Original Paper

Smartphone-Based Telemedicine Practice in Older Chinese Patients with Type 2 Diabetes Mellitus

Running title: Telemedicine in Older patients

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Abstract

Background: By reviewing the previous research of telemedicine, we have found out that old diabetic patients have difficulties in using computers, so it is unrealistic for medical teams to communicate with old diabetes patients anytime and anywhere. However, the popularity of smartphones and chatting applications has enabled old people of China to develop skills of chatting on smartphones and become familiar with smartphone operations. Therefore, we have designed an Mobile Health (m-Health) system for diabetics based on smartphones, which greatly streamlined operation interface and functions for maximum automation.

In addition, the smartphone-based telemedicine of diabetes has been designed
for old people.

**Objective:** To investigate smartphone-based telemedicine applications in the management of older Chinese patients with type 2 diabetes mellitus (T2DM).

Variables of interest included efficacy and safety.

**Methods:** A total of 91 older (age $>65$) patients with T2DM, who presented to our department, were included and randomly assigned to one of two groups.

Patients in the intervention group (n=44) were given glucometers capable of data transmission, and received advice pertaining to medications, diet, and exercise via a m-Health telemedicine system. Patients assigned to the control group (n=47) presented to traditional outpatient clinics for their medical care and
received no other interventions. We followed up patients in both groups at regular 3-month intervals.

**Results:** After 3 months, patients in the intervention group had significant ($P<0.05$) improvements in postprandial plasma glucose levels. After 6 months, patients in the intervention group exhibited decreasing trends in postprandial plasma glucose and glycosylated hemoglobin (HbA1C) levels compared with the baseline and those in the control group ($P<0.05$).

**Conclusions:** Smartphone-based telemedicine applications are effective for controlling blood glucose and lowering HbA1C in older Chinese patients with T2DM.
KEYWORDS: Telemedicine, Type 2 diabetes, Health management
Introduction

Diabetes mellitus is one of the top three chronic, non-infectious diseases, and a major threat to humans worldwide[1]. According to the International Diabetes Federation, the total number of patients with diabetes is over 366 million globally. By 2030, this number is expected to exceed 552 million[2]. Old peoples are at elevated risk of diabetes, and national diabetes screening efforts in China indicate that diabetes prevalence rates, in adults over 60 years of age were 20.40% (in 2008) and 22.86% (in 2010). Compared with 2002 estimates (6.80%), there was a 13.60% increase, by 2008, and a 16.06% increase by 2010, corresponding to a population of 38 million (2008) and 41 million (2010),
respectively[3-5]. Approximately one in five older patients with T2DM suffers from severe complications, including diabetic neuropathy, nephropathy, retinopathy, and vasculopathy, which were the major risk factors for renal failure, loss of sight, and loss of lower limbs. Diabetes and diabetic complications jeopardize patients’ life quality and expectancy, financially burdening patients and community healthcare systems. Because of this, prevention, early diagnosis, and treatment are crucial[6,7]. Many older patients are limited in their ability to access medical information. In addition, many have inadequate knowledge and awareness of diabetes-related hazards and poor self-control. Approximately two-thirds of older patients with diabetes were not aware
of their condition prior to the national general survey screening. Of those
diagnosed, over a half were not controlling their blood glucose efficiently[8].

Thus, preventive interventions, rather than therapeutic interventions, are
arguably more important. Enhancing access to medical information, and guiding
lifestyle changes can help patients improve their diabetes self-management
strategies.

Diabetes self-management includes dietary monitoring, exercise, self-
monitoring of blood glucose levels, and mental status adjustments. Telemedicine
management systems provide personalized medical training based on patient-
specific conditions. Because of this, telemedicine systems can improve diabetes
self-management, potentially preventing diabetic complications. However, many of these applications require use of personal electronic devices, posing a potential accessibility barrier to older patients who may be unaccustomed to this technology. Therefore, the applicability of telemedicine systems to older patients remains an area of considerable inquiry.

