Development of a mobile application to improve exercise accuracy and quality of life in knee osteoarthritis patients: a randomized controlled trial

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Abstract

Introduction Knee Osteoarthritis (OA) is a degenerative joint disease that needs consistent exercise and an accurate understanding of the condition for long-term maintenance. While the accessibility of outpatient care is essential for disease management, many patients lack the resources to receive adequate healthcare. To address this challenge, we developed a not-for-profit interactive mobile application that provides a disease-specific educational background and a structured exercise regimen to patients.

Material and methods “Rak Kao” (English translation: Love-Your-Knee) mobile application was designed to analyze the questionnaire data to assess the stage of knee OA and generate a personalized recommendation of treatment and exercise type using rule-based and Artificial Intelligence (AI) techniques. A single-blinded study was conducted with patients (n = 82) who were randomly assigned to the mobile application group (M-group) and the handout group (H-group). Patient groups were controlled for age, gender, BMI, onset of pain, grade of disease, education level, and occupation. Accuracy in performance of three prescribed knee exercises (catch-bend-down, stretch-touch-feet, and sit-stretch-hold) was evaluated. Clinical outcomes were evaluated before and after the 4-weeks program to assess the range of motion, symptoms, pain, physical activity, and quality of life via the KOOS and KSS scores.

Results Completion of the study led to significantly more overall exercise accuracy in the M-group (76.2%) than the H-group (52.5%). Activities of daily life, quality of life, ability to do sports and recreational activities were significantly more improved in the M-group than the H-group (p < .01). No difference in the range of motion between groups. Satisfaction of patients’ experience was higher in the M-group than the H-group (p = .001) after the 4-week regimen.

Conclusions With the better accuracy and outcomes for rehabilitation in the M-group than the H-group, we strongly recommend using our mobile application as a better alternative than handouts for exercises and information for patients with knee OA.

Trial registration ClinicalTrials.gov: NCT03666585

Keywords Knee osteoarthritis · Mobile application · Smartphone application · Knee exercises · Rehabilitation
Introduction

Knee osteoarthritis (OA) is a degenerative joint disorder that affects approximately 16% of adults, globally [1]. OA is characterized by the progressive degradation of cartilage in joints and causes pain and reduces joint mobility [2]. Currently, curative options for OA are surgical joint replacement and pharmacological treatment. Exercise and physical therapy are critical for disease management [3, 4]. However, most patients lack access to instruction or the motivation to adhere to an exercise regimen [5, 6]. Accordingly, there is an unmet need to develop a cost-effective strategy to mitigate disease progression that is accessible to most patients.

As mobile platforms have become increasingly accessible, the development of mobile applications (apps) has leveraged powerful computation, usability, and portability. This consistent innovation presents mobile apps as a powerful vehicle for health solutions. Currently, approximately 20 health apps per year are evaluated for US Food and Drug Administration approval [7]. The continual innovation of health apps offers a broad range of tools to the user, such as disease tracking, treatment options, relevant medical information, and consistent encouragement [8–10]. In the context of physical therapy for OA, the use of a mobile app has been shown to improve pain control and decrease opiate usage for patients in the postoperative setting [11]. Moreover, the ongoing COVID-19 pandemic has severely limited options for face-to-face training sessions with a therapist, negatively impacting the outcomes of patient rehabilitation [6, 12, 13]. Mobile apps have the potential to personalize educational programs and to monitor the patient's progress while still adhering to social-distancing restrictions. Therefore, we have developed “Rak Kao” (English translation: love your knee) as user-friendly health, not-for-profit mobile app to overcome some of these barriers [14].

The primary aim of this study was to evaluate if the use of this mobile app could improve the accuracy of rehabilitation of knee OA patients, compared to conventional educational handouts. The second aim was to compare the clinical outcomes between mobile app use and conventional educational handouts use in knee OA patients.

Materials and methods

App design and development

This mobile app was a collaboration between OA professionals and computer researchers. The app features four principles of knee OA in separate modules: (1) basic knowledge of the disease and symptoms, (2) available treatment options, (3) personalized assessment of the stage of severity, and (4) appropriate exercise instructions (Fig. 1). The education and disease assessment portions of the mobile app were designed to include important facts and common questions from the patients. One of the integral modules offers an adaptive test to assess patient symptoms from the questionnaire results. For instance, an adaptive knee OA assessment in module 3 evaluates the patient’s disease stage, ranging from mild to severe, according to the results of decision tree classification (Fig. 2).

