High engagement in mobile peer support is associated with better glycemic control in type 1 diabetes: A real-world study

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Keywords
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ABSTRACT
Aims/Introduction: Peer support for diabetes has become convenient and interactive after the emergence of mobile health (mHealth). We aimed to evaluate the association between engagement in peer support through the mHealth app and glycemic control in type 1 diabetes patients.

Materials and Methods: This retrospective study included adults with type 1 diabetes who had joined the mobile community "TangTangQuan" since May 2018 for at least 1 year. "Like", "comment" and "share" were the major interaction indicators of the mobile community and were used to assess engagement in peer support. The patients were divided into four engagement groups by quartile. The primary outcome was the change in glycosylated hemoglobin (HbA1c), mean fasting blood glucose (FBG) and postprandial blood glucose (PBG) from baseline to the 12th month. Other outcomes included the change of self-monitoring of blood glucose frequency, hypoglycemia frequency and the proportion of reaching optimal glycemic control.

Results: Among the 693 individuals, the HbA1c, mean FBG and PBG improved in the 12th month. Multiple regression analysis showed that higher engagement in peer support was associated with a greater reduction of HbA1c (β = −0.45, P < 0.001) and mean FBG (β = −0.82, P < 0.001). In the subgroup of poor glycemic control, the association between engagement in peer support and glycemic improvement still remained (HbA1c: β = −0.86, P = 0.002; FBG: β = −1.36, P = 0.001). The engagement in mobile peer support was positively correlated with educational level (odds ratio 1.42, P = 0.042), household income (odds ratio 1.43, P = 0.013) and the use of continuous subcutaneous insulin infusion (odds ratio 1.73, P = 0.009).

Conclusion: High engagement in mobile peer support was associated with better glycemic control in adults with type 1 diabetes.

INTRODUCTION
Optimal glycemic control could reduce the risk of developing diabetes-related complications and mortality in patients with type 1 diabetes12. However, maintaining long-term euglycemic control is a big challenge worldwide, despite the advance in drugs and technologies. It is reported that nearly three-quarters of adults with type 1 diabetes failed to achieve the glycemic target of glycosylated hemoglobin (HbA1c) <7%34. Optimal glycemic control depends on the patient’s self-management abilities and constant motivation because of the demanding lifestyle of daily self-monitoring and insulin dose adjustment56. Besides education on knowledge of diabetes management, social support has proved to be essential to improve the abilities and adherence to self-management among patients with type 1 diabetes7.
As a critical component of social support, peer support is emotional, appraisal and informational assistance provided by members who have suffered from the same illness as the target population. Peer support has been shown to improve glycemic control, alleviate negative emotions and improve the quality of life among patients with type 1 diabetes. Traditionally, peer support among patients with type 1 diabetes is implemented by focus groups, diabetes camps and face-to-face training sessions. However, several barriers prevent patients with type 1 diabetes from benefiting from peer support, including inflexible schedule, inaccessible social network, low socioeconomic status and remote residency.

Recently, the emergence of mobile health (mHealth) applications (apps) has provided a chance to enhance diabetes care accessibility and improve the quality of diabetes management. Compared with traditional peer support, mobile peer support has the advantages of convenience, low cost and broad coverage. Previous studies showed that participation in the type 1 diabetes mobile support community could empower patients by enhancing their knowledge and confidence. However, most of the studies were qualitative and explorative, and there is limited evidence on whether mobile peer support could improve glycemic control in patients with type 1 diabetes. Therefore, we aimed to investigate the association between mHealth-based interactive peer support and glycemic control among Chinese patients with type 1 diabetes, and its potential associated factors.

MATERIALS AND METHODS
Interactive peer support through the mHealth app

**TangTangQuan**

TangTangQuan (TTQ; [http://www.ttq.so/](http://www.ttq.so/)), developed by Shenzhen Aibaowei Biotechnology Co., Ltd., COI: 440306107659140, is a mHealth app designed to provide diabetes self-management education and support for patients with type 1 diabetes. Free download and registration of TTQ are available in major app stores for mobile phones in China. The mobile community aims to break the isolation of individual type 1 diabetes patients by socializing their self-management data and identifying their peers. The entire interaction is supervised by authenticated healthcare providers and peer leaders.

