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Design and Rationale of Behavioral Nudges for Diabetes Prevention (BEGIN): A Pragmatic, Cluster Randomized Trial of Text Messaging and a Decision Aid Intervention for Primary Care Patients with Prediabetes

Maria C. Vargas, MPH[a,b], **Gracia J. Pineda, MD**[a,b], **Vanessa Talamantes, BS**[a,b], **Maria Jose Leiva Toledo, BS**[a,b], **Andrew Owen, PhD**[a,b], **Paula Carcamo, BA**[c], **Wesley Gibbert, MD, MPH**[c,d], **Ronald T. Ackermann, MD, MPH**[a,b], **Namratha R. Kandula, MD, MPH**[a,b,e], **Kenzie A. Cameron, PhD**[a,b,e], **Juned Siddique, DrPH**[e], **Geoffrey C. Williams, MD, PhD**[f], **Matthew J. O'Brien, MD, MSc**[a,b,e]

[a]Division of General Internal Medicine and Geriatrics, Department of Medicine, Northwestern University Feinberg School of Medicine. 750 N. Lakeshore Drive, 10th floor, Chicago, IL 60611, USA

[b]Institute of Public Health and Medicine, Northwestern University Feinberg School of Medicine. 750 N. Lakeshore Drive, 6th floor, Chicago, IL 60611, USA

[c]Erie Family Health Centers. 1701 W. Superior Street, Chicago, IL 60622, USA

[d]Department of Family and Community Medicine, Northwestern University Feinberg School of Medicine. 680 N. Lakeshore Drive, 14th floor, Chicago, IL 60611, USA

[e]Department of Preventive Medicine, Northwestern University Feinberg School of Medicine. 680 N. Lakeshore Drive, 14th floor, Chicago, IL 60611, USA

[f]Division of Cardiology, Department of Medicine, University of Michigan Medical School. 24 Frank Lloyd Wright Dr., Suite 1300, Ann Arbor, MI 48106, USA

Abstract

BACKGROUND: Among 96 million U.S. adults with prediabetes, adoption of evidence-based treatment to prevent diabetes remains low. Primary care represents an essential venue for preventing diabetes, yet providers in this setting have limited time to address prevention. This highlights the need for low-touch interventions that promote diabetes prevention and are not delivered by primary care providers. Text messaging and decision aids displaying disease risk and

CORRESPONDING AUTHOR: Matthew J. O'Brien, MD, MSc / Northwestern University Division of General Internal Medicine and Geriatrics / 750 N. Lake Shore Drive, 6th Floor / Chicago, IL 60611, matthew.obrien1@northwestern.edu / P: 312-503-5046 / F: 312-503-335.

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treatment information have improved outcomes in prior research. However, these approaches have not been definitively studied for managing prediabetes.

METHODS: The Behavioral Nudges for Diabetes Prevention (BEGIN) trial is a pragmatic, cluster randomized trial testing the effectiveness of text messaging about diabetes prevention and a prediabetes decision aid. These interventions are being studied in 8 primary care clinics using a 2×2 factorial design, in which pairs of clinics are randomized in a 1:1:1:1 ratio to receive usual care, text messaging alone, prediabetes decision aid alone, or both interventions. A total of 656 patients are recruited to participate, receive the study interventions, and contribute data at baseline and 12 months. The primary outcome is 12-month weight change, and the secondary outcome is adoption of evidence-based treatment to prevent diabetes. Change in hemoglobin A1c is an exploratory outcome that will be assessed among participants with available values.

CONCLUSION: Findings from the BEGIN trial will provide evidence about the effectiveness of two novel, low-touch interventions focused on diabetes prevention in primary care, where patients are diagnosed with prediabetes and there is little prior research.

Keywords

Diabetes prevention; text messaging; decision aids; behavioral nudges; primary care

1. INTRODUCTION

Prediabetes affects 96 million U.S. adults, with up to 70% eventually developing type 2 diabetes (hereafter, diabetes).[1] Intensive lifestyle interventions like the Diabetes Prevention Program (DPP) that are focused on promoting weight loss and physical activity can reduce the incidence of diabetes by up to 58%.[2] The National Diabetes Prevention Program (NDPP) is a translation of the DPP lifestyle intervention that is offered by a network of provider organizations certified by the Centers for Disease Control and Prevention.[3] Clinical trials have also demonstrated that the medication metformin also promotes modest weight loss and lowers diabetes risk among adults with prediabetes.[2,4] Despite promising evidence of their effectiveness, NDPP and metformin are used by fewer than 5% of adults with prediabetes.[5,6] Barriers to using these treatments in primary care include patients with prediabetes having limited awareness or knowledge about the condition, inaccurate perceptions of their diabetes risk, and low motivation to adopt NDPP or metformin.[7–11] Primary care providers have limited knowledge about these treatments and little time to counsel patients about prevention.[12–14] These data highlight the need for brief, pragmatic, and scalable interventions to promote NDPP and metformin adoption in primary care.

There is a growing literature on text messaging as an effective intervention to change health behaviors. Some prior text messaging programs focusing on overweight and obesity have reported modest weight loss as well as improvement in weight-related behaviors.[15–17] Use of text messaging in multi-component interventions to prevent diabetes suggests the potential to promote treatment adoption and modest weight loss.[18,19] Decision aids may represent another brief and pragmatic intervention to improve prediabetes management in primary care. Decision aids are visual tools that facilitate treatment decisions by communicating information about diseases and treatment options. Our group developed a

prediabetes decision aid pamphlet that promoted adoption of both NDPP and metformin in a pilot study.[20,21]

The field of behavioral economics has demonstrated that subtle changes in the design of health information and treatment choices can have substantial short-term impacts on health behaviors. Employing approaches from this research, behavioral nudges involve manipulating health messages, options, and environments to make behavior change more likely and easier to enact.[22] Behavioral nudges have seen limited application for prediabetes, highlighting a potential opportunity to improve brief interventions aimed at promoting treatment adoption and modest weight loss among adults with this condition. Despite promising findings from earlier research, behavioral nudges have shown limited success predicting maintenance of health behaviors over time.[23] Self-determination theory has empirically demonstrated that long-term maintenance of health behaviors requires autonomous motivation.[24] Studies using self-determination theory have linked autonomous motivation to weight loss behaviors and medication adherence,[25–27] which are key targets for diabetes prevention.

