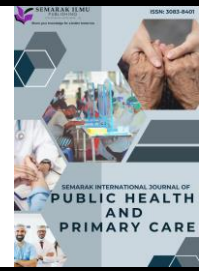




Semarak International Journal of Public Health and Primary Care

Journal homepage:
<https://semarakilmu.my/index.php/sijphpc/index>
ISSN: 3030-5519



NanoRehab: Conceptual Design of a Mobile Health Application Integrating Nanomedicine with Personalized Physiotherapy for Knee Osteoarthritis Management

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ARTICLE INFO

Article history:

Received 4 November 2024
Received in revised form 25 November 2024
Accepted 6 December 2024
Available online 15 December 2024

Keywords:

Mobile health application;
nanomedicine; rehabilitation,
personalized physiotherapy; knee
osteoarthritis

ABSTRACT

NanoRehab is a mobile health application designed to develop Knee osteoarthritis (KOA) management by assimilating nanomedicine with personalized rehabilitation plans. Initial development involved a wide-ranging review of existing health applications, KOA rehabilitation methods, and advancements in nanotechnology, recognising a significant need for tailored, adaptive solutions in KOA treatment. The app purposes to provide a personalized and adaptive solution for KOA management by using real-time data from wearable devices to adjust treatment protocols based on individual progress, in that way enhancing recovery outcomes. NanoRehab's features, together with personalized exercise regimens, nanomedicine monitoring, real-time progress tracking was evaluated through a potential user survey with 62 KOA patients. Survey results showed a high likelihood of app adoption, with 88% of participants stating strong interest and confidence in the app's potential to progress rehabilitation outcomes. This study highlights NanoRehab's potential as a complete digital health solution for KOA management, effectively integrating innovative treatment approaches to meet the personalized requirements of KOA patients.

1. Introduction

Knee osteoarthritis (KOA) is one of the most common forms of arthritis, expressively affecting quality of life, mobility, and independence, particularly among middle-aged and older adults. It is characterized by chronic pain, joint stiffness, and also progressive cartilage degradation, which often lead to physical limitations and also disability. The global burden of KOA is significant, with high prevalence rates interpreting to substantial healthcare costs and personal hardship [1]. Traditional management of KOA stereotypically includes a combination of physical therapy,

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<https://doi.org/10.37934/sijphpc.2.1.1119b>

pharmacological interventions, and also lifestyle modifications. In advanced cases, surgical options like joint replacement are measured. However, while these treatments help improve symptoms, they often fall short in providing a holistic, personalized approach tailored to separate patient needs and also preferences [2]. The last decade has seen important advancements in digital health technologies, particularly mobile health (mHealth) applications that enable remote monitoring, personalized care plans, and also patient engagement. Also, mHealth applications are demonstrating to be effective tools for chronic disease management, as they facilitate real-time data collection, enable teleconsultations, and let for a more tailored approach to patient care [3]. Despite these advancements, there is a clear gap in the integration of mHealth applications for KOA management that precisely addresses the need for personalized and dynamic treatment plans. Most existing mHealth applications are limited to overall physiotherapy or rehabilitation exercises without incorporating advanced treatment modalities that have shown promise in managing KOA, such as nanomedicine [4]. Nanomedicine, a rapidly advancing field, has demonstrated potential to target localized inflammation, encourage tissue regeneration, and enhance drug delivery with negligible side effects [5]. For KOA, nanomedicine suggests a promising avenue for targeted, effective intervention by delivering medication precisely to the affected joint areas. This accuracy reduces systemic exposure, enhances therapeutic efficacy, and also mitigates side effects that repeatedly accompany traditional pharmacological treatments. Despite these benefits, integrating nanomedicine into a personalized, mobile-enabled treatment regimen for KOA remains basically unexplored [6].

