid Substance Use Disorder	186,365 (63.4%)	231,888 (58.8%)	232,639 (58.8%)	<0.01, <0.01
National ADI[1]				<0.01, <0.01
Top 15% of Disadvantage	72,186 (24.6%)	96,455 (24.5%)	96,725 (24.4%)	
Bottom 85%	221,610 (75.4%)	297,969 (75.5%)	299,251 (75.6%)	
State ADI[1]				<0.01, <0.01
Top 20% of Disadvantage	91,544 (31.2%)	122,859 (31.2%)	123,243 (31.1%)	
Bottom 80%	202,252 (68.8%)	271,565 (68.8%)	272,733 (68.9%)	
Veteran Priority Group[2]				<0.01, <0.01
1	83,088 (28.3%)	115,387 (29.3%)	115,923 (29.3%)	
2	17,869 (6.1%)	24,281 (6.2%)	24,394 (6.2%)	
3	36,616 (12.5%)	49,204 (12.5%)	49,408 (12.5%)	
4	8,766 (3%)	11,385 (2.9%)	11,412 (2.9%)	
5	76,446 (26%)	99,455 (25.2%)	99,695 (25.2%)	
6	10,596 (3.6%)	14,280 (3.6%)	14,370 (3.6%)	
7	11,275 (3.8%)	15,140 (3.8%)	15,204 (3.8%)	
8	33,270 (11.3%)	43,929 (11.1%)	44,119 (11.1%)	
Missing	15,870 (5.4%)	21,363 (5.4%)	21,451 (5.4%)	
Marital status (%)				<0.01, <0.01
Single	34,253 (11.6%)	49,820 (12.6%)	49,948 (12.6%)	
Married	131,518 (44.8%)	174,117 (44.2%)	175,073 (44.2%)	
Divorced/Separated/Widowed	125,187 (42.6%)	166,471 (42.2%)	166,922 (42.2%)	
Unknown	2,838 (1%)	4,016 (1%)	4,033 (1%)	
Rurality (URH)[3]				<0.01, <0.01
Urban	169,902 (57.8%)	233,582 (59.2%)	234,468 (59.2%)	
Rural	94,917 (32.3%)	122,808 (31.1%)	123,309 (31.1%)	
Highly Rural	12,964 (4.4%)	16,464 (4.2%)	16,540 (4.2%)	
Missing	16,013 (5.5%)	21,570 (5.5%)	21,659 (5.5%)	
Distance to nearest VA facility, mean	15.8, 15.6	15.4, 15.4	15.4, 15.4	<0.01, <0.01
Parent Facility Complexity Score[4]				<0.01, <0.01
1a	139,123 (47.4%)	185,561 (47%)	186,509 (47.1%)	
1b	81,492 (27.7%)	109,446 (27.8%)	109,770 (27.7%)	
1c	36,678 (12.5%)	49,670 (12.6%)	49,783 (12.6%)	
2	13,227 (4.5%)	18,233 (4.6%)	18,292 (4.6%)	
3	19,593 (6.7%)	26,365 (6.7%)	26,435 (6.7%)	
Missing	3,683 (1.2%)	5,149 (1.3%)	5,187 (1.3%)	

[1] Area Deprivation Index (ADI) is a ranking of neighborhoods by socioeconomic disadvantage at the state or national level and is reported by the Neighborhood Atlas published by the Kind et al. research group from the University of Wisconsin-Madison. National ADI is ranked 1-100, and State ADI is ranked in deciles 1-10.
[2] Priority Group is a designation given by the VHA to each Veteran utilizing services and determines a Veteran's out-of-pocket cost/copayments, ranging from Group 1 with little to no out of pocket cost to group 8 with the highest out-of-pocket cost.
[3] Address rurality is reported by the VHA for each Veteran's primary address based on Rural-Urban Commuting Area Code (RUCA) associated with a Veteran's primary address Census Tract.

[4] Parent Facility Complexity Score is a designation used by VHA as a general measure of a facilities size, patient complexity, available clinical services, and academic affiliation. It ranges from a maximum of 1a to 3.

Table 2: Baseline characteristics of LCS eligible population by eligibility criteria, USPSTF and ACS

P values represent chi-squared comparisons of A vs B and A vs C for categorical variables, and T-tests for continuous variables.
Abbreviations: LCS = Lung cancer screening, USPSTF = United States Preventive Services Task Force, ACS = American Cancer Society, VA = Veteran's Affairs, ADI = Area deprivation index, N = number, SD = Standard deviation

	USPSTF 2013	USPSTF 2021	ACS
National Percentage LCS Eligible	23.1%	27.8%	27.9%
Regional estimates (N individuals with smoking data identified)	22.8%	26.7%	26.8%
North (213,690)	23.3%	27.7%	27.8%
South (527,419)	25.5%	30.9%	31.0%
Midwest (380,126)	19.8%	25.5%	25.7%
West (290,408)			
Estimated Nationwide eligible population, 2023	721,122	1,035,880	1,039,967

Table 3: Regional and National Estimates of Screen Eligible Patients.
Percentage represents proportion of individual aged 55-80 for USPSTF 2013 criteria, and proportion of individuals 50-80 for USPSTF and ACS Criteria.
Abbreviations: USPSTF = United States Preventive Services Task Force, ACS = American Cancer Society, LCS = Lung Cancer Screening, N = number

Supplemental Tables & Figures

Diagnosis	ICD-9 Codes	ICD 10 Codes
Depression	296.2-296.3x, 300.4, 300.4x, 300.9, 300.9x, 301.12, 309.0, 309.0x, 309.1, 309.1x, 309.28, 311, 311.x	F32.x, F32.xx, F33.x, F33.xx, F34.1, F43.21, F43.23, F48.9
Post-traumatic stress disorder	309.81	F43.10, F43.11, F43.12
Schizophrenia	295, 295.xx	F20.x, F20.xx
Substance Use Disorder	291, 291.xx, 292.0, 292.0x, 292.89, 292.9, 292.9x, 303, 303.xx, 304, 304.xx, 305, 305.0, 305.0x, 305.2-305.9x, 357.5, 425.5, 535.3, 571.0-571.3x, 760.71, 790.3, 977.3, 980.0, 980.9, E860-E860.1, E860.9, E947.3, V11.3, V79.1	F10-F16.xx, F18-F19.xx, F62.1, I42.6, K29.20, K29.21, K70.x, K70.xx, P04.3, Q86.0, R78.0, T50.991A, T51.0X1A, T51.0X2A, T51.0X3A,T51.0X4A, T51.91XA, T51.92XA, T51.93XA, T51.94XA, NOD.X, Z65.8, Z13.89

Supplemental eTable 1: ICD-9 and ICD-10 diagnostic does used to create composite indicators of comorbid mental illness and Substance Use Disorder

Variable	**No smoking data N=5,485,064**
Age (2016), mean, STD	65.4, 10.5
Sex, N (%)	
Male	5,087,384 (92.8%)
Female	397,677 (7.2%)
Ethnicity, N (%)	
White	3,494,434 (63.7%)
Black	827,838 (15.1%)
Asian	50,334 (0.9%)
Hispanic	275,348 (5%)
Other (AIAN, NHOPI, multi-race, unknown)	837,110 (15.3%)
Elixhauser Comorbidity, mean	3.2, 2.4
Comorbid Mental Illness	2,108,854 (38.5%)
National ADI	
Top 15%	1,717,220 (31.3%)
Bottom 85%	3,767,844 (68.7%)
State ADI	
Top 20%	1,932,922 (35.2%)
Bottom 80%	3,552,142 (64.8%)
Veteran Priority Group	
1	1,383,067 (25.2%)
2	326,189 (5.9%)
3	636,203 (11.6%)
4	105,814 (1.9%)

5	811,648 (14.8%)
6	234,048 (4.3%)
7	183,370 (3.3%)
8	872,448 (15.9%)
Missing	932,277 (17%)
Marital status (%)	
Single	493,492 (9%)
Married	3,182,483 (58%)
Divorced/Separated/Widowed	1,565,719 (28.5%)
Unknown	243,370 (4.5%)
Rurality (URIH)	
U	2,930,258 (53.4%)
R	1,426,347 (26%)
H	190,806 (3.5%)
Missing	937,653 (17.1%)
Distance to nearest VA facility, mean	15.7, 15.6
Parent Facility Complexity Score	
1a	2,336,263 (42.6%)
1b	1,194,084 (21.8%)
1c	758,021 (13.8%)
2	534,307 (9.7%)
3	597,657 (10.9%)
Excluded/Missing	64,732 (1.2%)

Supplemental eTable 2: Baseline Demographics for Individuals Without Smoking Data Found in Broader Cohort of Individuals 50-80 with at least 1 outpatient appointment at VHA.

Chapter 5: Manuscript 2

Centralization of Lung Cancer Screening: The Veterans Healthcare Administration's Experience 2015-2021

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Data Sharing Statement: There are legal restrictions on access to VA data placed by the Department of Veterans Affairs (VA), including identifying data and sensitive information. The analytic datasets used for this study are not permitted to leave the VA firewall without an express Data Use Agreement.

Declarations:
None.

Conflicts of Interest:
None.

Abbreviations:
LCS: Lung Cancer Screening
USPSTF: United States Preventive Services Task Force
EMR: Electronic Medical Record
PCP: Primary Care Physician
VHA: Veterans Health Administration
CT: Computed Tomography
ADI: Area Deprivation Index

Background:

Lung cancer screening (LCS) remains the most underutilized form of cancer screening recommended by the United States Preventive Services Task Force[11,18,19,58,87]. Of those eligible for screening which entailed an annual low-dose computed tomography (CT) scan for at risk current and former smokers, less than 20% have ever received a screening scan[21], and approximately 20% of those who enter screening receive appropriate follow up[22]. Multiple strategies have been proposed for improving the performance of lung cancer screening programs including risk prediction calculators[40] and utilization of biomarkers[41]. Yet these

interventions still require adequate recruitment and retention of eligible patients in screening programs to be effective.

One strategy that has shown promise for improving the uptake (the number of new patients entering screening) and adherence (the proportion of patients that receive appropriate and timely follow up and subsequent screenings) is LCS "centralization". Centralized screening programs commonly employ program coordinators, registries to track screening, electronic medical record (EMR) reminders for providers, performance metrics integrated into the EMR, dedicated tumor review boards, and dedicated staff to assist in counseling and enrolling in lung cancer screening and performing follow up[45]. A small body of studies suggest that centralized programs have an advantage in LCS uptake and adherence, including amongst racial and ethnic groups that have been historically marginalized from LCS [44–46]. Yet there remains significant heterogeneity and a lack of consensus of what program elements are central to a LCS program's success, and the relative importance of these elements[45].

The Veterans Health Administration (VHA) is the largest, nationally-integrated, health delivery system in the United States. As such, it provides an ideal opportunity to probe the impact of centralization on lung cancer screening rates. Centralization was first studied in the VHA in the VA Lung Cancer Screening Demonstration Project (LCSDP)[57,61,88]. The LCSDP reported high of rates of adherence around 82% at the first year at 65% at year 2, and roughly 2,103 patients were screened[57]. Notably, the LCSDP did not have a comparator/control group, and so it remains unclear the broader secular trends in LCS rates at similar facilities over this time period. And other researchers have reported that the gains in screening rates seen during the LCDSP were not maintained after the resourcing from the demonstration project concluded [61]. However, there has yet to be a large, nationwide analysis of the longitudinal comparative effectiveness of centralized LCS programs while controlling for potential causes of bias/confounding beyond these initial single site to multi-center studies.

Following the promising results of the LCDSP, the VHA committed significant research, administrative, information technology, and clinical resources into supporting centralization of LCS through 2 primary initiatives. The VA's National Center for Lung Cancer Screening (NCLCS) developed a standardized implementation protocol and an EMR-embedded platform to centralize a LCS program into either a fully centralized (termed "consult") model where the majority of LCS is performed by a dedicated care team, or a hybrid model where primary care physicians (PCPs) interact with LCS program staff and jointly manage screening and follow up. Additionally, the VA launched the Lung Precision Oncology Program (LPOP), a nationally coordinated research and clinical consortium that can provide funding and administrative support to enhance efforts to proactively address and treat lung cancer. One component of the LPOP program was to fund and support hiring LCS program staff at a subset of healthcare centers (termed "stations" in the VHA). This policy implementation supporting the roll out of centralization of LCS across the VHA's national network provides a robust natural experiment to study the comparative effectiveness of lung cancer screening programs. Across the VHA, there was a spectrum of when and how various programs implemented their LCS programs. LCS programs ranged from remaining decentralized/driven by primary care physicians, to transitioning to hybrid programs where primary care physicians work with LCS program staff to co-manage LCS, to fully centralized "consult" programs where primary care physicians refer patients to the screening program that then performs all aspects of screening and follow up. This heterogeneity combined with the quality of the VA's nationwide data repository provides a rich opportunity to compare longitudinal LCS program performance while also abstracting and controlling for potential patient and station-level confounders of LCS rates.

Objective:

The current study seeks to leverage qualitative survey data and structured medical record data to evaluate the longitudinal comparative effectiveness of lung cancer screening rates for uptake and adherence relative to program centralization while controlling for a number of station and

patient specific variables. To that end, we performed a mixed methods, multi-level, retrospective analysis by pairing qualitative surveys on LCS program centralization with VHA EMR data.

Methods

Study Population

The study cohort was identified utilizing the central EMR data repository for the VHA called the Corporate Data Warehouse (CDW). Unique veterans were identified who utilized at least 1 outpatient visit at the VHA from October 1, 2015 through September 30, 2021, corresponding to the 2016 through 2021 fiscal years. These years were selected to maximize the initial years during USPSTF's initial screening recommendation (made from 2013-2021[15,68]) and the adoption in 2015 of the Lung CT Screening Reporting & Data System (Lung-RADS), a standardized framework for interpreting LCS CT scans and recommending appropriate follow up[62]. Veterans were excluded due to not meeting the age requirements of being 55-80 during the study period (assessed annually), or if the medical record indicated a date of death prior to October 1, 2015. Data was abstracted for each individual in the dataset to obtain their age, sex, race/ethnicity, National Area Deprivation Index (ADI) which ranges from 1-100[38], State ADI which ranges in deciles from 1-10[38], Veteran priority group (a designation which determines a Veteran's out of pocket cost share for utilizing VA services), marital status, an individual's primary address rurality based on U.S. Department of Agriculture's Rural-Urban Commuting Area (RUCA) codes[74]. Due to small sample size, Veterans living in an insular/island rurality were dropped from the analysis (representing < 0.1% of the overall study cohort). Age was transformed into a categorical variable of those ages 55-64, 65-74, and 75-80. National ADI was dichotomized into those from the top 15 ADI of disadvantage and the bottom 84 ADI score, and State ADI was dichotomized into the top 2 deciles and the bottom 8 deciles of disadvantage. Higher values of each ADI measure correspond to higher disadvantage. Elixhauser Comorbidity Index was also calculated for each individual, and then dichotomized to those < 5 and ≥ 5, as 5

was roughly 1 SD above the mean comorbidity score in the dataset. Higher Elixhauser values correspond to higher comorbidity.

Additionally, veterans were assigned to a designated home facility (also called "parent stations" by the VHA) by an algorithm that compared average primary care utilization during each fiscal year, and assigned veterans to the facility of highest average utilization. The complexity score, a metric used by the VHA to indicate a facilities relative patient risk, academic affiliation, and resourcing, was attributed to each parent station[64,75].

Identification of Lung Cancer Screening Scans and LCS Eligible Population

CT scans were identified as likely performed for lung cancer screening by the following algorithm. Initial LCS scans were identified by 2 primary methods:

1. Current Procedural Terminology (CPT) codes G0297, S8032, or 71271
2. Having a Lung-RADS diagnostic code associated with the scan, cross referenced against a list of procedure names included in Supplemental Table 1.

The study team identified this methodology as the most sensitive and specific for identifying likely LCS scans based on previously published literature using VHA data[58,60,63] and based on exploratory analysis of this dataset.