The present retrospective study investigated the association between peer support engagement during the first year of registration and glycemic control of TTQ users with type 1 diabetes. The study population was from the T1D China Study, a large-scale population and hospital-based registration study enrolling patients with type 1 diabetes from 105 hospitals across China since 2014 (project to establish a longitudinal cohort of type 1 diabetes in China, [www.chictr.org.cn](http://www.chictr.org.cn), ChiCTR2000034642). The project aimed to establish a longitudinal cohort of type 1 diabetes patients in China to investigate disease epidemiology and improve type 1 diabetes management. Since 2018, TTQ has been introduced to the T1D China Study cohort by healthcare providers of the participating hospitals, and has become the largest online community for patients with type 1 diabetes in China. The registration and use of TTQ are at the disposal of the participants. For those who agree to use TTQ, the cohort participants and the investigators could incorporate electronic medical records into the personal diabetes diary module. In addition, a glucose meter that could automatically synchronize blood glucose readings to the app through Bluetooth wireless technology would be distributed to the cohort participants.

The study enrolled patients that registered in the TTQ mobile community after 1 May 2018 and stayed in the community for at least 12 months by 1 May 2021. According to the data from TTQ, the percentage of patients with type 1 diabetes who have used the app completely for 12 months was 82.6%, which showed the utility of TTQ and ensured an adequate sample size for the study. The baseline was defined as the first month after joining the TTQ mobile community. The inclusion criteria were as follows: (i) confirmed diagnosis of type 1 diabetes by endocrinologists from tertiary hospitals, and reconﬁrmed by healthcare provider’s follow up; (ii) aged at least 18 years at baseline; (iii) duration of type 1 diabetes for at least 1 year at baseline; and (iv) agreed to provide anonymized data. The exclusion criteria were as follows: (i) no HbA1c at baseline, or no fasting blood glucose (FBG) or postprandial blood glucose (PBG) records at least once a week during the first month after joining the TTQ mobile community; (ii) no HbA1c at the 12th month, or no FBG or PBG records at least once a week on average during the 12th month after joining the TTQ mobile community; (iii) peer leaders or healthcare providers despite confirmed diagnosis of type 1 diabetes; and (iv) withdrew consent to participate.

Data collection

The following data of the participants at baseline were obtained from TTQ: (i) demographics: age, sex, educational level and household per capita income; (ii) diabetes-related information:
duration of type 1 diabetes, age at type 1 diabetes onset, chronic diabetes complications (diabetic retinopathy, nephropathy or neuropathy, etc.), family history of diabetes, insulin treatment (multiple daily insulin injections [MDI], continuous subcutaneous insulin infusion [CSII] or premixed insulin) and use of continuous glucose monitoring (CGM). Although the guideline recommended MDI or CSII for patients with type 1 diabetes, a previous study showed that a considerable number of patients were still treated with premixed insulin in China. Age was grouped according to the definition of emerging adulthood (aged 18–30 years). Household per capita income was grouped based on the annual per capita income data of China. Family history of diabetes was defined as any type of diabetes, except gestational diabetes in first-degree relatives.

Assessment of peer support engagement
Social media platforms measure user engagement through various web analytics indicators. For online social media, such as Facebook, Instagram, Twitter, YouTube and Reddit, different interactive behaviors (including “like”, “comment” and “share”) represent different levels of engagement and expression with public relations. One research on Facebook showed that “like” was affective; “comment” was cognitive; and “share” was either affective or cognitive, or a combination of both. Accordingly, this study assessed peer support engagement by three interactive behaviors in the peer support community module of TTQ: the total frequency of “like”, “comment” and “share” within 1 year after registration. A higher frequency of the aforementioned behaviors meant a higher engagement level of the user. The eligible users were divided into four engagement groups (T1–T4, from lowest to highest) based on the interquartile range of the total frequency of the aforementioned three indices.

