Effectiveness of mobile phone messaging in prevention of type 2 diabetes by lifestyle modification in men in India: a prospective, parallel-group, randomised controlled trial

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Summary

Background Type 2 diabetes can often be prevented by lifestyle modification; however, successful lifestyle intervention programmes are labour intensive. Mobile phone messaging is an inexpensive alternative way to deliver educational and motivational advice about lifestyle modification. We aimed to assess whether mobile phone messaging that encouraged lifestyle change could reduce incident type 2 diabetes in Indian Asian men with impaired glucose tolerance.

Methods We did a prospective, parallel-group, randomised controlled trial between Aug 10, 2009, and Nov 30, 2012, at ten sites in southeast India. Working Indian men (aged 35–55 years) with impaired glucose tolerance were randomly assigned (1:1) with a computer-generated randomisation sequence to a mobile phone messaging intervention or standard care (control group). Participants in the intervention group received frequent mobile phone messages compared with controls who received standard lifestyle modification advice at baseline only. Field staff and participants were, by necessity, not masked to study group assignment, but allocation was concealed from laboratory personnel as well as principal and co-investigators. The primary outcome was incidence of type 2 diabetes, analysed by intention to treat. This trial is registered with ClinicalTrials.gov, number NCT00819455.

Results We assessed 8741 participants for eligibility. 537 patients were randomly assigned to either the mobile phone messaging intervention (n=271) or standard care (n=266). The cumulative incidence of type 2 diabetes was lower in those who received mobile phone messages than in controls: 50 (18%) participants in the intervention group developed type 2 diabetes compared with 73 (27%) in the control group (hazard ratio 0·64, 95% CI 0·45–0·92; p=0·015). The number needed to treat to prevent one case of type 2 diabetes was 11 (95% CI 6–55). One patient in the control group died suddenly at the end of the first year. We recorded no other serious adverse events.

Interpretation Mobile phone messaging is an effective and acceptable method to deliver advice and support towards lifestyle modification to prevent type 2 diabetes in men at high risk.

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See Online for a podcast interview with Ambady Ramachandran

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Introduction

Primary prevention of type 2 diabetes is needed to reduce its increasing prevalence globally, particularly in low-income and middle-income countries.[1] Several randomised controlled trials have shown that lifestyle modification can reduce conversion from prediabetes to type 2 diabetes by 50%.[2–7] However, such programmes are labour intensive and have not been widely implemented, even in high-income countries. Mobile phone messaging (text messaging or short message service [SMS]) is an alternative method for delivery of educational advice and motivation to achieve lifestyle modification.[8–12]

Much work has been done to assess the use of mobile technology in disease management.[13] If successful, this method could be scalable, because mobile phones—with the low cost of SMS and their instant transmission—are used worldwide by people of all socioeconomic statuses.[13,14] Although the number of mobile phone messages sent globally tripled between 2007, and 2010,[15] robust data to support a successful role of mobile phone messaging in disease management are scarce. A Cochrane review[13] included only four randomised trials of 182 participants to provide a scientific evidence base for mobile phone messaging in management of all long-term disorders, and none of the studies assessed prevention of type 2 diabetes. Other reviews[8,16] have emphasised the paucity of randomised trials, although some data for disease management is emerging[10,17,18] and a role for mobile phone messaging in improvement of adherence to antiretroviral therapy has been established for people with HIV infection.[19] Despite the restricted evidence for mobile phone messaging in disease prevention,[14] the method is effective as part of an intervention for smoking cessation.[20]

India has a high prevalence of type 2 diabetes and widespread mobile phone ownership. We assessed whether tailored mobile phone messaging encouraging lifestyle change could reduce incident type 2 diabetes compared with standard lifestyle advice in Indian men with impaired glucose tolerance.