This cluster randomized trial is evaluating the integration of behavioral nudges and autonomous motivation into low-touch interventions among primary care patients with prediabetes. Behavioral Nudges for Diabetes Prevention (BEGIN) will test the effectiveness of decision aid and text messaging interventions on promoting weight loss and adoption of diabetes prevention treatments.

2. MATERIAL AND METHODS

2.1 Study Setting, Design and Hypothesis

BEGIN is a clinic-level cluster randomized trial at Erie Family Health Centers (Erie), a large Midwestern federally qualified health center that offers NDPP for patients with prediabetes.[28] Following a 2×2 factorial design (Table 1), eight participating Erie sites were randomly assigned to one of the four experimental conditions listed in Table 1. We hypothesize that the prediabetes decision aid and text messaging interventions can promote weight loss (primary outcome) and adoption of NDPP and metformin (secondary outcomes). The factorial design enables evaluation of the main effects for each intervention component based on the following equations, which use the corresponding letters for each experimental condition shown in Table 1: decision aid = (a+c) - (b+d); and text message intervention = (b+c) - (a+d). In addition, we can estimate the interaction of the two intervention components as follows: (c-a) - (b-d). This interaction measures whether one intervention demonstrated greater effectiveness in the presence of the other vs. absence of the other.

2.2 Participants and Recruitment

Eligibility criteria are assessed through the electronic health record (EHR) using demographic data, diagnosis codes, laboratory values, clinical measurements, and medication prescriptions. Inclusion criteria are: age ≥18 years, prediabetes, overweight or obesity, language preference of English or Spanish, and having the ability to receive text messages. Prediabetes status is determined via an EHR algorithm requiring: 1) last

hemoglobin A1c value of 5.7–6.4% within the last 12 months; 2) absence of diagnosis codes for diabetes; and 3) no active orders for antidiabetic medication. Overweight or obesity is determined based on body mass index (BMI) ≥23kg/m^2 for Asian adults and ≥25kg/m^2 for all other racial and ethnic groups, using EHR weight measurements within one month of participants' enrollment.[29] The following exclusion criteria are intended to limit participation of those for whom NDPP or metformin adoption may be unlikely, inappropriate, or unsafe: age ≥80 years; dementia, current pregnancy, current antidiabetic medication use, elevated serum creatinine [>1.4mg/dL in women and >1.5mg/dL in men], uncontrolled hypertension [last measured blood pressure ≥180/100mmHg]), no office visits in the last 12 months, and any previous NDPP participation.

An opt-out recruitment letter is mailed to eligible patients explaining the nature of the study and study-related procedures, with a number to call to remove themselves from further recruitment efforts. One week later, research staff contact patients via text message, EHR portal message, and/or telephone to obtain verbal consent from those who do not opt-out. Patients expressing interest through their responses to any of these communications are enrolled in the trial, begin receiving study interventions, and contribute pragmatically collected EHR outcome data. Following the same procedures, the first 164 participants (i.e., 25% of the overall sample) are additionally invited to provide written consent via an encrypted text message link, enabling collection of questionnaire data that assess potential mediators and moderators of the study outcomes (Section 2.6).

2.3 Prediabetes Decision Aid Intervention

A full description and images from the decision aid have been published elsewhere.[20,21] Briefly, the BEGIN prediabetes decision aid is a pamphlet with the front side displaying information about the risk of developing diabetes without treatment, and the risk reduction associated with DPP and metformin. The reverse side includes an open-ended question asking patients to identify needs related to diabetes prevention, and select next steps for management. This tool was developed with a grounding in behavioral economics and Self-Determination Theory, which informed the content and visual display of information (Table 2).

We conducted a pilot study of our prediabetes decision aid with 40 participants, which took a mean of 6.8 (± 3.0) minutes to deliver.[21] We previously reported a significant reduction in decisional conflict, as well as adoption of NDPP or metformin among 30% of participants at 6 months.[20,21] These pilot findings were similar among participants who reviewed the tool in English or in Spanish.[20]

This decision aid is delivered during brief virtual visits by one of Erie's bilingual health educators, who is the designated 'prediabetes champion.' Participants who complete a decision aid visit receive $25 in compensation. If participants decide to join NDPP or take metformin any time after the decision aid visit, they are encouraged to contact the health educator or their primary care provider, respectively. Members of the study team conducted a one-day, case-based training for this health educator to deliver the decision aid following a standardized protocol used in their pilot decision aid study.[20] The same health educator previously completed training on CDC's NDPP curriculum and is responsible for delivering

this program to Erie patients, including participants enrolled in the trial. Erie delivers NDPP continuously using a virtual format, including several cohorts per year in both English and Spanish.

2.4 Prediabetes Text Messaging Intervention

Our group developed the prediabetes text messaging intervention by applying diverse academic expertise in behavioral economics, health communication, health behavior change, motivation science, and diabetes prevention. The text messaging intervention also leverages autonomous motivation and the same behavioral nudges used in the decision aid (Table 2). These theory-based approaches were used to design the health information presented in text messages and solicit participants' implementation intensions by 'nudging' them to adopt healthy lifestyle behaviors, NDPP, and metformin.

Content for this yearlong text messaging program includes information covering three areas: 1) prediabetes and evidence-based treatment options, namely NDPP and metformin; 2) nutrition and suggestions for healthy eating; and 3) physical activity, including tips for how to incorporate movement into weekly routines. In addition, we developed three text messages that prompt participants to join a virtual orientation about NDPP, 'nudging' them to select the date and time they will attend. Appendix Table 1 displays text message examples of each type described above.