While physical therapy and also medications provide essential relief for KOA, they commonly lack personalization and dynamic adaptability, particularly in addressing chronic, progressive pain and also inflammation unique to each patient [11]. Traditional approaches often bring broad-spectrum treatments that do not account for distinct variations in pain patterns, mobility limitations, or treatment responses. This gap is particularly evident in mobile health (mHealth) applications for KOA, where most apps provide general rehabilitation exercises without adapting to the precise condition or progress of each patient. With the increasing popularity of mHealth tools for chronic disease management, such applications have shown important potential to recover patient adherence and engagement, yet they characteristically focus on broad physiotherapy rather than targeted interventions [3]. Furthermore, nanomedicine, with its potential for precise drug delivery to inflamed areas in the knee, offers an innovative pathway for KOA treatment by minimizing systemic side effects and also maximizing local therapeutic efficacy. Nevertheless, nanomedicine's potential remains largely untapped in digital health tools. Integrating nanotechnology within an mHealth application could provide personalized KOA care that adjusts in real-time, tracking both patient-reported symptoms and physiological data to optimize therapeutic regimens. It is significant to address this gap by conceptualizing NanoRehab, a novel mobile application that synergizes nanomedicine with individualized physiotherapy [17]. By including real-time data feedback and also adaptive treatment protocols, NanoRehab aims to deliver an integrated, patient-centered solution that extends beyond standard rehabilitation apps, paving the way for more reactive, effective KOA management.

By keeping above mentioned facts, the NanoRehab mobile health application was theorized by this research team. NanoRehab integrates the precision of nanomedicine with customized physiotherapy regimens that acclimatize based on real-time data from wearable devices [7]. This integration is intended to provide KOA patients with a comprehensive management tool that enhances engagement, facilitates self-monitoring, and also adjusts to individual progress and responses to treatment. By combining advanced digital health features with nanotechnology, NanoRehab aims to create a lively, interactive platform that not only supports physical

rehabilitation but also enables close monitoring of nanomedicine efficacy and also patient-reported outcomes [8]. The development of NanoRehab included collaboration between software developers, healthcare professionals, and KOA experts to ensure that the app's features align with both medical standards and patient needs [9]. Following prototype completion, a user survey was conducted to evaluate the app's design, functionality, and overall potential for adoption among KOA patients [10]. The objective of the study is to integrate nanomedicine with personalized physiotherapy in the NanoRehab mobile health application to improve the management of KOA by tailoring treatment plans based on real-time data and individual patient responses.

2. Methodology

The theoretical development of the NanoRehab app followed a structured and evidence-based approach. First, a comprehensive literature review was conducted to assess current mobile health solutions for KOA, identifying significant limitations, particularly in personalized care and also nanomedicine integration. Based on these perceptions, the app's main features were conceptualized, including personalized rehabilitation plans, nanomedicine tracking, pain and inflammation monitoring. Following the prototype development, a survey was conducted to estimate the app's functionality and potential adoption. Finally, KOA patients were surveyed using a structured questionnaire designed to apprehension their perspectives on the app's key features, ease of use, and complete utility. Data was analysed using Microsoft Excel 2021 to present responses and provide a clear overview of user interest in each feature.

3. Results

3.1 Mobile App Outline

NanoRehab is intended to support personalized rehabilitation by tracking progress, managing exercises, and enhancing recovery outcomes. Through Figure 1, the outline of this mobile application is demonstrated.