Methods

Study design and participants

We did this prospective, parallel-group, randomised controlled trial at ten sites in southeast India between Aug 10, 2009, and Nov 30, 2012. Working Indian men were screened for eligibility by questionnaire. The men were employed in public-sector and private-sector industrial units in southeast India (Chennai, Tamil Nadu and Visakhapatnam, Andhra Pradesh). The study was done in the workplace and because 96% of the employees were men, we included only men in the trial. Participants' jobs were self-classed as unskilled, skilled, or clerical or executive. Eligibility criteria were no diabetes (self-reported) or major illness, such as cancer, chronic liver or kidney disease; no disorders with cognitive impairment, severe depression or mental imbalance; no physical disability that would prevent regular physical activity; no recruitment in another trial; age 35–55 years; ownership of a mobile phone and ability to read and understand mobile phone messages in English; a positive family history of type 2 diabetes; and a BMI of 23 kg/m² or more. The study protocol was approved by the Ethics Review Committee of the India Diabetes Research Foundation. An independent safety committee assessed study progress with unmasked data at 6-monthly intervals. All patients gave written informed consent. Participants' physicians were informed of their participation in the trial.

***Panel 1*: Standard lifestyle advice and assessment of adherence**

Dietary recommendations

We individualised the dietary recommendations to balance food intake and physical activity and to maintain appropriate bodyweight. The advice included:

- Avoidance of simple sugars and refined carbohydrates
- Reduce total fat intake (<20 g per day)
- Restrict use of saturated fat
- Include more fibre-rich food—eg, whole grains, legumes, vegetables, and fruits

Dietary adherence

- Poor: not following the advice for more than 5 days a week (non-adherent)
- Fair: occasional deviation, following advice for 2–4 days a week (adherent)
- Good: strictly following diet advice for more than 5 days a week (adherent)

Physical activity recommendation

- To enhance aerobic exercise like walking, cycling, and jogging in sedentary patients
- Brisk walk for a minimum of 30 min per day (or equivalent), as a realistic goal with proven effectiveness
- Walk 3–4 km in 30 min at least 5 days a week
- Cycle 6–7 km in 30 min
- If occupation involves strenuous work, no specific advice

Physical activity adherence

- Poor: less than 150 min per week (non-adherent)
- Fair: 150–250 min per week (adherent)
- Good: more than 250 min per week or if occupation involved strenuous work (adherent)

Randomisation and masking

A central investigator not involved in analysis of trial data used a computer-generated randomisation sequence (Matlab randperm version 6) based on Marsaglia's algorithm[21] to randomly allocate patients (1:1) to individually tailored mobile phone messaging or to a control group that received standard lifestyle modification advice at baseline only.

Laboratory personnel and principal and co-investigators were masked to the participants' group allocation until the end of the study. Field staff and participants were, by necessity, not masked.

Procedures

After screening for eligibility, capillary blood glucose was measured with a glucometer (Accu-Check Sensor, Roche Diagnostics, Mannheim, Germany) at the participants' workplace 2 h after consuming 75 g oral glucose. Amongst the patients identified with impaired glucose tolerance, we invited those with 2 h blood glucose values of 8·9 mmol/L or more for a confirmatory oral glucose tolerance test within 1 week. During the second test, we collected venous blood samples at 0, 30, and 120 min.

At baseline, all participants received personalised education and motivation about healthy lifestyle principles, and written information about diet and physical activity. The prescribed lifestyle changes were similar to those used in a previous trial in India.[3] Participants were advised to balance food intake and physical activity and to achieve and maintain an appropriate bodyweight (panel 1). For physical activity, we asked participants with strenuous occupations and those who either walked or cycled for more than 30 min per day, or who already exercised regularly in other ways, to continue these activities (panel 1). We advised individuals who were sedentary or did light physical activity, as assessed in the initial interview, to walk briskly every day for a minimum of 30 min (panel 1).

After prescribing lifestyle changes, we reassessed all participants clinically and biochemically every 6 months from baseline. No additional lifestyle information or advice was routinely given by personal contact after the baseline visit in either the control or the intervention groups, except in response to specific queries from participants. In addition to standard lifestyle modification advice, participants in the intervention group received mobile phone messages at frequent intervals. These messages contained information about healthy lifestyle, the benefits of physical activity and diet, cues to start physical activity and healthy dietary practices, and

strategies to avoid relapse and remain motivated to maintain physical activity and healthy dietary habits.

The mobile phone message content at any time was based on the transtheoretical model of behavioural change.[22,23] This model is a stage-based concept of behavioural change, with individuals moving between discrete, qualitatively different stages of perception and action in relation to behavioural change. The model identifies five stages in the process of adoption of change: pre-contemplation, contemplation, preparation, action, and maintenance. In both groups, the transtheoretical model stage of each participant was assessed by questionnaire at baseline and review visits and the mobile phone message content in the intervention group was tailored according to their model stage.