The methodology of abstracting smoking data from the VA's EMR has been previously described in detail (chapter 4). We created estimates of the average number of veterans aged 55-80 who utilized services at each parent station over the study period using an algorithm that compared average primary care utilization during each fiscal year, and assigned veterans to the facility of highest average utilization. We then matched each parent station with an estimate of the proportion of veterans meeting USPSTF 2013 screening eligibility criteria (the LCS eligibility criteria typically used at the time of the study period to determine eligibility). For stations with < 1000 veterans queried for their smoking data, or for stations without any available smoking data, we estimated smoking data by matching stations with the nearest station of the same complexity score with adequate available smoking data. To mitigate variance in sample size

between stations of available smoking data, we additionally created a scaling factor that scaled the average proportion of veterans meeting LCS eligibility based on all available data with the station-specific estimated proportion of veterans LCS eligible based on the sample size of veterans with smoking data. The equation for the scaling factor is reproduced below.

$$\left(\left(\frac{\sqrt{(Total\ veterans\ 55-80)\ -(Veterans\ with\ unknown\ smoking\ status)}}{\sqrt{Total\ Veterans\ 55-80}}\ \times\ (\%\ eligible)\right)\right.$$

$$\left.+\left(1-\frac{\sqrt{(Total\ veterans\ 55-80)\ -(Veterans\ with\ unknown\ smoking\ status)}}{\sqrt{\sqrt{Total\ Veterans\ 55-80}}}\right)(Nationwide\ LCS\ Eligibility\ \%)\right)$$

We then created station-specific estimates of the LCS eligible population based on the following equation:

$(estimated\ \%\ of\ Veterans\ LCS\ eligible\ for\ the\ station)$ x
$(Average\ Number\ of\ Unique\ Veterans\ age\ 55-80\ seen\ at\ a\ station\ annually)$

Uptake and Adherence Calculations

Uptake assessed the rate of new Veterans receiving their first, i.e. incident, lung cancer screening. It was calculated as the quarterly number of unique, new veterans who underwent screening at an individual station. It was quantified either as a count, or a proportion divided by the estimated LCS-eligible population at that station.

Adherence assessed whether an individual received appropriate and timely follow up after their initial/incident lung cancer screening. It was defined as a binary outcome at the first expected follow up interval based on the Lung CT Screening Reporting & Data System (Lung-RADS) score at the time of initial LCS scan to determine the time period of appropriate follow up. Lung-RADS is a quality assurance tool published by the American College of Radiology to standardize LCS CT reporting and management recommendations. Because a Lung-RADS score was essential to defining the period for expected follow up, we excluded any scans that did not have an associated Lung-RADS score from the adherence analysis, representing around 26% of the available initial LCS scans with complete data. Figure 1 depicts the criteria

and time intervals used to determine adherence. Adherence was calculated both for a target range and minimum acceptable range. Adherence for Lung-RADS 1, 2, and 3 was defined by undergoing a second LCS scan based on the procedure names defined in Supplemental Table 1 within the time period defined for adherence outlined in Figure 1. Adherence for Lung-RADS 4A, 4B, and 4X was coded as undergoing a CT Scan, positron emission tomography (PET) scan, or invasive procedure in the expected timeframe. PET scans were identified using the CPT Codes 78811, 78812, 78813, 78814, 78814, or 78816. Invasive procedures were identified using a series of CPT and ICD-9 and ICD-10 codes previously published by members of the study team for determining adherence in VHA data[60].

Qualitative Survey Data on LCS Centralization

To increase sample size for qualitative surveys of centralization practices, data on LCS program centralization was abstracted and combined from 2 previously conducted qualitative surveys that were furnished to the study team. The first was conducted in August through December 2021 and published by Nunez et al. previously[89]. The second included unpublished internal survey data conducted by the VA's National Center for Lung Cancer Screening (NCLCS) during 2022 and 2023. Two independent coders abstracted and combined data from both survey sources. When discrepancies were found, coders returned to primary survey to achieve consensus on intended responses. Stations were coded into 3 broad categories of self-reported centralization: decentralized, consult (or fully centralized), and hybrid. Additionally, to create a more objective measure of centralization, an indicator variable was created for 7 itemized elements of centralization: a LCS coordinator, oversight board, LCS registry, EMR reminders, coordinator assistance with shared-decision making conversations, LCS tumor board, and whether centralized LCS staff performed tracking of scans performed in the community (CITC). The study team then created an ordinal scale of centralization by summing these itemized elements and creating a 3 level categorical variable based on logical cut-points in the distribution of responses. A score of 0-3 was categorized as decentralized, 4/5 as low

centralization, and 6/7 as high centralization. We then created a time-varying indicator variable for when centralization was initiated at a given station, anchored to the quarter in which an LCS coordinator was hired or a program reported they started their centralized program. The date of an individual's initial LCS scan was then compared to this time varying indicator to determine the centralization of the facility *at the time of initial scan,* and this centralization status was used for categorization in all subsequent analyses. We additionally made a time varying indicator for the quarters that overlapped with the early days of the COVID19 pandemic (quarters 19-21) and late COVID19 pandemic (quarters 22-24).

Statistical Analysis

All statistical analyses were performed in compliance with VA data use regulations, on VA furnished servers, and using the build of the R statistical software package version 4.4.1 and STATA MP version 18 furnished by the VA Informatics and Computing Infrastructure (VINCI). To model LCS uptake, we fit a multi-level, Poisson model via a generalized estimating equation (GEE) with patients nested within facilities and random effects at the facility-level, with an offset term for the size of the estimated LCS eligible population at that facility. We additionally attempted to fit a simple Poisson model and zero-inflated Poisson model (data not shown), but found these models were unable to converge or to be adequately specified to model the variance in the data. For adherence, we fit a generalized additive logistic regression model again with random effects at the station level, for the size of the estimated LCS eligible population at that facility. The generalized additive model was selected due to its increased computational speed/efficiency given the large size of the dataset, while yielding similar results to a logistic regression model[90]. Model output was reported as Incidence Rate Ratios (IRRs) for Poisson regression and Odds Ratios (OR) for logistic regression. All sensitive data was stored and analyzed on VINCI servers behind the VA's firewall in accordance with VA data use and security rules. We evaluated statistical significance at an alpha of 0.05 level.

This study was approved as review exempt by the Greater Los Angeles Veterans Affairs Healthcare System Institutional Review Board given its low risk to patients and purely retrospective nature. All analyses were performed between November 2023 and August 2024.

Results:

Figure 2 depicts the number of individuals identified from multiple data sources, and the ultimate number of individuals utilized for subsequent analysis. A total of 192, 994 individuals were identified who had initial LCS scans and no missing demographic data. Of those, a subset of 118,348 individuals were identified with complete data for inclusion in our uptake model including qualitative survey data on their LCS program practices relative to centralization. 108,692 were utilized in our model of centralization based on an itemized, ordinal measure of centralization, and 104,892 for our model utilizing self-reported centralization. This represented data from 82 facilities with the study-defined ordinal measure of centralization and 75 facilities with self-reported centralization status. For our adherence model, a total of 142,687 individuals were identified from the uptake cohort who had initial scans that had an identified Lung-RADS score to determine the period of appropriate follow up. Of those, a total of 109,023 individuals had complete data for inclusion in our adherence model, 93,205 for our analysis based on an ordinal measure of centralization, and 89,709 for our model for self-reported centralization.

Uptake:

Table 1 presents the baseline characteristics of the individuals identified as having undergone an initial LCS scan for inclusion in our uptake analysis. Initial exploratory analysis found that fewer that <1% of incident CT scans identified occurred before the start of the study period (data not shown), so all Veterans were assumed to be LCS eligible at the start of the study. Centralization was determined by whether a program reported it was decentralized or centralized *at the time an individual entered* screening, i.e. a facility that centralized during the study period would count some quarters as decentralized and subsequently as centralized. The

majority (41.6%) underwent screening at a site that was decentralized at the time of initial scan, followed by 34.7% screened at hybrid programs and 23.7% at fully centralized/consult programs. The majority were White (75.5%), followed by Black (18.7%) and Hispanic (3.6%). 19.4% lived in the top 15% of disadvantaged communities as ranked by national ADI, and 26.8% lived in the top 20% of disadvantage communities in each state. The majority lived in urban settings (68.4%) and received their care at facilities of the highest size/resourcing as measured by facility complexity score (49.2% at 1a facilities).

Given concerns that the magnitude of this abrupt downturn in screening rates around the COVID19 pandemic could impact model fit, we incorporated a categorical indicator variable for whether screening occurred in the period before the pandemic (corresponding to before April 2020), during the first several months of lockdowns (April to December 2020), or after December 2020. We additionally included a linear time indicator variable to capture the general trend in uptake over time. Table 2 presents the model output for a multivariate Poisson regression via a generalized estimating equation modeling the rate ratio of LCS uptake (in quarterly count of new individuals entering screening) predicted by a facility's centralization status while controlling for time period relative to the pandemic, size/resourcing of the facility performing screening, individual race/ethnicity, primary address national ADI rank, primary address rurality, broad out-of-pocket cost for receiving VA services, and overall health status as measured by Elixhauser Comorbidity Index. This model is multi-level, with individual patients nested within facilities. As such, model output for individual-level characteristics are reported based on the estimated effect of a 10% proportional increase in the representation of that individual characteristic in the population served at a facility. Given the lack of consensus in what defines a centralized program, we included centralization both as self-reported and based on an itemized, ordinal measure of centralization elements reported at a facility, ranking from decentralized, low centralization, to high centralization. Included in the model was an offset term for the estimate LCS eligible population at each facility as a balancing measure for station

catchment area size, preventing large stations with high LCS eligible populations from outweighing smaller stations.

We found no statistically significant difference in LCS uptake between decentralized programs and either low or high centralization as measured by our itemized ordinal measure of centralization, all else equal. We found no statistically significant difference in uptake for self-reported hybrid centralized programs, but we did notably see a 50% decrease in the rate of uptake at self-reported fully centralized/consult programs (IRR 0.50, 95% CI 0.28-0.89). Generally, we saw a gradual 5% quarterly increase in uptake over time. Relative to pre-COVID19 pandemic levels, the early quarters and late quarters of the pandemic were associated with significantly lower uptake of screening. We did not see a statistically significant difference in LCS screening uptake based on a facilities complexity score (a measure of its size, academic affiliation, and specialty services offered). For individual characteristics like race/ethnicity, primary address National ADI, primary address rurality, out-of-pocket cost for services as measured by priority group, and medical comorbidity as measured by Elixhauser Comorbidity Index, we modeled the impact of a 10% increase in the proportion of individuals having that characteristic in the population served at the facility. Based on this 10% increase threshold, we did not see any statistically significant difference in uptake based on these individual characteristics. In summary, after controlling for the impact of the COVID19 pandemic, we found broadly no statistically significant difference in LCS uptake for our ordinal measure of centralization or for self-reported hybrid programs relative to decentralized programs, but did see uptake reduced at self-reported fully centralized/consult facilities. Changes in the proportion of Veterans' race/ethnicity, primary address ADI or rurality, out-of-pocket cost, and medical comorbidity was not statistically significantly associated with changes in a facilities uptake rate.

Adherence:

Table 3 describes the baseline characteristics of the cohort of individuals included in our adherence model. This subset of individuals had initial/incident scans with an identifiable Lung-RADS score that allowed for determination of the appropriate follow up interval. Adherence was defined as receiving appropriate diagnostic follow up or subsequent screening after initial CT scan based on the time intervals outlined in Figure 1. Adherence for the current analysis was only assessed at this first follow-up interval after initial screening and not longitudinally for the current analysis. Overall, 32.8% of the cohort had target adherence in follow up after their initial scan, and 39.6% met minimum adherence. When stratified by Lung-RADS score, adherence ranged from 30.5% to 62.3% and increased with increasing severity/suspicion of malignancy. The majority of veterans had a benign appearing initial scan (Lung-RADS 1&2, 80.1%), had their initial scan at a station that self-reported was decentralized at the time of the first scan (47.8%), lived in urban settings (67.4%), and received care at facilities with the largest size and academic/specialist resourcing (52.9%).

Again, given concerns for the impact of the pandemic on timely follow up, we incorporated a categorical time variable indicating time relative to the start of the pandemic lockdowns similar to our uptake model. Additionally, we examined adherence both at more stringent target range and a more lenient minimum range as outlined in Figure 1, to allow more time for follow up to be achieved in case it was disrupted by the pandemic.

Table 4 presents the output from our multivariate logistic regression via a generalized additive model that modeled likelihood of adherence predicted by a facility's centralization while controlling for the time period relative to the pandemic, size/resourcing of the facility performing screening, and an individual's race/ethnicity, primary address national ADI rank, primary address rurality, broad out-of-pocket cost for receiving VA services, and overall health status as measured by Elixhauser Comorbidity Index. This model is performed at the individual level predicting the outcome of being adherent at the first expected follow-up interval after initial/incident screening based on Lung-RADS score. Globally, the likelihood of adherence was

lower for the time periods early and late during the pandemic. Compared to decentralized programs, we found a statistically significant higher likelihood of target adherence at facilities that self-reported hybrid programs and programs with lower elements of centralization, all else equal (OR 1.57, 95% CI 1.42-1.73 and OR 1.3, 95% CI 1.19-1.41 respectively). We did not find a statistically significant difference in likelihood of adherence between decentralized programs and self-reported consult programs or programs with higher elements of centralization, all else equal. When evaluated for a more lenient minimum adherence criteria, centralized programs broadly had higher odds of adherence to follow up (OR 2.66, 95% CI 2.44-2.91 for hybrid programs, OR 1.19, 95% CI 1.07-1.31 for consult programs, OR 1.95, 95% CI 1.80-2.11 for programs with lower elements of centralization, OR 1.88, 95I CI 1.67-2.12 for programs with higher elements of centralization).

We did not find a statistically significant difference in adherence based on the facilities overall size/resourcing. We did find that Black Veterans had lower odds of meeting target and minimum adherence when compared to White Veterans (OR 0.9 and 0.93 respectively) . We found that Veterans coming from more disadvantaged home addressed by ADI and more rural and highly rural home addresses had modestly lower odds of being adherent, as did those with higher out of pocket costs for seeking VA services and who had higher comorbidities as measured by Elixhauser Comorbidity Index.

Centralization Elements

To explore the impact of individual elements of centralization, we created indicator variables for programs that reported having an LCS coordinator, a registry of LCS scans, using EMR-based reminders for providers to prompt them when screening was due for their patients, and whether the screening coordinator assisted in performing shared-decision making conversations for individuals entering screening. We then performed more simplified models predicting either the uptake or adherence of screening as predicted by if a program reported these elements of centralization at the time an individual entered screening. These models

additionally included the same time indicator variables accounting for the time period relative to the pandemic used in previous models (data not shown as model output similar to values in Tables 3 and 4).

Table 5 presents model output of a Poisson regression via a generalized estimating equation predicting uptake of screening by each of these elements of centralization. For the elements of centralization modeled, we did not see any statistically significant association with the quarterly rate of new individuals entering screening.

Table 6 presents model output of a logistic regression via a generalized additive model predicting adherence to follow up by each of these elements of centralization and the general time period relative to the pandemic. For target adherence, we found statistically significant higher odds of individuals receiving timely follow up at facilities that reported an LCS coordinator (OR 1.2, 95% CI 1.12-1.30), using EMR reminders (OR 1.57, 95% CI 1.40-1.77), and having LCS coordinators assist with shared-decision making conversations (OR 1.18, 95% CI 1.02-1.36) at the time of initial scan. When assessed for the more lenient minimum adherence timeframe, all 4 elements of centralization were associated with statistically significant higher odds of adherence when reported at the time of an individual's initial scan (LCS coordinator OR 1.87, LCS registry OR 2.13, EMR reminders OR 3.24, and LCS coordinator assistance with SDM OR 2.05).

Discussion:

The current analysis is the largest to date evaluating the comparative effectiveness of screening programs with a focus on the implementation of centralization. We should note that the severity of Lung-RADS scores reported in our current analysis suggests the higher lung cancer risk in this patient population. Compared to the NLST, a higher proportion of veterans in our study had concerning findings (Lung-RADS 3-4) compared to post-hoc analysis of the NLST cohort[62] (19.9% vs 5.8-7.3%). We found similar proportions of veterans with Lung-RADS

category 1-4 as has been previously reported in a veteran cohort from 2015-2019[60]. This likely reflects enrichment for lung cancer risk given smoking behavior and demographics in the cohort that utilized VA services.