Adaptive knee osteoarthritis assessment

To assess the stage of OA, Love-Your-Knee uses an adaptive assessment, based on decision tree, to determine the disease stage. Once the disease stage is determined, the
system recommends the appropriate exercise types and the number of sets as well as provides the basic knowledge for OA symptom management. With its ability to facilitate the information exchange between the patient and the doctor, the app can be effectively utilized as a personalized solution for assessing the stage of knee OA, monitoring disease progression, and promoting physical therapy and rehabilitation exercise.

**Study design**

This prospective single-blind randomized controlled trial (RCT) was approved by the institutional review board committee at our institution (COA034/2561), registered at clinicaltrials.gov (NCT03666585), and conducted between September 2018 and June 2019. Informed consent was obtained from all patients prior to participation. Participants were not given compensation nor were there any competing interests on behalf of the study investigators. A patent application of this mobile app was filed in our country under No. 1801005898. Data from this study are available upon reasonable request.

**Patient inclusion criteria**

Patients who were included in this study ranged from 40–80 years old and diagnosed with either unilateral or bilateral primary knee OA according to the American College of Rheumatology (ACR) criteria [15]. Additionally, the patients must own and be able to use smartphones with an Android operating system. Patients were excluded if they have had knee replacement surgery, if they had significant medical comorbidities that interfere with the rehabilitation exercise (previous stroke, cardiac diseases, severe hypertension, severe obesity, chronic obstructive pulmonary disease, low back pain, chronic pain, depression, and visual or hearing impairments), or if they have been instructed to our particular exercises prior to the study recruitment period.

**Randomization**

Eligible patients were randomized into 2 groups: mobile app self-directed exercise guidance group (M-group) and conventional education handout self-directed exercise guidance group (H-group) (n = 44 and 45, respectively) (Fig. 3). At the time of enrollment, each patient was assigned a computer-generated number. Patients were randomized into groups based on this number; those who received an even number were assigned to the M-group and those who received an odd number were assigned to the H-group. Demographics including age, gender, side, body mass index (BMI), onset of knee pain, education level, Kellgren and Lawrence grading from radiography (KL grade) [16], range of motion (ROM), the Knee injury and Osteoarthritis Outcome Score (KOOS) [17], and the Knee Society scores (KSS) [18] were recorded. Patients in both groups received the same information regarding knee OA disease background and exercise instruction.
**Intervention**

After group assignment, patients received instruction of exercise via mobile app for M-group and handouts for H-group. The standard instruction of three exercises includes (1) catch-bend-down, (2) stretch-touch-feet, and (3) sit-stretch-hold (Fig. 4). Catch-bend-down is a partial squat in which the patient holds the backrest of a chair with both hands and slowly bends both of his/her knees to 90-degree flexion. The patient was then asked to hold the squat for 10 s before slowly recovering to stand (Fig. 4a). Stretch-touch-feet is a hamstring stretch in which the patient sits on the floor with both knees fully extended, and then hinges forward from their hips to reach towards their feet (Fig. 4b). Patients were asked to hold the stretch for 10 s, and then slowly recover to a normal posture. Sit-stretch-hold is a knee extension exercise, in which the patient sits on a chair and then slowly raises his/her foot to contract their quadriceps. Patients were asked to hold for the extension 10 s before they slowly release (Fig. 4c).

**Outcome measurement**

All outcomes were evaluated at 4 weeks of self-guided practice by another clinician who was blinded to the trial intervention. The primary measurement of this study was the patient’s ability to correctly perform the three prescribed exercises. Patients were asked to perform the three exercises 10 times each. The exercise was considered to be performed correctly if the patient accurately completed 8 out of 10 repetitions. The secondary measurement was clinical outcomes in terms of ROM, KOOS [17] categories (symptoms, pain, activities of daily living, sports and recreation activities, and quality of life), and KSS [18] categories (objective knee score, satisfaction, expectation, and functional activity). The ROM was measured using a goniometer with a patient in the supine position.

