Smartphone application versus written material for smoking reduction and cessation in individuals undergoing low-dose computed tomography (LDCT) screening for lung cancer: a phase II open-label randomised controlled trial

Sanna Iivanainen,[a,b,c] Antti Kurtti,[b,h] Viktor Wichmann,[a,h] Heidi Andersen,[d,e] Antti Jekunen,[d,e] Riitta Kaarteenaho,[b,c,f] Tuula Vasankari,[e,g] and Jussi P. Koivunen[a,b,c,*]

[a]Cancer Center Oulu University Hospital, Finland
[b]University of Oulu, Finland
[c]Medical Research Center Oulu, Finland
[d]Vaasa Central Hospital, Finland
[e]University of Turku, Finland
[f]Center of Internal Medicine and Respiratory Medicine, Oulu University Hospital, and Research Unit of Biomedicine and Internal Medicine, University of Oulu, Oulu, Finland
[g]Filha, Helsinki, Finland

The Lancet Regional Health - Europe 2024;42: 100946

Published Online 25 May 2024
https://doi.org/10.1016/j.lanepe.2024.100946

Summary

Background Counseling, nicotine replacement, and other cessation medications have been proven effective in smoking cessation. The wide-scale adoption of smartphones and other mobile devices has opened new possibilities for scalable and personalized smoking cessation approaches. The study investigated whether a smartphone application would be more effective than written material for smoking cessation and reduction in smoking in individuals undergoing low-dose computed tomography (LDCT) screening for lung cancer (NCT05630950).

Methods This randomized controlled trial enrolled 201 current smokers with marked smoking history (smoked ≥15 cigarettes/day for ≥25 years or smoked ≥10 cigarettes/day for ≥30 years). Participants were stratified by age and pack-years and randomized in 1:1 fashion to the developed smartphone application (experimental arm) or written material (standard of care). All the subjects underwent LDCT screening. Self-reported smoking cessation at three and six months were the primary endpoints of the study. The smoking-related secondary endpoints of the study were the percentage of individuals who had reduced the number of smoked cigarettes/d from the baseline.

Findings Between Nov 18, 2022, and Apr 14, 2023, 201 patients were screened at Oulu University Hospital, Finland, of whom all were randomly assigned to smartphone application (n = 101) or written cessation material (n = 100); 200 were included in the full analysis set. Study arms were well-balanced for all the studied demographic factors. Subjects randomized to the smartphone application arm had significantly higher rates for self-reported smoking cessation at three (19.8 versus 7.1%; OR 3.175 CI 95% 1.276–7.899) and six months (18.8 versus 7.1%; OR 2.847 CI 95% 1.137–7.128). In the experimental arm, individuals with a frequent use of the application had a higher chance for smoking cessation at three ($p < 0.001$) and six months ($p = 0.003$).

Interpretation The study showed that the developed smartphone application increases the likelihood for smoking cessation in individuals undergoing lung cancer LDCT screening.

Funding AstraZeneca, Roche, and Cancer Foundation Finland.

Keywords: Smoking cessation; Smartphone application; Lung cancer screening; LDCT; Behavioral change technique

*Corresponding author. Cancer Center, Oulu University Hospital, PB22, Oulu 90029, Finland.
E-mail address: jussi.koivunen@pohde.fi (J.P. Koivunen).
[h]Shared author position.

Research in context

Evidence before this study

We searched PubMed database on Feb 22, 2024, for published reports in any language using the search terms "smoking cessation" and "lung cancer screening" and applied a filter of "Randomized Controlled Trial" which resulted in 67 publications. We manually reviewed all the publications and selected the ones reporting results from randomized controlled trials in lung cancer screening context (n = 11). None of these trials investigated smartphone application based smoking cessation. Of these 11 trials, four reported positive results in long-term smoking cessation over the controls arms. The effective approaches included telephone counseling ± pharmacotherapy, pharmacological agent cytisine, and internet self-resources.

Added value of this study

To our knowledge, this is the first study to report a benefit of smartphone based smoking cessation in individuals undergoing LDCT lung cancer screening. We included individuals who had access to a smartphone, were active smokers, and eligible for LDCT screening. We were able to show that smartphone application increases smoking cessation rates over written cessation materials at three and six months. Given the promising results, feasibility and cost-effectiveness of the smartphone application, this approach could directly be implemented to lung cancer screening programs or further validated in combination to other smoking cessation interventions.

Implications of all the available evidence

Lung cancer screening is a teachable moment for smoking cessation and, therefore, it promotes health benefits past early cancer detection. There is no established standard practice for smoking cessation in the context of lung cancer screening but it is reasonable to assume that cessation methods would be similarly effective in the population. A few smoking cessation methods have been shown to be effective in LDCT setting including smartphone application by the current study. Future research should aim to identify the most effective and clinically feasible approach in smoking cessation.