Three members of the research team (MCV, MJO, GCW) drafted text message content and requested regular written feedback from the other study investigators (RTA, NRK, KAC). Each message was discussed during weekly meetings, and edited (MCV, MJO, GCW) until consensus was reached. The one-year content development process was also guided by an expert advisory group composed of Erie clinicians and staff, additional academic experts, and national stakeholders in diabetes prevention. This advisory group, which also helped develop the BEGIN prediabetes decision aid,[20] met quarterly by video conference to review selected text message content and provide feedback. After the research team incorporated their edits and comments, advisory group members provided written approval of the completed text messaging program. We then conducted semi-structured interviews with 14 Erie patients assessing their reactions to selected text messages, which resulted in minor edits that were incorporated. The final text messaging program was translated into Spanish by bilingual members of our research team following established principals of forward and backward translation with cultural adaptation processes.[30]

The final program includes 93 text messages, delivered twice weekly in months 1–6 and weekly during months 7–12. Thirty-one text messages allow for bidirectional communication, with subsequent automated messages based on participants' response to the initial message. Participants' responses to messages soliciting their interest in NDPP or metformin are monitored daily by Erie staff and the research team, enabling personalized outreach to schedule relevant services. Participants who express interest in joining NDPP are invited to attend a virtual orientation session that describes the program and outlines expectations for participation. Those who wish to participate are scheduled to join Erie's NDPP program.

2.5 Randomization Procedures

Eight participating Erie clinics were randomized in pairs to deliver the following experimental conditions in a 1:1:1:1 ratio: a) decision aid alone; b) text messaging alone; c) both interventions; and d) usual care. We used covariate-based constrained randomization to achieve relative balance on clinic-level characteristics across experimental conditions.[31] We chose the following clinic-level variables to control imbalance: clinic volume (i.e., number of annual visits), clinic percent female, and clinic mean BMI.

With eight clusters and four experimental conditions, there are 2,520 possible allocation schemes. Using a modified version of the balance metric,[32] which gave additional weight to clinic volume,[33] we calculated a balance score for each allocation and randomly selected one of the allocations in the top 10% of unique balance scores. After randomization, study investigators and the statistical analyst were blinded to experimental condition. Blinding of participants and providers is not possible due to the nature of the interventions and their delivery according to clinic site.

2.6 Study Measures

Primary and secondary outcomes are collected on all study patients at baseline, 6 and 12 months using pragmatically collected data from the EHR. As mentioned above, 25% of the sample completes questionnaires that assess patient-reported measures at baseline, 6, and 12 months using an individualized text message link to Research Electronic Data Capture (REDCap).[34] Additional compensation of $25 is provided for completion of each questionnaire. Participants who do not complete questionnaires independently using this link receive up to three calls from research study staff members to administer the survey measures over the phone. All study questionnaires are administered in English or Spanish, according to participants' preferred language. The schedule for collecting study data is displayed in Table 3.

2.6.1 Primary, secondary, and exploratory endpoints—Because weight loss was a dominant predictor of preventing diabetes in the landmark DPP trial and translational studies of NDPP,[35–37] our primary study outcome is weight change from baseline to 12 months. Assessment of the primary outcome uses EHR weight measurements collected routinely during in-person primary care visits at Erie. The baseline weight is measured at participants' first office visit during the study period, called the index visit. The last measured weight within 12 months is the follow-up weight used to calculate mean weight change. The research team will contact participants without a clinic-based follow-up weight to schedule a weight measurement. The last measured height closest to the index visit is used to calculate body mass index (BMI), a secondary outcome.

Treatment adoption and adherence are secondary endpoints. Metformin adoption is defined as ≥1 prescription order. Duration of metformin use is defined by the time between the first and last order, allowing a grace period of 30 days between consecutive orders. Adoption of NDPP is defined by attending ≥1 session at Erie's program, which has received the highest level of recognition from the CDC's Diabetes Prevention Recognition Program.[3,38] Session attendance is a continuous adherence measure for NDPP, which is recorded in the EHR and

can be assessed pragmatically. For the 164 participants who are completing study surveys, questions about adoption of metformin and NDPP enable self-report of these secondary outcomes.

Prior studies have shown that even temporary glycemic improvements are associated with long-term reduction in diabetes risk.[39] Therefore, change in hemoglobin A1c (A1c) is assessed as an exploratory outcome. The most recent A1c value before the index visit is considered the baseline A1c. And the first routinely collected A1c measurement between six and 24 months after the index visit is the follow-up value used to estimate A1c change. This longer time period used to assess A1c change attempts to capture the greatest number of available values, given the likelihood of missing data at 12 months.[40]

2.6.2 Mediating variables—The following survey measures assessing potential mediators of the study outcomes are obtained from 25% of participants who complete questionnaires. Perceived risk of developing diabetes and knowledge about diabetes risk are measured using the validated Risk Perception Survey for Developing Diabetes.[41,42] We also measure perceived diabetes risk with a single item used in previous studies: "How would you estimate your risk of developing diabetes, expressed in percentage?" using an 11-point scale from 0–100%.[43] The Decisional Conflict Scale is a widely used instrument measuring the perceived quality of treatment decisions. Intention to adopt NDPP or metformin will be assessed separately with a single item using a validated 15-point scale, categorized as 1–5 (yes), 6–10 (unsure), and 11–15 (no).[44] Autonomous motivation will be assessed using Shortened Scales for Vitality, Need Supportiveness, and Autonomous Motivation.[45]

2.6.3 Moderating variables—Among all study patients, we will examine the following sociodemographic characteristics as potential moderators of observed treatment effects: age, sex, race, ethnicity, insurance status, preferred language, and BMI. Among the questionnaire subsample, numeracy and health literacy are assessed using validated instruments and analyzed as moderators.

2.7 Sample Size

We determined the sample size based on obtaining 80% power to detect a main effect on 12-month weight change of ≥2.2lb for either intervention component. This is justified by data from the landmark Diabetes Prevention Program trial demonstrating a 16% reduction in the incidence of diabetes for every 2.2lb of weight lost.[35] This minimal clinically important weight change is further justified by the potential for a relatively small difference in the primary outcome due to the low-touch nature of the interventions. Our sample size calculation assumes an intra-cluster correlation of 0.01, an intra-subject correlation of 0.97, residual standard deviation of 8.1lbs, and a loss to follow-up rate of 12%. These values were obtained from a prior longitudinal analysis of weight change in Erie patients with prediabetes.[46] Based on these assumptions, we plan to recruit a total of 656 participants to have 576 participants (72 per clinic) at follow-up.