When evaluating LCS uptake, we found that there was no significant difference in screening uptake rates at self-reported hybrid centralization programs and broadly based on our ordinal measure of centralization when compared to decentralized programs. Paradoxically, we did however find that self-reported consult/fully centralized programs were associated with lower rates of uptake. There are a number of potential explanations for this finding. Many the programs that fully centralized their LCS programs did so late in our study period. Broad centralization likely takes significant time and training, and there may be a general learning period and gradual role out after implementation before the benefit materializes, and this training/role out is likely to vary by facility. Our model cannot fully capture that learning period of early implementation, and it's possible that with a longer study period, these fully centralized programs would improve their uptake rates relative to hybrid or decentralization programs. Additionally, there may be a ceiling effect at high volume programs. The individuals who are easiest/most willing to engage with screening may be recruited rapidly initially as programs implement. However, the rate of new individuals entering screening may taper as the individuals remaining, beyond new individuals aging into screening eligibility, may either have barriers to healthcare access or may be the most reticent to participate in screening. If the facilities that self-selected to fully centralize their programs were already high performance programs before centralizing, they may be disproportionally hampered by this ceiling effect compared to programs with lower screening rates relative to their eligible population. We cannot, however, rule out the possibility that there could be a bottle-neck in throughput in fully centralized programs as the smaller LCS program staff attempt to screen a population that was previously served by a larger number of primary care physicians. Additionally, it's possible that the loss of PCP's longitudinal rapport and trust with patients may lead to decreased patient

willingness to engage with screening. Hybrid programs that still rely significantly on primary care physician's interactions with patients during initial invitation to screening may not suffer from the loss of this PCP-patient rapport compared to fully centralized/consult programs.

In the current analysis, we didn't see significant differences in uptake for Black veterans relative to White veterans, but we did see lower uptake for Hispanic Veterans. The lack of a Black/White disparity in LCS uptake is similar to what has been reported in other cancer screening in the VHA such as prostate cancer screening[91], and similar survival for lung cancer[92]. It also suggests that there does not appear to be different rates of participating in screening based on hesitancy or stigma as has been cited previously[93]. This supports prior studies in and outside the VHA that reinforced that Black veterans participate in LCS at similar rates once actually referred to screening[27,88]. It remains unclear the driver of the disparity in uptake seen amongst Hispanic veterans, and future research should focus on elucidating the potential barriers in this ethnic group. Our findings are contrary to prior assessment of a smaller cohort of VHA screening that found Hispanic veterans were more likely than White veterans to participate in LCS[94]. There is evidence that Hispanic individuals are less likely to meet LCS eligibility criteria relative to cancer risk, which may be a potential explanation of these findings[80]. We notably also saw lower odds of adherence for Black Veterans compared to White Veterans, corresponding to 10% lower odds of meeting target adherence and around 7% lower odds of meeting the more lenient minimum adherence targets, all else equal. Our findings recapitulate others researchers findings of Black/White disparities for LCS adherence[26,46], and highlights the continued need for research into novel interventions beyond centralization alone to close this disparity. We did not see statistically significant lower odds for Hispanic Veterans relative to White Veterans for being adherent in follow up, but as this population only represented 3.6% of the overall study, our study may have been relatively underpowered to find a statistically significant difference.

When evaluating adherence, we found that broadly centralization was associated with higher odds of individuals receiving timely and appropriate follow-up. When evaluated by the more permissive minimum adherence timeframes given potential delays associated with the COVID19 pandemic, these effect sizes are even more impressive in favor of centralization. Self-reported hybrid programs appeared to be associated with the highest odds of minimum adherence, around 2.6 fold higher odds of delivering appropriate and timely follow up compared to decentralized programs when evaluated by these more permissive minimum adherence timeframes. We postulate this again may be due to leveraging aspects of the longitudinal relationship/trust that many patients develop with their PCPs over time. However, our observational study cannot definitively demonstrate that hybrid centralization is the optimal screening strategy in all settings, and future research is needed to fully characterize the drivers of the higher adherence rates at hybrid programs seen in the current study.

These findings provide a number of potential policy implications for healthcare facilities considering centralizing their lung cancer screening programs. Centralization of lung cancer screening programs does appear to be associated with significantly higher odds of timely follow up, but appears to have mixed effects on LCS uptake. For facilities considering implementing centralization, it's possible that one size need not fit all. For large facilities with a large LCS eligible population, a hybrid program may provide the optimal balance of program performance and adherence while diffusing the recruitment of individuals into screening across the primary care physicians working at that facility. Conversely, a facility serving a smaller LCS eligible population may find a fully centralized/consult program can serve their patient population with improved standardization and economies of scale by concentrating LCS resources. Additionally, we must acknowledge that the vertical integration of the healthcare system that is true in the VHA is not true in every healthcare system and may make implementing fully centralized programs impractical. These programs additionally are associated with significant resources to implement. Given primary care physicians are still leveraged significantly for

hybrid programs, hybrid programs may be relatively less cost and personnel intensive to implement. Our study suggests that hybrid programs may strike the right balance between centralized coordination and PCP's longitudinal rapport with patients, and can still lead to significant improvements in a program's LCS adherence. Furthermore, hybrid programs may be an attractive implementation for healthcare systems that lack the vertical integration of the VA that facilitates implementation of fully centralized screening programs.

It's possible the hybrid model could further be optimized to unburden PCPs while still leveraging their longitudinal relationships with patients, especially during the initial recruitment to participate in screening. Given the time required to conduct and document a shared decision making conversation required for screening, these conversations could be facilitated by trained allied health professionals. But PCPs could still reinforce and highly encourage their patients to participate in screening, and furthermore to participate annually should they remain eligible. Centralized resources could still provide significant support on behalf of PCPs for the coordination of appropriate and timely follow up as our data suggests adherence is especially where hybrid programs excel. This hypothesis one our group intends to explore further in future research.

Because these elements of centralization are both highly correlated and contingent (i.e. a facility cannot have a coordinator assist in shared decision making conversations without having a coordinator, nor can a facility have EMR reminders without some version of registry/tracking, etc), the current analysis is unable to conclude the relative impact of these elements of centralization to each other, and the magnitude of the odds ratios should not be interpreted as to their relative importance. It is very possible that there could be a synergistic effects of these elements of centralization that our current model cannot account for, nor can our analysis prove that elements that did not have statistically significant higher odds are not still quintessential to a well-functioning screening program. However, it does seem that each of these elements are associated with higher odds of having individuals return in follow up as

measured by minimum adherence, and many are associated with higher odds of achieving target adherence. Additionally, some of the EMR based interventions are easy to implement without significant investment in additional personnel and may be appealing first steps for the most resource-limited healthcare systems.

Limitations:

Our study is not without limitations, many of which stem from the study's observational nature. Facilities included in this analysis frequently self-selected to implement centralization in their lung cancer screening programs. Subsequently, there may be unmeasured qualities of these facilities that led to their success beyond centralization, whether that be increased awareness about LCS, provider enthusiasm, or additional resource investment more broadly into LCS efforts. Our study team attempted to utilize station complexity score as a surrogate of this increased academic affiliation and resourcing. Additionally, there could be confounding due to the distribution of where LCS scans are available. Prior researchers have highlighted the geographic disparities in LCS availability especially for more rural populations[63,95,96], and centralized facilities frequently based in more urban centers may have disproportionally served populations with easier access to screening scanners. Our models did control for rurality at the individual level, but detailed geographic mapping of LCS availability was outside the scope of the current study.

Secondarily, our study utilized administrative data which can be misclassified. Our study relied on a standardized algorithm for identifying scans as likely performed for lung cancer screening. If facilities are coding studies without Lung-RADS scores or using alternative diagnostic coding, their studies may be missing particularly from our adherence analysis. We however believe that Lung-RADS adoption is a characteristic of a high-quality LCS program. Additionally, our study is only able to account for care received at VHA facilities, and it is likely that veterans may have also sought either through co-insurance like Medicare or via care paid for by the VA but delivered at non-VHA, community facilities. This may be especially relevant for

veterans who live a long distance from their nearest VA facility especially veterans of the highest rurality, and subsequently may seek care closer to their home address. Additionally, there was missingness that limited the ability to calculate some data elements like Elixhauser Comorbidity Index that is correlated with healthcare system access. We, however, felt it important to include this covariate in our models as an important balancing measure to evaluate if patients with high medical comorbidity may be less likely to be offered screening (presumably due to perceived lower benefit).

Third, our study is limited by the precision of the observational data used to characterize facilities LCS programs. The NCLCS survey was not designed specifically as a scientific organizational survey. Both surveys were administered across the VA but were subject to missingness related to response and recall bias of respondents commonly seen with voluntary survey responses. Additionally, our study had to rely on the precision of the questions and responses available, and therefore a more nuanced analysis of each facility's implementation methodology was not possible without conducting extensive surveys of our own with facilities which was outside the scope of the current analysis. We do however believe the current analysis is still representative of broad trends that could be expected with implementing centralization of LCS.

Conclusion:

Rapid improvement in LCS rates will undoubtedly be one component of improving lung cancer mortality. Centralization of lung cancer screening programs is one intervention that has shown promise. Our study presents the largest to date investigating the impact of centralization of lung cancer screening programs on LCS rates. Centralization was associated with broad improvements in lung cancer screening adherence, and hybrid programs had similar rates of uptake. Given half of lung cancers were discovered in follow up in the National Lung Screening Trial (NLST), adherence in follow up is critical to achieving the 20% reduction in lung cancer

mortality seen in the landmark trial[8]. Furthermore, our study harnessed observation, nationwide data and therefore may be more representative of the impact of centralization in the real-world and in multiple varied practice settings. It is unlikely that every healthcare system can broadly fully centralize its LCS efforts. However, this research suggests that there are implementable elements of screening that may be more broadly implementable like EMR reminders and centralized registries, and many of the benefits of centralization are achieved by the less personnel intensive hybrid programs.

Tables & Figures

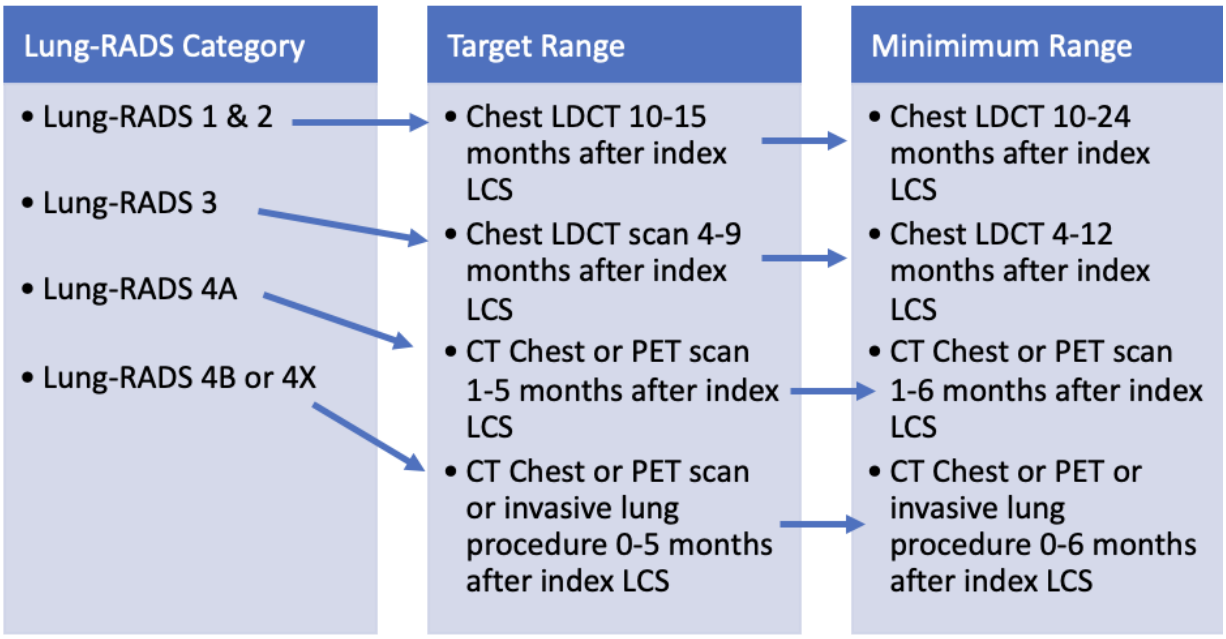

Figure 4: Adherence algorithm by Lung-RADS score
Lung-RADS is a quality assurance tool published by the American College of Radiology to standardize LCS CT reporting and management recommendations. The Lung-RADS categories range from 1, negative, to 4, suspicious for malignancy, with additional sub-categories in Lung-RADS 4. Target and Minimum Ranges were based on intervals for adherence follow up based on those utilized for the NLST[8] and liberal adherence timeframes previously published by study team members[60].

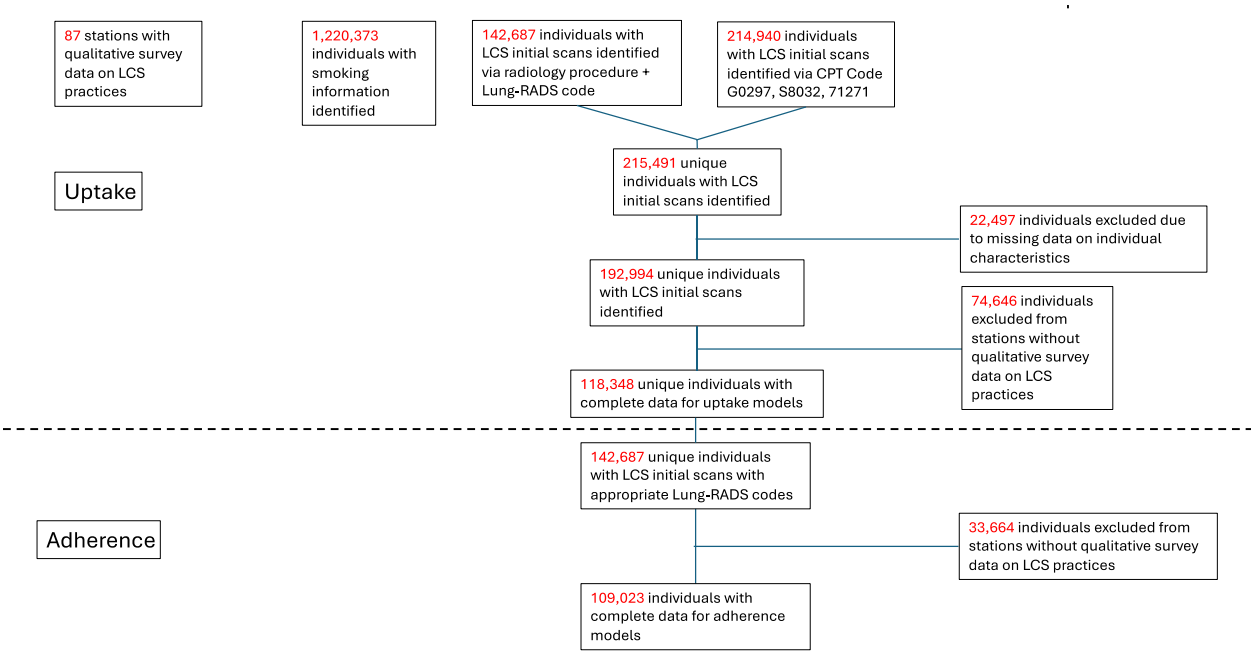

Figure 5: Flowchart of data sources and complete cases utilized for analysis

	Overall (N=192994)
Lung-RADS Category	
Missing	83230
- 1 & 2	87907 (80.1%)
- 3	13216 (12.0%)
- 4A	5794 (5.3%)
- 4B & 4X	2847 (2.6%)
Station Centralization, Self-Reported	
Missing	26992
- Hybrid	57528 (34.7%)
- Consult	39417 (23.7%)
- Decentralized	69057 (41.6%)
Station Centralization, Ordinal	
Missing	19571
- Low	56808 (32.8%)
- High	26343 (15.2%)
- Decentralized	90272 (52.1%)
Race/Ethnicity	
Missing	8345
- NH White	139367 (75.5%)