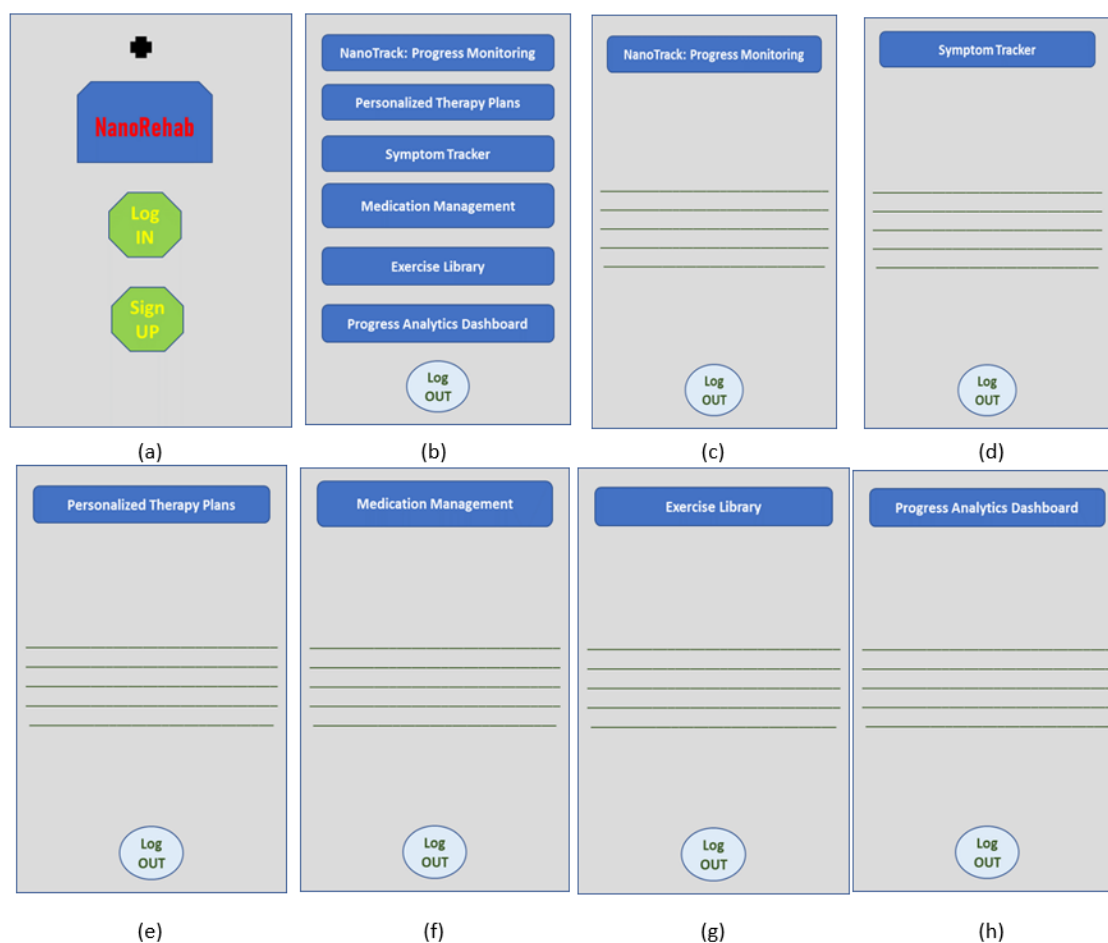


Fig. 1. Mobile app outline

3.2 Features and Descriptions Overview

This app includes a range of ground-breaking features designed to enhance user experience and functionality. The Table 1 below provides an organized overview of the app's primary features, offering insights into each feature's functionality and purpose.

Table 1

Features and brief descriptions

Feature Name	Description
NanoTrack: Progress Monitoring	Permits patients to track their treatment progress over time, using MRI and also other imaging to visualize nanomedicine effects.
Personalized Therapy Plans	Offers customized physiotherapy plans based on KOA severity, activity levels, and also response to nanomedicine, with adjustments based on continuing assessments.
Symptom Tracker	Enables patients to log symptoms, pain, and activity daily, assisting healthcare providers in analyzing trends for treatment adjustments.
Medication Management	Delivers reminders and information about nanomedicine dosages, administration methods, and also side effects, tracking schedules.
Exercise Library	Delivers a comprehensive library of physiotherapy exercises specifically designed for KOA management, with videos and also instructions for safe and effective practice.
Progress Analytics Dashboard	An interactive dashboard displaying key metrics like pain levels, mobility scores, and also exercise adherence to help evaluate treatment efficiency.

3.3 Potential User Survey

A total 82 KOA patients were surveyed among them 51 were male and 31 were female. Among the 82 patients, 46 patients were from Bangladesh, 9 patients were from Malaysia and 27 patients were from Pakistan. Through Figure 2, survey outcome was expressed.