**Statistical analysis**

The present study’s sample size was calculated based on the reported accuracy of rehabilitation exercise in knee OA patients [19] to be 25 knees per group to ensure sufficient power of 80 with a significant difference ($P = 0.05$, 2-sided significance level). To compensate for potential losses to follow-up of 20%, at least 32 knees per group should be recruited. All comparisons were analyzed by independent $t$ tests and chi-square tests (SPSS version 23; SPSS Inc, Chicago, IL). The normal distribution of the data was verified before parametric tests were applied. Welch’s correction was used to correct for comparisons with unequal variances. All data were presented as mean ± standard deviation and
comparisons were considered statistically significant if the $p$ value was less than 0.05, two-tailed.

**Results**

Eighty-nine patients met the inclusion criteria for this study: 44 patients were allocated to the M-group and 45 patients were allocated to the H-group. There were 2 patients (4.5%) in the M-group and 5 patients (11.1%) in the H group who did not follow-up and thus were excluded from the final results. Table 1 outlines the demographics of the patients in this RCT. Patients on this trial were age, gender, side, BMI, and the onset of knee pain-matched: the average age of patients in the M group was 62.2 ± 6.8 years and that in the H group was 63.0 ± 9.7 years. Females constituted 85.7% of the M group and 92.5% of the H group. The average BMI of individuals in the M group was 27.1 ± 4.7, and that in the H group was 26.4 ± 5.2. Additionally, patients were matched for education level with the majority of patients from both groups have received at least junior high school level education. Overall, approximately 40, 37 and 20% of patients in both groups had a KL grade [16] of 2, 3, and 4, respectively. Finally, patients between the two groups were also matched for the ROM, KOOS [17] categories, and KSS [18] categories.

Although there was no significant improvement in the ROM of the knee in either group after 4 weeks of exercise, patients in both groups had improvement in functional outcomes measured by KOOS [17] and KSS [18] (Tables 2, 3). To assess the benefit of using the mobile app during rehabilitation, we compared KOOS [17] and KSS [18] of patients between the groups after the 4-week regimen. According to patient evaluations, patients in the M group had stronger overall functional outcomes than patients in the H group (Table 4). Specifically, patients in the M group reported better daily life, ability to do sports and recreation, higher satisfaction and expectation. Importantly, patients in the M group reported a significantly better quality of life than patients in the H group ($p < 0.01$).

Finally, we evaluated the ability of each patient to correctly perform each of the three prescribed exercises at the end of the 4-week regimen. Overall, patients in the M group completed all of the exercises more accurately than those in the H group ($p = 0.022$) (Table 5). Among the three exercises, the M group significantly performed exercise 1 more accurately than the H group ($p = 0.005$) while not significantly in exercise 2 and 3 ($p = 0.185$ and $p = 0.189$, respectively).

**Discussion**

This study investigated an interactive and user-friendly mobile app and assessed its effectiveness in delivering exercise instruction and disease education to patients and
improving clinical outcomes and satisfaction. This RCT found that patients who had a rehabilitation regimen delivered by the mobile app had improved the accuracy of rehabilitation, activities of daily life, quality of life, and ability to do sports and recreational activities compared to conventional educational handouts. The mobile app also improved patient’s satisfaction and expectation in knee performance compared to traditional handouts.

Muscle-strengthening exercises for knee OA rehabilitation improve pain and functional capacity [20–22]. Osteoarthritis Research and Society International (OARSI) also recommended that osteoarthritis patients should be encouraged to undertake regular aerobic, muscle strengthening, and range of motion exercises [23, 24]. To ensure effective rehabilitation, the prescribed exercise regime must be performed accurately, and regularly [22]. Three exercises regularly