In an earlier telemedicine study, we found that elderly patients experienced challenges related to computer use. In this study, a computer was designed to automatically transmit blood glucose meter readings. However, the computer was not a portable device; thus passing information from the patient to the computer and further to the medical team was not very realistic[9]. The
emerging popularity of smartphones and chat applications has led a subset of older patients to become interested in smartphone use. Although some users find computers difficult to master, others are more open to learn using a smartphone, demonstrating proficiency with respect to smartphone use that far exceeds their proficiency with respect to computer use. Previous summary reports on internet-based telemedicine involving the elderly highlight the drawbacks. Considering known obstacles in smartphone use, we designed a smartphone-based m-Health management platform. To encourage their use by older patients, we designed the user interface application functions to facilitate operating with maximum possible simplicity and automation. This research sought to explore the efficacy
of smartphone-based m-Health management systems for use by older patients with T2DM.
Research Design and methods

Subjects

From March to September 2016, we conducted a randomized controlled trial to evaluate the efficacy of an m-Health management system in improving conditions of older patients with diabetes. All study patients attended the outpatient endocrinology department of the First Affiliated Hospital of Jilin University. Inclusion criteria were age over 65 years, glycosylated hemoglobin level 7.0%–10.0%, and able to use a smartphone. Exclusion criteria were illiteracy, severe comorbid conditions, including serum creatinine > 132.6 umol/L (male) or 123.8 umol/L (female), AST or ALT ≥2.5 × upper normal limit,
severe diabetic complications, medication non-compliance, insulin pump use, and involvement in (or planned involvement with) other clinical trials.

**Ethics**

The ethics committee of the First Affiliated Hospital of Jilin University approved this study, and has been registered at the China Clinical Trial Registration Center with a registration number of ChiCTR1800015214, and all subjects provided written informed consent prior to any study-related procedures. The study protocol was designed in accordance with the Declaration of Helsinki.

**Study design**
Patients selected after applying the inclusion and exclusion criteria were randomly assigned to either the intervention or control group. Patients in the intervention group were trained to independently use the m-Health management app and upload glucometer data, which was then automatic transmitted to medical server (the glucometer was connected to the smartphone via bluetooth).

The patients measured their blood glucose levels at least two times per day for 2–3 days per week. The medical teams logged on to the system and sent medical advice and reminders to patients to monitor their glucose levels via app message (intervention group), or via telephone every 2 weeks. Patients in the control group received a free glucometer and were followed up through conventional
outpatient clinic appointments. Control group subjects were not limited with respect to the number of visits, but they were instructed to monitor and record their blood glucose data regularly. All control group subjects were followed up within the outpatient clinic at 3-month intervals. Patients in both groups underwent physical examinations, blood biochemical testing, follow-up clinic visits, and ambulatory therapy by the same medical team.

The study dietitian offered guidance for glucose monitoring and provided dietary advice based on each patient's individual blood glucose fluctuations. Patients in the experimental group used app-based diet management software to input daily food. Each day the dietitian received patient-specific dietary
information over the m-Health application. This information was analyzed and used as the basis for once-monthly recommendations sent from the dietitian to patients in the intervention group. The control group received dietary guidance from dietitians during face-to-face meetings at baseline and at the conclusion of all study-related procedures. Information regarding daily calorie consumption was obtained from patients in the intervention group via text message. The patients were instructed on how to text pedometer data to study personnel. This information was analyzed, and each patient in the intervention group was provided with guidance related to aerobic and resistance-based exercises.
Statistical analysis

Data were processed with SPSS17.0. Normally distributed variables were presented as mean±SD, and skewed variables were presented as median (quartile range). During intergroup comparisons, normally distributed data were tested by independent-sample t-tests and skewed data were tested using Mann–Whitney U-tests. In intra-group comparison, normally distributed variables were tested by paired t-test, and skewed variables were tested by Wilcoxon rank sum test. 