Outcome measurements and definitions
The primary outcome of the present study was the change of the HbA1c, mean FBG and mean PBG from baseline to 1 year after registration. The study extracted HbA1c records, and glucose readings tagged as FBG and PBG in TTQ, which derived from self-report or automatically synchronized data of eligible users during the study period. For self-report self-monitoring of blood glucose (SMBG), the patient was required to tag glucose values with specific time, such as “fasting”, “after breakfast”, “after lunch” and “after supper”, when they uploaded their glucose values. For automatically synchronized glucose values, TTQ could synchronize the glucose values of compatible glucometers (Aicare® and VivaChek®) through Bluetooth. When the patient tested their blood glucose by these glucometers, the patient could select corresponding time, such as “fasting” and “postprandial”. To ensure the accuracy of glucose values, the staff of TTQ instructed all the patients how to upload or synchronize their glucose values within the first month of registration. Based on the data of FBG and PBG, we defined baseline mean FBG or mean PBG as the arithmetic mean of the entire FBG or PBG values during the first month of registration. Similarly, we defined mean FBG or mean PBG of the 12th month as the arithmetic mean of the entire FBG or PBG values during the 12th month of registration.

Other outcomes included the change of SMBG frequency (times per week), hypoglycemia frequency (blood glucose <3.9 mmol/L, times per week) and the proportion of reaching optimal glucemic control (HbA1c <7.0%, FBG <7.0 mmol/L, PBG <10.0 mmol/L). The hypoglycemia frequency was further classified into level 1 hypoglycemia (3.0 mmol/L ≤ blood glucose < 3.9 mmol/L) frequency and level 2 hypoglycemia (blood glucose <3.0 mmol/L) frequency. Furthermore, the study investigated potential factors that were associated with the engagement in mobile peer support.

Statistical analysis
Continuous variables are presented as the mean ± standard deviation, and categorical variables are shown as frequencies and their percentages. Comparisons among the four groups were analyzed by one-way ANOVA or non-parametric test, where appropriate. Self-comparison during the study period was analyzed by paired t-test or the χ²-test. Multiple regression analysis was carried out to investigate the association between the engagement level of peer support and glycemic improvement while adjusting confounding factors. The potential factors associated with the engagement in mobile peer support were explored by ordinal logistic regression and were shown by a forest plot. In the model test, P < 0.05 showed that the odds ratio (OR) value of at least one variable was statistically significant. The test of parallel lines showed a good model fit with the observed values (χ² = 31.317, P > 0.05). A two-sided P-value <0.05 was considered statistically significant. Statistical analyses were carried out with GraphPad Prism 8.4.3 software (GraphPad Software Inc., San Diego, CA, USA), SPSS version 23.0 software (IBM Corporation, Armonk, NY, USA), statistical program R (version 3.6.3; The R Foundation for Statistical Computing, Vienna, Austria) and Empower (R) (X&Y Solutions Inc., Boston, MA, USA).

RESULTS
Characteristics of study participants
A total of 693 eligible adults with type 1 diabetes using the TTQ app were included in the analysis (Figure 1). Baseline characteristics of the participants were presented in Table 1. The mean age was 31.0 ± 9.5 years, and 66.1% (458/693) of them were women. The average duration of type 1 diabetes was 8.3 ± 6.8 years; 64.9% (450/693) of the participants had an age at type 1 diabetes onset ≥18 years; 29.6% (205/693) had chronic diabetes complications; 47.6% (330/693) were treated by MDI and 35.6% (247/693) by CSII; and 13.1% (91/693) used CGM (FreeStyle Libre®, n = 60; Dexcom G5®, n = 22; Dexcom G6®, n = 9). No participant changed the treatment during the study period of 12 months.
Glycemic control at baseline and the 12th month after registration of TTQ
Glycemic control of the participants at baseline and the 12th month is shown in Figure 2. Overall, the participants showed better glycemic control after joining TTQ for 1 year compared with the baseline (baseline vs 12th month: HbA1c: 6.9 ± 1.3% vs 6.6 ± 1.3%, \( P < 0.001 \); FBG: 7.57 ± 2.28 mmol/L vs 7.22 ± 2.40 mmol/L, \( P = 0.006 \); PBG: 8.35 ± 2.25 mmol/L vs 8.06 ± 2.47 mmol/L, \( P = 0.021 \)). A larger proportion of the participants achieved the target of HbA1c <7.0% 1 year after registration (baseline vs 12th month: 62.2% vs 70.4%, \( P = 0.001 \)). The hypoglycemia frequency decreased significantly after 1 year (baseline vs 12th month: 1.4 ± 1.9 times per week vs 0.8 ± 1.4 times per week for overall hypoglycemia, \( P < 0.001 \); baseline vs 12th month: 0.8 ± 1.1 times per week vs 0.6 ± 1.0 times per week for level 1 hypoglycemia, \( P < 0.001 \); baseline vs 12th month: 0.6 ± 0.9 times per week vs 0.3 ± 0.5 times per week for level 2 hypoglycemia, \( P < 0.001 \)), whereas the SMBG frequency did not change significantly.