Introduction

Lung cancer is the leading cause of cancer mortality in the Western world while smoking is the most important risk-factor for the disease.[1] Lung cancer is often asymptomatic in the early stages and, as such, often diagnosed at an advanced disease setting in which curative intent treatments are not feasible. Annual lung cancer screening of individuals with marked smoking history using low-dose computed tomography (LDCT) can induce a stage shift towards localized disease, decrease lung cancer mortality, and, possibly, increase overall survival.[2,3] United States Preventive Services Taskforce recommends yearly LDCT for adults aged 50–80 years who have a 20 pack-year smoking history, currently smoke, or have quit within the past 15 years.[4] Elsewhere, LDCT screening is a part of recommended healthcare in very limited number of countries.

Traditional methods for smoking cessation include written material, counseling, nicotine replacement (NRT), and cessation medications. While all aforementioned means of smoking cessation have been proven effective, their benefit varies based on mode-of-action as well as individual differences.[5–11] Smartphones and mobile devices have opened new possibilities for digital and social media-based smoking cessation approaches. Meta-analyses have shown that smartphone applications can be effective with OR of 1.25–1.51 (CI 95% 0.99–1.56, 1.24–1.84) for abstinence.[12] Furthermore, smartphone approaches are more effective when used in combination with pharmacotherapy and physical participant recruitment.[13] The tested smartphone applications are generally based on behavioral change technique, cognitive behavioral therapy, social cognitive theory, and mindfulness. More scientific evidence regarding the effectiveness of smartphone-based smoking cessation methods, and how they compare with the other methods in use, as well as on the adoption of mobile health applications in elderly, is required.[13–15]

Smoking cessation intervention is recommended within the LDCT screening program for lung cancer.[16] Support towards smoking cessation is more effective when given in conjunction with cancer screening regardless of the screening result.[17–19] A systematic review has shown that 7–23% of the individuals participating in LDCT programs achieve smoking cessation.[20] However, the methods for smoking cessation in LDCT screening context are not well established.

The current study investigated whether a smartphone application would be more effective than written material for smoking cessation and reduction in smoking in individuals undergoing low-dose computed tomography (LDCT) screening for lung cancer. Here, we report the smoking related primary (self-reported smoking cessation at three and six months) and secondary (individuals who had reduced number of smoked cigarettes/d from the baseline) outcomes of the study.

Methods

Study design

LDCT–SC–FI (Low-dose CT screening for lung cancer combined to different smoking cessation methods in Finland) is a randomized controlled trial investigating different smoking cessation methods in subjects undergoing lung cancer screening with low-dose CT. The

study also prospectively evaluates feasibility and outcomes of LDCT screening (offered to all the study participants) in Finland, and potential biomarkers for early cancer detection. The study subjects fulfilling I/E-criteria are randomized in 1:1 fashion to a yearly LDCT with standard smoking cessation (written material) or the same LDCT screening approach combined to a smartphone application-based smoking cessation (experimental). The study is powered (80%) with 155 subjects to detect 15% difference with 90% confidence (75 versus 90%) in the number of active smokers at three and six months after inclusion. With the expected dropout rate, the sample size was adjusted to 200. For the positive trial outcome, both primary outcomes needed to be statistically significant.

The study was approved by the Ethics committee of Northern Ostrobothnia Hospital District (EETTKM 21/2022). All the participants signed an informed consent before any study procedures. The study subjects were not compensated for their participation. Of note, LDCT lung cancer screening is not among the publicly funded cancer screenings in Finland. The study was conducted in accordance with the Declaration of Helsinki and Good Clinical Practice guidelines.

Participants

Eligibility followed closely to the NELSON lung cancer screening trial criteria.[2] The main inclusion criteria included an age of 50–74, a marked smoking history (smoked ≥15 cigarettes/day for ≥25 years or smoked ≥10 cigarettes/day for ≥30 years), an active smoking status (smoking during the last two weeks including regular [daily smoking] and occasional [non-daily smoking] habits), and access to a smartphone (iPhone or Android). The main exclusion criteria, as in the NELSON trial included a moderate or bad self-reported health, current or past melanoma, lung, renal or breast cancer, and a chest CT examination less than one year before the inclusion.