- NH Black	34536 (18.7%)
- Hispanic	6685 (3.6%)
- Other	4061 (2.2%)
Age	
- 55-64	74129 (38.4%)
- 65-74	103459 (53.6%)
- 75-80	15406 (8.0%)
National ADI[1]	
Missing	8387
- Less Disadvantaged	148835 (80.6%)
- More Disadvantaged	35772 (19.4%)
State ADI[1]	
Missing	8387
- Less Disadvantaged	135145 (73.2%)
- More Disadvantaged	49462 (26.8%)
Priority Group[2]	
Missing	4898
- 1-3	97249 (51.7%)
- 4-8	90847 (48.3%)
Elixhauser Comorbidity Index	
Missing	64173
- Mean (SD)	3.115 (2.275)
- Range	0.000 - 20.000
Elixhauser, dichotomized	
Missing	64173
- Less Than 5	100319 (77.9%)
- At Least 5	28502 (22.1%)
Veteran Rurality[3]	
Missing	4995
- Urban	128512 (68.4%)
- Rural	53027 (28.2%)
- Highly Rural	6460 (3.4%)
Parent Facility Complexity[4]	
- 1a-High Complexity	94903 (49.2%)
- 1b-High Complexity	49825 (25.8%)
- 1c-High Complexity	39177 (20.3%)
- 2-Medium Complexity	5669 (2.9%)
- 3-Low Complexity	3420 (1.8%)
Facility Rurality[3]	
- Urban	187797 (97.3%)
- Rural	5197 (2.7%)

[1] Area Deprivation Index (ADI) is a ranking of neighborhoods by socioeconomic disadvantage at the state or national level and is reported by the Neighborhood Atlas

published by the Kind et al. research group from the University of Wisconsin-Madison. National ADI is ranked 1-100, and State ADI is ranked in deciles 1-10, with higher scores corresponding to increased disadvantage.
[2] Priority Group is a designation given by the VHA to each Veteran utilizing services and determines a Veteran's out-of-pocket cost/copayments, ranging from Group 1 with little to no out of pocket cost to group 8 with the highest out-of-pocket cost.
[3] Address rurality is reported by the VHA for each primary address based on United States Department of Agriculture (USDA) Rural-Urban Commuting Area Code (RUCA) associated with the Census Tract of that address.
[4] Parent Facility Complexity Score is a designation used by VHA as a general measure of a facilities size, patient complexity, available clinical services, and academic affiliation. It ranges from a maximum of 1a to 3.

Table 4: Baseline Characteristics of Uptake Cohort
Percentages reported exclude missing data.

	Ordinal Centralization				Self-Reported Centralization			
Characteristic	**N**	**IRR[1]**	**95% CI[1]**	**p-value**	**N**	**IRR[1]**	**95% CI[1]**	**p-value**
Ordinal Centralization	108,692							
Decentralized		—	—					
Low		0.80	0.49, 1.29	0.363				
High		0.64	0.37, 1.10	0.108				
Self-Reported Centralization					104,892			
Decentralized						—	—	
Hybrid						0.93	0.59, 1.45	0.74
Consult						0.50	0.28, 0.89	0.019
Time in quarters (linear)		1.05	1.01, 1.10	0.009		1.05	1.01, 1.10	0.013
Time Period (categorical)								
Before Apr 2020		—	—			—	—	
Between Apr and Dec 2020		0.47	0.38, 0.59	<0.001		0.48	0.38, 0.60	<0.001
After Dec 2020		0.74	0.59, 0.92	0.008		0.74	0.59, 0.94	0.012
Parent Facility Complexity								
1a-High Complexity		—	—			—	—	
1b-High Complexity		1.33	0.73, 2.40	0.354		1.41	0.80, 2.46	0.23
1c-High Complexity		1.02	0.48, 2.19	0.960		0.91	0.40, 2.05	0.81
2-Medium Complexity		0.61	0.19, 1.94	0.403		2.38	0.75, 7.56	0.14
3-Low Complexity		0.39	0.20, 0.78	0.007		0.72	0.37, 1.40	0.33
NH Black (10% ↑)		0.96	0.85, 1.08	0.499		0.95	0.86, 1.06	0.38
Hispanic (10%↑)		0.64	0.46, 0.88	0.007		0.58	0.41, 0.82	0.002
NH Other (10%↑)		1.11	0.83, 1.48	0.475		2.00	0.63, 6.36	0.24
Top 15% Disadvantage National ADI (10%↑)		1.16	0.96, 1.41	0.134		1.11	0.93, 1.33	0.25
Individual Rurality								
Rural (10%↑)		0.84	0.67, 1.05	0.127		0.89	0.71, 1.11	0.29
Highly Rural (10%↑)		1.34	0.80, 2.25	0.264		0.67	0.32, 1.42	0.30
Priority Group 4-8 (10%↑)		0.86	0.64, 1.16	0.329		0.90	0.67, 1.21	0.50
Elixhauser >= 5 (10%↑)		1.11	0.68, 1.84	0.671		1.39	0.84, 2.29	0.21

[1]IRR = Incidence Rate Ratio, CI = Confidence Interval

Table 5: Multivariate Model Output for Quarterly Uptake Rate By Centralization

Incidence Rate Ratios (IRRs) are reported from a Poisson model via a generalized estimating equation. The left column reports output for centralization measured by our ordinal indicator variable based on reported itemized elements of centralization, and the right column reports model output for stations self-reported centralization status. For individual-level characteristics (Race/Ethnicity, National ADI of primary address, Rurality of primary address, assigned priority group, and Elixhauser Comorbidity Index), IRR's are based on the predicted ratio difference based on a 10% increase in the proportion of individuals with that characteristic.

Abbreviations: Apr = April, Dec = December, NH = Non-Hispanic, ADI = Area Deprivation Index, ↑= increase

	1 & 2 (N=87344, 80.1%)	3 (N=13108, 12.0%)	4A (N=5752, 5.3%)	4B & 4X (N=2819, 2.6%)	Total (N=109023)	p value
Target Adherence						< 0.001
Missed	60702 (69.5%)	8296 (63.3%)	3237 (56.3%)	1062 (37.7%)	73297 (67.2%)	
Met	26642 (30.5%)	4812 (36.7%)	2515 (43.7%)	1757 (62.3%)	35726 (32.8%)	
Minimum Adherence						< 0.001
Missed	54005 (61.8%)	7792 (59.4%)	3085 (53.6%)	1021 (36.2%)	65903 (60.4%)	
Met	33339 (38.2%)	5316 (40.6%)	2667 (46.4%)	1798 (63.8%)	43120 (39.6%)	
Station Centralization, Ordinal						< 0.001
Missing	5768	800	502	220	7290	
Decentralized	47579 (58.3%)	6453 (52.4%)	2902 (55.3%)	1407 (54.1%)	58341 (57.3%)	
Low	25192 (30.9%)	4669 (37.9%)	1883 (35.9%)	880 (33.9%)	32624 (32.1%)	
High	8805 (10.8%)	1186 (9.6%)	465 (8.9%)	312 (12.0%)	10768 (10.6%)	
Station Centralization, Self-reported						< 0.001
Missing	8947	1182	657	308	11094	
Decentralized	38058 (48.5%)	5311 (44.5%)	2336 (45.8%)	1128 (44.9%)	46833 (47.8%)	
Hybrid	23959 (30.6%)	3872 (32.5%)	1534 (30.1%)	845 (33.7%)	30210 (30.8%)	
Consult	16380 (20.9%)	2743 (23.0%)	1225 (24.0%)	538 (21.4%)	20886 (21.3%)	
Race/Ethnicity						< 0.001
Missing	3906	537	243	129	4815	
NH White	62472 (74.9%)	9854 (78.4%)	4433 (80.5%)	2125 (79.0%)	78884 (75.7%)	
NH Black	16875 (20.2%)	2133 (17.0%)	845 (15.3%)	454 (16.9%)	20307 (19.5%)	
Hispanic	2225 (2.7%)	339 (2.7%)	113 (2.1%)	41 (1.5%)	2718 (2.6%)	
Other	1866 (2.2%)	245 (1.9%)	118 (2.1%)	70 (2.6%)	2299 (2.2%)	
Age (categorical)						< 0.001
55-64	36178 (41.4%)	4807 (36.7%)	1826 (31.7%)	731 (25.9%)	43542 (39.9%)	
65-74	45322 (51.9%)	7162 (54.6%)	3318 (57.7%)	1724 (61.2%)	57526 (52.8%)	
75-80	5844 (6.7%)	1139 (8.7%)	608 (10.6%)	364 (12.9%)	7955 (7.3%)	
National ADI[1]						0.13
Missing	3306	609	335	306	4556	
Less Disadvantaged	66037 (78.6%)	9874 (79.0%)	4247 (78.4%)	1932 (76.9%)	82090 (78.6%)	
More Disadvantaged	18001 (21.4%)	2625 (21.0%)	1170 (21.6%)	581 (23.1%)	22377 (21.4%)	
State ADI[1]						0.006
Missing	3306	609	335	306	4556	
Less Disadvantaged	61980 (73.8%)	9242 (73.9%)	3910 (72.2%)	1800 (71.6%)	76932 (73.6%)	
More Disadvantaged	22058 (26.2%)	3257 (26.1%)	1507 (27.8%)	713 (28.4%)	27535 (26.4%)	
Priority Group[2]						< 0.001
Missing	1732	355	211	244	2542	
1-3	44028 (51.4%)	6519 (51.1%)	2657 (48.0%)	1253 (48.7%)	54457 (51.1%)	
4-8	41584 (48.6%)	6234 (48.9%)	2884 (52.0%)	1322 (51.3%)	52024 (48.9%)	
Elixhauser Comorbidity Index						< 0.001
Mean (SD)	3.074 (2.254)	3.073 (2.282)	3.118 (2.315)	3.268 (2.337)	3.081 (2.263)	
Range	0.000 - 19.000	0.000 - 17.000	0.000 - 20.000	0.000 - 18.000	0.000 - 20.000	
Elixhauser, dichotomized						0.017
Less Than 5	68437 (78.4%)	10284 (78.5%)	4482 (77.9%)	2140 (75.9%)	85343 (78.3%)	
At Least 5	18907 (21.6%)	2824 (21.5%)	1270 (22.1%)	679 (24.1%)	23680 (21.7%)	

Individual Rurality[3]						0.12
Missing	1774	361	214	246	2595	
Urban	57780 (67.5%)	8630 (67.7%)	3664 (66.2%)	1691 (65.7%)	71765 (67.4%)	
Rural	24880 (29.1%)	3657 (28.7%)	1673 (30.2%)	787 (30.6%)	30997 (29.1%)	
Highly Rural	2910 (3.4%)	460 (3.6%)	201 (3.6%)	95 (3.7%)	3666 (3.4%)	
Parent Facility Complexity Score[4]						< 0.001
1a-High Complexity	46150 (52.8%)	6738 (51.4%)	3231 (56.2%)	1531 (54.3%)	57650 (52.9%)	
1b-High Complexity	23830 (27.3%)	3496 (26.7%)	1471 (25.6%)	775 (27.5%)	29572 (27.1%)	
1c-High Complexity	13801 (15.8%)	2111 (16.1%)	760 (13.2%)	369 (13.1%)	17041 (15.6%)	
2-Medium Complexity	1413 (1.6%)	157 (1.2%)	90 (1.6%)	50 (1.8%)	1710 (1.6%)	
3-Low Complexity	2150 (2.5%)	606 (4.6%)	200 (3.5%)	94 (3.3%)	3050 (2.8%)	
Parent Station Rurality[3]						0.017
Urban	85648 (98.1%)	12893 (98.4%)	5663 (98.5%)	2759 (97.9%)	106963 (98.1%)	
Rural	1696 (1.9%)	215 (1.6%)	89 (1.5%)	60 (2.1%)	2060 (1.9%)	

[1] Area Deprivation Index (ADI) is a ranking of neighborhoods by socioeconomic disadvantage at the state or national level and is reported by the Neighborhood Atlas published by the Kind et al. research group from the University of Wisconsin-Madison. National ADI is ranked 1-100, and State ADI is ranked in deciles 1-10, with higher scores corresponding to increased disadvantage.
[2] Priority Group is a designation given by the VHA to each Veteran utilizing services and determines a Veteran's out-of-pocket cost/copayments, ranging from Group 1 with little to no out of pocket cost to group 8 with the highest out-of-pocket cost.
[3] Address rurality is reported by the VHA for each primary address based on United States Department of Agriculture (USDA) Rural-Urban Commuting Area Code (RUCA) associated with the Census Tract of that address.
[4] Parent Facility Complexity Score is a designation used by VHA as a general measure of a facilities size, patient complexity, available clinical services, and academic affiliation. It ranges from a maximum of 1a to 3.

Table 6: Adherence cohort baseline characteristics, stratified by Lung-RADS score at initial scan

P-values reported are 1 way analysis of variance (ANOVA) tests between columns.

Characteristic	N	OR[1]	95% CI[1]	p-value	N	OR[1]	95% CI[1]	p-value	N	OR[1]	95% CI[1]	p-value	N	OR[1]	95% CI[1]	p-value
Facility Ordinal Centralization Status	93,205								93,205							
Decentralized		—	—							—	—					
Low		1.3	1.19, 1.41	<0.001						1.95	1.80, 2.11	<0.001				
High		1.13	0.99, 1.29	0.07						1.88	1.67, 2.12	<0.001				
Self-Reported Centralization Status					89,709								89,709			
Decentralized						—	—							—	—	
Hybrid						1.57	1.42, 1.73	<0.001						2.66	2.44, 2.91	<0.001
Consult						0.93	0.83, 1.03	0.16						1.19	1.07, 1.31	0.001
Time Period																
Before Apr 2020		—	—			—	—			—	—			—	—	
Between Apr and Dec 2020		0.48	0.46, 0.50	<0.001		0.48	0.46, 0.50	<0.001		0.64	0.62, 0.67	<0.001		0.62	0.59, 0.64	<0.001
After Dec 2020		0.3	0.29, 0.32	<0.001		0.31	0.29, 0.32	<0.001		0.33	0.32, 0.35	<0.001		0.33	0.32, 0.35	<0.001
Parent Station Complexity																
1a-High Complexity		—	—			—	—			—	—			—	—	
1b-High Complexity		0.98	0.47, 2.06	0.957		1	0.48, 2.08	>0.99		0.98	0.42, 2.31	0.97		1.02	0.45, 2.31	0.97
1c-High Complexity		1.03	0.44, 2.40	0.941		0.93	0.40, 2.17	0.86		1.03	0.39, 2.72	0.96		0.9	0.35, 2.33	0.82
2-Medium Complexity		1.04	0.23, 4.76	0.958		1.14	0.23, 5.64	0.87		0.95	0.16, 5.48	0.95		0.99	0.16, 5.96	0.99
3-Low Complexity		0.84	0.30, 2.33	0.738		0.51	0.15, 1.65	0.26		0.73	0.23, 2.36	0.60		0.34	0.09, 1.24	0.10
Race/Ethnicity																
NH White		—	—			—	—			—	—			—	—	
NH Black		0.9	0.87, 0.94	<0.001		0.9	0.86, 0.94	<0.001		0.93	0.89, 0.97	<0.001		0.93	0.89, 0.97	<0.001
Hispanic		0.94	0.85, 1.04	0.254		0.94	0.85, 1.04	0.26		0.95	0.86, 1.04	0.29		0.95	0.86, 1.04	0.27
Other		0.99	0.89, 1.09	0.778		0.97	0.87, 1.08	0.58		1	0.91, 1.11	0.98		0.98	0.88, 1.09	0.73
National ADI																
Less Disadvantaged		—	—			—	—			—	—			—	—	
More Disadvantaged		0.95	0.92, 0.99	0.011		0.95	0.92, 0.99	0.006		0.96	0.92, 0.99	0.01		0.95	0.92, 0.99	0.011
Veteran Rurality																
Urban		—	—			—	—			—	—			—	—	
Rural		0.96	0.93, 1.00	0.028		0.96	0.92, 0.99	0.014		0.96	0.93, 0.99	0.015		0.95	0.92, 0.99	0.008
Highly Rural		0.92	0.85, 1.00	0.047		0.89	0.81, 0.97	0.011		0.92	0.85, 1.00	0.04		0.89	0.82, 0.98	0.014
Priority Group																
1-3		—	—			—	—			—	—			—	—	
4-8		0.91	0.88, 0.94	<0.001		0.91	0.88, 0.94	<0.001		0.9	0.87, 0.93	<0.001		0.9	0.88, 0.93	<0.001
Elixhauser Comorbidity Index																
Less Than 5		—	—			—	—			—	—			—	—	
At Least 5		0.87	0.84, 0.90	<0.001		0.87	0.83, 0.90	<0.001		0.87	0.84, 0.90	<0.001		0.87	0.84, 0.90	<0.001
Smooth Random Effect for Parent Station				<0.001				<0.001				<0.001				<0.001

[1]OR = Odds Ratio, CI = Confidence Interval

Table 7: Multivariate Model Output of Target and Minimum Adherence by Centralization

Model output reports Odds Ratios (OR) based on logistic regression. The left two columns report the outcome of target adherence predicted by an ordinal indicator variable of centralization and self-reported centralization. The right 2 columns reports the outcome of minimum adherence as predicted by an ordinal indicator variable of centralization and self-reported centralization.