Association between engagement in mobile peer support and glycemic control
According to the engagement level of mobile peer support, the participants were divided by quartile into T1 (n = 173), T2 (n = 173), T3 (n = 173) and T4 (n = 174) group (T1–T4, from lowest to highest). The frequency of interactive behaviors in each group ranged 0–50, 51–177, 178–540 and 546–3,681, respectively. The change in median frequency of interactive behaviors is shown in Figure 3. As shown in Table 2, there was statistical significance in the change of HbA1c (–0.2 ± 1.4% vs –0.2 ± 1.5% vs –0.4 ± 1.2% vs –0.6 ± 1.3%, for the T1, T2, T3 and T4 group, respectively, \( P = 0.028 \)) or mean FBG (0.12 ± 3.00 mmol/L vs –0.22 ± 2.66 mmol/L vs –0.55 ± 2.39 mmol/L vs –0.73 ± 2.11 mmol/L, for T1, T2, T3 and T4 group, respectively, \( P = 0.011 \)). The participants with higher engagement levels showed better improvement of HbA1c and mean FBG. However, there was no statistical significance in the change of mean PBG, SMBG frequency or hypoglycemia frequency.

Multiple regression analysis was further carried out to analyze the association between the engagement level of peer support and glycemic improvement (Table 3). After adjusting multiple confounding factors, including age, sex, educational level, household per capita income, duration of type 1 diabetes, insulin treatment, CGM use, baseline HbA1c, baseline FBG and baseline PBG, the results showed that compared with the T1 group, the T3 group and T4 group were associated with better change of HbA1c (\( \beta = -0.26, 95\% \) confidence interval [CI] –0.50 to –0.01, \( P = 0.039 \), for the T3 group; \( \beta = -0.45, 95\% \) CI –0.70 to –0.21, \( P < 0.001 \), for the T4 group) and mean FBG (\( \beta = -0.51, 95\% \) CI –0.97 to –0.05, \( P = 0.031 \), for T3 group; \( \beta = -0.82, 95\% \) CI –1.29 to –0.36, \( P < 0.001 \), for T4 group).

The stratified analysis showed that in the subgroup of poor glycemic control (baseline HbA1c ≥7.0% or mean FBG ≥7.0 mmol/L), the association between engagement level of peer support and glycemic improvement still remained (HbA1c: \( \beta = -0.86, P = 0.002 \); FBG: \( \beta = -1.36, P = 0.001 \); Table 4).

Factors associated with the engagement level of mobile peer support
Ordinal logistic regression was carried out to determine the factors associated with the engagement level of peer support. As shown in the forest plot (Figure 4), higher engagement level was associated with higher educational level (OR 1.42, 95% CI 1.01–2.00, \( P = 0.042 \)), higher household per capita income (OR 1.43, 95% CI 1.08–1.91, \( P = 0.013 \)) and the use of CSII (OR 1.73, 95% CI 1.14–2.60, \( P = 0.009 \)). The participants in the highest engagement group (T4 group) had the largest proportion of tertiary education or above (83.9%, \( \chi^2 = 8.925, P = 0.030 \)), annual household per capita income ≥$US4,525
In the present retrospective study, significant glycemic improvement was observed in the participants after 1 year of using the TTQ app. The results showed that a greater reduction of HbA1c and FBG was associated with a higher level of engagement in mobile peer support. Factors associated with high engagement level included higher educational level, higher household per capita income and the use of CSII.

Diabetes mHealth apps are beneficial for glycemic control in patients with diabetes. However, the results of different studies were varied. A recent meta-analysis including eight studies using mHealth apps in diabetes care suggested a slight improvement in mean HbA1c by 0.25% in the mHealth group.