Randomization

The study recruitment was initiated Nov 18th 2022 and the last subject was included Apr 14th 2023. Even though the study was planned to be a multicenter trial, the inclusion took place only in a single center (Oulu University Hospital, Oulu, Finland) because of the rapid inclusion at the initially opened site. The recruitment was carried out by newspaper, internet advertisements and informing relevant healthcare units at hospital district. Pre-screening was done by phone. Physical screening visit was performed at the site where participating individuals signed the informed consent. Eligibility was verified by a study nurse according to a checklist. Study subjects did not receive any compensation for the participation and all the study procedures were free of charge. Eligible subjects were randomized by study nurses with block method (sequentially numbered containers with a block size of ten, study arm written on a paper in an opaque, sealed envelope) in 1:1 fashion with stratification according to pack years (<30 py or ≥30 py), and age (<65 or ≥65 y) to smartphone-based smoking cessation and control (written smoking cessation material) arms. The stratification factors were selected based on the assumption that bias could be generated by 1) adoption of smartphone use in elderly and 2) higher pack-years to be associated with lesser likelihood of smoking cessation. The random allocation sequence (randomization envelopes and numbered blocks) was generated by the investigators (JPK and SI) to ensure concealment. Because of an inability to blind the study participants from the intervention, as well as self-reported smoking cessation being the primary endpoint of the study, the study personnel were not blinded.

The study follow-up includes communication of the first LDCT screening result to the participants via mail. In addition, smoking cessation status is verified by phone (study nurses calling the participants) at three and six months after inclusion. Another physical visit and LDCT screening investigation is planned at one year. Survival and cancer status are followed up to three years from electronic patient records.

Procedures

The developed, novel smoking cessation application supports the smokers in cessation process and aids them to retain smoking-free lifestyle. The theoretical and functional concept was created by the study team members and the technical execution was done under subcontract by a company specialized in mobile application development (Techinspire, Oulu, Finland). The core concepts behind the developed application include cognitive behavioral (enhancing self-awareness, problem solving skills, goal setting and coping with cravings) and social cognitive theories (e.g. competence in quitting and managing tempting situations), and acceptance and commitment therapy as well as mindfulness (e.g. personalized cessation plan, psychological reflection, attention and mindful coping with negative affective states and cravings). The individuals use the application for goal setting, decision-making, information sharing, and personal empowerment in smoking cessation, as well as for overall management of their health. The functionalities of the application include collection of demographics, a weekly symptom questionnaire with personalized feedback, mindfulness practices, virtual cessation coach, and altering features according to the smoking status. Direct functionalities related to cessation include self-reflection on the habitual aspects of smoking, and a guided smoking cessation planning. The user is reminded with push notifications to complete the preplanned tasks. The standalone application is Android and iPhone compatible with cloud-based database back-up. All the communication between the app

and the database is protected by means of an SSL digital certificate on the server, which will provide end-to-end encrypted communications. The application was beta-tested with up to ten users. The used application was downloaded on participants' smartphones on the randomization visit which was assisted by the study nurse. The participants also received a one-page written leaflet on how to use the application.

The written materials used for smoking cessation are based on Finnish Current Care Guideline for Prevention and Treatment of Smoking and Nicotine Addiction (https://www.kaypahoito.fi/hoi40020?tab=suositus) that is also available online (https://www.kaypahoito.fi/khp00042). A printed version of the patient guide was handed out to study subjects in the control arm. At six-month smoking status call, participants in the control arm were offered a possibility to start using the smoking cessation application. No other counseling for smoking cessation was provided to the participants during the study visits regardless of the study arm.

The LDCT–SC–FI study protocol for LDCT interpretation follows the NELSON study protocol.[2] In brief, all the study subjects undergo LDCT screening within six weeks from the randomization and are informed of the results by mail. If no further procedures are required (negative or NODCAT I-II), the next LDCT was scheduled for 1 y (±two months). With intermediate LDCT results (NODCAT III), a follow-up scan is performed at three months. With positive LDCT results (NODCAT IV), the patient is referred to the pulmonary medicine department for further evaluation. The radiation exposure of a single LDCT (effective dose) was estimated to be 1.6–2.4 mSv, which corresponds to about ½–1 y background radiation exposure.

Outcomes

Data collected at baseline included age, gender, employment history, relationship status, information and communication technology (ICT) experience, detailed smoking and cessations history, nicotine dependency score (Fagerström), and medical conditions (ICD-10).

The primary outcomes of the study are self-reported smoking cessation at three and six months (±one month) after the inclusion. Smoking related secondary outcomes included reduction in smoking (cigarettes/d) compared to baseline (≥50%) and mean number of reduced cigarettes/d at same time points which were introduced to the protocol in version 1.2 jointly with the possibility to cross-over from control arm to the smartphone application use at six months (Feb 14th, 2023). The smoking data was collected via phone, and re-calls were made if the initial contact was non-successful. If a study participant did not undergo the first LDCT screening examination, the individual was excluded from the study, and replaced.

The application use and its' association to smoking cessation was studied in the experimental arm. The smartphone application included weekly symptom questionnaires and the frequency of application use was investigated by analyzing the number of completed symptom questionnaires.