Centralization Characteristic	N[1]	IRR[1]	95% CI[1]	p-value

LCS Coordinator Hired	139,027	0.8	0.55, 1.17	0.25
LCS Registry Installed	113,613	0.55	0.29, 1.07	0.07
LCS EMR Reminders Initiated	91,324	0.9	0.53, 1.52	0.69
LCS Coordinator SDM Support Available	80,342	0.52	0.26, 1.05	0.06

[1] N= Number of individuals included in model, IRR = Incidence Rate Ratio, CI = Confidence Interval

Table 8: Model of Uptake Predicted by Elements of Centralization
Reported values are Incidence Rate Ratios (IRRs) based on Poisson regression via a generalized estimating equation for models including an indicator variable for the element of centralization. Models also included a linear time variable corresponding to the quarter, and a categorical variable time period relative to the early and late COVID19 pandemic in which the scan was performed (data not shown).

	Target Adherence				Minimum Adherence		
Predictor	***N[1]***	***OR[1]***	***95% CI[1]***	***p-value***	***OR[1]***	***95% CI[1]***	***p-value***
LCS Coordinator Hired by First Exam Date	79,793	1.2	1.12, 1.30	<0.001	1.87	1.75, 2.00	<0.001
LCS Registry Installed by First Exam Date	65,153	0.94	0.82, 1.08	0.381	2.13	1.85, 2.44	<0.001
LCS EMR Reminders Initiated by First Exam Date	49,496	1.57	1.40, 1.77	<0.001	3.24	2.91, 3.61	<0.001
LCS Coordinator SDM Support by First Exam Date	44,461	1.18	1.02, 1.36	0.027	2.05	1.80, 2.35	<0.001

[1] N= Number of individuals included in model OR = Odds Ratio, CI = Confidence Interval

Table 9: Model of Adherence Predicted by Elements of Centralization
Reported values are Odds ratios based on logistic regression for bivariate models including an indicator variable for the element of centralization and the time period in which the scan was performed. Models also control for time period relative to the COVID19 pandemic (data not shown). Abbreviations: LCS = Lung Cancer Screening, SDM = Shared Decision-Making

Chapter 6: Manuscript 3

Improving Disparities? Centralization of Lung Cancer Screening and Race in the Veterans Healthcare Administration

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Declarations:
None.

Conflicts of Interest:
None.

Abbreviations:
LCS: Lung Cancer Screening
USPSTF: United States Preventive Services Task Force
EMR: Electronic Medical Record
PCP: Primary Care Physician
VHA: Veterans Health Administration
CT: Computed Tomography
ADI: Area Deprivation Index

Background:

There have been well described and longstanding racial disparities in lung cancer mortality and penetration of lung cancer screening in the United States (LCS). Lung cancer is the leading cause of cancer-related death[1], and that mortality is even higher amongst Black individuals. African American/Black individuals suffer the highest age-adjusted lung cancer incidence and the highest mortality rate of any racial/ethnic group[23]. African American/Black men in particular have the highest lung cancer mortality of any group in the United States, often at lower smoking intensity than other groups[24]. Additionally, studies have shown that Black individuals who develop lung cancer were less likely to be LCS eligible based on the United

States Preventive Services Task Force (USPSTF) initial 2013 LCS recommendation[25,97]. Compounding this disparity, recent systematic reviews of LCS data demonstrated that African Americans are screened at lower rates than their White counterparts, and less likely to receive subsequently follow-up[26,27]. However, these systematic reviews suggest African Americans participate at similar rates as their White counterparts once actually referred for LCS. These findings suggest that biases in referral or differential barriers to access may underlie these racial disparities in LCS rates rather than patient reticence.

"Centralization", or the utilization of dedicated health providers and centralized electronic medical record (EMR)-embedded tracking and reminder platforms to coordinate LCS programs, has shown exciting promise as a potential strategy for improving LCS rates especially amongst historically marginalized racial/ethnic groups. Centralization has been associated with broad improvement in rates of LCS uptake, or the number of new individuals entering screening, and adherence, or the proportion of individuals who receive timely follow up and repeated screening if indicated[44,45,56,57]Notably, centralization has also been associated with improved screening rates in Black individuals. Recently, a multi-center analysis of 5 lung cancer screening programs suggested that centralized lung cancer screening programs may perform better at improving Black/White disparities in screening rates compared to decentralized programs[46]. Yet many of the previously published literature relied on single center or smaller multi-center studies, and there has yet to be a large, nationally representative study of the impact of centralization on LCS rates. Additionally, these studies did not always control for potential patient and facility characteristics that may confound the relationship between program centralization and screening rates.

Though it remains unclear what precisely leads to centralized LCS programs improving Black/White disparities in screening rates, some potential hypotheses are apparent. With centralization and standardization of LCS procedures and tracking, there may be mitigation of individual provider bias or knowledge-gaps around LCS-eligibility, leading to more equitable

invitation to enter screening and receive subsequent follow up. Yet centralization is a multi-level intervention[45] that could be labor and resource intensive for some healthcare systems to implement. Additionally, there is variability in how centralization is implemented, ranging from fully centralized programs where primary care physicians "consult" a dedicated team that coordinates screening from intake through follow up, to more hybrid models where primary care physicians work with LCS program staff to coordinate screening. Evaluating what may be the ideal LCS model especially for improving Black/White disparities can benefit from more nuanced analysis of hybrid and fully centralized/consult models together. Healthcare systems could additionally gain valuable insights as to where/how to deploy their resources.

The Veterans Health Administration (VHA) provides a unique opportunity to study the impact of LCS centralization across a nationwide, integrated healthcare system that serves a racially diverse population at high risk for lung cancer. Notably, around 30% of Veterans are current tobacco product users[51], and around 13% are Black/African American[52]. Moreover, those who enter military service are more racially and ethnically diverse than those who do not, enriching the diversity of the patient population served by the VHA[53]. The population served by the VHA is majority male[67], and men represent the sex with the highest rates of lung cancer incidence and mortality[2]. Black/White disparities in LCS rates have been previously reported among Veterans[72,98]. In contrast, the Lung Cancer Demonstration Project suggested similar rates of screening for Black and White Veterans when centralization was implemented at 8 pilot facilities in the VHA[56], and improved Black/White disparities in adherence[57]. This study notably lacked a control group, however. Following the publication of these studies, the VHA actively supported healthcare facilities (called "stations" in the VHA) to centralize their LCS programs. This period of transition, as certain facilities elected to centralize their LCS programs, provides a robust natural experiment to investigate the comparative effectiveness of LCS programs relative to when certain programs centralized. Additionally, it provides an opportunity to model facility-

and individual-level characteristics that may confound the association of centralization and screening rates.

Objective:

We seek to investigate the relationship between race and LCS rates, and how LCS program centralization may moderate that relationship. To that end, we performed a mixed methods, multi-level, retrospective analysis by pairing qualitative surveys on LCS program centralization with VHA data in a subset of White and Black individuals.

Methods:

Study Population

The study cohort was identified utilizing the central EMR data repository for the VHA called the Corporate Data Warehouse (CDW). Unique Veterans were identified who utilized at least 1 outpatient visit at the VHA from October 1, 2015 through September 30, 2021, corresponding to the 2016 through 2021 fiscal years. Veterans were excluded due to not meeting the age requirements of being 55-80 during the study period (assessed annually), or if the medical record indicated a date of death prior to October 1, 2015. From this broader population, we identified a subset of individuals who were identified as non-Hispanic White or non-Hispanic Black. All further analyses were performed within this subset of White and Black individuals. Data was abstracted for each individual in the dataset to obtain their age, sex, National Area Deprivation Index (ADI) which ranges from 1-100[38], State ADI which ranges in deciles from 1-10[38], Veteran priority group (a designation which determines a Veteran's out of pocket cost share for utilizing VA services), marital status, an individual's primary address rurality based on U.S. Department of Agriculture's Rural-Urban Commuting Area (RUCA) codes[74], and distance to the nearest VHA facility in miles. National ADI was dichotomized into those from the top 15 ADI of disadvantage and the bottom 84 ADI score, and State ADI was dichotomized into the top 2 deciles and the bottom 8 deciles of disadvantage. Higher values of

each ADI measure correspond to higher disadvantage. Elixhauser Comorbidity Index was also calculated for each individual, and then dichotomized to those < 5 and ≥ 5, as 5 was roughly 1 SD above the mean comorbidity score in the dataset. Higher Elixhauser values correspond to higher comorbidity. Veterans living in an insular/island rurality were dropped from the analysis (representing < 0.1% of the overall study cohort). International Classification of Diseases ICD-9 and ICD-10 diagnostic codes for comorbid mental illness (made from an aggregate of the diagnoses of depression, post-traumatic stress disorder (PTSD), and schizophrenia) and substance abuse were used to identify patient's holding these diagnoses. These diagnostic codes adapted from diagnostic codes published by prior researchers using VHA data[60].

Additionally, Veterans were assigned to a designated home facility (also called "parent stations" by the VHA) by an algorithm that compared average primary care utilization during each fiscal year, and assigned Veterans to the facility of highest average utilization. The complexity score, a metric used by the VHA to indicate a facilities relative patient risk, academic affiliation, and resourcing, was attributed to each parent station[64,75].

Qualitative Surveys and Lung Cancer Screening Uptake and Adherence

We have previously described our methodology for dataset construction including abstraction of EMR data and qualitative surveys, identification of LCS scans, and assessment of LCS uptake and adherence (chapter 5). Briefly, we utilized abstracted qualitative data on LCS centralization to generate time varying indicator variables for each LCS program included in the current analysis. We utilized a set of radiology procedure names, Current Procedural Terminology (CPT) codes, International Classification of Diseases (ICD)-9 and ICD-10, and the presence of a Lung-RADS score to identify likely LCS scans and follow up procedures. We additionally utilized available structured smoking data to create estimates of the screening eligible population, scaled by the proportion of Black & White Veterans at that facility.

Statistical Analysis

To model LCS uptake, we fit a multi-level, Poisson model via a generalized estimating equation (GEE) with patients nested within stations and random effects at the station level. For adherence, we fit a generalized additive logistic regression model again with random effects at the station level. The generalized additive model was selected due to its increased computational speed/efficiency given the large size of the dataset, while yielding similar results to a logistic regression model[90]. All sensitive data was stored and analyzed on VINCI servers behind the VA's firewall in accordance with VA data use and security rules. We evaluated statistical significance at an alpha of 0.05. All statistical analysis was performed in compliance with VA data-use regulations, on VA furnished servers and using the build of the R statistical software package version 4.4.1 and STATA MP version 18 furnished by the VA Informatics and Computing Infrastructure (VINCI).

Results

Figure 1 presents a flow chart of the individuals identified for the study cohort. Out of a total of 1.2 million unique Black and White Veterans, 173,903 had undergone initial LCS scans, of which 112,662 had complete data for inclusion in our uptake analysis. Of those with initial screening scans identified, 85,452 had an associated Lung-RADS score and complete data for inclusion in our adherence analysis.

Table 1 presents the baseline characteristics of the overall 1.2 million person cohort of Black & White Veterans. A lower percentage of Black Veterans in the cohort met LCS eligibility by 2013 USPSTF criteria compared to White Veterans (17.1% vs 22.3% respectively). Overall, compared to White Veterans, Black Veterans tended to be younger, have higher rates of comorbid mental illness and substance use diagnoses, be more likely to live in the highest areas of disadvantage as measured by National and State ADI, were more likely to be single or divorced/separate/widowed, and were more likely to live in Urban setting. Subsequently, compared to White Veterans, Black Veterans lived closer to their nearest VHA facility, and a

higher proportion sought care at facilities with larger size and higher specialty services/academic affiliation as measured by facility complexity score, as these facilities are typically in urban settings.

Uptake:

Table 2 presents the combined baseline characteristics of Black and White Veterans who underwent screening. The majority of Veteran's had an initial scan that was benign or negative based on Lung-RADS score (Lung-RADS scores 1&2, 80%). The majority of Veterans were screened at decentralized programs (41.2%), followed by self-reported hybrid programs (34.7%) and fully centralized/consult programs (24.1%). 80.1% of the screened cohort was White, 19.9% was Black. The majority (67.6%) reported a primary address in an urban setting. The majority (48.6%) were screened at facilities with complexity scores associated with the largest size, specialty resourcing, and academic affiliation.

LCS uptake was defined as the quarterly count of new individuals entering screening relative to the proportional LCS eligible population at each facility. The first CT screening scan identified for an individual in the study period was considered their incident/initial scan. Given <1% of screening scans were identified prior to the study period, every individual was considered as eligible at the start of the study. To include an indicator for the overall decrease in LCS rates seen during the early and late pandemic we previously described (chapter 5), we included in our model a categorical time indicator variable that corresponded to whether screening occurred in the period before the pandemic (corresponding to before April 2020), during the first several months of lockdowns (April to December 2020), or after December 2020.

To explore the degree to which facility centralization may moderate the association of race on LCS uptake, we fit a Poisson regression via a generalized estimating equation of the quarterly rate of new individuals entering screening predicted by a facility self-reported centralization status, race, and the interaction of race and facility centralization. Our model also controlled for time period relative to the pandemic, size/resourcing of the facility performing

screening, race, primary address national ADI rank, primary address rurality, broad out-of-pocket cost for receiving VA services, and overall health status as measured by Elixhauser Comorbidity Index. Included in the model was an offset term for the estimate LCS eligible population at each facility as a balancing measure for the size of a population served at a facility, preventing large stations with high LCS eligible populations from outweighing smaller stations. For individual characteristics like race, primary address National ADI, primary address rurality, out-of-pocket cost for services as measured by priority group, and medical comorbidity as measured by Elixhauser Comorbidity Index, we modeled the impact of a 10% increase in the proportion of individuals having that characteristic in the population served at the facility.

Table 3 presents our model output. We found that generally there was a quarterly 5% increase in new Veterans entering screening over the study period (IRR 1.05, 95% CI 1.01-1.10) corresponding to the overall secular trend in uptake rates. We found that compared to pre-pandemic, the early and late time periods of the pandemic were associated with significant decreases in LCS uptake (IRR 0.48, 95% CI 0.28-0.61 and IRR 0.74, 95% CI 0.58-0.93 respectively). We did not find a statistically significant difference in the LCS uptake rate comparing decentralized, hybrid, and fully centralized/consult stations. Nor did we find a statistically significant difference in LCS uptake associated with a 10% increase in a facility's Black population served. We did, however, find a statistically significant interaction between self-reported hybrid LCS programs and Black race, corresponding to a 14% increase in LCS uptake for every 10% increase in the proportion of Black Veterans at that facility, all else equal (IRR 1.14, 95% CI 1.01-1.28). We did not find a statistically significant interaction between fully centralized/consult facility and Black race in our model.

There did not appear to be any significant difference in LCS uptake based on facility complexity. We also did not find any statistically significant association between a 10% change in the proportion of individuals living in high disadvantage locations as ranked by National ADI, living in rural/highly rural locations, having increased out-of-pocket cost based on Veteran

assigned priority group, nor having increased medical comorbidity as measured by Elixhauser Comorbidity Index.