A mobile phone messaging delivery manager website based on the transtheoretical model stage was created in partnership with Intel (Bangalore, India). The messages were delivered by a commercial service provider (Unicel technologies, India). They contained fewer than 160 characters and 60–80 messages were created for each transtheoretical model stage and sent cyclically, such that participants would not be likely to receive the same message in a 6-month period (on the basis of them receiving two to four messages per week). The assumption was that the participants would move from a pre-action stage to an action stage. The timing (0500–0800 h or 1700–2000 h) and frequency of mobile phone messaging were tailored to the participants' preferences, which were assessed at the 6-monthly visits. Panels 2 and 3 show sample messages. Participants were informed of the mechanisms for delivery of mobile phone messages and were expecting them in the agreed format.

The primary outcome was incident type 2 diabetes. Secondary outcomes were BMI, waist circumference, systolic and diastolic blood pressure, lipid profile (total and HDL cholesterol and triglycerides), total dietary energy intake, and physical activity score. The acceptability of mobile phone messaging was assessed by questionnaire in the intervention group. Ancillary analysis variables were not prespecified and included HOMA-IR and insulinogenic index calculated at baseline, and estimates of adherence to dietary and physical activity recommendations.

Oral glucose tolerance tests were done at baseline, 12 months, and 24 months, and were assessed by WHO recommendations.[24] Plasma was separated within 1 h for biochemical analysis. The samples were kept at –20°C for insulin assay. To minimise discomfort and inconvenience, at 6 months and 18 months a capillary blood sample was taken 2 h after oral glucose was given in the fasting state. If this value was 11·1 mmol/L or greater, a 2 h oral glucose tolerance test was done within 1 week with venous plasma sampling in the fasting state, and at 30 min and 2 h after glucose consumption. Type 2 diabetes was defined by a fasting plasma glucose concentration of 7·0 mmol/L or more or a concentration from the 2 h oral glucose tolerance test of 11·1 mmol/L or more, or both.[24] Participants diagnosed with type 2

Panel 2: Examples of mobile phone message reminders for physical activity, tailored according to stage of transtheoretical model

Pre-contemplation
- "Physical activity helps to maintain normal blood sugar and blood pressure."
- "Active life makes you live longer."

Contemplation
- "Moderate physical activity keeps you healthy."
- "Desk-bound job? Take short walk to relax your body and mind."

Preparation
- "Use stairs instead of a lift."
- "Get off the bus one or two stops ahead and walk to the destination."

Action
- "All you need is 30 minutes of moderate physical activity on most days of the week."
- "A good exercise can keep your mind stress free."

Maintenance
- "Were there many missed walks this month? No worries start today."
- "Are you stressed out! Stress increases blood sugar. Go for a walk and relax."

Panel 3: Examples of intervention-group mobile phone message reminders for diet, tailored according to stage of transtheoretical model

Pre-contemplation
- "Eat healthy, be healthy and be happy."
- "Regular eating pattern helps to maintain normal blood sugar."

Contemplation
- "Avoid snacks while watching TV, you may overeat."
- "Neither fast nor feast, have a balanced diet"

Preparation
- "Increase fibre rich foods, fruits and vegetables and whole cereals."
- "Make your plate colourful by adding lots of vegetables."

Action
- "Take fruits as a whole and not as a juice."
- "Fruits are delicious and nutritious, include them as part of your diet."

Maintenance
- "Skipping breakfast will make you overeat at lunch."
- "Hope you had a healthy week!"

diabetes were referred to their physicians for further management.