2.8 Statistical Analyses

All analyses will be conducted by the statistical analyst (AO) in collaboration with the study biostatistician (JS) using R Version 4.2.1.[47]

2.8.1 Analyses of primary, secondary, and exploratory outcomes—Descriptive statistics will summarize participants' sociodemographic characteristics and baseline clinical variables overall and by clinic site. Table 4 presents these data for potentially eligible patients receiving their primary care at the eight participating clinics, from whom the study sample is recruited. We will model weight change from the index visit to 12-months using a three-level linear mixed-effects regression model with random intercepts for clinic site and participant. Due to clinic-level randomization, there is a risk of imbalance in clinic- and participant-level characteristics between experimental conditions. However, our use of covariate-based constrained clinic randomization procedures (Section 2.5) is designed to minimize this risk. Models will adjust for the following individual characteristics: sex, age, race, ethnicity, and insurance status, and time—recorded as the number of days between the index visit and the follow-up weight assessment. To assess the effect of the low-touch study interventions on weight change, we will include indicator variables for the decision aid (on/off) and the text messaging program (on/off) and their interaction with time. The coefficients on these interactions estimate the difference in weight change among participants who received the intervention component versus those who did not. A Sattherwaite degree-of-freedom correction will be used when estimating the significance of intervention effects.[48,49] We will examine effects of the study interventions on treatment adoption as a secondary outcome, using a mixed-effects logistic regression model with a random clinic effect and a similar set of covariates as the primary model.[50] We will use the primary linear model to examine change in BMI and A1c.

2.8.2 Exploratory analyses examining interaction, moderation, and mediation effects—We will explore the interaction of the decision aid and text message interventions by including an interaction term for these two interventions in the model described above. These analyses will examine whether the combined effect of the two interventions is greater than the sum of their individual effects. Exploratory moderation analyses will fit models similar to the primary analyses but will include moderator by intervention interaction terms. We will assess moderators one at a time in separate models. Moderation by educational attainment, health literacy, and numeracy will be assessed among the 25% of participants who complete study questionnaires. Exploratory mediation analyses will be conducted only in participants who complete study questionnaires, using causal mediating tests to account for multiple mediators and potential confounders. Specifically, we will decompose the total effect of the intervention as the sum of path-specific indirect effects (effects of the mediators) and the direct effect (effect of the intervention when the mediators are fixed).[32]

We fit two sets of models. The first is a model of weight change that is similar to our primary model but now including the mediating variables, their interaction with the intervention indicator variables, and their interaction with each other. The second set of models is for the mediators themselves as a function of the intervention, using a model

similar to our primary model but where the mediator is the outcome. Direct and indirect effects are estimated using Monte Carlo integration by drawing from the distribution of the mediators and using the draws to predict the outcome for a given subject. The average of these predictions across subjects is the effect of interest.

2.9 Missing Data

We anticipate missing follow-up weight data for approximately 12% of study participants who do not attend an office visit after the index visit. Some of these participants may not complete follow-up weight measurements by invitation. In order to use all available data, we will explore multiply imputing missing outcomes for these participants.[51] Imputation models will be fit separately by clinic and will include baseline age, weight, sex, race, ethnicity, and insurance status, assuming missing data are missing at random.[52] As missing participants may be systematically different from observed participants, we will perform sensitivity analyses investigating how robust our inferences are to departures from the missing at random assumption.[53,54]

2.10 Ethics, Trial Registration, and Funding

The BEGIN trial received approval by the Northwestern University Institutional Review Board and is registered under the protocol NCT04869917 at Clinical.Trials.gov. This study is funded by the National Institutes of Health (R18-DK123375). The funder had no role in the BEGIN study design or the writing of this report.

3. DISCUSSION

BEGIN tests the effectiveness of a prediabetes decision aid and a text messaging intervention to promote modest weight loss and adoption of evidence-based diabetes prevention treatments. Decision aids and text messages have proven effective in the management of other clinical conditions but have not been definitively studied for diabetes prevention. The low-touch nature of the study interventions, which require little time from primary care staff to implement, represents another strength. While health educators delivering our prediabetes decision aid are not available in all primary care clinics, health education is often provided by clinical staff members such as nurses, dieticians, or diabetes educators. Neither intervention is delivered by primary care providers, who face the greatest challenges to implementing preventive care during brief clinical encounters.[13] If proven effective, the decision aid and text messaging interventions have potential for scalability and sustainability. This is especially true for the latter, which is delivered automatically and requires little staff effort to monitor participants' responses.

The BEGIN interventions employ nudges from the field of behavioral economics that have seen limited application for diabetes prevention. The behavioral economic principles used in this study included framing information in ways that are motivating, prompting implementation intentions, and enabling participants' choice to adopt NDPP or metformin. Stronger behavioral nudges, such as guiding treatment choice through altering default options, are particularly effective when patients do not have strong preferences and the optimal choice is clear.[55] Because decisions about adopting diabetes prevention treatment

are complex and highly personal, we did not follow this approach. Our study interventions also leverage autonomous motivation from Self-Determination Theory, which has been demonstrated to promote maintenance of health behavior changes over time. Our theoretical grounding is both novel and important, given research suggesting that behavioral nudges alone may not lead to long-term behavior change.[23]

The BEGIN trial has some notable limitations. Because the study interventions are of limited intensity, they may not produce modest weight loss alone. However, this primary outcome is expected if the study interventions motivate participants to engage with NDPP or take metformin. The secondary outcomes of NDPP and metformin adoption are assessed pragmatically using EHR data, which may bias ascertainment of evidence-based treatment use. However, participants in the questionnaire subsample will provide self-reported data for these secondary outcomes. The questionnaire subsample being comprised of the first 164 participants enrolled could introduce potential bias from secular trends related to weight loss or NDPP program attendance.

It is unlikely that BEGIN participants will take concurrent weight loss medications because over 80% of Erie patients with prediabetes either lack health insurance or have Medicaid insurance,[46] which does not cover these medications in Illinois. However, we will explore use of weight loss medications in sensitivity analyses. While the BEGIN interventions contain similar information and employ the same behavioral nudges, the text messaging program includes more frequent participant contact that may promote greater effectiveness. The decision aid involves live contact with a health educator that may have a larger impact on participants' lifestyle choices or decision to adopt treatment. Our factorial design enables their evaluation both individually and in combination.