Adherence:

LCS adherence was defined as a binary outcome of whether an individual received appropriate diagnostic follow up or subsequent screening at the first follow-up after initial scan as determined by the initial scan's Lung-RADS score. Supplemental eFigure 1 outlines the time intervals utilized for defining adherence. Again, we included in our model a categorical time indicator variable that corresponded to whether expected follow up occurred in the period before the pandemic (corresponding to before April 2020), during the first several months of lockdowns (April to December 2020), or after December 2020. Additionally, we examined adherence both at more stringent target range and a more lenient minimum range as outlined in Supplemental eFigure 1, to allow more time for follow up to be achieved in case it was disrupted by the pandemic.

To explore the degree to which facility centralization may moderate the association of race with LCS adherence, we fit a logistic regression via a generalized additive model of LCS adherence predicted by facility self-reported centralization, race, and the interaction of race and facility centralization. Our model also controlled for time period relative to the pandemic, size/resourcing of the facility performing screening, race, primary address national ADI rank, primary address rurality, broad out-of-pocket cost for receiving VA services as measured by Veteran assigned priority group, and overall health status as measured by Elixhauser Comorbidity Index. Table 4 presents odds ratios (OR) from our model output.

Broadly, the early and late pandemic was associated with lower odds of individuals being adherent to follow up at either the target or more lenient minimum adherence time frames. We found that, compared to decentralized LCS program, hybrid LCS programs were associated with higher adherence to follow up at both target and the more lenient minimum adherence time frames, all else equal (OR 1.54, 95% CI 1.39-1.71 and OR 2.68, 95% CI 2.44-2.95). Compared

to decentralized programs, we did not find a statically significant difference in target adherence for fully centralized/consult programs, but we did for minimum adherence (OR 1.17, 95% CI 1.05-1.31). We found that compared to White individuals, Black individuals had lower odds of being adherent at the target time frame (OR 0.88, 95% CI 0.83-0.94) and the more lenient minimum adherence timeframe, all else equal (OR 0.92, 95% CI 0.92-0.98). We did not find a statistically significant association between the interaction of facility centralization and race for either hybrid or consult programs.

We did not find a significant association between parent facility complexity and LCS adherence. We did find lower odds of adherence with rising proportions of individuals living in addresses with the most disadvantage as ranked by National ADI, more rural addresses, having more out-of-pocket costs for VHA services as measured by priority group, and higher comorbidity as measured by Elixhauser Comorbidity Index.

Discussion

Our study is the largest to date that evaluates the comparative effectiveness of centralization of lung cancer screening programs and its potential moderation of Black/White disparities in LCS rates within the VHA. Our study additionally uses real-world data with a large dataset of comparator decentralized screening programs, a notable knowledge-gap in the current literature that suggests the benefits of centralization. Given the double burden in Black communities of higher lung cancer incidence[24] and reported lower screening rates in broadly in the United States[27] and amongst Black Veterans[72], it is critical to identify the interventions that ameliorate these disparities. Furthermore, it's paramount that interventions designed to improve screening rates do so equitably, and do not further perpetuate prior disparities.

Our study confirmed that a lower proportion of Black Veteran's met 2013 LCS eligibility criteria, echoing prior studies demonstrating concern that a disproportionate number of African American/Black smokers were not eligible for screening based on the 2013 USPSTF eligibility

criteria[25,97]. This disparity was sighted in part as motivating the USPSTF to expand eligibility in 2021[68]. Evaluating the impact of these expanded eligibility criteria is outside the scope of the current project, but it is clear that significant attention has focused on improving Black/White disparities in LCS rates, and the potential opportunity for centralization to ameliorate those disparities.

We found that hybrid lung cancer screening programs improves lung cancer screening rates for Black Veterans, accounting for a 14% increase in new Veterans entering screening for every 10% increase in the proportion of Black Veterans at a given facility. This finding is notable as it suggests these programs may be uniquely better able to improve LCS entry rates for African Americans compared to decentralized programs. There are a number of potential explanations of this finding. With implementation of centralization for lung cancer screening, there is likely increased provider education about screening and increased standardization for identifying those individuals who may benefit from screening. This increased education and standardization may improve any provider-level knowledge gaps or biases in who is offered screening. Equitable offering of LCS appears key to improving Black/White LCS disparities, as prior studies have suggested that lower offering of LCS to Black individuals may be linked to lower screening rates, and Black individuals participate in screening at similar rates as White individuals once actually referred for screening[27]. This is also suggested by our model not finding a statistically significant difference in LCS uptake with changing proportions of Black Veterans in a LCS program. Hybrid programs may additionally have an advantage over fully centralized/consult programs by leveraging the longitudinal relationship of primary care providers with their patients. It is likely patient-provider trust is paramount to agreement screening, as highlighted in surveys of Black Veterans[99].

Our study unfortunately showed that Black Veterans were less likely to receive appropriate and timely follow up. Centralization did not seem to significantly moderate this association. It is possible that centralization is unable to overcome potential unique barriers to

access that prevent Black Veterans from receiving timely follow up after initial screening. The baseline characteristics of the populations in our study cohort suggest that Black Veterans were more likely to live in locations with the highest disadvantage as ranked by national ADI, and this is in spite of the fact that many Black Veterans live closer to their nearest VHA facility than White Veterans. There may be additional location-based vulnerability/barriers that centralization doesn't address. There is interest in further exploring this possibility, as researchers have explored attempting to bring screening directly to areas of high disadvantage through mobile screening[100,101]. Additionally, there could be a number of unmeasured patient or provider level characteristics that may be disproportionate barriers to subsequent screening or adherence in follow up after a positive screen for Black Veterans. Additional diagnostic studies for positive screening entails navigating multiple providers or radiology visits in a timely fashion, which may compound disparities and barriers to screening. Our study also found that Black Veterans had higher rates of comorbid mental illness and substance use diagnoses, which has been shown by study team members to be associated with higher odds of delayed or absent adherence[60]. Future studies should investigate if interventions beyond centralization could better ameliorate these disparities.

Limitations:

There are some inherent limitations to the current study that are linked to its observational nature. Facilities included in this analysis frequently self-selected to implement centralization in their lung cancer screening programs. Subsequently, there may be unmeasured qualities of these facilities that led to their success beyond centralization, whether that be increased awareness about LCS, provider enthusiasm, or additional resource investment more broadly into LCS efforts. Our study team attempted to utilize station complexity score as a surrogate of this increased academic affiliation and resourcing. Additionally, our study is unable to measure provider-level characteristics or implicit biases that may impact Black Veteran participation in LCS and follow up, and must rely on more aggregate,

facility-level characteristics. There could be confounding due to the geographic distribution of where LCS scans are available. Prior research has demonstrated the geographic clustering of LCS availability in the VHA near urban centers[63], most facilities that centralized their screening programs were located in urban areas, and the Black Veterans in our study were proportionally more likely to live in urban centers than White Veterans. Our analysis did control for Veteran rurality, but there could be additional nuances to geographic access not captured by the current analysis.

In addition, our study utilized administrative data which can be misclassified. We also utilized qualitative surveys that may be at risk for response and recall bias, and may have imprecise responses. We attempted to control for imprecision for surveys by utilizing independent coders to abstract surveys, but subsequently rely on broad categories of centralization in the current study. Furthermore, our study is only able to account for care received at VHA facilities, and it is likely that Veterans may have also sought either through co-insurance like Medicare or via care paid for by the VA but delivered at non-VHA, community facilities. This may be especially relevant for Veterans who live a long distance from their nearest VA facility especially Veterans of the highest rurality, and subsequently may seek care closer to their home address. The majority of Black Veterans in our analysis lived in urban settings and nearer to a VHA facility than White Veterans, so we suspect missingness to bias towards the White Veteran population in our study.

There are a number of unique characteristics to the VHA that are distinct from other healthcare systems. Those who utilize the VHA have near universal health insurance benefits, and so the current study is unable to investigate the impact health insurance may have on LCS uptake and adherence. As highlighted, the population served is overwhelmingly male. Additionally, the VHA is vertically integrated which may additionally improve access and coordination of infrastructure and health providers central to LCS. Despite these distinctions from other healthcare systems in the US, we believe the results still have generalizable lessons

for a number of different healthcare systems and practice settings as LCS is a priority for many healthcare systems beyond the VHA, and the population served by the VHA faces some of the same social determinants of health and barriers to access as other healthcare systems.

Conclusion:

Identifying the most effective strategies for improving Black/White disparities in LCS rates is a nationwide priority, directly contributing to changing USPSTF eligibility guidelines. With multiple competing priorities for primary care physicians and healthcare systems, it is also critical to identify the interventions that are the most effective. Our study suggests that hybrid centralized programs that match primary care physicians with centralized EMR and LCS support staff may have an advantage in particularly recruiting new Black individuals into screening. These programs may also be appealing to healthcare systems as they support primary care physicians who already have a high burden of daily tasks[50], but still leverage their longitudinal relationships and rapport with their patients. However, we found persistent racial disparities in adherence in follow up in this population of Veterans served by the VHA. Beyond simply highlighting disparities, there is still urgent need to identify interventions that not only invite Black Veterans equitably into the benefits of LCS, but notably also ensure they receive those benefits by delivering timely follow up for positive results and timely repeat screening annually for those who remain eligible. Only then will these communities see the morbidity and mortality improvement that comes from lung cancer screening, and hopefully help close the racial disparities that still plague lung cancer outcomes to this day.

Tables & Figures

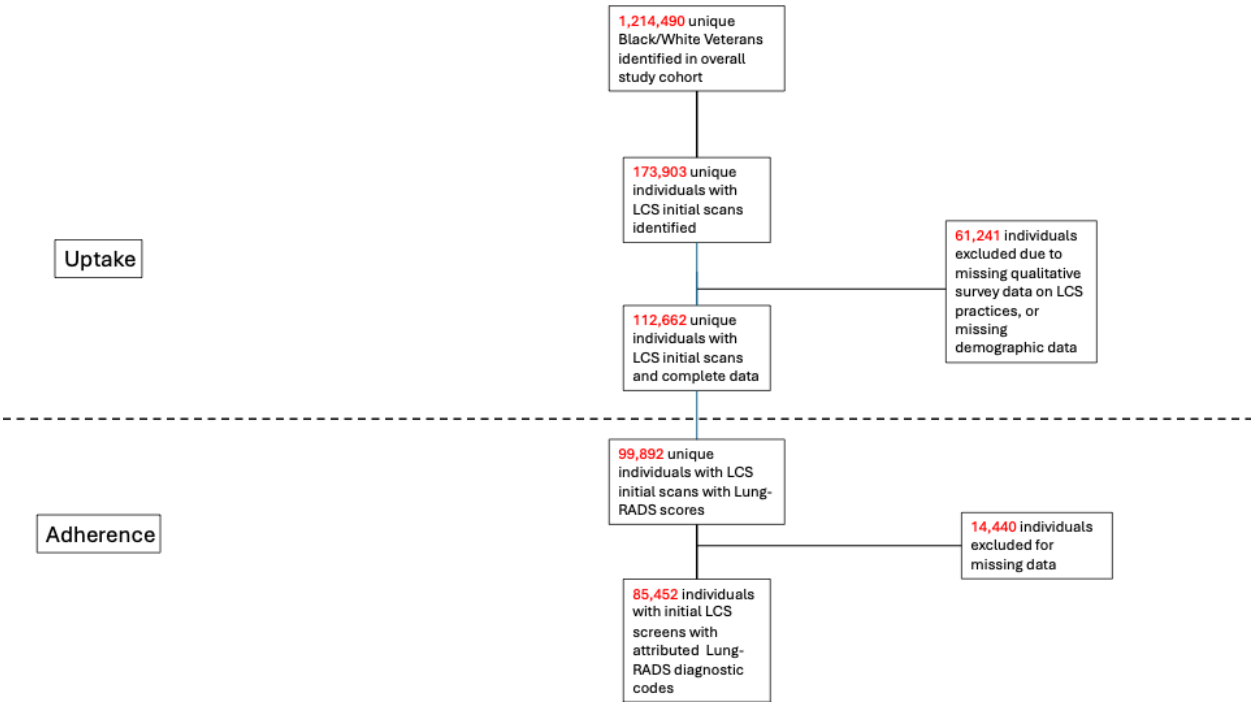


Figure 6: Flow Chart of Study Cohort

Variable	NH White Veterans N=986,500 (81.2%)	NH Black Veterans N=227,990 (18.8%)
Age (2016), mean (SD)	63.5 (8.1)	60.1 (7.7)
Sex, N (%)		
Male	932,467 (94.5%)	205,767 (90.3%)
Female	54,033 (5.5%)	22,223 (9.7%)
N 2013 USPSTF LCS Eligibility (%)	219,850 (22.3%)	38,889 (17.1%)
Elixhauser Comorbidity, mean (SD)	2.9 (2.1)	3.4 (2.3)
Comorbid Mental Illness	466,821 (47.3%)	133,921 (58.7%)
Comorbid Substance Use Disorder	441,169 (44.7%)	131,992 (57.9%)
National ADI		
Top 15% Disadvantage	193,966 (19.7%)	68,715 (30.1%)
Bottom 85%	792,534 (80.3%)	159,275 (69.9%)
State ADI		
Top 20% Disadvantage	258,727 (26.2%)	77,626 (34%)
Bottom 80%	727,773 (73.8%)	150,364 (66%)
Veteran Priority Group		
1 (lowest out-of-pocket cost)	291,857 (29.6%)	86,365 (37.9%)
2	68,986 (7%)	14,852 (6.5%)
3	142,923 (14.5%)	24,380 (10.7%)
4	16,330 (1.7%)	7,449 (3.3%)
5	171,986 (17.4%)	47,870 (21%)
6	59,330 (6%)	4,328 (1.9%)
7	38,637 (3.9%)	8,812 (3.9%)
8 (highest out-of-pocket cost)	131,506 (13.3%)	23,566 (10.3%)
Missing	64,945 (6.6%)	10,368 (4.5%)
Marital status (%)		
Single	87,790 (8.9%)	40,123 (17.6%)
Married	582,935 (59.1%)	95,604 (41.9%)
Divorced/Separated/Widowed	309,022 (31.3%)	90,979 (39.9%)
Unknown	6,753 (0.7%)	1,284 (0.6%)
Individual Rurality		
Urban	543,668 (55.1%)	180,222 (79.1%)
Rural	332,606 (33.7%)	35,429 (15.5%)
Highly Rural	44,857 (4.6%)	1,871 (0.8%)
Missing	65,369 (6.6%)	10,468 (4.6%)
Distance to nearest VA facility in miles, mean (SD)	16.5 (15.5)	10.8 (10.7)
Parent Facility Complexity Score		
1a	463,785 (47%)	126,855 (55.6%)
1b	266,352 (27%)	66,742 (29.3%)
1c	131,731 (13.4%)	23,420 (10.3%)
2	50,659 (5.1%)	4,647 (2%)
3	65,933 (6.7%)	4,679 (2.1%)
Excluded/Missing	8,040 (0.8%)	1,647 (0.7%)

[1] Area Deprivation Index (ADI) is a ranking of neighborhoods by socioeconomic disadvantage at the state or national level and is reported by the Neighborhood Atlas published by the Kind et al. research group

from the University of Wisconsin-Madison. National ADI is ranked 1-100, and State ADI is ranked in deciles 1-10, with higher scores corresponding to increased disadvantage.
[2] Priority Group is a designation given by the VHA to each Veteran utilizing services and determines a Veteran's out-of-pocket cost/copayments for seeking VHA services, ranging from Group 1 with little to no out of pocket cost to group 8 with the highest out-of-pocket cost.
[3] Address rurality is reported by the VHA for each primary address based on United States Department of Agriculture (USDA) Rural-Urban Commuting Area Code (RUCA) associated with the Census Tract of that address.
[4] Parent Facility Complexity Score is a designation used by VHA as a general measure of a facilities size, patient complexity, available clinical services, and academic affiliation. It ranges from a maximum of 1a to 3.