We measured height at baseline. Weight (BMI), waist circumference, and blood pressure (mean of two readings) by sphygmomanometer were measured at each visit by standard procedures. Plasma glucose (hexokinase method, coefficient of variation <3% at 10·0 mmol/L and 20·0 mmol/L) was measured at each visit. Fasting triglycerides, total cholesterol and HDL cholesterol were measured annually with an auto analyser with appropriate quality control. Plasma insulin was measured at baseline in the fasting state, at 30 min, and 2 h after oral glucose consumption by chemiluminescence (ELICA, Roche diagnostics). We calculated insulin resistance at baseline and at year 2 with the international HOmeostasis Model Assessment of Insulin Resistance (HOMA-IR) formula ([fasting insulin (mU/l)xfasting glucose (mmol/l)]/22·5).[25] We calculated the insulinogenic index at baseline and at year 2 by dividing the increment in insulin at 30 min by glucose at 30 min during the oral glucose tolerance test.[26]

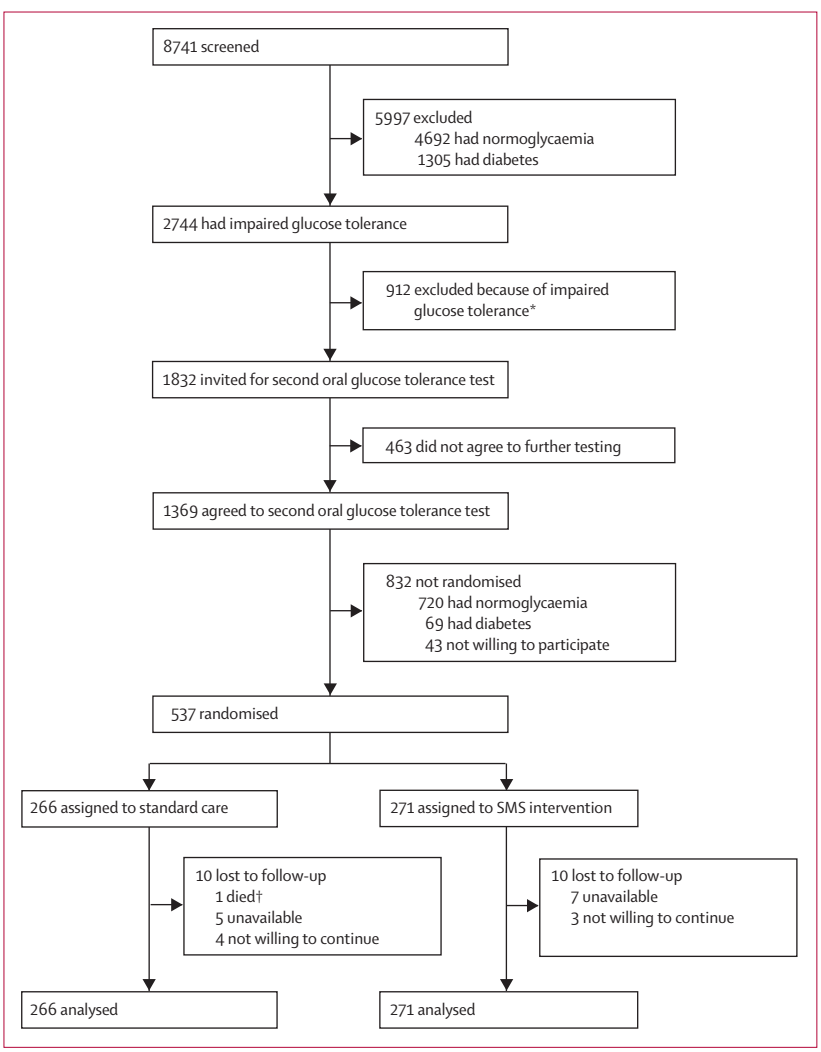

Figure 1: **Trial profile**
*2 h glucose <8·9 mmol/L. †Cardiac arrest.

Physical activity and dietary intake were assessed by questionnaire completed with fieldworkers at baseline and during the 6-monthly reviews. Physical activity was quantified on a score of 7–70.[3] The activity questionnaire was based on that used previously in south-Asian Indians in an epidemiological UK survey, which we used in our previous study of diabetes prevention in India,[3,27] but was slightly modified for the Indian environment. At each visit we assessed dietary intake by 24 h recall. Information about adherence to recommendations for dietary intake and physical activity was recorded at the 6-monthly reviews. Adherence was self-reported, on the basis of weekly patterns, and was scored as poor, moderate, or good (panel 1).[3] For statistical analysis, we categorised data as adherent or non-adherent. We calculated energy intake for individual food items with the National Institute of Nutrition guidelines for India.[28]

We assessed acceptability of mobile phone messages in the intervention group with a short questionnaire developed specifically for this trial. Scoring (0 or 1) was based on responses to questions about message content and frequency, ease of understanding, whether the messages were considered a disturbance, and whether it was perceived as helpful in improvement of lifestyle. A total score of 6 was the most acceptable and 0 the least. The questionnaire also queried the preferred time of day to receive mobile phone messages and invited suggestions for improvements. Assessments were done by seven field staff trained in undertaking glucose tolerance tests and biometric measurements. Training was done by central training staff with use of continuous training methods previously used in our diabetes projects in India.[3] Each person had a designated role to minimise inter-individual error.