| Table 1 Patient demographics |
|-------------------------------|
|                             | M-group (n=42) | H-group (n=40) | p value |
| Age ( yrs)                  | 62.2 ± 6.8     | 63.0 ± 9.7     | 0.673   |
| Gender (%)                  |               |               |         |
| Male                        | 6 (14.3)       | 3 (7.5)        | 0.266   |
| Female                      | 36 (85.7)      | 37 (92.5)      |         |
| Side (%)                    |               |               |         |
| Left                        | 9 (21.4)       | 10 (25.0)      | 0.451   |
| Right                       | 33 (78.6)      | 30 (75.0)      |         |
| BMI ( kg/m^2)               | 27.1 ± 4.7     | 26.4 ± 5.2     | 0.531   |
| Time in yrs since the onset of knee pain (%) | | |
| < 2 yrs                     | 19 (45.2)      | 20 (50.0)      | 0.417   |
| ≥ 2 yrs                     | 23 (54.8)      | 20 (50.0)      |         |
| KL grade (%)                |               |               |         |
| KL grade 2                  | 17 (40.5)      | 17 (42.5)      | 0.515   |
| KL grade 3                  | 15 (35.7)      | 16 (40.0)      | 0.432   |
| KL grade 4                  | 10 (23.8)      | 7 (17.9)       | 0.441   |
| Education level (%)         |               |               |         |
| < Junior high school        | 14 (33.3)      | 11 (27.5)      | 0.370   |
| ≥ Junior high school        | 21 (50.0)      | 25 (62.5)      | 0.180   |
| ≥ bachelor                  | 7 (16.7)       | 4 (10.0)       | 0.289   |
| Occupation (%)              |               |               |         |
| Housewife                   | 27 (64.3)      | 22 (55.0)      | 0.264   |
| Professional and administration | 8 (19.0)     | 8 (20.0)       | 0.567   |
| Merchant and employee       | 7 (16.7)       | 10 (25.0)      | 0.255   |
| Care giver (%)              | 1 (2.4)        | 2 (5.0)        | 0.611   |
| ROM (°)                     | 126.3 ± 7.3    | 124.0 ± 5.9    | 0.537   |
| KOOS (%)                    |               |               |         |
| Symptoms                    | 67.3 ± 13.3    | 62.0 ± 4.1     | 0.150   |
| Pain                        | 72.0 ± 6.8     | 69.3 ± 5.9     | 0.261   |
| Activities of daily living  | 71.6 ± 9.0     | 67.1 ± 6.9     | 0.102   |
| Sports and recreational activities | 70.5 ± 5.2 | 68.2 ± 10.1    | 0.393   |
| Quality of life             | 69.5 ± 6.2     | 64.7 ± 8.7     | 0.066   |
| KSS (%)                     |               |               |         |
| Objective knee score        | 29.5 ± 14.2    | 27.4 ± 14.8    | 0.802   |
| Satisfaction score          | 23.0 ± 3.0     | 22.4 ± 4.6     | 0.449   |
| Expectation score           | 14.1 ± 0.6     | 14.0 ± 0.7     | 0.754   |
| Functional activity score   | 56.3 ± 3.5     | 54.6 ± 14.6    | 0.779   |

BMI Body mass index, KL Kellgren and Lawrence system for classification of osteoarthritis of knee, ROM, range of motion, KOOS, Knee Injury and Osteoarthritis Outcome Score, KSS Knee Society score

a Presented as mean ± standard deviation
b Presented as number of patients
Table 2 Outcomes of M-group at pre-test and after 4 weeks of the mobile app self-directed exercise

|                      | Pre-test | 4 wk   | p value |
|----------------------|----------|--------|---------|
| ROM*(°)              | 126.3 ± 7.3 | 129.0 ± 6.5 | 0.457  |
| KOOS*                | 29.5 ± 14.2 | 32.8 ± 12.9 | 0.464  |
| Symptoms             | 67.3 ± 13.3 | 70.7 ± 11.0 | 0.045* |
| Pain                 | 72.0 ± 6.8  | 73.3 ± 7.2  | 0.089  |
| Activities of daily living | 71.6 ± 9.0  | 80.4 ± 9.8  | 0.138  |
| Quality of life      | 69.5 ± 6.2  | 79.6 ± 10.7 | <0.001*|
| KSS*                 | 22.4 ± 4.6  | 23.6 ± 3.1  | 0.183  |

*ROM range of motion, KOOS Knee Injury and Osteoarthritis Outcome Score, KSS Knee Society score
*Presented as mean ± standard deviation
*Indicates a statistically significant difference with p value < .05

Table 3 Outcomes of H-group at pre-test and after 4 weeks of handout self-directed exercise

|                      | Pre-test | 4 wk   | p value |
|----------------------|----------|--------|---------|
| ROM*(°)              | 124.0 ± 5.9 | 125.9 ± 5.6 | 0.676  |
| KOOS*                | 27.4 ± 14.8 | 29.3 ± 14.8 | 0.457  |
| Symptoms             | 62.0 ± 4.1  | 65.3 ± 5.2  | 0.049* |
| Pain                 | 69.3 ± 5.9  | 70.7 ± 5.9  | 0.077  |
| Activities of daily living | 67.1 ± 6.9  | 71.2 ± 7.0  | 0.184  |
| Quality of life      | 64.7 ± 8.7  | 71.2 ± 7.8  | 0.021* |