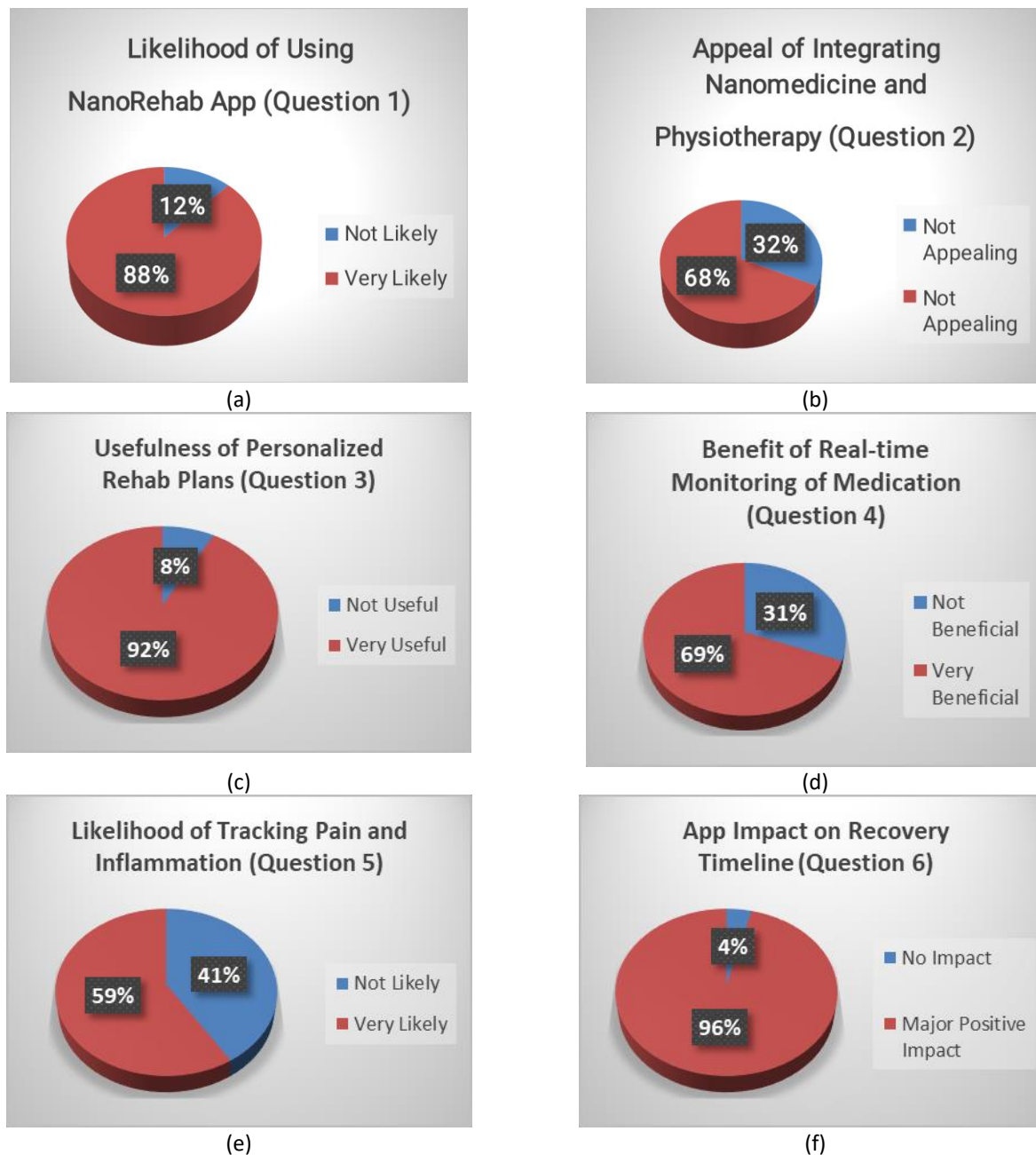


Fig. 2. Potential user survey outcome

4. Discussion

The development of NanoRehab represents a noteworthy advancement in managing KOA, a condition usually associated with chronic pain, joint stiffness, and a progressive decline in mobility. Traditional approaches to KOA rehabilitation often include standardized treatment plans that fail to address the exclusive needs of individual patients, hypothetically resulting in reduced patient