In conclusion, results from the BEGIN trial will provide needed evidence about the potential for low-touch interventions to promote diabetes prevention in primary care. Our study interventions have been developed and are being tested in a safety-net community health center, where diabetes risk is higher than other primary care settings and innovative interventions like ours are rarely available.[56] Therefore, the BEGIN trial may provide insights about how to achieve health equity in preventing diabetes, a condition characterized by persistent and substantial racial and ethnic disparities. Future research should study pragmatic and potentially scalable interventions leveraging behavioral nudges in other primary care settings.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Declaration of interests

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Dr. Ackerman has received consultant fees from UnitedHealth Group unrelated to this study. The other authors have no potential competing financial interests.

REFERENCES

1. Gerstein HC, Santaguida P, Raina P, et al. Annual incidence and relative risk of diabetes in people with various categories of dysglycemia: a systematic overview and meta-analysis of prospective studies. Diabetes Res Clin Pract. Dec 2007;78(3):305–12. doi:10.1016/j.diabres.2007.05.004 [PubMed: 17601626]
2. Knowler W, Barrett-Connor E, Fowler S, et al. Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin. N Engl J Med. 2002;346(6):393–403. doi: DOI: 10.1056/NEJMoa012512. [PubMed: 11832527]
3. Albright AL, Gregg EW. Preventing type 2 diabetes in communities across the US: the National Diabetes Prevention Program. Am J Prev Med. 2013;44(4):S346–S351. [PubMed: 23498297]
4. Ramachandran A, Snehalatha C, Mary S, Mukesh B, Bhaskar A, Vijay V. The Indian Diabetes Prevention Programme shows that lifestyle modification and metformin prevent type 2 diabetes in Asian Indian subjects with impaired glucose tolerance (IDPP-1). Diabetologia. 2006;49(2):289–297. doi: doi: 10.1007/s00125-005-0097-z. [PubMed: 16391903]
5. Gruss SM, Nhim K, Gregg E, Bell M, Luman E, Albright A. Public Health Approaches to Type 2 Diabetes Prevention: the US National Diabetes Prevention Program and Beyond. Curr Diab Rep. Aug 5 2019;19(9):78. doi:10.1007/s11892-019-1200-z [PubMed: 31385061]
6. Tseng E, Yeh HC, Maruthur NM. Metformin Use in Prediabetes Among U.S. Adults, 2005–2012. Diabetes Care. Jul 2017;40(7):887–893. doi:10.2337/dc16-1509 [PubMed: 28373205]
7. Rosal MC, Borg A, Bodenlos JS, Tellez T, Ockene IS. Awareness of diabetes risk factors and prevention strategies among a sample of low-income Latinos with no known diagnosis of diabetes. Research Support, N.I.H., Extramural. Diabetes Educ. Jan-Feb 2011;37(1):47–55. doi:10.1177/0145721710392247 [PubMed: 21220363]
8. Troughton J, Jarvis J, Skinner C, Robertson N, Khunti K, Davies M. Waiting for diabetes: perceptions of people with pre-diabetes: a qualitative study. Patient Educ Couns. Jul 2008;72(1):88–93. doi:10.1016/j.pec.2008.01.026 [PubMed: 18367365]
9. Hivert MF, Warner AS, Shrader P, Grant RW, Meigs JB. Diabetes Risk Perception and Intention to Adopt Healthy Lifestyles Among Primary Care Patients. Diabetes Care. Oct 2009;32(10):1820–2. doi:10.2337/dc09-0720 [PubMed: 19592631]
10. Salmela SM, Vahasarja KA, Villberg JJ, et al. Perceiving need for lifestyle counseling: findings from Finnish individuals at high risk of type 2 diabetes. Research Support, Non-U.S. Gov't. Diabetes Care. Feb 2012;35(2):239–41. doi:10.2337/dc11-1116 [PubMed: 22190673]
11. O'Brien MJ, Moran MR, Tang JW, et al. Patient Perceptions About Prediabetes and Preferences for Diabetes Prevention. Diabetes Educ. Dec 2016;42(6):667–677. doi:10.1177/0145721716666678 [PubMed: 27621093]
12. Tseng E, Greer RC, O'Rourke P, et al. National Survey of Primary Care Physicians' Knowledge, Practices, and Perceptions of Prediabetes. J Gen Intern Med. Sep 9 2019;doi:10.1007/s11606-019-05245-7
13. Porter J, Boyd C, Skandari MR, Laiteerapong N. Revisiting the Time Needed to Provide Adult Primary Care. J Gen Intern Med. Jul 1 2022;doi:10.1007/s11606-022-07707-x
14. Kandula NR, Moran MR, Tang JW, O'Brien MJ. Preventing Diabetes in Primary Care: Providers' Perspectives About Diagnosing and Treating Prediabetes. Clin Diabetes. Jan 2018;36(1):59–66. doi:10.2337/cd17-0049 [PubMed: 29382980]
15. Silina V, Tessma MK, Senkane S, Krievina G, Bahs G. Text messaging (SMS) as a tool to facilitate weight loss and prevent metabolic deterioration in clinically healthy overweight and obese subjects: a randomised controlled trial. Scand J Prim Health Care. Sep 2017;35(3):262–270. doi:10.1080/02813432.2017.1358435 [PubMed: 28812403]