Statistical analysis

With the assumption of a 30% cumulative incidence of type 2 diabetes over 2 years (in our previous study in India, which had similar eligibility criteria,[3] the incidence was 55% over 3 years), at 5% significance with 80% power, 214 participants per group were needed for a 40% reduction in progression to type 2 diabetes to be detected. In a meta-analysis of behavioural modification studies[7] the mean reduction was 50% and we assumed that mobile phone messaging would be less effective than personal contact. We aimed to recruit 514 participants (257 in each group) to allow for 20% dropout rate during follow-up.

We did analysis by intention to treat. We calculated the estimated cumulative incidence of type 2 diabetes using unadjusted Cox regression analysis to compute the hazard ratio (HR) and survival curve for the intervention versus the control groups. The number needed to treat and 95% CI to prevent one case of type 2 diabetes as the inverse of the absolute risk reduction (RR) and its 95% CI. To assess the effects of the intervention on

secondary outcomes (and ancillary analysis variables) we used mixed-linear regression modelling with maximum likelihood parameter estimation for continuous variables. We log-transformed skewed variables (triglycerides and physical activity score) before analysis. Differences in the estimated marginal means between the groups with 95% CIs are shown. We analysed categorical outcomes (adherence to diet and physical activity) with a generalised estimating equation-based logistic regression analysis, with adjustment for baseline values and time. The corresponding odds ratios (and associated 95% CIs) with p values are shown.

We computed changes by subtraction of final follow-up values from baseline values; for participants who developed type 2 diabetes, we regarded the values at the time of diagnosis as final. We used Cox regression analysis to assess the effect of change in secondary outcome, and ancillary analysis variables; baseline values of 2 h glucose; HOMA-IR; and insulinogenic index on incident type 2 diabetes. We did statistical analyses with SPSS (version 19.0).

This study is registered with ClinicalTrials.gov, number NCT00819455.

Role of the funding source

The evaluation board of the UK–India Education and Research Initiative (UKIERI) assessed the outline protocol in a competitive funding process, but neither UKIERI nor the World Diabetes Foundation had a role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

Figure 1 shows the trial profile. Of 2744 eligible participants, 1369 (50%) agreed to a second oral glucose tolerance test. Of these, 580 (42%) had persistent impaired glucose tolerance, of whom 43 (7%) did not wish to participate further. 537 participants were randomly assigned to the mobile phone messaging intervention (n=271) or to standard care (n=266), and were included in the primary analysis. Baseline characteristics were similar between groups (table 1). Most workers were in a skilled or clerical or executive role (table 1). At entry, no participant in either group was receiving lipid modifying treatment, but 69 (26%) in the intervention group and 69 (25%) in the standard care group were taking hypotensive drugs. Dietary energy intake, compatibility of diet with advice during the trial, and the distribution of physical activity scores were similar in both groups at baseline (table 1). At final follow-up, the response rate was 96% (n=517; figure 1).The mean duration of follow-up was 20·2 months (SD 7·0).

Three patients (two [<1%] in the control group and one [<1%] in the intervention group) were diagnosed with type 2 diabetes by treating physicians outside the trial. These patients were included in analysis after the diagnosis was confirmed from medical records. Other cases were ascertained during the trial. Including the three patients who had already been diagnosed, 50 (18%) men in the intervention group developed type 2 diabetes over the 2 years compared with 73 (27%) control patients (absolute risk reduction 9%; figure 2).The intervention reduced the incidence of type 2 diabetes during the course of the study (β –0·447; figure 2). The number needed to treat to prevent one case of type 2 diabetes was 11 (95% CI 6–55).