Table 10: Baseline Characteristics of Study Cohort
Percentages reported are column percentages.
Abbreviations: NH = Non-Hispanic, ADI = Area Deprivation Index, SD = Standard Deviation

	Overall (N=173903)
Lung-RADS Categories	
-Missing	74011
- 1 & 2	79877 (80.0%)
- 3	12091 (12.1%)
- 4A	5319 (5.3%)
- 4B & 4X	2605 (2.6%)
Station Centralization, self-reported	
Missing	24641
- Hybrid	51731 (34.7%)
- Consult	36010 (24.1%)
- Decentralized	61521 (41.2%)
Race	
- NH White	139367 (80.1%)
- NH Black	34536 (19.9%)
Age	
- 55-64	66377 (38.2%)
- 65-74	93652 (53.9%)
- 75-80	13874 (8.0%)
National ADI	
Missing	7543
- Less Disadvantaged	134118 (80.6%)
- More Disadvantaged	32242 (19.4%)
State ADI	
- N-Miss	7543
- Less Disadvantaged	121509 (73.0%)

- *More Disadvantaged*	44851 (27.0%)
Priority Group	
Missing	4462
- *1-3*	86830 (51.2%)
- *4-8*	82611 (48.8%)
Elixhauser Comorbidity Index	
Missing	56618
- *Mean (SD)*	3.121 (2.276)
- *Range*	0.000 - 20.000
Elixhauser, Categorical	
Missing	56618
- *Less Than 5*	91241 (77.8%)
- *At Least 5*	26044 (22.2%)
Individual Rurality	
Missing	4524
Urban	114521 (67.6%)
Rural	48917 (28.9%)
Highly Rural	5941 (3.5%)
Parent Facility Complexity	
- *1a-High Complexity*	84470 (48.6%)
- *1b-High Complexity*	45350 (26.1%)
- *1c-High Complexity*	35993 (20.7%)
- *2-Medium Complexity*	5183 (3.0%)
- *3-Low Complexity*	2907 (1.7%)
Facility Rurality	
Urban	169114 (97.2%)
Rural	4789 (2.8%)

Table 11: Baseline Characteristics of Scanned Cohort

Percentages reported are column percentages. Missing values are not included in the percentage totals.

Abbreviations: NH = Non-Hispanic, ADI = Area Deprivation Index, SD = Standard Deviation

Characteristic	***N[1]***	***IRR[1]***	***95% CI[1]***	***p-value***
	99,882			
Self-Reported Centralization				
Decentralized		—	—	
Hybrid		0.67	0.35, 1.28	0.228
Consult		0.7	0.17, 2.83	0.619
NH Black (↑10%)		0.96	0.86, 1.08	0.543

Self-Reported Centralization x NH Black (↑10%)			
*Hybrid * NH Black (↑10%)*	1.14	1.01, 1.28	0.029
*Consult * NH Black (↑10%)*	0.91	0.60, 1.37	0.655
Time in quarters (linear)	1.05	1.01, 1.10	0.014
Time period (categorical)			
Before Apr 2020	—	—	
Between Apr and Dec 2020	0.48	0.38, 0.61	<0.001
After Dec 2020	0.74	0.58, 0.93	0.011
Parent Facility Complexity			
1a-High Complexity	—	—	
1b-High Complexity	1.35	0.76, 2.39	0.304
1c-High Complexity	0.99	0.46, 2.15	0.983
2-Medium Complexity	2.14	0.73, 6.23	0.163
3-Low Complexity	0.6	0.30, 1.18	0.136
National ADI >= 85 (↑10%)	1.19	0.98, 1.43	0.072
Individual Rurality			
Rural (↑10%)	0.91	0.73, 1.13	0.38
Highly Rural (↑10%)	0.89	0.45, 1.75	0.726
Priority Group 4-8 (↑10%)	0.88	0.67, 1.16	0.365
Elixhauser >= 5 (↑10%)	1.24	0.76, 2.03	0.398

[1]IRR = Incidence Rate Ratio, CI = Confidence Interval, N=Number

Table 12: Multivariate Model of Uptake with Interaction Between Race and Centralization

Incidence Rate Ratio's (IRRs) are reported for a Poisson regression via a generalized estimating equation predicting the quarterly uptake of new individuals entering screening predicted by centralization, race, and the interaction of centralization and race, while controlling for time period, parent facility complexity, National ADI, an individual's primary address rurality, out-of-pocket cost for VHA services based on a Veteran's assigned priority group, and higher medical comorbidity based on Elixhauser Comorbidity Index. For individual-level characteristics (Race/Ethnicity, National ADI of primary address, Rurality of primary address, assigned priority group, and Elixhauser Comorbidity Index), IRR's are based on the predicted ratio difference based on a 10% increase in the proportion of individuals with that characteristic.
Abbreviations: Apr = April, Dec = December, NH = Non-Hispanic, ADI = Area Deprivation Index, ↑= increase

	Target Adherence + Self-Reported Centralization				*Minimum Adherence + Self-Reported Centralization*			
Characteristic	**N**	**OR[1]**	**95% CI[1]**	**p-value**	**N**	**OR[1]**	**95% CI[1]**	**p-value**
Self-Reported Centralization	85,452				85,452			

Decentralized	—	—		—	—	
Hybrid	1.54	1.39, 1.71	<0.001	2.68	2.44, 2.95	<0.001
Consult	0.92	0.82, 1.03	0.133	1.17	1.05, 1.31	0.003
Self-Reported Centralization x Race/Ethnicity						
*Hybrid * NH Black*	1.03	0.94, 1.13	0.495	1	0.92, 1.10	0.931
*Consult * NH Black*	1.04	0.94, 1.16	0.411	1.03	0.93, 1.13	0.601
Race/Ethnicity						
NH White	—	—		—	—	
NH Black	0.88	0.83, 0.94	<0.001	0.92	0.87, 0.98	0.005
End of Target Follow-Up Window						
Before Apr 2020	—	—				
Between Apr and Dec 2020	0.48	0.46, 0.50	<0.001			
After Dec 2020	0.31	0.29, 0.32	<0.001			
End of Minimum Follow-Up Window						
Before Apr 2020				—	—	
Between Apr and Dec 2020				0.61	0.59, 0.64	<0.001
After Dec 2020				0.33	0.32, 0.35	<0.001
Parent Station Complexity						
1a-High Complexity	—	—		—	—	
1b-High Complexity	1.02	0.49, 2.13	0.952	1.04	0.46, 2.35	0.927
1c-High Complexity	0.9	0.39, 2.12	0.817	0.88	0.34, 2.27	0.794
2-Medium Complexity	1.15	0.23, 5.69	0.86	0.99	0.17, 5.90	0.991
3-Low Complexity	0.51	0.16, 1.68	0.269	0.34	0.09, 1.25	0.104
National ADI						
Less Disadvantaged	—	—		—	—	
More Disadvantaged	0.96	0.92, 0.99	0.024	0.96	0.93, 1.00	0.028
Veteran Rurality						
Urban	—	—		—	—	
Rural	0.96	0.92, 0.99	0.02	0.96	0.92, 0.99	0.015
Highly Rural	0.88	0.80, 0.97	0.01	0.89	0.81, 0.98	0.012
Priority Group						
1-3	—	—		—	—	
4-8	0.9	0.88, 0.93	<0.001	0.9	0.87, 0.92	<0.001
Elixhauser Comorbidity Index						
Less Than 5	—	—		—	—	

At Least 5	0.86	0.83, 0.90	<0.001	0.87	0.84, 0.90	<0.001
Smooth Random Effect for Parent Station			<0.001			<0.001

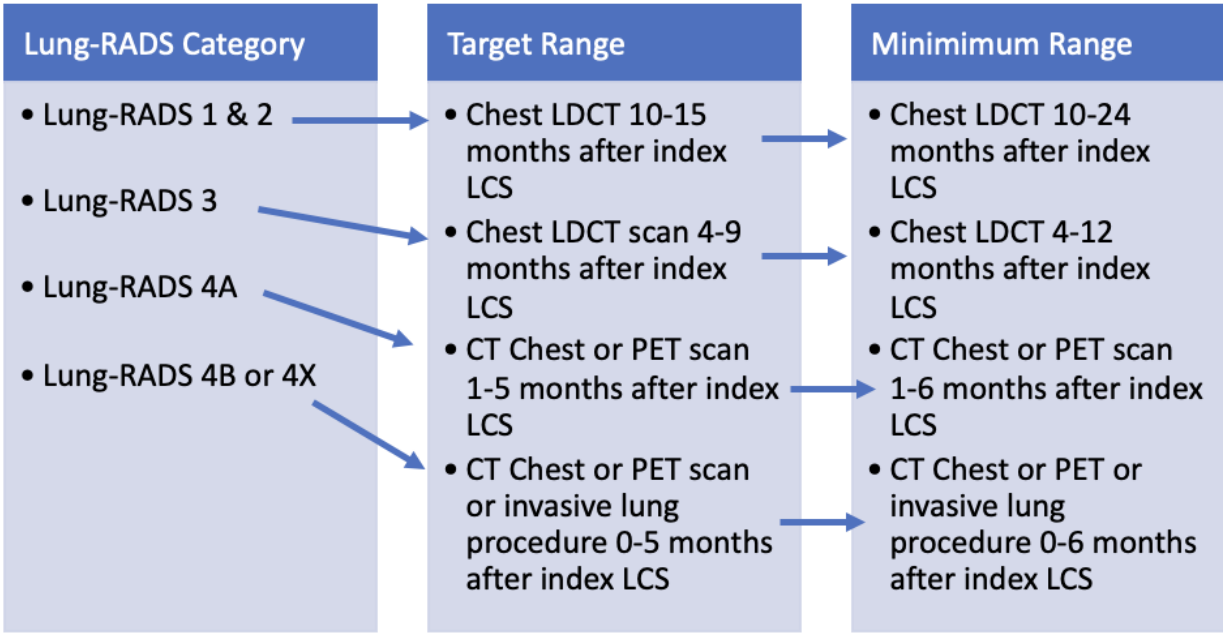
[1]OR = Odds Ratio, CI = Confidence Interval

Table 13: Multivariate Model of Adherence with Interaction Between Race and Centralization

Odds Ratios (ORs) are reported for a logistic regression via a generalized additive model predicting the adherence of individuals entering screening predicted by centralization, race, and the interaction of centralization and race, while controlling for time period, parent facility complexity, National ADI, an individual's primary address rurality, out-of-pocket cost for VHA services based on a Veteran's assigned priority group, and higher medical comorbidity based on Elixhauser Comorbidity Index.

Abbreviations: Apr = April, Dec = December, NH = Non-Hispanic, ADI = Area Deprivation Index

Supplemental Tables and Figure



Supplemental eFigure 1: Adherence algorithm by Lung-RADS score

Lung-RADS is a quality assurance tool published by the American College of Radiology to standardize LCS CT reporting and management recommendations. The Lung-RADS categories range from 1, negative, to 4, suspicious for malignancy, with additional sub-categories in Lung-RADS 4. Target and Minimum Ranges were based on intervals for adherence follow up based on those utilized for the NLST[8] and liberal adherence timeframes previously published by study team members[60].

Chapter 7: Summative Discussion, Future Directions, and Policy Implications

The current analysis sought to investigate the comparative effectiveness of a promising intervention, centralization of lung cancer screening programs, and it's association with lung cancer screening rates. With the significant morbidity and mortality caused by lung cancer, ongoing disparities, and poor utilization of lung cancer screening to date, all health systems are charged with rapidly improving LCS in an effort to curb the damage of this devastating disease. Though smoking rates nationwide have decreased in recent generations[81], the generations that smoked most heavily are now developing lung cancers. Therefore, healthcare systems need interventions that can rapidly improve screening rates to reach these patients while their cancer can be identified and cured. Centralization of LCS programs is one such intervention, with reported higher screening rates previously reported after implementation. However, centralization can both personnel and resource intensive, and it is pragmatically unlikely that every healthcare system will be able to fully centralize their LCS efforts. There is additionally variability in how centralization is implemented. Therefore, it is also critical to highlight the elements of centralization associated with the highest improvements in screening rates to better inform health systems where to focus potentially limited resources. Furthermore, it is essential to evaluate if centralization equitably improves screening rates amongst population with historic barriers to accessing screening. These considerations were primary motivation of this dissertation.

Describing the Smoking Patterns of Veterans

In our first analysis, we leveraged recently implemented structured data elements for capturing detailed smoking histories to perform the largest analysis to date describing Veteran smoking behavior based on patient reported smoking history. The VHA has previously performed regular surveys that include estimates of smoking rates and behavior[67,82], in addition

to the availability of national cross-sectional surveys like the Behavioral Risk Factor Surveillance System (BRFSS) or National Health Interview Survey (NHIS). However, these surveys did not have specific packs-per-day and years smoked estimates that are essential to calculating pack-year smoking history, the essential measure of lifetime cigarette exposure used in LCS eligibility guidelines. We previously also demonstrated the significant challenges in using previously available structures smoking data or abstracting data from the medical record to quantify LCS eligibility[69–71]. Therefore, this analysis provides a significant improvement in the precision of quantifying the distribution of lung cancer screening eligibility in the VHA. Quantifying the breath of the eligible population, and accurately attributing the size of that eligible population to the facilities serving those Veterans was also a critical balancing measure to our future analyses.

We were able to identify smoking histories of over 1.4 million Veterans in our dataset. Our analysis demonstrated that during our study period of 2015-2021, a larger proportion of Veterans (23.1%) reported smoking histories that met 2013 USPSTF eligibility criteria, a higher proportion than had previously been estimated[72]. We were also able to use our LCS eligibility estimates to create nationwide estimates of the LCS eligible population based on multiple criteria including the 2013 USPSTF recommendation, 2021 USPSTF recommendation, and the 2023 ACS recommendation. Based on the current expanded eligibility from the 2021 USPSTF recommendation, we estimate that over 1 million Veterans are likely eligible for LCS. These estimates are the first to date estimating the impact of the expansion of LCS eligibility in the VHA, and highlight the significant lung cancer risk and implementation challenge the VHA faces in implementing LCS broadly.

Evaluating the Comparative Effectiveness of LCS based on Program Centralization

In our second analysis, we turned to evaluating the comparative effectiveness of LCS program centralization over time by utilizing VHA EMR data, qualitative surveys on LCS

screening programs, and the smoking data analyzed in our first analysis. Centralization represented in our opinion one of the most promising interventions to bring about significant improvements in LCS uptake and adherence[44,56,60,102]. Yet these results were yet to be replicated at scale beyond single or smaller multi-center studies, and often lacked a large control groups with high-volume decentralized screening programs. Furthermore, these analyses rarely controlled for potential facility- and individual-level confounders. The VHA represented a perfect natural experiment to investigate centralization's comparative effectiveness and close these knowledge gaps. As centralization was gradually implemented across the VHA, there was a range of facilities that had LCS programs of various sizes and relative centralization that could be compared while controlling for potential confounding. As there is significant variability in what centralization means for various programs, we also wanted to evaluate centralization as it was self-reported by programs based on survey, and also based on a more objective ordinal measure based on the total number of itemized elements of centralization reported by a program.

Our team explored a number of different potential models for our analysis. We noted a significant skew in our uptake and adherence data likely caused by the COVID19 pandemic and subsequent de-prioritization of non-urgent care during early lockdowns, or disruptions to care and reticence to risk COVID19 exposure for patients. We subsequently added multiple time indicators to capture this significant secular trend in the data and still allow model fit to be achieved. Beyond these considerations, the datasets were often quite large and computationally challenging to run, and our initial basic Poisson or zero inflated negative binomial models had challenges converging/running in a timely fashion.

We ultimately elected to use a generalized estimating equation (GEE) to fit a Poisson regression to model quarterly uptake. The GEE allowed our model to capture both intra-facility variability in screening rates over time for stations that transitioned from decentralized to more centralized programs over the study period, but also inter-facility differences in uptake rate

comparing decentralized and centralized facilities. We additionally explored a conditional Poisson model, but this model is only able to explore the intra-facility difference in screening rates pre and post centralization initiation. This model is unable to capture inter-facility differences in LCS rates. Additionally, this model would be unable to control for any characteristics that were fixed over the study period (like facility complexity score). For these reason, we elected the GEE as the preferred model for this study's purposes. Based on recommendations from our statistical consultants, we also elected to model the impact of individual level characteristics based on proportional change of their representation in the population served by a given facility. This was operationalized by a 10% change in the proportion of individuals with each of these characteristics. To model adherence, we selected the a generalized additive model (GAM) to fit a logistic regression to model adherence for its increased efficiency in large datasets like those of this study while yielding similar results to a logistic regression model[90].