16. Spring B, Schneider K, McFadden HG, et al. Multiple behavior changes in diet and activity: a randomized controlled trial using mobile technology. Arch Intern Med. May 28 2012;172(10):789–96. doi:10.1001/archinternmed.2012.1044 [PubMed: 22636824]
17. Spring B, Duncan JM, Janke EA, et al. Integrating technology into standard weight loss treatment: a randomized controlled trial. JAMA Intern Med. Jan 28 2013;173(2):105–11. doi:10.1001/jamainternmed.2013.1221 [PubMed: 23229890]
18. Block G, Azar KM, Romanelli RJ, et al. Diabetes Prevention and Weight Loss with a Fully Automated Behavioral Intervention by Email, Web, and Mobile Phone: A Randomized Controlled Trial Among Persons with Prediabetes. J Med Internet Res. Oct 23 2015;17(10):e240. doi:10.2196/jmir.4897 [PubMed: 26499966]
19. Xiao H, Adams SR, Goler N, et al. Wellness Coaching for People With Prediabetes: A Randomized Encouragement Trial to Evaluate Outreach Methods at Kaiser Permanente, Northern California, 2013. Prev Chronic Dis. Nov 25 2015;12:E207. doi:10.5888/pcd12.150251 [PubMed: 26605707]
20. Bandi K, Vargas MC, Lopez A, et al. Development and Evaluation of a Prediabetes Decision Aid in Primary Care: Examining Patient-Reported Outcomes by Language Preference and Educational Attainment. Sci Diabetes Self Manag Care. Jun 2021;47(3):216–227. doi:10.1177/26350106211009189 [PubMed: 34000911]
21. O'Brien MJ, Cameron KA, Vargas MC, et al. Evaluation of a Prediabetes Decision Aid on Patient-Reported Outcomes in Primary Care: A Pilot Study. J Gen Intern Med. Apr 12 2020;doi:10.1007/s11606-018-4436-4
22. Patel MS, Volpp KG, Asch DA. Nudge Units to Improve the Delivery of Health Care. N Engl J Med. Jan 18 2018;378(3):214–216. doi:10.1056/NEJMp1712984 [PubMed: 29342387]
23. Möllenkamp M, Zeppernick M, Schreyögg J. The effectiveness of nudges in improving the self-management of patients with chronic diseases: A systematic literature review. Health Policy. 2019;123(12):1199–1209. doi:10.1016/j.healthpol.2019.09.008 [PubMed: 31676042]
24. Ryan RM, Patrick H, Deci EL, Williams GC. Facilitating health behaviour change and its maintenance: Interventions based on self-determination theory. European Health Psychologist. 2008;10(1):2–5.
25. Williams GC, Freedman ZR, Deci EL. Supporting autonomy to motivate patients with diabetes for glucose control. Diabetes Care. Oct 1998;21(10):1644–51. doi:10.2337/diacare.21.10.1644 [PubMed: 9773724]
26. Williams GC, Grow VM, Freedman ZR, Ryan RM, Deci EL. Motivational predictors of weight loss and weight-loss maintenance. J Pers Soc Psychol. Jan 1996;70(1):115–26. doi:10.1037//0022-3514.70.1.115 [PubMed: 8558405]
27. Williams GC, Rodin GC, Ryan RM, Grolnick WS, Deci EL. Autonomous regulation and long-term medication adherence in adult outpatients. Health Psychol. May 1998;17(3):269–76. doi:10.1037//0278-6133.17.3.269 [PubMed: 9619477]
28. Erie Family Health Center. Preventing and Managing Diabetes Accessed September 16 2022. https://www.eriefamilyhealth.org/diabetes/
29. Hsu WC, Araneta MR, Kanaya AM, Chiang JL, Fujimoto W. BMI cut points to identify at-risk Asian Americans for type 2 diabetes screening. Diabetes Care. 2015;38(1):150–8. doi:10.2337/dc14-2391 [PubMed: 25538311]
30. Wild D, Grove A, Martin M, et al. Principles of Good Practice for the Translation and Cultural Adaptation Process for Patient-Reported Outcomes (PRO) Measures: Report of the ISPOR Task Force for Translation and Cultural Adaptation. Value Health. 2005;8(2):94–104. doi:10.1111/j.1524-4733.2005.04054.x [PubMed: 15804318]
31. Moulton LH. Covariate-based constrained randomization of group-randomized trials. Clin Trials. 2004;1(3):297–305. doi:10.1191/1740774504cn024oa [PubMed: 16279255]
32. Vansteelandt S, Daniel RM. Interventional Effects for Mediation Analysis with Multiple Mediators. Epidemiology. Mar 2017;28(2):258–265. doi:10.1097/ede.0000000000000596 [PubMed: 27922534]

33. Li F, Lokhnygina Y, Murray DM, Heagerty PJ, DeLong ER. An evaluation of constrained randomization for the design and analysis of group-randomized trials. Stat Med. May 10 2016;35(10):1565–79. doi:10.1002/sim.6813 [PubMed: 26598212]
34. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)--a metadata-driven methodology and workflow process for providing translational research informatics support. J Biomed Inform. Apr 2009;42(2):377–81. doi:10.1016/j.jbi.2008.08.010 [PubMed: 18929686]
35. Hamman RF, Wing RR, Edelstein SL, et al. Effect of weight loss with lifestyle intervention on risk of diabetes. Diabetes Care. 2006;29(9):2102–7. doi: doi: 10.2337/dc06-0560. [PubMed: 16936160]
36. Campione JR, Ritchie ND, Fishbein HA, et al. Use and Impact of Type 2 Diabetes Prevention Interventions. Am J Prev Med. Oct 2022;63(4):603–610. doi:10.1016/j.amepre.2022.04.002 [PubMed: 35718629]
37. Perreault L, Kahn SE, Christophi CA, Knowler WC, Hamman RF, Diabetes Prevention Program Research G. Regression from pre-diabetes to normal glucose regulation in the diabetes prevention program. Diabetes Care. Sep 2009;32(9):1583–8. doi:10.2337/dc09-0523 [PubMed: 19587364]
38. Centers for Disease Control and Prevention. National Diabetes Prevention Program Accessed September 13 2022. https://nccd.cdc.gov/DDT_DPRP/Registry.aspx
39. Perreault L, Pan Q, Mather KJ, Watson KE, Hamman RF, Kahn SE. Effect of regression from prediabetes to normal glucose regulation on long-term reduction in diabetes risk: results from the Diabetes Prevention Program Outcomes Study. The Lancet. 2012;379(9833):2243–2251. doi:10.1016/s0140-6736(12)60525-x
40. Shealy KM, Wu J, Waites J, Taylor NA, Blair Sarbacker G. Patterns of Diabetes Screening and Prediabetes Treatment during Office Visits in the US. J Am Board Fam Med. Mar-Apr 2019;32(2):209–217. doi:10.3122/jabfm.2019.02.180259 [PubMed: 30850457]
41. Walker EA, Mertz C, Kalten MR, Flynn J. Risk Perception for Developing Diabetes Comparative risk judgments of physicians. Diabetes Care. 2003;26(9):2543–2548. [PubMed: 12941716]
42. Walker EA, Caban A, Schechter CB, et al. Measuring comparative risk perceptions in an urban minority population: the risk perception survey for diabetes. Diabetes Educ. 2007;33(1):103–10. doi:10.1177/0145721706298198 [PubMed: 17272796]
43. Adriaanse MC, Snoek FJ, Dekker JM, et al. Perceived risk for Type 2 diabetes in participants in a stepwise population-screening programme. Diabet Med. Mar 2003;20(3):210–5. [PubMed: 12675665]
44. O'Connor A User Manual–Measures of Decision/Choice Predisposition. Ottawa Hospital Research Institute. Accessed August 1, 2022. https://decisionaid.ohri.ca/docs/develop/User_Manuals/UM_ChoicePredisposition_Decision.pdf
45. Levesque CS, Williams GC, Elliot D, Pickering MA, Bodenhamer B, Finley PJ. Validating the theoretical structure of the Treatment Self-Regulation Questionnaire (TSRQ) across three different health behaviors. Health Educ Res. Oct 2007;22(5):691–702. doi:10.1093/her/cyl148 [PubMed: 17138613]
46. O'Brien MJ, Vargas MC, Lopez A, et al. Development of a novel clinical decision support tool for diabetes prevention and feasibility of its implementation in primary care. Prev Med Rep. 2022/10/01/ 2022;29:101979. doi:10.1016/j.pmedr.2022.101979 [PubMed: 36161117]
47. A language and environment for statistical computing. R Foundation for Statistical Computing. 2022. https://www.R-project.org/.
48. Kahan BC, Forbes G, Ali Y, et al. Increased risk of type I errors in cluster randomised trials with small or medium numbers of clusters: a review, reanalysis, and simulation study. Trials. Sep 6 2016;17(1):438. doi:10.1186/s13063-016-1571-2 [PubMed: 27600609]
49. Kuznetsova A, Brockhoff PB, Christensen RHB. lmerTest package: tests in linear mixed effects models. J Stat Softw. 2017;82(13)doi:10.18637/jss.v082.i13
50. Hedeker D, Gibbons RD. Longitudinal data analysis. vol 451. John Wiley & Sons; 2006.
51. Little RJ, Rubin DB. Statistical analysis with missing data. vol 333. John Wiley & Sons; 2014.
52. Buuren SV, Groothuis-Oudshoorn K. mice: Multivariate Imputation by Chained Equations in R. J Stat Softw. 2010;doi:10.18637/jss.v045.i03