Statistical analysis

Data analysis was carried out using SPSS version 29.0.1. For dichotomic variables, Two-sided Pearson Chi–Square test was used to calculate univariate Odds ratios with 95% Wald confidence limits. For continuous variables, independent samples two-sided T-test was applied to estimate the mean difference with 95% Wald confidence limits. In addition to univariate analysis, binary logistic regression adjusted for pack-years and age was carried out for the primary endpoint with 95% Wald confidence limits; p-values of <0.05 were considered statistically significant. Missing data was not replaced. Based on the statistical analysis plan of the study (first version 1.0, May 2nd 2022; final version 1.1, Feb 14th, 2023), the first and final analysis for the primary and smoking related secondary end-points were planned when at least six months of follow-up was available for all the study participants. The initial data analysis for these endpoints was carried out blinded of the intervention on Nov 28th, 2023. The study was registered at clinicaltrials.gov (NCT05630950).

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results

All the study participants were included at Oulu University Hospital in the context of LDCT lung cancer screening study between Nov 18, 2022 and Apr 24, 2023. All the subjects (n = 201) assessed fulfilled the eligibility criteria, while the screening failure rate was 0%. The study subjects were randomized in 1:1 fashion to smoking cessation smartphone application (n = 101) or written smoking cessation material (n = 100). All the participants underwent baseline LDCT screening examination and individuals who missed the examination were excluded from the study (n = 1). Smoking status at three and six months (primary endpoint) was assessed for 101 (100%) subjects in the experimental arm, and 97 (98%) and 93 (94%) in the control arm (Fig. 1).

The median age of study subjects was 60 years and 51% of them were female (n = 102). Of smoking related demographics, the median number of pack-years was 31 while the number of smoked cigarettes per day was 15. The detailed demographics are presented in Table 1. Study arms were balanced for all the studied baseline

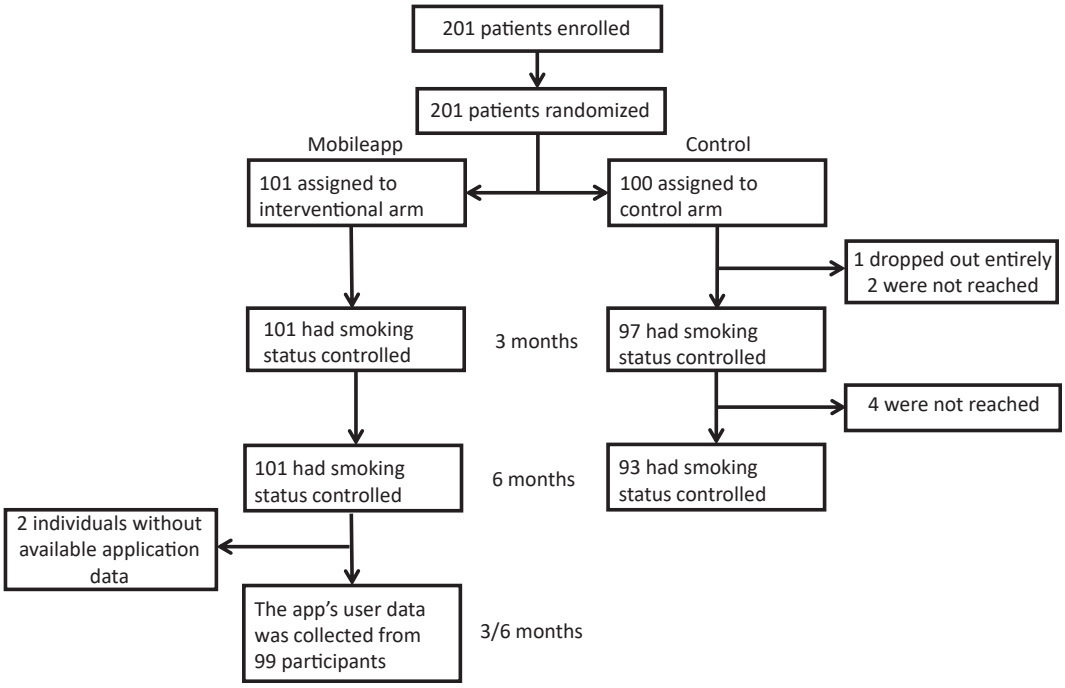

Fig. 1: Study flowchart.

variables (Table 1). Only direct adverse events associated with the primary trial interventions (smartphone application or LDCT) were to be reported as adverse events. As expected, no adverse events were registered in the trial.