$P<0.05$ indicated a statistically significant difference. Study figures were created using SigmaPlot.
Results

A total of 91 subjects were included after applying the inclusion and exclusion criteria and randomly assigned to the intervention (n=44) and control (n=47) groups. Baseline data of both groups are detailed in Table 1. No significant differences were observed between groups in age, physical examination, and biochemical indices.

Three months after the trial began, we noted significant improvement in HbA1C levels comparing to the baseline data for both groups ($P<0.01$; Table 2 and Figure 1). These improvements did not significantly vary relative to group assignment ($P>0.05$; Figure 2). Patients in the intervention group exhibited
improvement (downward trend) in postprandial plasma glucose levels relative to baseline; however, these improvements did not rise to the level of statistical significance. Among intervention group patients, postprandial plasma glucose levels were significantly decreased compared with those among control group patients (P<0.05; Figure 3).

By the sixth month, HbA1C continued to progressively decrease among intervention group patients, and 6-month levels were significantly lower than those recorded at baseline (P<0.05) and control group levels (P<0.05; Figure 1).

These decreases (comparing to baseline data) were higher in the intervention group than the control group (1.0% vs 0.66%, P<0.05; Figure 2). The
intervention group postprandial glucose levels demonstrated continuous improvement compared with baseline ($P<0.01$) and 3-month levels ($P<0.05$).

Intervention group levels were also significantly lower than control group levels ($P<0.01$; Figure 3).

At 6 months, we obtained satisfaction survey results from patients in the experimental group. Each question was worth one point, and the highest possible score was seven points. Higher point totals indicated better satisfaction. The average satisfaction score was 6.3±0.78. Individual questions measured current treatment satisfaction (0.89±0.19), if telehealth monitoring was convenient (0.81±0.20), did telehealth monitoring assist patients with self-monitoring of
blood glucose (0.93±0.14), did telehealth monitoring assist patients with diet and exercise management (0.85±0.20), did telehealth monitoring help raise diabetes awareness (0.98±0.08), did telehealth monitoring help relieve depression (0.96±0.12), and would the patient be willing to recommend telehealth monitoring to others (0.91±0.02) (Table 3).
Discussion

Past investigations suggest that telemedicine can improve blood glucose control in patients with diabetes[10,11], but the applicability of telemedicine for older patients is rarely discussed. Research by Lim et al[12] and Bond et al[13]. in patients with T2DM older than 60 years of age indicated that patients who used an m-Health management system showed more significant decreases in HbA1c levels and lower incidence of hypoglycemia than those who received traditional, outpatient follow-up.

We completed a 6-month, prospective, randomized controlled trial of the m-Health telemedicine system in patients with T2DM over 65 years of age. The
results indicated that intervention group postprandial plasma glucose and HbA1c levels were significantly lower than the control group levels. After 3 months, postprandial plasma glucose was 1.02 mmol/L lower than that at baseline, and by the sixth month, postprandial plasma glucose levels in intervention group patients were progressively decreased by nearly 2.23 mmol/L relative to baseline. We also observed statistically significant differences when comparing the intervention and control groups. In the intervention group, HbA1c level decreased by 1% between baseline and third month, whereas in the control group, the level decreased by 0.66%. Although the HbA1C levels of both groups were not significantly different, by the 6 month the intervention group showed
continuous improvement and significantly lower HbA1C levels than the control group.

These findings suggest that older patients require time to familiarize with the m-Health system. However, after self-training and getting help from family, the positive effects of telemedicine were evident because patients independently used the portable smartphones[14]. In this research, both groups showed improved blood glucose and HbA1c levels. This may be attributable to personalized medicine and dietary and exercise plans provided to all subjects.