53. Siddique J, Harel O, Crespi CM. Addressing Missing Data Mechanism Uncertainty using Multiple-Model Multiple Imputation: Application to a Longitudinal Clinical Trial. Ann Appl Stat. Dec 1 2012;6(4):1814–1837. doi:10.1214/12-aoas555 [PubMed: 23503984]

54. Daniels MJ, Hogan JW. Missing data in longitudinal studies: Strategies for Bayesian modeling and sensitivity analysis. John Wiley & SonsJohn Wiley & Sons; 2008.

55. Patel MS, Navathe AS, Liao JM. Using Nudges to Improve Value by Increasing Imaging-Based Cancer Screening. J Am Coll Radiol. Jan 2020;17(1 Pt A):38–41. doi:10.1016/j.jacr.2019.08.025 [PubMed: 31541658]

56. Resources Health & Administration Services. Health Center Program Uniform Data System (UDS) Data Overview. Accessed September 13, 2022. https://data.hrsa.gov/tools/data-reporting/program-data?grantNum=H80CS00115

Table 1:

BEGIN Factorial Design

Experimental Condition	BEGIN Intervention Components[a]	
	Decision Aid	Text Messaging
a	On	Off
b	Off	On
c	On	On
d	Off	Off

[a]Main effects of an intervention component are estimated by comparing clinics in an experimental condition where the component is turned “On” to those where it is turned “Off.” For example, the main effect of the decision aid is (a+c) – (b+d).

Table 2:
Application of Theory-Guided Approaches in the BEGIN Study Interventions

Theory-Guided Approach	Definition	Example of Application in Decision Aid Intervention	Example of Application in Text Messaging Intervention
Behavioral Economics/ Behavioral Nudges			
Message framing	Different descriptions of the same health problem or treatment option are used to motivate related behaviors.	Text emphasizes the potential gains in joining a diabetes prevention program, as opposed to the losses expected from not joining the program.	Text messages about physical activity focus on the benefits participants may feel, rather than the adverse consequences of not doing physical activity.
Position effects	The first option presented in a list is more likely to be chosen than those displayed later.	Data displays about the benefits and risks of NDPP appear before risk information about metformin and not adopting treatment.	Text messages presenting information about NDPP are delivered prior to messages about metformin.
Focusing effects	Health risk information is presented before decision options.	Prediabetes health risk information is provided at the top of the decision aid before presentation of treatment options.	Initial text messages present information about prediabetes as health condition prior to presenting treatment options.
Active choice	Decision-makers are asked to make an immediate choice instead of waiting for them to opt-in.	The reverse side of the decision aid prompts participants to choose “What are my next steps?” with a list of options.	Messages about virtual NDPP orientation sessions require participants to select the time they will attend, rather than asking them to opt-in.
Social incentives	The impact of social relationships and social support on health behavior are addressed.	Pamphlet presents information about behavioral norms among patients with prediabetes by describing what others are doing to improve their health.	Messages about NDPP describe the social support derived from other participants as a benefit of joining the program.
Self-Determination			
Theory			
Autonomous motivation	Lasting behavior change requires internalizing values and regulation of relevant behaviors, and then integrating them with one’s sense of self.	Language prompts participants to formulate a preliminary treatment plan. To promote autonomy, participants are asked “What are you willing to do to prevent diabetes?”	Text messages address factors that motivate healthy lifestyle behaviors and the decision to adopt NDPP and/or metformin.