The percentage of active smokers at three and six months were the primary endpoints of the study. In the smartphone smoking cessation application arm (experimental) at three months, there was a lower number of active smokers (80.2 versus 91.8%, p = 0.009) corresponding to a univariate OR of 3.175 (CI 95% 1.276–7.899) for smoking cessation. At six months, the significance for the reduced number of active smokers retained (81.2 versus 86.9%, p = 0.021) with an observed univariate OR of 2.847 (CI 95% 1.137–7.128) for smoking cessation. The binary logistic regression

	Application n (%)/mean	Control n (%)/mean
All	101	99
Age	61.35	59.96
Gender		
Male	48 (47.5)	50 (50.5)
Female	53 (52.5)	49 (49.5)
Relationship status		
Single	32 (31.7)	26 (26.3)
In a relationship	69 (68.3)	73 (73.7)
ICT[a] skills		
Novice	7 (6.9)	8 (8.1)
Average	51 (50.5)	47 (47.5)
Experienced	43 (42.6)	44 (44.4)
How many cigarettes/d	15.53	16.70
Pack years	32.72	33.57
Fagerström test	2.75	2.92
How many times quitted	2.96	3.44

[a]Information and communication technology.

Table 1: **Demographics.**

	Application n (%)	Control n (%)	OR (95% CI) univariate	p-value[a]	OR (95% CI) logistic regression[b]	p-value
At three months	101 (100)	97 (98.0)				
Smokers	81 (80.2)	90 (91.8)				
Non-smokers	20 (19.8)	7 (7.1)	3.175 (1.276–7.899)	0.010	3.089 (1.235–7.726)	0.016
At six months	101 (100)	93 (93.9)				
Smokers	82 (81.2)	86 (86.8)				
Non-smokers	19 (18.8)	7 (7.0)	2.847 (1.137–7.128)	0.021	2.811 (1.115–7.085)	0.028

[a]Pearson Chi-Square. [b]Stratified for pack-years and age.

Table 2: **Smoking status at three and six months in the intention to treat population.**

adjusted for pack-year and age was carried out for the primary co-endpoints. In these analysis, three- and six-month cessation were very similar to univariate analysis (OR 3.089, CI 95% 1.235–7.726; OR 2.811, CI 95% 1.115–7.085) (Table 2). We also carried out a subgroup analysis for smoking cessation at three months based on the core baseline factors. The benefit of the smartphone application with respect to smoking cessation was observed in age ≥65 y, females, average ICT skills, pack years ≥30, and high Fagerström score (Supplementary Table S1).

We performed an exploratory analysis on trial participants' use of other medical therapies for smoking cessation. NRT use was recorded in 25.3% and 20.6% of the study participants at three and six months while no difference was detected between the study arms. Only two individuals had used other medical therapies for smoking cessation (Supplementary Table S2). We further assessed the association of NRT use and its' relationship to smoking cessation at three months. As expected, NRT use was associated with smoking cessation (OR 5.848; CI 95% 2.493–13.699). When assessing the effect of NRT between study arms, an increased chance or trend for smoking cessation was detected among the non-NRT users (OR 4.841; CI 95% 1.009–23.232) and NRT users (OR 2.787; CI 95% 0.794–9.778) in the application arm (Supplementary Table S3).

Smoking related secondary outcomes of the study included percentage of individuals who had reduced smoking from the baseline. The individuals who achieved smoking cessation were excluded from this analysis. Over both study arms, 21.1% and 29.7% of the subjects had reduced the number of smoked cigarettes/d ≥ 50% at three and six months. When the outcomes were analyzed between the study arms, we observed reduced smoking from baseline in the application arm with an OR of 2.347 (1.098–5.035) at three months while the effect was not retained at six-month time point (OR 1.199, CI 95% 0.618–2.326). Furthermore, individuals in the application arm had a non-significant reduction in the mean number of smoked cigarettes/d (4.26 versus 3.28 at three months; 4.78 versus 4.23 at six months) (Table 3).

We further investigated the correlation between smoking cessation and the frequency of application use in the experimental arm. We used the number of completed symptom questionnaires (scheduled weekly with push notifications) integrated in the application as a measure for use. The results showed that the application use was more common among the individuals who quit smoking. At three and six months, non-smokers had a higher mean number of completed questionnaires (14.05 and 13.17) compared to smokers (5.71 and 6.01) with $p < 0.001$ and $p = 0.003$ (Table 4).

	Application n (%)	Control n (%)	OR/mean difference (95% CI)	p-value[a]
At three months	81 (100)	90 (100)		
No reduction (<50%)	58 (71.6)	77 (85.6)		
Reduction (≥50%)	23 (28.4)	13 (14.4)	2.347 (1.098–5.035)	0.025
How many cigarettes less/d (mean)	4.26	3.28	0.198 (−0.428 to 2.391)	0.171
At six months	82 (100)	86 (100)		
No reduction (<50%)	56 (68.3)	62 (72.1)		
Reduction (≥50%)	26 (31.7)	24 (27.9)	1.199 (0.618–2.326)	0.590
How many cigarettes less/d (mean)	4.78	4.23	0.548 (−0.998 to 2.094)	0.484

[a]Pearson Chi-Square/T-test.