*ROM range of motion, KOOS Knee Injury and Osteoarthritis Outcome Score, KSS Knee Society score
*Presented as mean ± standard deviation
*Indicates a statistically significant difference with p value < .05

prescribed to knee OA patients are catch-bend-down, stretch-touch-feet, sit-stretch-hold. With a mobile app, the patients completed these exercises with a significantly higher rate of accuracy which may suggest the ability of patients to continue appropriate rehabilitation in a long term [6, 25, 26]. In line with our findings, patients with musculoskeletal conditions who received exercise instruction by a mobile app had better adherence to their home exercises than those who received common paper handouts [27]. A different RCT compared adherence to home-based exercise between knee OA patients who used a mobile application and those who used handouts and found that those who used the mobile had a better adherence rate, lower VAS-pain scores, and stronger improvements of physical function and lower-limb muscle strength [28]. It is worthy to note that our trial assessed knee OA patients that did not require surgery; however, in the postoperative setting, the use of a mobile app during rehabilitation led to reduced opiate usage for pain management [11] and may become a promising tool in improving functional outcomes [29]. Thus, this developed mobile app has proven to be a valuable tool for OA patients for motivating patients to exercise, educating patients on disease progression and improving the accuracy of rehabilitation.

Although our RCT is a short-term study, we predict that this app will improve the long-term compliance with the rehabilitation program. This app not only provides instruction, but also insights into their personal condition. Our mobile app includes a list of common questions that are used to assess the degree of OA progression. Utilization of this questionnaire may provide knowledge of the physical condition and motivation to adhere to rehabilitation efforts. Additionally, this application has a section that provides the patients with an educational background of the disease, that may benefit the patients in a variety of ways, including increasing daily activities and reducing anxiety [30, 31].

It is important to consider the limitations of this study. First, the patients included in this study were able to efficiently use smartphones, which may not be reflective of a larger elderly population. Second, according to the structure of the study, it is impossible to blind the participants to their intervention. This knowledge can potentially skew self-reported outcomes. Third, the majority of the patients were females (89.0%). However, this gender bias is always observed in OA patients [32]. The gender bias may be solved by randomization according to gender in future study. Fourth, there is no consensus on the definition of a method to measure patients’ adherence to exercise [33, 34]. We believed that a patient’s ability to accurately perform the exercises at the final follow-up reflects adherence to home exercise; however, this may not always be the case. Fifth, there is a lack of normative data of KSS to assess the patients. There are no reference values to differentiate which patients have improved significantly. Finally, a long-term follow-up study is needed to prove the sustained positive effect of the mobile application use on adherence to exercise and the health status of the patients on this trial.

Electronic health has been introduced recently to support patient’s adherence to home exercise programs and exercise interventions to reduce pain and improve physical function in OA patients [35–37]. A major advantage to mobile apps is that patients can easily access exercise information on their mobile phones. Therefore, patients can learn to perform the exercises...
at any time, not just when they are at home. Interactive features of this application, such as exercise tracking and motivational animations, are attributes that can engage and motivate the users. Future developments include introducing a social component to the rehabilitation program, which allows for patients who have improved symptoms and reduced pain over time to encourage newer users. Additional features include music, video instruction, alerts, and awards. This app has the potential to provide a healthy community of users to support each other and exercise together, promoting an effective way to manage knee OA.

**Conclusion**

This RCT supports the hypothesis that the developed mobile app is an effective way to deliver rehabilitation education and instruction to knee OA patients. The results show that OA patients using this app were able to exercise correctly and enjoyed usage their exercise regimen with significant improvement of symptom progression as indicated by KSS and KOOS category scores. Thus, the use of our mobile app for short-term disease maintenance and treatment of OA benefits patients and represents a potential approach for long-term rehabilitation.

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**Declarations**

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical approval** The study has been performed in compliance with the Helsinki Declaration, has been approved by the ethical committee of Navamindradhiraj University COA034/2561) and registered at clinicaltrials.gov (NCT03666585).

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