Table 3:

BEGIN Data Collection Schedule

Study Sample and Variables	Question / Instrument[a]	Source	Baseline	Month 6	Month 12
All study patients [b]					
Outcomes					
Weight		EHR	x	x	x
Hemoglobin A1c		EHR	x	x	x
Metformin adoption		EHR		x	x
NDPP adoption		EHR		x	x
Moderators					
Age		EHR	x		
Sex/gender		EHR	x		
Race/ethnicity		EHR	x		
Language preference		EHR	x		
Insurance Status		EHR	x		x
Questionnaire subsample only [c]					
Outcomes					
Metformin adoption[d]		Survey			x
NDPP adoption[d]		Survey			x
Moderators					
Educational attainment		Survey	x		
Health Literacy	Health Literacy Screening Questions	Survey	x		
Numeracy	Subjective Numeracy Scale	Survey	x		
Mediators					
Perceived diabetes risk	“How would you estimate your risk of developing diabetes, expressed in percentage?” using an 11-point scale from 0–100%.”	Survey	x	x	x
Intention to adopt treatment	Decision Choice Predisposition	Survey	x	x	x
Decisional Conflict	Decisional Conflict Scale	Survey	x	x	x
Knowledge about diabetes risk	Risk Perception Survey-Diabetes Mellitus	Survey	x	x	x

Study Sample and Variables	Question / Instrument[a]	Source	Baseline	Month 6	Month 12
Autonomous motivation	Scales for Vitality, Need Supportiveness, and Autonomous Motivation	Survey	x	x	x

NDPP = National Diabetes Prevention Program; EHR = Electronic health record

[a]Citations for the validated instruments used to assess potential mediators and moderators are provided in the manuscript text.

[b]Study outcomes and selected moderators will be collected pragmatically using EHR data for all study participants.

[c]As described in Section 2.2, the first 164 participants (i.e., 25% of the total sample) complete written informed consent and complete study surveys using validated instruments to measure the constructs listed in Table 3.

[d]The questionnaire subsample will answer questions about taking metformin and attending NDPP, which will complement pragmatically collected EHR data for this secondary outcome.

Table 4:

Characteristics of Primary Care Patients at Participating Clinic Sites

Characteristic[a]	Overall (n=11,13)	Clinic 1 (n=1,716)	Clinic 2 (n=1,578)	Clinic 3 (n=2,059)	Clinic 4 (n=937)	Clinic 5 (n=1,632)	Clinic 6 (n=442)	Clinic 7 (n=1,454)	Clinic 8 (1,312)
sex[b]									
Female	7,329 (65.8)	1,164 (67.8)	979 (62.0)	1,209 (58.7)	676 (72.1)	993 (60.8)	252 (57.0)	1,014 (69.7)	1,042 (79.4)
Male	3,795 (34.1)	552 (32.2)	598 (37.9)	850 (41.3)	261 (27.9)	639 (39.2)	190 (43.0)	438 (30.1)	267 (20.4)
Mean age, years	41.8 (15.2)	42.3 (14.8)	40.4 (15.9)	43.2 (15.2)	44.3 (15.3)	42.0 (15.4)	40.3 (14.9)	42.8 (15.1)	38.1 (13.9)
Age, years									
18–30	3,044 (27.3)	454 (26.5)	508 (32.2)	510 (24.8)	192 (20.5)	462 (28.3)	136 (30.8)	360 (24.8)	422 (32.2)
31–45	3,724 (33.5)	581 (33.9)	494 (31.3)	660 (32.1)	315 (33.6)	525 (32.2)	143 (32.4)	469 (32.3)	537 (40.9)
46–60	2,957 (26.6)	457 (26.6)	373 (23.6)	604 (29.3)	291 (31.1)	433 (26.5)	116 (26.2)	437 (30.1)	246 (18.8)
>60	1,405 (12.6)	224 (13.1)	203 (12.9)	285 (13.8)	139 (14.8)	212 (13.0)	47 (10.6)	188 (12.9)	107 (8.2)
Race									
White	7,256 (65.2)	1,027 (59.9)	732 (46.4)	1,305 (63.4)	687 (73.3)	1,140 (69.9)	251 (56.8)	1,088 (74.8)	1,026 (78.2)
Black	1,249 (11.2)	187 (10.9)	382 (24.2)	151 (7.3)	24 (2.6)	136 (8.3)	120 (27.1)	140 (9.6)	109 (8.3)
Asian	484 (4.0)	38 (2.2)	191 (12.1)	141 (6.9)	22 (2.4)	22 (1.4)	2 (0.4)	20 (1.4)	12 (0.9)
Other[c]	228 (2.1)	37 (2.2)	30 (1.9)	56 (2.7)	40 (4.3)	26 (1.6)	6 (1.4)	17 (1.2)	16 (1.2)
Missing[d]	1,949 (17.5)	427 (24.9)	243 (15.4)	406 (19.7)	164 (17.5)	308 (18.9)	63 (14.3)	189 (13.0)	149 (11.4)
Ethnicity									
Hispanic	7,752 (69.6)	1,284 (74.8)	599 (38.0)	1,383 (67.2)	819 (87.4)	1,244 (76.2)	284 (64.3)	1,057 (72.7)	1,082 (82.5)
Non-Hispanic	2,008 (18.0)	233 (13.6)	611 (38.7)	399 (19.4)	57 (6.1)	204 (12.5)	123 (27.8)	223 (15.3)	158 (12.0)
Missing	1,370 (12.3)	199 (11.6)	368 (23.3)	277 (13.5)	61 (6.5)	184 (11.3)	35 (7.9)	174 (12.0)	72 (5.5)
Language									
Spanish	5,619 (50.5)	881 (51.3)	377 (23.9)	1,030 (50.0)	695 (74.2)	918 (56.3)	229 (51.8)	877 (60.3)	612 (46.6)
English	5,511 (49.5)	835 (48.7)	1,201 (76.1)	1,029 (50.0)	242 (25.8)	714 (43.8)	213 (48.2)	577 (39.7)	700 (53.4)
Mean body mass index, kg/m^2	32.4 (6.1)	32.8 (6.3)	32.1 (6.5)	32.2 (6.2)	31.9 (5.2)	32.3 (5.9)	32.9 (6.5)	32.8 (6.1)	32.2 (6.1)
Mean hemoglobin A1c, %	5.90 (0.19)	5.91 (0.19)	5.92 (0.19)	5.90 (0.18)	5.91 (0.18)	5.91 (0.19)	5.92 (0.20)	5.90 (0.18)	5.87 (0.18)

[a] Data are expressed as n (%) for categorical variables and mean (SD) for continuous variables.

[b] Overall, 6 patients at participating clinics were missing data for sex: Clinic 2 (1); Clinic 7 (2); and Clinic 8 (3). These patients are not included in the rows for male or female.

[c] This category included patients identified as Native American, Alaska Native, Native Hawaiian, and/or Pacific Islander.

[d] This category included patients with missing fields or marked as "Unspecified," "Patient Declined," and "State Prohibited."