Table 3: **The number of individuals with reduced smoking (≥50% of the baseline number of smoked cigarettes) at three and six months (excluding non-smokers).**

	Non-smoker n (%)/mean	Smoker n (%)/mean	Mean difference (95% CI)	p-value[a]
All, at three months	19 (95.0)	80 (98.7)		
Mean number of filled symptom questionnaires	14.05	5.71	8.340 (3.876–12.804)	<0.001
All, at six months	18 (94.7)	81 (98.8)		
Mean number of filled symptom questionnaires	13.17	6.01	7.154 (2.503–11.806)	0.003

[a]T-test.

Table 4: **Application use assessed by the number of filled weekly symptom questionnaires (up to 24 weeks) according to smoking status at three and six months.**

Discussion

In the current study, we investigated the efficacy of a smartphone application for smoking cessation compared to written material. The studied smartphone application was developed by the study group and aimed to support both in smoking cessation and retaining a smoke-free lifestyle. The study was performed in a prospective RCT setting in the context of LDCT lung cancer screening. The results of the study showed that smoking cessation was significantly more common among the individuals randomized to the smartphone application arm.

Smoking is the leading risk-factor for lung cancer and smoking cessation clearly prevents the disease as well as improves outcomes.[1] Lung cancer screening using LDCT induces a stage shift towards localized disease and decreases lung cancer mortality.[2,3] Smoking cessation is an integral part of lung cancer screening programs and screening offers a teachable moment for smoking cessation intervention in a high-risk population. In addition, smoking related disease burden, not only in the context of cancer, is enormous, and the economic costs of tobacco use are substantial. It is estimated that tobacco smoking kills more than eight million people each year, including approximately 1.3 million non-smokers who are exposed to second-hand smoke, a loss of human capital that is preventable with smoking cessation.[21–23]

To our knowledge, this study is the first to report the results of a smartphone application-based smoking cessation in RCT setting among individuals participating in LDCT lung cancer screening. The RCT evidence of smoking cessation interventions in LDCT setting is limited and standard practice remains to be elucidated. Previous studies have shown that counseling and pharmacological agent cytisine increase chances for long-term smoking cessation.[24,25] Furthermore, NRT is a valid aid for smoking cessation also in LDCT setting.[20] In our trial, both study arms were well balanced for all the baseline factors (e.g. age, gender, information and communication technology skills, smoking history, nicotine dependency). In the study, smoking status could be verified with a very high frequency which is likely related to the study setting investigating smoking cessation in LDCT screening context. Our reported ORs for smoking cessation at three (3.175) and six months (2.847) are the highest or among the highest ever reported from RCT trials investigating smoking cessation mobile applications.[13,26] Since this is the first study investigating the developed application, we cannot conclude whether the observed excellent results are related to the specific features of the application, study population (LDCT lung cancer screening), or to both. Previous data show rates of 7–23% for smoking cessation in LDCT screening context which is in the same range as is observed in our trial (19.8–18.8% versus 7.1–7.4%).[20] Furthermore, we observed higher frequency of smoking reduction (≥50%) from baseline in the application arm at three months suggesting that the benefits of the approach are not limited to smoking cessation. Smoking reduction has its own health effects (e.g. reduced lung cancer and cardiovascular disease risk) and individuals who decrease smoking are more likely to attempt and achieve smoking cessation later.[27,28]

In the subgroup analyses for smoking cessation, all the ORs favored the application arm suggesting that the effect was irrespective of demographics and NRT use. The number of study subjects in the subgroups was relatively low which causes uncertainty to these analyses. The application seemed to be more efficacious in older age (≥65 years), females, and higher pack-years (≥30 py) among others. Older age has been linked to higher rates of smoking cessation in the context of LDCT lung cancer screening.[24,25,29–31] Conversely to our study, male gender and lower pack years have been shown to be associated with increased smoking cessation in some LDCT screening studies.[32] Since we investigated a unique intervention for smoking cessation, the differences in subgroups compared to other published LDCT study results are not surprising.

We also investigated the frequency of application use, and its' association with smoking cessation. As expected, the individuals who quit smoking had higher rates of application use. This favors the explanation that the features of the application are meaningful to the users, and ease smoking cessation. Analogously, a recent meta-analysis has identified that applications with higher adherence rates are associated with a lower risk for continued smoking.[13]

Our study has some obvious limitations. First, the study recruitment occurred only in a single center. In addition, the primary endpoint was a self-reported smoking cessation without biochemical affirmation. Nevertheless, most of the previous smoking cessation studies have used self-reported rates as their primary endpoint and this seems to follow closely to biochemically verified results.[11] Even though the number of participants in our study was moderate, the observed results were in line with our original sample size calculations. Of note, smartphone applications in lifestyle changes, such as smoking cessation, offer a drug-free approach compared to prescription medication, or NRT. If LDCT lung cancer screening programs are to be implemented in widescale to the current clinical healthcare practices, mobile applications could offer a feasible, cost-efficient, personalized, and scalable solution to integrate smoking cessation interventions.