Table 1 | Baseline characteristics of study participants (n = 693)

| Characteristic                        | Value                                      |
|--------------------------------------|--------------------------------------------|
| Age (years)                          | 31.0 ± 9.5                                 |
| Age group†                           |                                            |
| <30 years                            | 372 (53.7%)                                |
| ≥30 years                            | 321 (46.3%)                                |
| Sex                                   |                                            |
| Male                                 | 235 (33.9%)                                |
| Female                               | 458 (66.1%)                                |
| Duration of type 1 diabetes (years)  | 8.3 ± 6.8                                   |
| Duration group                        |                                            |
| <10 years                            | 464 (67.0%)                                |
| ≥10 years                            | 229 (33.0%)                                |
| Age at type 1 diabetes onset         |                                            |
| <18 years                            | 243 (35.1%)                                |
| ≥18 years                            | 450 (64.9%)                                |
| Chronic complications of diabetes‡   |                                            |
| No                                   | 488 (70.4%)                                |
| Yes                                  | 205 (29.6%)                                |
| Educational level                    |                                            |
| Lower than tertiary education        | 147 (21.2%)                                |
| Tertiary education or above          | 546 (78.8%)                                |
| Annual household per capita income§  |                                            |
| <US$4,525                            | 305 (44.0%)                                |
| ≥US$4,525                            | 388 (56.0%)                                |
| Family history                       |                                            |
| Negative                             | 606 (87.4%)                                |
| Positive                             | 87 (12.6%)                                 |
| Insulin treatment                    |                                            |
| MDI                                  | 330 (47.6%)                                |
| CSII                                 | 247 (35.6%)                                |
| Premixed insulin                     | 116 (16.7%)                                |
| CGM use                              |                                            |
| No                                   | 602 (86.9%)                                |
| Yes                                  | 91 (13.1%)                                 |

Data were presented as mean ± standard deviation or frequency (percentage). †Age was grouped according to the definition of emerging adulthood (aged 18–30 years)30. ‡Self-reported diabetic retinopathy, nephropathy and/or neuropathy. §Household per capita income was grouped based on the annual per capita income data of China (US$1 ≈ 6.63 Chinese yuan in 2018)31. CGM, continuous glucose monitoring; CSII, continuous subcutaneous insulin infusion; MDI, multiple daily injections.

Figure 2 | Changes of glycosylated hemoglobin (HbA1c), mean fasting blood glucose (FBG), mean postprandial blood glucose (PBG), self-monitoring of blood glucose (SMBG) frequency and hypoglycemia frequency from baseline to the 12th month in different engagement levels of mobile peer support. (a) Change of HbA1c from baseline to the 12th month; (b) change of mean FBG from baseline to the 12th month; (c) change of mean FBG from baseline to the 12th month; (d) change of SMBG frequency from baseline to the 12th month; and (e) change of hypoglycemia frequency from baseline to the 12th month.

(30,000 yuan; 60.3%, χ² = 6.121, P = 0.106) and the use of CSII (44.8%, χ² = 12.938, P = 0.044).
French study that included 180 adults with type 1 diabetes with poor glycemic control (HbA1c ≥8.0%) found that the mHealth app, Diabeo, improved HbA1c control after 6 months without changing the frequency of SMBG and hypoglycemic episodes. Another study showed that the diabetes management app SocialDiabetes could improve the estimated HbA1c and reduce the risk of hypoglycemia, independent of the frequency of using the app. In the present study, we observed a moderate reduction of HbA1c (~0.3%), mean FBG (~0.34 mmol/L), mean PBG (~0.29 mmol/L) and hypoglycemia frequency (~0.5 times per week) after 12 months, without change of SMBG frequency in the overall population.

Peer support can improve self-management behaviors among patients with type 1 diabetes. It creates an exceptional opportunity to reflect on daily life by sharing their experiential knowledge. Nowadays, computer programs and mobile apps can mediate frequent interaction with peers by e-mail, texting and other forms through the Internet. A previous report showed that peer support was the most demanded function of online software and mHealth apps. One qualitative study showed that using a Facebook group as the peer support platform empowered the patients with type 1 diabetes to improve their glycemic control. Another study showed that the major activity of diabetes-related Google+ communities was providing peer support and information. However, there is no quantitative evidence to show the relationship between patient engagement in mobile peer support and glycemic control. We assessed the engagement level in mobile peer support by the TTQ app, and provided evidence that higher engagement in mobile peer support was associated with better glycemic control. Furthermore, mobile peer support can save resources and mitigate the deficiencies of traditional peer support.