However, without distant supervision and continuous guidance, it is difficult to determine long-uterm and stable efficacy; thus, long-term follow-up is essential
for elderly patients with diabetes[15]. During the study, 13 control group subjects (hyperglycemia 7 and hypoglycemia 6) and 5 intervention group subjects (hyperglycemia 4 and hypoglycemia 1) were administered adjusted drug doses but the same drug type, both groups did not show serious adverse events such as hypoglycemia or hyperglycemia and aggravated complications. The intervention group had significantly fewer hypoglycemic events compared with the control group. This may have occurred because via the m-Health platform, the medical team was able to quickly identify hypoglycemia risk and quickly provide a warning to avoid further hypoglycemia. After the trial, over 89% patients in the intervention group continued to measure their blood glucose 2–3
days each week. Intervention group satisfaction survey responses indicated that frequent communication via the m-Health platform with the medical team enhanced patients’ understanding of diabetes, increased awareness, and helped ease depression symptoms.

In general, telemedicine facilitates good glycemic control in patients with diabetes aged over 65 years. Telemedicine assisted the medical team with patient monitoring and allowed the team to provide timely warnings of hypoglycemia or hyperglycemia risk as well as encouraged patients to continue their diet and exercise plan.

The present research showed that real-time tracking of older patients with
diabetes by the m-Health system improved communication between doctors and patients. Blood glucose levels were effectively controlled and patients’ compliance improved after implementation of m-Health monitoring.

Telemedicine applications appear effective and safe for use by older patients with diabetes.

Acknowledgements

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Authors’ Contributions

Lin Sun and Shugang Xi were responsible for thesis writing, Hong Zhang, Huan Wang and Yakun Feng were responsible for the literature collection, Yufeng Deng, Haimin Wang, Xianchao Xiao and Gang Wang for the clinical trials, Yuan Gao and Guixia Wang for statistics, Chenglin Sun is in charge of the overall research design.

Conflicts of Interest

None declared.
References


8. Ahmad Sharoni SK, Abdul Rahman H, Minhat HS, Shariff-Ghazali S, Azman Ong MH. The effects of self-efficacy enhancing program on foot self-care behaviour of older adults with diabetes: A randomised controlled trial


Figure legends

**Figure 1** The follow-up HbA1c levels of the two groups. After 3 months, HbA1c levels in both groups were significantly improved compared with baseline data ($P < 0.01$). Six months later, intervention group HbA1c was lower than baseline ($P < 0.01$), as were the control group HbA1c levels ($P < 0.05$).

**Figure 2** The mean change in HbA1c levels of both groups. The mean change in HbA1c levels from baseline to 6 months in the intervention group was significantly higher than that in the control group ($P < 0.05$).

**Figure 3** The follow-up PBG levels in the two groups. At the end of 3 and 6 months, the intervention group PBG was significantly lower than the control group PBG ($P < 0.05$ and $P < 0.01$). $^aP < 0.05$, $^bP < 0.01$ versus baseline. $^*P < 0.05$, $^*P <$
0.01 versus control group.