In this study, we have shown the positive effects of the mobile application approach to smoking cessation in LDCT screening context, however, its' performance in other clinical settings might differ. Thus, further clinical validation might be required to generalize the results outside of the LDCT lung cancer screening population. It would be of interest to investigate our application concurrently with other smoking cessation interventions since previous data have shown a synergistic effect of the dual intervention of smartphone application and pharmacotherapy in smoking cessation.[13]

Our study investigated smartphone-based smoking cessation in the context of LDCT lung cancer screening. We show that the developed smartphone application increases the chance to achieve self-reported smoking cessation by three-fold compared to the standard of care. To our knowledge, this is the first published RCT study investigating a smart phone-based smoking cessation approach in individuals participating in lung cancer LDCT screening.

Contributors

JPK, SI, HA, AJ, RK, and TV designed the study. JPK, SI, and AK collected the data. JPK, SI, AK, and VW analyzed data and drafted the manuscript. All the authors read and approved the final version of the manuscript.

Data sharing statement

Data collected for the study will be made available on a reasonable request to the corresponding author.

Declaration of interests

SI reports institutional grants from AstraZeneca and Roche for the conduct of the current study. SI reports personal fees from MSD, Roche, BMS, AstraZeneca, Novartis, Takeda, Eisai, and lecture fees from Siemens Healthineers, all outside the submitted work. AK, VW, HA, and AJ declare no conflict of interest. RK reports consulting, lecture, and advisory board fees from Boehringer Ingelheim, a virtual congress cost from Novartis, an advisory board fee from MSD, outside the submitted work. TV reports advisory board fees from NordicInfu Care, MSD and AstraZeneca outside the submitted work. JPK reports institutional grants from AstraZeneca and Roche for the conduct of the current study. JPK reports a personal grant for conduct of the study from Cancer Foundation Finland. JPK reports personal fees from Roche, AstraZeneca, Janssen, BMS, Merck, Amgen, Novartis, Merck KgA, Sanofi, and Pfizer, lecturing fees from Siemens Healthineers, all outside of the submitted work. JPK is a part-time employee of Faron Pharmaceuticals.

Acknowledgements

This study was supported by AstraZeneca, Roche, and Cancer Foundation Finland.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.lanepe.2024.100946.

References

1 Tesfaw LM, Dessie ZG, Mekonnen Fenta H. Lung cancer mortality and associated predictors: systematic review using 32 scientific research findings. *Front Oncol*. 2023;13:1308897. https://doi.org/10.3389/FONC.2023.1308897.
2 de Koning HJ, van der Aalst CM, de Jong PA, et al. Reduced lung-cancer mortality with volume CT screening in a randomized trial. *N Engl J Med*. 2020;382:503–513.
3 Aberle D, Adams A, Berg C, et al. Reduced lung-cancer mortality with low-dose computed tomographic screening. *N Engl J Med*. 2011;365:395–409.
4 Krist AH, Davidson KW, Mangione CM, et al. Screening for lung cancer: US preventive Services task force recommendation statement. *JAMA*. 2021;325:962–970.
5 Livingstone-Banks J, Ordóñez-Mena JM, Hartmann-Boyce J. Print-based self-help interventions for smoking cessation. *Cochrane Database Syst Rev*. 2019;1:CD001118. https://doi.org/10.1002/14651858.CD001118.PUB4.
6 Lancaster T, Stead LF. Individual behavioural counselling for smoking cessation. *Cochrane Database Syst Rev*. 2017;3:CD001292. https://doi.org/10.1002/14651858.CD001292.PUB3.
7 Lindson N, Chepkin SC, Ye W, Fanshawe TR, Bullen C, Hartmann-Boyce J. Different doses, durations and modes of delivery of nicotine replacement therapy for smoking cessation. *Cochrane Database Syst Rev*. 2019;4:CD013308. https://doi.org/10.1002/14651858.CD013308.
8 Howes S, Hartmann-Boyce J, Livingstone-Banks J, Hong B, Lindson N. Antidepressants for smoking cessation. *Cochrane Database Syst Rev*. 2020;4:CD000031. https://doi.org/10.1002/14651858.CD000031.PUB5.
9 Thomas KH, Dalili MN, López-López JA, et al. Smoking cessation medicines and e-cigarettes: a systematic review, network meta-analysis and cost-effectiveness analysis. *Health Technol Assess*. 2021;25:1–224.
10 Hughes JR, Stead LF, Hartmann-Boyce J, Cahill K, Lancaster T. Antidepressants for smoking cessation. *Cochrane Database Syst Rev*. 2014;2014:CD000031. https://doi.org/10.1002/14651858.CD000031.PUB4.
11 Auer R, Schoeni A, Humair J-P, et al. Electronic nicotine-delivery systems for smoking cessation. *N Engl J Med*. 2024;390:601–610. https://doi.org/10.1056/NEJMoa2308815.
12 Sha L, Yang X, Deng R, et al. Automated digital interventions and smoking cessation: systematic review and meta-analysis relating efficiency to a psychological theory of intervention perspective. *J Med Internet Res*. 2022;24:e38206.
13 Guo YQ, Chen Y, Dabbs ADV, Wu Y. The effectiveness of smartphone app–based interventions for assisting smoking cessation: systematic review and meta-analysis. *J Med Internet Res*. 2023;25:e43242.
14 Zhou X, Wei X, Cheng A, et al. Mobile phone-based interventions for smoking cessation among young people: systematic review and meta-analysis. *JMIR Mhealth Uhealth*. 2023;11:e48253. https://doi.org/10.2196/48253.
15 Liu N, Yin J, Tan SSL, Ngiam KY, Teo HH. Mobile health applications for older adults: a systematic review of interface and persuasive feature design. *J Am Med Inf Assoc*. 2021;28:2483–2501.
16 Wood DE, Kazerooni EA, Aberle D, et al. NCCN Guidelines® insights: lung cancer screening, version 1.2022. *J Natl Compr Canc Netw*. 2022;20:754–764.
17 Kauczor HU, Baird AM, Blum TG, et al. ESR/ERS statement paper on lung cancer screening. *Eur Radiol*. 2020;30:3277–3294.