In the present study, the educational level was associated with engagement in mobile peer support. The participants in the highest engagement group had the largest proportion of tertiary education or above. This finding was consistent with a study on breast cancer, which showed that digital literacy was positively correlated to educational level, and women with lower digital literacy were more likely to report difficulties in the Internet-based peer support groups. The possible explanation for our observation was that participants with higher educational level had a more favorable attitude toward using mobile apps for diabetes self-management, and became more

**Table 2** Comparison of glycemic control from baseline to the 12th month in different engagement levels of mobile peer support

| Glycemic control                  | Engagement level (lowest T1 to highest T4) | P-value |
|-----------------------------------|--------------------------------------------|---------|
|                                   | T1 (n = 173)                               |         |
| Frequency of interactive behaviors (times per year) | 0–50                                      |         |
| HbA1c at baseline (%)             | 69 ± 1.3                                   | 0.621   |
| Change of HbA1c (%)               | –0.2 ± 1.4                                 | 0.028   |
| Mean FBG at baseline (mmol/L)     | 7.41 ± 2.15                                | 0.555   |
| Change of mean FBG (mmol/L)       | 0.12 ± 0.30                                | 0.011   |
| Mean PBG at baseline (mmol/L)     | 8.32 ± 0.24                                | 0.777   |
| Change of mean PBG (mmol/L)       | –0.24 ± 0.26                               | 0.856   |
| SMBG frequency at baseline (times per week) | 173 ± 143                                 | 0.329   |
| Change of SMBG frequency (times per week) | –31 ± 150**                               | 0.684   |
| Hypoglycemia frequency at baseline (times per week) | 1.2 ± 1.9                                 | 0.220   |
| Change of hypoglycemia frequency (times per week) | –0.04 ± 0.20*                            | 0.275   |
| Level 1 hypoglycemia frequency at baseline (times per week) | 0.8 ± 0.11                               | 0.383   |
| Change of level 1 hypoglycemia frequency (times per week) | –0.02 ± 0.14*                            | 0.506   |
| Level 2 hypoglycemia frequency at baseline (times per week) | 0.05 ± 0.10                              | 0.146   |
| Change of level 2 hypoglycemia frequency (times per week) | –0.02 ± 0.08**                           | 0.139   |

Data are presented as mean ± standard deviation or range. *P < 0.05 at 1 year versus baseline, **P < 0.01 at 1 year versus baseline. FBG, fasting blood glucose; HbA1c, glycosylated hemoglobin; PBG, postprandial blood glucose; SMBG, self-monitoring of blood glucose.
positive in the mobile community. The household per capita income was the second factor associated with engagement in mobile peer support in the present study. Previous studies observed a similar association between family income and engagement in mHealth of diabetes. It was reported that observed a similar association between family income and mobile peer support in the present study. Previous studies income was the second factor associated with engagement in mHealth use, baseline glycosylated hemoglobin (HbA1c), baseline fasting blood glucose (FBG) and baseline postprandial blood glucose (PBG). Reference group. CI, confidence interval.

Table 3: Association between the engagement level of mobile peer support and glycemic control by multiple regression analysis

| Glycemic control     | Engagement level | Crude model | Adjusted model |
|----------------------|------------------|-------------|----------------|
|                      |                  | β (95% CI)  | P-value        | β (95% CI)  | P-value  |
| Change of HbA1c      | T1‡              | 0           | 0              | 0           | 0         |
|                      | T2               | −0.04 (−0.33, 0.25) | 0.775 | 0.01 (−0.24, 0.25) | 0.961 |
|                      | T3               | −0.19 (−0.48, 0.10) | 0.189 | −0.26 (−0.50, −0.01) | 0.039 |
|                      | T4               | −0.40 (−0.69, −0.11) | 0.006 | −0.45 (−0.70, −0.21) | <0.001 |
| Change of mean FBG   | T1               | 0           | 0              | 0           | 0         |
|                      | T2               | −0.34 (−0.88, 0.20) | 0.213 | −0.22 (−0.67, 0.24) | 0.358 |
|                      | T3               | −0.68 (−1.22, −0.14) | 0.014 | −0.51 (−0.97, −0.05) | 0.031 |
|                      | T4               | −0.85 (−1.39, −0.31) | 0.002 | −0.82 (−1.29, −0.36) | <0.001 |
| Change of mean PBG   | T1‡              | 0           | 0              | 0           | 0         |
|                      | T2               | −0.08 (−0.66, 0.49) | 0.774 | −0.04 (−0.52, 0.45) | 0.885 |
|                      | T3               | 0.05 (−0.52, 0.63) | 0.852 | 0.09 (−0.40, 0.58) | 0.725 |
|                      | T4               | −0.19 (−0.76, 0.39) | 0.526 | −0.22 (−0.71, 0.27) | 0.372 |

