Self-assessment of Rheumatoid Arthritis Disease Activity Using a Smartphone Application
Development and 3-month Feasibility Study

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Rheumatoid arthritis, disease activity, smartphone, self-assessment, feasibility study

Summary
Introduction: This article is part of the Focus Theme of Methods of Information in Medicine on “Methodologies, Models and Algorithms for Patients Rehabilitation”.
Background: Rheumatoid arthritis (RA) is a progressive inflammatory disease that causes damage to multiple joints, decline in functional status, and premature mortality. Thus, effective and frequent objective assessments are necessary. Then, we developed a self-assessment system for RA patients based on a smartphone application.
Objective: The purpose of this study was to investigate the feasibility of a self-assessment system for RA patients using a smartphone application.
Methods: We measured daily disease activity in nine RA patients who used the smartphone application for a period of three months. A disease activity score (DAS28) predictive model was used and feedback comments relating to disease activity were shown to patients via the smartphone application each day. To assess participants’ RA disease activity, the DAS28 based on the C-reactive protein level was measured by a rheumatologist during monthly clinical visits.
Results: The disease activity measured by the application correlated well with the patients’ actual disease activity during the 3-month period, as assessed by clinical examination. Furthermore, most participants gave favourable responses to a questionnaire administered at the end of the 3-month period containing questions relating to the ease of use and usefulness of the system.
Conclusions: The results of this feasibility study indicate that the DAS28 predictive model can longitudinally predict DAS28 and may be an acceptable and useful tool for assessment of RA disease activity for both patients and healthcare providers.

1. Introduction
Rheumatoid arthritis (RA) is a progressive inflammatory disease that causes damage to multiple joints, decline in functional status, and premature mortality [1, 2]. Treatment comprises medication to control inflammation and multidisciplinary interventions aimed at reducing symptoms and maximizing self-management [3]. Because the symptoms experienced by RA patients fluctuate, close monitoring is required. Traditional monitoring methods involve recording patients’ subjective assessments on paper. These methods lack objectivity and are not capable of recording subtle changes that occur daily. Effective and frequent objective assessments are necessary.

Over recent years, smartphones have become ubiquitous in developed countries, are now less expensive than previously, and can save large amounts of data and convey these data via both wireless transmission and e-mail. And, these advantages have been used in the studies of RA management [4]. A previous study indicated that RA patients are willing to use smartphone application for their self-management [5]. Based on these previous reports, we hypothesized that patients with RA may be able to easily self-monitor their daily disease activity at home using their smartphone and the self-monitor is of medical significance. We developed a novel method to assess RA disease activity via smartphones, without
the need for laboratory tests or visits to a doctor [6]. We focused on joint symptoms, activities of daily living (ADL), and gait parameters as daily and non-invasive measurements that predict disease activity. Previous studies indicated that the accelerometers contained in smartphones can measure gait parameters accurately [7], and RA disease activity was significantly associated with the gait parameters recorded by smartphones [8]. Furthermore, non-invasive self-assessment of a combination of joint symptoms, limitations of ADL, and walking ability via a smartphone application can adequately predict RA disease activity [9].

Here, we report a 3-month trial of this self-assessment system. The purpose of this study was to investigate the feasibility of a self-assessment system for RA patients using a smartphone application.

2. Methods

2.1 Subjects

The participants were 10 RA outpatients at the rheumatology outpatient clinic of Kyoto University Hospital. All enrolled participants had RA as defined by the American College of Rheumatology 1987 or 2010 criteria. We excluded patients based on the following exclusion criteria: the presence of other musculoskeletal disorders, cognitive disorders, Parkinson’s disease, stroke, or inability to walk unassisted for >15 m without using walking aids. Patients who had previously undergone surgery on the lower extremities were also excluded. Patients’ medications were not changed during the study period. Although all the participants have not used smartphone and the participant’s skill of smartphone was at moderate level, one participant withdrew from the study due to difficulty using the smartphone because the participant had never used a standard mobile phone. Nine participants were therefore included in the trial and final analysis.

The smartphones (dimensions: 119 × 60 ×10.9 mm; weight: 121 g; AQUOS PHONE f SH-13C; Android 2.3; Sharp Co., Osaka, Japan) used in this study included an acceleration sensor, a recording device, and an application for processing the acceleration signals. We also installed an application in the smartphone that allowed patients to measure their daily RA parameters themselves using the application over a 3-month period.

Written informed consent was obtained from each participant in accordance with the guidelines approved by the Kyoto University Graduate School of Medicine.

2.2 Measuring Daily Disease Activity Using a Smartphone

Our previous study showed that it is possible to measure disease activity score (DAS28) using a smartphone application in a cross-sectional way [9]. The DAS28 predictive model consists of subjective measurements such as tender joint counts (TJC) and the modified health assessment questionnaire (mHAQ) [10], and objective gait balance measurements.

Self-assessed TJC and mHAQ were recorded on a smartphone application that we developed (Figure 1). Measurements were recorded via a touchscreen questionnaire on the smartphone. The TJC was reported according to 49 joints used by American College of Rheumatology in a smartphone application. The mHAQ disability index assesses 8 ADL, including dressing and grooming, rising, eating, walking, hygiene, reach, grip, and community activities. The mHAQ is expressed on a scale ranging from 0 to 3, where 0 = no disability and 3 = severe functional disability.