engagement and also less-than-optimal outcomes. In contrast, NanoRehab introduces a more dynamic, patient-centered resolution that combines the precision of nanomedicine with the customization of physiotherapy, offering a personalized rehabilitation practice tailored to each patient's specific condition and progress [11]. This innovative integration of advanced therapeutics and digital health technology marks a promising shift in KOA management, with the potential to meaningfully improve both treatment outcomes and patient satisfaction. One of the standout features of NanoRehab is its capability to craft Personalized Therapy Plans by analyzing real-time data collected from wearable devices and also patient input. Traditional rehabilitation approaches often adopt a one-size-fits-all approach, which may not effectively accommodate each patient's evolving requirements [12]. NanoRehab, however, uses real-time assessments to endlessly adjust therapy plans based on KOA severity, daily physical activity levels, and also the patient's response to ongoing nanomedicine treatments. This personalized approach has been progressively recognized in recent research, highlighting that tailored rehabilitation procedures can lead to more significant improvements in pain relief and joint function.

The survey directed as part of this study reinforces these findings, with 92% of participants rating the personalized therapy plans as a highly appreciated aspect of their recovery journey, highlighting the importance of individualized care. Another critical feature of NanoRehab is its NanoTrack: Progress Monitoring system, which allows patients to track their treatment development over time using advanced imaging techniques such as MRI. This feature allows users to envisage the effects of nanomedicine treatments on joint health, providing valuable insights into the progression of their condition. The aptitude to monitor the precise impact of treatments, especially in conjunction with physiotherapy, offers patients and also healthcare providers a prevailing tool for making timely, data-driven adjustments to the therapy plan [13]. The synchronization of nanomedicine with physiotherapy sessions purposes to amplify therapeutic effects when they are most needed, addressing a crucial gap in present KOA treatments. Survey responses showed that 68% of users found this integration of nanomedicine with rehabilitation appealing, although some participants expressed doubts, signalling the need for more comprehensive user education on the assistances of nanotechnology in KOA management. The Symptom Tracker feature lets patients to log pain, activity levels, and other symptoms daily, offering healthcare providers valuable data for monitoring trends and also making treatment adjustments [14]. While the survey results presented that 69% of users recognized the potential benefits of this feature, 31% remained indeterminate about its value. For some users, the process of tracking symptoms in real-time may appear cumbersome or overly complex. Abridging the user interface and providing clear examples of how this data contributes to improved treatment outcomes could help lessen these concerns. Similar tracking technologies have been effectively applied in other areas of healthcare, such as cardiac rehabilitation, where real-time feedback has been shown to improve patient adherence and overall outcomes [15]. NanoRehab aims to replicate these successes, empowering KOA patients to take a more active role in their rehabilitation by making knowledgeable decisions based on real-time progress. Another key component of NanoRehab, providing patients with reminders and information about their nanomedicine dosages, administration methods, and also potential side effects. This tool also tracks schedules and also alerts patients about refills or necessary consultations with their healthcare providers. Medication adherence is an important factor in the long-term management of KOA, and this feature is intended to support patients in staying on track with their treatments. By aligning medication schedules with physiotherapy sessions, NanoRehab maximizes the therapeutic benefits of both nanomedicine and also rehabilitation exercises, ensuring that patients receive the full advantage of their treatment schedule [16]. In addition to these features, NanoRehab includes a widespread Exercise Library,

offering a wide range of physiotherapy exercises tailored precisely for KOA management. The library includes detailed videos and also instructions for safe and effective practice, allowing patients to confidently perform their exercises at home. The addition of a Progress Analytics Dashboard further enhances the rehabilitation experience by providing patients with a strong view of key metrics such as pain levels, mobility scores, and exercise adherence. This communicating tool allows both patients and healthcare providers to track improvements over time, enabling more precise adjustments to the rehabilitation plan as needed [17]. One of NanoRehab's exclusive contributions to KOA management is its emphasis on community support. The app fosters a sense of connection among users, allowing them to share their experiences and also offer support through the retrieval process. Social support has been proven to play a serious role in managing chronic conditions like KOA, as peer encouragement can meaningfully improve motivation and adherence to rehabilitation routines [18]. By incorporating this feature, NanoRehab provides an all-inclusive approach to patient care, addressing not only physical but also psychological well-being.