Repeated measures ANOVA showed no significant effect of the intervention on BMI, waist circumference, blood pressure, or serum cholesterol and triglycerides, but the effect on HDL cholesterol was significant (table 2). Total dietary energy intake was lower in the intervention group than in the control group, whereas physical activity scores did not differ (table 2).At the end of follow-up, a greater proportion of participants in the intervention group were adherent to diet than in the standard-care group (table 2), but adherence to physical activity recommendations did not differ between the two groups (table 2). Significant predictors of incident type 2 diabetes were high BMI, low dietary compliance, high baseline HOMA-IR and 2 h plasma glucose, and reduced baseline insulinogenic index

	Control group (n=266)	Intervention group (n=271)
Age (years)	46·1 (4·6)	45·9 (4·8)
Occupation		
Unskilled	11 (4%)	9 (3%)
Skilled	170 (64%)	164 (61%)
Clerical or executive	85 (32%)	98 (36%)
Family history of diabetes	131 (49%)	150 (55%)
BMI (kg/m²)	25·8 (3·0)	25·8 (3·3)
Waist circumference (cm)	92·7 (7·3)	92·6 (7·1)
Blood pressure (mmHg)		
Systolic	123·4 (14·3)	123·1 (13·6)
Diastolic	80·2 (8·4)	80·2 (8·4)
Receiving hypotensive drugs	69 (26%)	69 (25%)
Plasma glucose (mmol/L)		
Fasting	5·70 (0·55)	5·63 (0·53)
2 h	8·90 (0·86)	8·79 (0·78)
Serum lipids (mmol/L)		
Total cholesterol	4·91 (0·94)	4·87 (0·89)
HDL cholesterol	0·90 (0·19)	0·90 (0·21)
Triglycerides	1·6 (1·2–2·3)	1·6 (1·1–2·1)
HOMA-IR*	3·2 (1·5)	3·0 (1·3)
Insulinogenic index (pmol/mmol)	48·9 (27·9–78·5)	47·6 (30·0–81·7)
Dietary energy intake (kcal/24 h)	2100·0 (278·0)	2121·0 (296·0)
Baseline diet compatible with advice during trial	136 (51%)	141 (52%)
Physical activity score	36 (31–56)	36 (27–54)

Data are mean (SD), n (%), or median (IQR), unless otherwise indicated. HOMA-IR=HOmeostasis Model Assessment of Insulin Resistance. *Dimensionless measure.

Table 1: **Baseline characteristics**

(table 3). Significance of each variable was sustained on entry into a Cox proportional hazard model (data not shown). Randomisation group was not included in this model due to co-linearity with dietary compliance.

The frequency of mobile phone messaging at baseline was decided individually in line with participants' wishes and initially a median of 18 messages per month (range 8–24) were requested. At final follow-up, the median requested was 12 (range 8–16). Analysis of the acceptability questionnaire data showed that messages were generally welcomed, and the median questionnaire score out of 6 was 5 (range 3–6). No more than eight (3%) of 271 people at any review stated that receiving the messages was disturbing them.

One patient in the control group died suddenly at the end of the first year. We recorded no other serious adverse events.