18 Van Der Aalst CM, Van Klaveren RJ, Van Den Bergh KAM, Willemsen MC, De Koning HJ. The impact of a lung cancer computed tomography screening result on smoking abstinence. *Eur Respir J*. 2011;37:1466–1473.

19 Brain K, Carter B, Lifford KJ, et al. Impact of low-dose CT screening on smoking cessation among high-risk participants in the UK Lung Cancer Screening Trial. *Thorax*. 2017;72:912–918.

20 Moldovanu D, De Koning HJ, Van Der Aalst CM. Lung cancer screening and smoking cessation efforts. *Transl Lung Cancer Res*. 2021;10:1099–1109.

21 Siddiqi K, Husain S, Vidyasagaran A, Readshaw A, Mishu MP, Sheikh A. Global burden of disease due to smokeless tobacco consumption in adults: an updated analysis of data from 127 countries. *BMC Med*. 2020;18:222. https://doi.org/10.1186/S12916-020-01677-9.

22 Banks E, Joshy G, Weber MF, et al. Tobacco smoking and all-cause mortality in a large Australian cohort study: findings from a mature epidemic with current low smoking prevalence. *BMC Med*. 2015;13:38. https://doi.org/10.1186/S12916-015-0281-Z.

23 Doll R, Peto R, Boreham J, Sutherland I. Mortality in relation to smoking: 50 years' observations on male British doctors. *BMJ*. 2004;328:1519–1528.

24 Pastorino U, Ladisa V, Trussardo S, et al. Cytisine therapy improved smoking cessation in the randomized screening and multiple intervention on lung epidemics lung cancer screening trial. *J Thorac Oncol*. 2022;17:1276–1286.

25 Iaccarino JM, Duran C, Slatore CG, Wiener RS, Kathuria H. Combining smoking cessation interventions with LDCT lung cancer screening: a systematic review. *Prev Med*. 2019;121:24–32.

26 Rupp A, Rietzler S, Di Lellis MA, et al. Digital smoking cessation with a comprehensive guideline-based app—results of a nationwide, multicentric, parallel, randomized controlled trial in Germany. *Nicotine Tob Res*. 2024;26(7):865–902.

27 Chang JT, Anic GM, Rostron BL, Tanwar M, Chang CM. Cigarette smoking reduction and health risks: a systematic review and meta-analysis. *Nicotine Tob Res*. 2021;23:635–642.

28 Begh R, Lindson-Hawley N, Aveyard P. Does reduced smoking if you can't stop make any difference? *BMC Med*. 2015;13:1–5.

29 Su Z, Li X, Wu H, et al. The impact of low-dose CT on smoking behavior among non-smokers, former-smokers, and smokers: a population-based screening cohort in rural China. *Cancer Med*. 2023;12:4667–4678.

30 Tammemägi MC, Berg CD, Riley TL, Cunningham CR, Taylor KL. Impact of lung cancer screening results on smoking cessation. *J Natl Cancer Inst*. 2014;106:dju084. https://doi.org/10.1093/JNCI/DJU084.

31 Townsend CO, Clark MM, Jett JR, et al. Relation between smoking cessation and receiving results from three annual spiral chest computed tomography scans for lung carcinoma screening. *Cancer*. 2005;103:2154–2162.

32 Pistelli F, Aquilini F, Falaschi F, et al. Smoking cessation in the ITALUNG lung cancer screening: what does 'teachable moment' mean? *Nicotine Tob Res*. 2020;22:1484–1491.