| Glycemic control     | Engagement level | Crude model | Adjusted model |
|----------------------|------------------|-------------|----------------|
|                      |                  | β (95% CI)  | P-value        | β (95% CI)  | P-value  |
| HbA1c ≥7.0%          | T1†              | −0.14 (−0.65, 0.37) | 0.585 | −0.37 (−0.91, 0.17) | 0.175 |
| HbA1c <7.0%          | T2               | 0.17 (−0.12, 0.45) | 0.261 | −0.12 (−0.39, 0.16) | 0.398 |
| FBG ≥7.0 mmol/L      | T3               | −0.46 (−1.28, 0.37) | 0.277 | −0.94 (−1.78, −0.10) | 0.030 |
| FBG <7.0 mmol/L      | T4               | −0.02 (−0.55, 0.50) | 0.928 | −0.39 (−0.90, 0.12) | 0.131 |
| PBG ≥10.0 mmol/L     | T1†              | 0.27 (−1.17, 1.72) | 0.712 | 0.71 (−0.78, 2.20) | 0.352 |
| PBG <10.0 mmol/L     | T2               | −0.05 (−0.60, 0.50) | 0.858 | −0.05 (−0.60, 0.49) | 0.851 |

†Adjusted for age, sex, educational level, household per capita income, duration of type 1 diabetes, insulin treatment, continuous glucose monitoring (CGM) use, baseline glycosylated hemoglobin (HbA1c), baseline fasting blood glucose (FBG) and baseline postprandial blood glucose (PBG). Reference group. CI, confidence interval.

Table 4: Stratified analysis of the association between the engagement level of mobile peer support and glycemic control by baseline glycosylated hemoglobin, fasting blood glucose and postprandial blood glucose

| Glycemic control | Engagement level (lowest T1 to highest T4) | Crude model | Adjusted model |
|------------------|--------------------------------------------|-------------|----------------|
|                  | T1†                                        | β (95% CI)  | P-value        | β (95% CI)  | P-value  |
| Change of HbA1c  | HbA1c ≥7.0%                                | −0.14 (−0.65, 0.37) | 0.585 | −0.37 (−0.91, 0.17) | 0.175 |
|                  | HbA1c <7.0%                                | 0.17 (−0.12, 0.45) | 0.261 | −0.12 (−0.39, 0.16) | 0.398 |
| Change of mean FBG | FBG ≥7.0 mmol/L                            | −0.46 (−1.28, 0.37) | 0.277 | −0.94 (−1.78, −0.10) | 0.030 |
|                  | FBG <7.0 mmol/L                            | −0.02 (−0.55, 0.50) | 0.928 | −0.39 (−0.90, 0.12) | 0.131 |
| Change of mean PBG | PBG ≥10.0 mmol/L                           | 0.27 (−1.17, 1.72) | 0.712 | 0.71 (−0.78, 2.20) | 0.352 |
|                  | PBG <10.0 mmol/L                           | −0.05 (−0.60, 0.50) | 0.858 | −0.05 (−0.60, 0.49) | 0.851 |

Reference group. CI, confidence interval; FBG, fasting blood glucose; HbA1c, glycosylated hemoglobin; PBG, postprandial blood glucose.

that the proportions of the participants using CSII and MDI were 35.6% and 47.6%, respectively, which accounted for 83.3% choosing intensive therapy, whereas 16.7% chose premixed insulin. A previous study showed the steady use of MDI and intensive therapy. There was a possibility that a change from premixed insulin to MDI or CSII had occurred because of the educational component of TTQ. Currently, there is no literature

mixed insulin to MDI or CSII had occurred because of the

51, intensive therapy including MDI and CSII were recommended by the current guideline. Compared with previous studies in China, there was a much higher proportion of participants in the present study choosing intensive therapy. There was a possibility that a change from premixed insulin to MDI or CSII had occurred because of the educational component of TTQ. Currently, there is no literature
Increased engagement level of mobile peer support