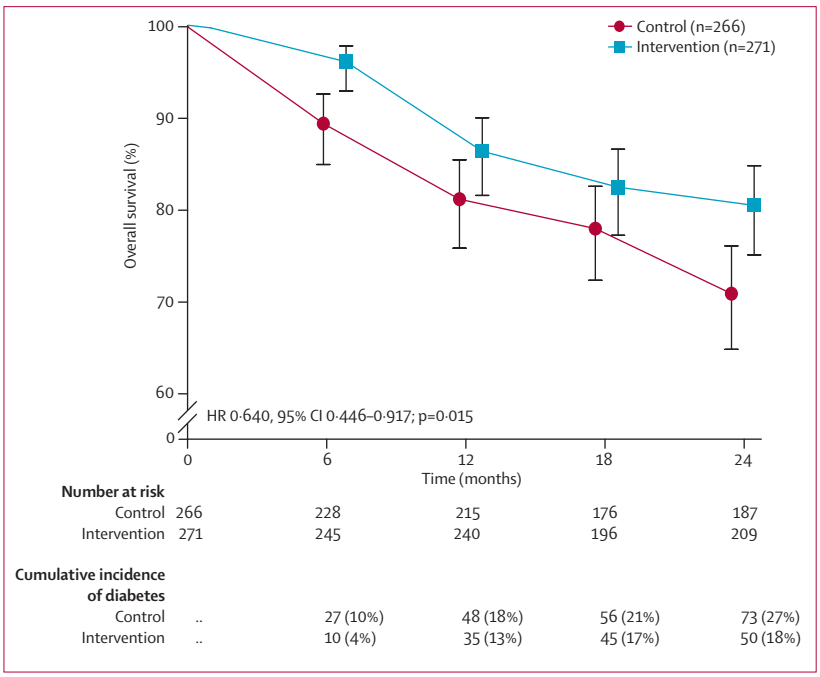

***Figure 2*: Probability of remaining free of type 2 diabetes**
Data are n (%), unless otherwise indicated. Error bars show 95% CIs. Eligibility assessed according to WHO criteria. HR=hazard ratio.

Discussion

Our findings show that mobile phone messaging can be an effective technique for lifestyle modification to reduce incidence of type 2 diabetes. The mobile phone messages were generally well accepted (panel 4).

Participants in this trial were at particularly high risk for development of type 2 diabetes on the basis of 2 h glucose concentrations at first oral glucose tolerance test. The cumulative incidence of type 2 diabetes was lower in those who received the mobile phone messaging intervention than in controls. We noted the glycaemic benefits from mobile phone messaging early in the study (at 6 months), showing that their effect was rapid. The reduction in progression to type 2 diabetes was similar in magnitude to that reported in our previous study of diabetes prevention in India in which personal contact methods were used.[3]

We aimed to induce dietary change and increase physical activity. Mobile phone messaging was associated with reduced dietary energy intake on recall; however, reported physical activity and bodyweight were similar in the intervention and control groups. This apparent

	Control group (n=266)	Intervention group (n=271)	Difference in mean change (95% CI)
Anthropometry			
BMI (kg/m²)	25·0 (5·4)	25·0 (5·5)	−0·05 (−0·46 to 0·37)
Waist circumference (cm)	92·6 (7·7)	92·6 (7·9)	0·04 (−0·56 to 0·64)
Blood pressure (mm Hg)			
Systolic	121·4 (13·0)	121·4 (13·0)	0·04 (−0·96 to 1·03)
Diastolic	78·8 (7·4)	78·7 (7·3)	−0·07 (−0·64 to 0·49)
Serum lipids (mmol/l)			
Total cholesterol	4·9 (0·9)	4·9 (0·9)	0·010 (−0·08 to 0·10)
HDL cholesterol	0·9 (0·2)	1·0 (0·2)	0·033 (0·011 to 0·054)
Triglycerides*	1·60 (1·22–2·27)	1·52 (1·16–2·09)	−0·080 (−0·17 to −0·06)
Dietary energy intake (kcal)	2042·5 (269·8)	1998·7 (295·4)	−43·7 (−65·5 to −22·0)
Physical activity score*	38·0 (25·0–54·0)	39·0 (27·0–54·0)	−1·0 (−2·0 to 0)
Difference in percentage adherence (OR [95% CI]; p value)†			
Diet	..	1·357 (1·008–1·826; p=0·0442)	..
Physical activity	..	1·110 (0·779–1·573; p=0·572)	..

Data are mean (SD) or median (IQR), unless otherwise indicated. We used mixed-linear regression analysis, taking into account visit and intervention, to generate estimated marginal means and difference in mean change (95% CI) at the end of follow-up. *Log-transformed data (by back transformation). †Logistic regression analysis with repeated measures taking into account visit and intervention to compare adherence to diet and physical activity between groups.

***Table 2*: Secondary outcomes and adherence to dietary intake and physical activity recommendations at the end of follow-up**

	HR (95%CI)	p value
2 h glucose*† (mmol/L)	1·728 (1·406–2·122)	<0·0001
HOMA-IR‡	1·175 (1·075–1·285)	<0·0001
Insulinogenic index† (pmol/mmol)	0·993 (0·988–0·998)	0·006
Change in BMI (kg/m²)	1·329 (1·151–1·535)	<0·0001
Change in dietary adherence	0·482 (0·327–0·710)	<0·0001

We entered significant predictors of incident diabetes into a Cox proportional hazards model; randomisation group was not included as a variable because of co-linearity with change in dietary adherence. HOMA-IR=HOmeostasis Model Assessment of Insulin Resistance. BMI=body-mass index. *By oral glucose tolerance test. †At baseline. ‡Dimensionless measure.