### Tables

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Intervention</th>
<th>( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>47</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>68.04(66-72)</td>
<td>67.9(66-71)</td>
<td>0.85</td>
</tr>
<tr>
<td>Male/Female</td>
<td>18/29</td>
<td>19/25</td>
<td></td>
</tr>
<tr>
<td>DM duration (years)</td>
<td>11.52±7.73</td>
<td>11.19±6.39</td>
<td>0.80</td>
</tr>
<tr>
<td>FBG (mmol/L)</td>
<td>7.78±1.85</td>
<td>8.0±2.54</td>
<td>0.41</td>
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<tr>
<td>PBG (mmol/L)</td>
<td>12.44±3.37</td>
<td>13.10±4.13</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td>3 months</td>
<td>6 months</td>
<td>P</td>
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<tr>
<td>------------------</td>
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</tr>
<tr>
<td>HbA1c(%)</td>
<td>7.88±0.64</td>
<td>7.84±0.73</td>
<td>0.53</td>
</tr>
<tr>
<td>TC(mmol/L)</td>
<td>4.92±1.24</td>
<td>5.00±0.97</td>
<td>0.76</td>
</tr>
<tr>
<td>TG(mmol/L)</td>
<td>2.31±1.85</td>
<td>2.41±1.82</td>
<td>0.80</td>
</tr>
<tr>
<td>HDL-C(mmol/L)</td>
<td>1.21(1.05-1.40)</td>
<td>1.09(0.85-1.25)</td>
<td>0.28</td>
</tr>
<tr>
<td>FBG(mmol/L)</td>
<td>7.57±2.15</td>
<td>7.20±1.70</td>
<td>0.41</td>
</tr>
<tr>
<td>BG(mmol/L)</td>
<td>13.15±3.64</td>
<td>12.09±3.35</td>
<td>0.04</td>
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<tr>
<td>HbA1c(%)</td>
<td>7.18±0.85</td>
<td>6.97±0.65</td>
<td>0.25</td>
</tr>
<tr>
<td>TC(mmol/L)</td>
<td>4.84±1.08</td>
<td>4.94±0.80</td>
<td>0.86</td>
</tr>
<tr>
<td>TG(mmol/L)</td>
<td>1.69±0.97</td>
<td>1.66±0.84</td>
<td>0.98</td>
</tr>
<tr>
<td>HDL-C(mmol/L)</td>
<td>1.34(1.12,1.51)</td>
<td>1.30(1.07,1.45)</td>
<td>0.39</td>
</tr>
<tr>
<td>LDL-C(mmol/L)</td>
<td>2.99(2.08,3.52)</td>
<td>2.87(2.64,3.27)</td>
<td>0.56</td>
</tr>
<tr>
<td>BMI</td>
<td>23.25(22.13,26.83)</td>
<td>23(22.68,24.98)</td>
<td>0.66</td>
</tr>
</tbody>
</table>

Blood pressure (mmHg)

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Intervention</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systolic</td>
<td>136.04±19.37</td>
<td>132.55±11.82</td>
<td>0.55</td>
</tr>
<tr>
<td>Diastolic</td>
<td>80.00(73.50-90.00)</td>
<td>83.00(74.00-87.75)</td>
<td>0.99</td>
</tr>
</tbody>
</table>

Data are mean±SD or median(interquartile ranges). DM, Diabetes mellitus; FBG, Fasting plasma glucose; PBG, Postprandial plasma glucose; HbA1c, Hemoglobin A1c; TC, Total cholesterol; TG, Triglyceride; HDL-C, High density lipoprotein-cholesterol; LDL-C, Low density lipoprotein-cholesterol; BUN, Blood urea nitrogen; Cr, Creatinine; AST, Aspartate Aminotransferase; ALT, Alanine aminotransferase; r-GT, r-Glutamyltransferase; BMI, Body mass index.

**Table 2. The follow-up data of the two groups**

Data are mean±SD or median(interquartile ranges)

aP<0.05, bP<0.01 versus baseline.
<table>
<thead>
<tr>
<th>Question</th>
<th>Score</th>
<th>mean±SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Are you satisfied with current treatment?</td>
<td>Dissatisfied</td>
<td>0.89±0.19</td>
</tr>
<tr>
<td>2. Is it convenient for you receive telemedical management?</td>
<td>Inconvenient</td>
<td>0.81±0.20</td>
</tr>
<tr>
<td>3. Is it helpful to self-monitoring of blood glucose?</td>
<td>Not helpful.</td>
<td>0.93±0.14</td>
</tr>
<tr>
<td>4. Is it helpful adhere to diet and exercise management?</td>
<td>Not helpful.</td>
<td>0.85±0.20</td>
</tr>
<tr>
<td>5. Is telemedical management helpful for the knowledge of diabetes?</td>
<td>Not helpful.</td>
<td>0.98±0.08</td>
</tr>
<tr>
<td>6. Is telemedical management helpful to relieve Mental distress?</td>
<td>Not relieved.</td>
<td>0.96±0.12</td>
</tr>
<tr>
<td>7. Will you recommend telemedical management to others?</td>
<td>No.</td>
<td>0.91±0.02</td>
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