| Characteristics                                      | OR (95% CI) | P-value |
|------------------------------------------------------|-------------|---------|
| Sex (Female vs. Male)                                | 1.14 (0.85, 1.53) | 0.387 |
| Age² (≥ 30 vs. < 30 years)                           | 0.99 (0.71, 1.36) | 0.939 |
| Duration (≥ 10 vs. < 10 years)                       | 0.94 (0.67, 1.33) | 0.745 |
| Age at T1D onset (≥ 18 vs. < 18 years)               | 0.93 (0.64, 1.33) | 0.679 |
| Chronic diabetic complications‡ (Yes vs. No)         | 1.33 (0.98, 1.81) | 0.069 |
| Education level (Tertiary or above vs. Lower than tertiary) | 1.42 (1.01, 2.00) | 0.042 |
| Household per capita income§ (≥ 4,525 vs. < 4,525 USD) | 1.43 (1.08, 1.91) | 0.013 |
| Family history (Positive vs. Negative)               | 0.73 (0.48, 1.12) | 0.153 |
| Insulin treatment (MDI vs. Premixed insulin)         | 1.29 (0.87, 1.92) | 0.202 |
| Insulin treatment (CSII vs. Premixed insulin)        | 1.73 (1.14, 2.60) | 0.009 |
| CGM usage (Yes vs. No)                               | 1.37 (0.92, 2.04) | 0.123 |
| HbA₁c at baseline (< 7.0 vs. ≥ 7.0 %)                | 1.18 (0.86, 1.62) | 0.310 |
| FBG at baseline (< 7.0 vs. ≥ 7.0 mmol/L)             | 0.92 (0.68, 1.24) | 0.574 |
| PBG at baseline (< 10.0 vs. ≥ 10.0 mmol/L)           | 0.94 (0.65, 1.36) | 0.745 |

Figure 4 | Factors associated with the engagement level of mobile peer support by forest plot. †Age was grouped according to the definition of emerging adulthood (aged 18–30 years)30. ‡Self-reported diabetic retinopathy, nephropathy and/or neuropathy. §Household per capita income was grouped based on the annual per capita income data of China (1 SUS1 ≈ 6.63 Chinese yuan in 2018)31. CGM, continuous glucose monitoring; CI, confidence interval; CSII, continuous subcutaneous insulin infusion; FBG, fasting blood glucose; HbA1c, glycosylated hemoglobin; MDI, multiple daily injections; OR, odds ratio; PBG, postprandial blood glucose; T1D, type 1 diabetes; USD, United States dollar.

There were also several limitations in the present study. First, most of the participants in our study had relatively reasonable glycemic control at baseline, with good educational background and income. Our findings suggested that patients with relatively good glycemic control, high educational level and high income could improve glycemic control by using the functions provided by mHealth app. However, the participants could not fully represent patients with type 1 diabetes in China, especially the patients with poor glycemic control of low socioeconomic status. Second, due to the limitation of data availability, we could not obtain enough available data of other modules, such as medical information (e.g., hospitalization or emergency room visit due to hypoglycemia or hyperglycemia), educational information and lifestyle information (including dietary habit and physical activity), which might also improve glycemic control. Third, we were unable to determine what proportions of interactive indicators were effective in glycemic improvement based on the current data. Fourth, given the nature of the retrospective single arm observational study, we could only investigate
the association between mobile peer support and glycemic control, which limited the generalization of the conclusion.

In conclusion, high engagement in peer support through the mHealth app was associated with better glycemic control in patients with type 1 diabetes. The associated factors of high engagement in mobile peer support included higher educational level, higher household per capita income and the use of CSII.

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DISCLOSURE
The authors declare no conflict of interest.

Approval of the research protocol: The T1D China Study conformed to the ethical guidelines of the Declaration of Helsinki, and was approved by the Ethics Committee of the Third Affiliated Hospital of Sun Yat-sen University (Approval No. [2014] 2-1051).

Informed consent: All patients provided informed consent when recruited to the TTQ platform.

Registry and the registration no. of the study/trial: The approval date was 12 July 2020 (registration no. ChiCTR2000034642).

Animal studies: N/A.

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SUPPORTING INFORMATION
Additional supporting information may be found online in the Supporting Information section at the end of the article.

Appendix S1 | Introduction of the basic model and algorithms of TangTangQuan.