The survey results with 62 KOA patients provided valued feedback on NanoRehab's features, highlighting both its strengths and also areas for potential improvement. Particularly, 88% of users expressed a strong likelihood of adopting NanoRehab as part of their treatment, while 96% believed it would definitely impact their recovery. Nevertheless, some users expressed concerns about the complexity of the nanomedicine integration and also real-time symptom tracking, suggesting that additional educational efforts are needed to advance user understanding and engagement with these advanced features. Simplified tutorials, clear explanations of nanotechnology's benefits, and also demonstrations of how real-time tracking can accelerate recovery could help address these concerns and further improve the user experience [19]. Overall, NanoRehab represents a cutting-edge resolution for KOA rehabilitation by integrating personalized therapy plans, nanomedicine, real-time data tracking, and also community support. Its aptitude to address the limitations of current static treatment methods positions NanoRehab as a comprehensive digital health tool that can meaningfully enhance the quality of life for KOA patients [20]. Moving forward, efforts to improve complex features and also expand educational resources will be critical in ensuring that NanoRehab is accessible and effective for a broad range of users, solidifying its role as an indispensable companion in the journey to improved health and rehabilitation outcomes for KOA patients [21].

5. Patient Support and Education Plan

To maximize patient engagement and also guarantee effective app use, a well-structured user education and also support system is very crucial. This approach includes interactive tutorials that guide patients through key features, making navigation and also usage simple as well as intuitive. An all-inclusive FAQ section will be addressed for common concerns and deliver instant answers, reducing the need for direct assistance. Furthermore, accessible customer support options, such as live chat or email support, offer users personalized help when required, further enhancing their experience. By merging these resources, the support plan will foster patient confidence in using the app, ultimately improving adherence and health outcomes of KOA patients.

6. Implementation Challenges

Applying a healthcare app in real-world settings presents several challenges that need careful consideration to ensure its achievement. One of the primary obstacles is the seamless integration with existing electronic health record (EHR) systems, which is vital for secure data sharing and

continuity of care but often involves complex technical requirements. Moreover, healthcare providers may need training to use and also interpret the app's features effectively, particularly if it familiarizes new workflows or tools for patient interaction. Ensuring compliance with regulatory standards for data privacy and security is another critical aspect that can pose challenges. Finally, securing provider buy-in and adapting the app to fit within established clinical practices can impact both adoption rates and patient outcomes, underscoring the need for a strategic implementation strategy.

7. Longitudinal Studies on Patient Engagement and Retention

Future research should incorporate longitudinal studies to assess patient engagement and retention strategies within the NanoRehab app. By tracking user interactions and also engagement patterns over an extended period, these studies can classify which features—such as personalized reminders, gamification, and regular feedback—are most operative in sustaining long-term app usage. This approach would provide insights into how patient commitment evolves and also how consistent engagement impacts rehabilitation outcomes, eventually guiding improvements to ensure lasting benefits.

6. Conclusion

NanoRehab presents a ground-breaking resolution for managing KOA by integrating personalized physiotherapy, nanomedicine, and also real-time tracking into one cohesive platform. The overwhelmingly positive user feedback highlights its potential to revolutionize KOA rehabilitation, offering a more dynamic and also tailored approach to patient care. To confirm wider adoption, addressing concerns about feature complexity and also enhancing educational resources, particularly on the use of nanomedicine, will be key. With its innovative approach, NanoRehab is composed to reshape digital health solutions for KOA, offering a holistic and also adaptive platform that supports both patient engagement and recovery. Future improvements could further boost accessibility and user-friendliness, setting a new benchmark in digital healthcare for KOA and also similar musculoskeletal conditions.

Authors' Contribution

Sidra Sabir contributed to the conceptualization of the NanoRehab mobile health application and Abdul Haseeb Bhutta conducted the literature review, while AHM Mahmudur Rahman completed the app concept creation and manuscript writing, serving as the supervisor for this research project.

Acknowledgement

The research team is really thankful to those KOA patients who participated in the potential user survey.

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