Our analysis demonstrated that there was no significant difference in LCS uptake between decentralized, hybrid, or models of low or high centralization based on our ordinal measure of centralization. We did, however, find that consult models had a statistically lower rate of LCS uptake. This finding of lower uptake in consult/fully centralized models was unexpected especially given previously published studies. We hypothesize that a number of factors may have contributed to this finding. First, many consult programs implemented late into our study time period. We anchored the start date for LCS programs to the date of coordinator hiring or the date the program stated they started their LCS program. However, it is possible that for several months after a coordinator is hired, a program may not be fully functional at its peak efficiency. Various programs may gradually role out LCS programs from a subset of clinics to then their broader facility, and there is likely time needed to educate providers on the new LCS workflow. Given the likely increased administrative burden and necessary training for personnel to implement these programs even relative to hybrid programs, it's possible there was

not enough lead time in our study period to observe these program's full potential. Conversely, we must also consider that consult programs may inherently be disadvantaged compared to hybrid or decentralized programs, potentially due to the relative removal of the primary care physician from the initial encounter, or from a potential bottle-neck effect of decreased throughput for consult LCS program personnel at especially large programs. Anecdotally, our study team has heard reports from other facilities where a single coordinator may be responsible for hundreds or thousands of Veterans, a staffing ratio that is significantly higher than even the busiest primary care physicians.

When evaluated for LCS adherence in follow up, centralized programs broadly were associated with increased relative performance to decentralized programs. Hybrid programs had especially increased relative rates of screening at meeting more lenient minimally-acceptable time period for expected follow up from positive studies or subsequent screening for those who remain eligible, greater than doubling the odds of adherence compared to decentralized programs. We included this more lenient window for follow up given potential delays caused by the pandemic. We saw similar but lower magnitude increased adherence across our ordinal measure of centralization and for fully centralized/consult programs. In summary, our analysis suggests the most significant benefit from centralization is a significant improvement in achieving LCS adherence, rather than increasing LCS uptake.

We also wished to explore the impact of discrete elements of centralization on LCS rates, namely programs having an LCS coordinator, screening registry, EMR reminders for providers, or shared decision making support from program staff. We did not find a statistically significant association between these elements of centralization and LCS uptake, but we did see varied and significant increases in LCS adherence associated with these elements of centralization. As these elements of centralization are highly correlated with one another and some are contingent on each other, this analysis is unlikely to fully elucidate the relative importance of these LCS elements, and there additionally could be synergy between elements

that is unable to be partitioned based on how our dataset is currently coded. We do however feel comfortable in concluding that centralization broadly is associated with improved LCS adherence, and logically many of these elements like an LCS registry, coordinator, and EMR reminders could be synergistically beneficial in facilitating adherence.

Our model also demonstrated racial/ethnic disparities in LCS uptake for Hispanic Veterans relative to White Veterans, and LCS adherence for Black Veterans relative to White Veterans. Beyond simply reporting racial disparities, it is critical for research to identify interventions best suited for attenuating these disparities. As our study cohort was best powered to compare Black/White differences in LCS rates, this finding spurred the desire in manuscript 3 to further evaluate if centralization was associated with improved racial/ethnic LCS disparities by evaluating if centralization moderated the relationship of LCS uptake and adherence with race.

Evaluating if Centralization May Improve LCS Black/White Disparities

In our final analysis, we used a subset of Black & White Veterans from Chapter 5 to further investigate the relationship between race, centralization, and LCS rates. Prior researchers have shown centralization broadly being associated with improved Black/White disparities in LCS rates[46]. However, their study was limited to 5 centers and only categorized programs broadly into centralized and decentralized programs. We again leveraged the GEE Poisson model for LCS uptake and the GAM logistic model for LCS adherence.

Interestingly, despite not seeing an overall Black/White difference in uptake rates associated with the increasing proportional racial representation at a facility, we did find that hybrid LCS programs had a statistically significant increased rate for Black Veterans, accounting to a 14% increase rate of LCS uptake for every 10% increase in the proportion of the population that is Black. We suspect there may still be a Black/White disparity in LCS uptake, but that our model is unable to resolve this disparity based on 10% changes in population representation.

When evaluated for adherence, we did not see a statistically significant interaction between either centralization model and LCS adherence. There notably remained a Black/White disparity in LCS adherence, all else equal, regardless of facility centralization status.

Based on this analysis, we postulate that hybrid programs may differentially outperform decentralized programs at uptake/recruitment of Black individuals into screening. However, when evaluated for adherence, centralization wasn't itself associated with increased odds of Black individuals receiving timely follow up, all else equal. Considering our findings from Chapter 5, it's possible that centralization does broadly significantly improve the odds of receiving appropriate follow up after initial screening, but does not necessarily improve Black/White disparities in adherence in follow up. Given similar Black/White participation in screening in this population served by the VHA, we also query the possibility that centralization may have a more significant association with increasing Black individuals entering screening in populations where a more significant baseline disparity in LCS rates exists.

Our study is the only analysis to date to evaluate the interaction between centralization and race, and one of the largest to evaluate the association of race with LCS rates in the VHA to date. Given the persistent disparities in Black/White adherence rates, it is still critical to identify interventions beyond centralization that ameliorate this disparity.

Limitations

There are limitations to the conclusions that can be raised from the current analysis. The VA's CDW is a uniquely comprehensive nationwide dataset from the nation's largest integrated healthcare system, the VHA. However, it is not comprehensive to all care that its participants may seek. Notably, care sought outside of VA facilities, even if that care is ultimately paid for by VA benefits, is not routinely uploaded into the CDW and available for researchers beyond broad claims data. This CITC claims data is messy and commonly

contains duplicates. Though efforts are underway to standardize and improve data entry prospectively, readily interpretable data is simply unavailable for the time period of the current analysis. We do, however, plan to explore available Medicare/Medicaid claims data matched with the study cohort to evaluate care patients receive outside the VHA paid for via their dual coverage. This can increase the data capture beyond care just received at the VHA, though there will still be some missingness for care Veterans seek from other insurance providers or pay for out of pocket.

The qualitative survey data utilized in the current study provided a broad glimpse into the LCS practices across the VA. However, these surveys were not designed by organizational behavior or implementation science researchers, nor were they implemented using survey best practices. Subsequently, the survey data includes imprecise responses, incomplete responses and missingness, and likely response and recall bias. We suspect facilities that are more organized in their LCS efforts are more likely to be able to identify a responsible individual knowledgeable enough to answer surveys, and this may correlate with station centralization. We hoped to mitigate this by using facilities pre-centralization as part of our decentralized dataset to increase statistical power. Additionally, combining qualitative surveys often necessitated abstraction of centralization efforts to broad categories and general dates of implementation. It is to be expected that the implementation of screening at various sites may be variable, with some sites potentially piloting programs in a few clinics and then expanding. Furthermore, programs may take some time to train and get up to speed as new personnel or providers become acquainted with their services. The current study is unable to measure these facility-specific nuances in implementation with the available survey data. Nor are we able to interrogate provider-specific characteristics, and rather nest patients within primary healthcare facilities. We do, however, believe that much of this variability will be distributed equally across the dataset, and the studies large size can likely mitigate some of this facility to facility, and provider to provider, variability.

Our research additionally relies on EMR data that can be misclassified. For example, the study team spent extensive exploratory analysis and data cleaning to identify scans likely performed for lung cancer screening. However, with significant variability in how various facilities code CT scans and how those scan results are subsequently reported, there remains the possibility that scans performed for LCS are missing from our dataset. We corroborated our algorithm with multiple other published studies using VHA data[60,63,103], in addition to consulting with the National Center for Lung Cancer screening, and subsequently are confident our methodology is commensurate with other researchers in the field.

Furthermore, there are valid considerations as to the generalizability of VHA data. The patient population is largely male, and there may be different likelihood of and the VHA administers one of the largest universal insurance benefits in the country beyond Medicare/Medicaid. The interaction of healthcare insurance and out of pocket costs must be assumed to impact the likelihood of seeking preventive services like LCS or in receiving follow up[104]. Initial preventive services recommended by the USPSTF like LCS are typically coffered without out of pocket costs by many insurance providers as a result of the Affordable Care Act. However, follow up diagnostic procedures, provider visits, and subsequent care may not be covered. Though we attempted to use Veteran priority group as a general surrogate for out of pocket costs for seeking VHA services broadly, we cannot assess with the current study how these costs to patients may further be barriers to receiving LCS.

Our findings therefore must be interpreted within the limitations of the data available to the study team and the methodologic decisions made to operationalize that data. However, we are confident that the VHA still presents one of the best and largest data sources for probing the impact of an intervention like centralization, and combining that data with our available qualitative surveys allowed us to perform the largest assessment to date using real-world data. The results subsequently still are of significant value not only to VHA facilities and researchers, but to the broader healthcare community engaged in LCS efforts.

Future Research

We intend to use the insights and dataset created for this project for multiple future analyses. The current project provided valuable insights and lessons into database management and cleaning using VHA data, in addition to valuable insights into the available data related to LCS. I intend to use this work as the foundation for a VA career development award or NIH K level mentored award to further my growth as an investigator committed to improving LCS outcomes.

There are additional analyses we desire to perform for the current analysis prior to publication, including additional sensitivity analyses for our chapter 5 and 6 manuscript confirming our model yields similar results when evaluated at only the highest complexity facilities. I also hope to work with my analyst team to recode our elements of centralization variables to account for correlation and contingency in the data to attempt to compare the relative effectiveness of centralization elements.

The analysis from chapter 4 has already led to a collaboration with Drs. Drew Moghanaki, co-lead of our local LPOP site, and Haley Tupper, a general surgery resident at UCLA. Our team has applied for funding to use the VHA smoking history data to investigate if total smoking duration (in years) would be a superior eligibility criteria to improve Black/White disparities in LCS eligibility than pack years based on research in the Southern Community Cohort Study[105]. We are hopeful such research could suggest potentially more equitable eligibility criteria that concurrently may be easier to quantify and implement for providers and patients alike, as patients may vary in the amount smoked during periods in their lives but most can recall when they began smoking.

Our analysis in chapters 5 and 6 only looked at a composite evaluation of adherence, and our data suggested that adherence improved as a screening scan was more suspicious/worrisome. This is of course a welcome finding, as one should hope that the most serious scans receive adequate and timely follow up. However, there may be nuances to

likelihood of adherence based on the Lung-RADS score of the initial scan that could be further explored. Additionally, we only looked at adherence at the first time point after initial scan. For those who remain eligible for recurrent annual screening, we are actively planning to work with project collaborators to perform an analysis of longitudinal adherence over multiple scans.

Additionally, we have applied for an obtained matched Medicare and Medicaid claims data for the individuals in our current study cohort. These matched datasets would allow assessments for care outside the VA and improve potential missingness not at random for care Veterans receive outside the VHA. This may be especially true for rural veterans and those who have difficulty accessing VHA services at VHA facilities. There are additionally prospective datasets that capture VA paid for care that is delivered in the community. During the time period of the current study (2015-2021), the available datasets are unfortunately likely too plagued by duplicates and potentially misclassified claims to be easily used in the current study. However, there are improved and more standardized datasets that have been launched in recent years that would allow for more readily accessible inclusion of this care received in the community related to LCS. Additionally, I remain committed to exploring the association of Social Vulnerability Index on screening rates and have the opportunity to build this data onto the address data in the current dataset.

Finally, our hypothesis on the importance of primary care physician-patient trust for initial LCS patient recruitment, but the potential benefit for centralization to improve follow up (as evinced by our adherence findings from Chapter 5) is testable in future studies. I hope to use this to develop a pilot study as part of my planned career development award to further grow my experience from purely retrospective analyses like the current study to designing and implementing interventions. Using the insights from this analysis, once could implement a hybrid program that pairs PCP-patient rapport for recruitment of patients into screening, but still unburdens PCPs with a focus on then leveraging fully centralized resources for adherence in follow up, as this is where it appears these programs excel. There could additionally be

adoption of telemedicine resources to further expedite program reach especially for Veteran's with difficulty accessing VHA facilities. Finally, implementing targeted resources for your most high risk patients who face the greatest barriers to screening could be a methodology to close persistent disparities in screening follow up.

Policy Implications

The current study leveraged data from the VHA, but there are numerous insights that are applicable both within the VHA and to the broader healthcare community. Centralization is likely more feasible in large, vertically integrated healthcare systems like the VHA. Additionally, the VHA can make nationwide incentives or mandate practice changes. However, there are a number of policy implications that likely extend to many healthcare systems beyond the VHA.

We suspect that hybrid centralized programs are most likely to be implemented broadly than fully centralized/consult models. Primary care physicians already are tasked with performing the majority of evaluation and referral for cancer screening like LCS. It is easy to imagine they could be overburdened with multiple competing responsibility in a finite visit. Yet they have robust, longitudinal relationships with their patients and subsequently develop significant trust and rapport with their patients. We postulate the improved performance of hybrid programs in part could be attributed to that trust. In an attempt to still unburden PCPs, LCS programs may focus on leveraging their relationship and trust for reinforcing the initial shared decision making conversations for screening. LCS programs could still unburden PCPs by using other trained health professionals to perform and document shared decision making conversations, but then encourage PCPs to reinforce and encourage participants to participate in screening.

The Centers for Medicare & Medicaid Services (CMS) has already changed policy to allow for unburdening PCPs from conducting all SDM and LCS follow up by allowing other trained health professionals like nurses conduct these conversations[16]. Additional policy

changes could be implemented to ease LCS implementation, like simplification of eligibility criteria. Then LCS program staff could provide additional support by assisting in the coordination and tracking of repeat screening or recommended follow up following that initial conversation. Healthcare systems may find hybrid model more appealing due to its potentially easier implementation through EMR interventions and a smaller dedicated team of centralized LCS staff than the increased administrative and personnel resources to implement new care lines in dedicated LCS clinics and teams that often are needed for fully centralized/consult programs. As many provider practices are increasingly being bought/managed by larger healthcare systems[106], there may be greater opportunity for more LCS efforts to be partially centralized into hybrid programs.

Furthermore, many elements of hybrid programs could be centralized at the county or even state level. And these efforts could provide significant cost savings through the diagnosis and treatment of early-stage lung cancer. Resource-limited county and safety-net hospital systems may find implementing hybrid programs to be a significant way to decrease healthcare costs through early intervention for lung cancer, while also improving morbidity and mortality of the patients they serve. For primary care practices that are not affiliated with larger healthcare systems, or for healthcare systems without the resources to initiate centralized LCS, counties or states could fund the establishment of centralized LCS registries through local Departments of Public health even if the administrative burden of hiring coordinators or referring patients to a complex and fractured provider network of screening or follow up may be too cumbersome for these departments to coordinate independently.

Conclusions:

The analyses contained in this thesis focused on evaluating centralization as an intervention to improve LCS rates, and the lessons that can be gleaned in multiple practice settings beyond the VHA. In order to achieve the 20% cancer-related mortality benefit seen in

the National Lung Screening Trial, programs presumably have to achieve the high adherence rates near 90% seen in the trial[8]. Against the backdrop of abysmally low penetration of LCS following its initial recommendation in 2013, centralization efforts particularly within the VHA[102] achieved some of the closest adherence rates to those from the National Lung Screening Trial. However, it was yet to be determined if these promising results persisted at scale using real world data relative to other high performing decentralized programs. This thesis submission sought to provide insights into these questions. Our results particularly of the comparative effectiveness of hybrid models may be the most effective models to emulate while also being potentially easier for healthcare systems to implement. In addition, hybrid models may still benefit from further refinement as important racial and ethnic disparities persist in spite of the vertical integration and near universal health insurance coverage available to VHA users. These disparities are likely to only be more magnified across the United States' fragmented system of providers and health insurers. We believe the current study is an important contribution to identifying what works at scale in the real world, and providing evidence to researchers and healthcare systems alike for the interventions that are likely to increase LCS rates for their patients.

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