***Table 3*: Independent, significant change in secondary outcome variables and baseline variable predictors of incident diabetes**

independence of glycaemic benefit from bodyweight reduction or increase in physical activity has been reported in some previous conventional diabetes prevention programmes.[2,3] In this study, we assessed physical activity by questionnaire only, a method that could have missed small changes. Although we have previously shown increased physical activity in lifestyle practice groups,[3] as with other studies,[4,5] the physiological basis for benefit is unclear. At follow-up, concentrations of HDL cholesterol were slightly, but significantly, higher in the control versus the intervention groups. Weight loss and increased physical activity are two determinants of circulating concentrations of HDL, but in our study we could not be sure of the mechanism behind this finding. Raised concentrations have been reported previously in similar studies of prediabetes interventions.[4,29]

Our results show that baseline 2 h concentrations of plasma glucose and HOMA-IR were predictive of incident type 2 diabetes, and increased β-cell function was protective. Irrespective of study group, increased BMI was associated with high incidence of type 2 diabetes, which is in line with previous findings.[4,5]

Our study has some limitations. First, we included only working men. Women's responses and reactions to mobile phone messages might differ from those of men, but we would have recruited insufficient women to assess the effects of sex. Therefore, investigators of future studies should assess the effectiveness and acceptability of SMS in women and in other groups of men. Second, the setting was in an urban population in India. The application of mobile phone messaging to other populations should be studied. Third, although our methodology attempted to minimise bias, the fieldworkers were, by necessity, not masked; thus, we cannot exclude the possibility of bias, however unlikely. We used the transtheoretical model as the basis for the lifestyle modification strategy. Although this model has a substantial evidence base,[22] it is not uniformly accepted[23] and we cannot be sure of its importance in this trial because other methods were not studied.

Because mobile phone messaging is potentially scalable and likely to be low cost, its use in large prevention programmes warrants assessment, especially because the benefits of prevention or delaying of onset of type 2 diabetes can persist for up to 20 years.[30–32] Furthermore, benefits extend to other cardiovascular risk factors and possibly to cardiovascular events.[27] Finding a way to implement behaviour modification programmes cost-effectively remains a medical challenge. Personal contact methods will probably remain expensive, and innovative solutions have been sought for primary care and workplace settings.[33] Mobile phone messaging could form part of an alternative strategy.

***Panel 4*: Research in context**

Systematic review

We searched PubMed, Cocharane reviews, and Google for systematic reviews and published original studies from 2002 onwards that were written in English. We used the search term "prevention and management of diabetes and other chronic diseases using mobile phones". Previous studies have shown that type 2 diabetes can be prevented or delayed by lifestyle modification programmes delivered by direct contact methods .[7] Furthermore, a previous systematic review[16] showed that mobile phone messages can help induce lifestyle change, including smoking cessation. Evidence from randomised trials of the effectiveness of mobile phone messaging in the management of chronic disease is scarce, as are findings for type 2 diabetes management or prevention.[8,13,16]

Interpretation

This trial is the first to show benefit from a targeted mobile phone messaging intervention as a technique in the prevention of type 2 diabetes. Our findings showed similar preventive effectiveness as that noted with direct contact methods.[3] Mobile phone messaging was acceptable to the recipients, is potentially scalable, could be delivered at low cost, and is now part of an alternative strategy.

Contributors

AR and DGJ were the principal investigators and designed and undertook the study and prepared the manuscript. CS supervised the study conduct, analysed the data, and prepared the manuscript. JR contributed to recruitment, data collection, and statistical analysis, and helped in manuscript writing. SS and MS contributed to recruitment and data collection. AN, ASS, IFG, NC, AM, NO, CT, and KGA helped in interpretation of the results and reviewed the manuscript.

Conflicts of interest

DGJ and NC are supported by the UK National Institute for Health Research (NIHR). Imperial College London is grateful for support from the NIHR Collaboration for Leadership in Applied Health Research and Care and the Imperial NIHR Biomedical Research Centre. We declare that we have no conflicts of interest.

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