The participants were instructed to walk along a 15-m walkway at their preferred speed every day. All participants wore their usual walking shoes, avoiding high heels and hard-soled shoes. Trunk linear accelerations were measured by participants themselves with the smartphones as they walked on the walkway. The smartphone was kept adjacent to the L3 spinous process, using a semi-elastic belt. The L3 spinous process is close to where the body’s center of mass is believed to be located during quiet standing [11]. The accelerometer of the smartphone was sampled at 33 Hz. The recorded signals were analyzed by an android application [7]. The autocorrelation peak (AC) was then calculated as the gait parameter of the degree of gait balance, according to previous studies [12].

Figure 1
Simulation of the smartphone touchscreen for inputting the number of tender joints and swollen joints (similar screen) and mHAQ. The characters of these screens are written in Japanese.
measures were self-recorded by participants daily for three months. It takes about five minutes to complete these measurements and the participants were instructed to make these measurements in the morning.

The DAS28 predictive model was calculated as the following formula using the results of regression analysis: the DAS28 predictive model = 2.380 + (0.110 × TJC) + (0.080 × mHAQ) + (−1.187 × AC). The details of the data measurement algorithms used in the system have been described previously, based on 65 RA patients [9].

### 2.3 Self-assessed Disease Activity Feedback System

According to the DAS28 measured by participants’ smartphones each day, daily feedback comments about their disease activity were automatically shown on the smartphone screen following self-assessment. The smartphone sends the data to a server via the Internet. Data are stored in the server of Kyoto University Hospital as lifelogs. The size of data for one self-measurement was approximately 4 KB and data format was Field Data Markup Language (FDML) [13–15]. After this, their measurements and the disease activity comments were automatically sent to rheumatologists. Patients also can view their own lifelogs using their smartphones at any time [6].

Comments altered according to the mean value of the measurements from the previous three days. If the DAS28 was 0.6 points lower than the mean value of the preceding three days, positive comments were shown by the software automatically (e.g. Disease activity is well controlled today. You can go out actively). If the difference between the DAS28 of a certain day and the mean value of the preceding three days was < 0.6 points, comments indicating maintenance of the status quo were shown (e.g. Disease activity is relatively good today. You can live your life as usual). If the DAS28 predictive model score on a certain day was 0.6 points higher than the mean value of the preceding three days, negative comments were shown (Figure 2). We defined the cut-off point (0.6 points) as based on the European League Against Rheumatism response criteria [16].

### 3. Results and Discussions

#### 3.1 Baseline Demographic and Clinical Characteristics of Participants

Table 1 shows the baseline demographic and clinical characteristics of participants.

| Age (y) | 56.6 ± 13.9 |
| Female (n) | 8 |
| Height (cm) | 159.1 ± 9.2 |
| Weight (kg) | 55.4 ± 10.2 |
| Disease duration (y) | 10.6 ± 8.3 |

### 2.4 RA Disease Activity

To assess participants’ RA disease activity, the DAS28 based on the C-reactive protein level (DAS28-CRP) [17] (the instrument usually used to measure RA disease activity) was measured by a rheumatologist during monthly clinical visits. The DAS28-CRP includes four parameters: TJC, swollen joint count, serum C-reactive protein level, and patient’s global assessment of disease status using a visual-analogue scale. The DAS28-CRP’s cut-off points of 2.6, 3.2, and 5.2 have been proposed to be indicative of remission, low disease activity, and high disease activity, respectively. The DAS28 is a generally accepted reliable, valid, and responsive measure of disease activity in patients with RA [18–20].

### 3.2 Relationship between DAS28-CRP and the DAS28 Predictive Model Score in Study Participants

Figure 3 shows the relationship between DAS28-CRP and the DAS28 predictive model score on the same day. There are therefore four data points for each subject and there is a dashed line as the regression line in Figure 3. Self-assessed disease activity as measured via smartphone was well correlated with actual disease activity over the 3-month period. However, the correlation may be weak when the subjects have high point of DAS 28, whose data were slightly displaced from the regression line.

| Abbreviations: DAS = disease activity score | mean ± SD |
| DAS28-CRP | 2.26 ± 1.19 |

Figure 2. Simulation of the smartphone touchscreen for daily feedback comments (negative comment)
We should investigate the way to improve the accuracy of measuring their self-assessed disease activity.

### 3.3 Questionnaire Following the 3-month Observation Period

After the 3-month observation period, we carried out a questionnaire survey to investigate participants’ opinions on the disease activity monitoring system. The results of the questionnaire study are shown below. Most participants gave favourable responses to the four questions. A previous study also indicated that RA patients were willing to use and pay for it [5]. However, age, motivation for performing self-management, and habituation of using Internet were the factors influencing the application adoption [5]. We should survey more opinions from RA patients in the future study.

**Q1) Could you record your body condition and your life every day?**

i) No problem. (n = 8)

ii) I could record with little problem. (n = 1)

iii) I could not record. (n = 0)

**Q2) Did you feel the feedbacks of the system suitable to your body condition?**

i) Very suitable. (n = 7)

ii) To some extent. (n = 2)

iii) Some feedbacks were suitable, but some were not. (n = 0)

iv) Not very suitable. (n = 0)

v) Not suitable at all. (n = 0)

**Q3) Were the feedbacks helpful for you to live your life?**

i) Very helpful. (n = 0)

ii) Helpful. (n = 6)

iii) Some feedbacks were suitable, but some were not. (n = 3)

iv) To some extent. (n = 0)

v) Not helpful at all. (n = 0)

**Q4) Did you feel nervous or confident to share information (about gait and body condition) with doctors?**

i) Very confident. (n = 2)

ii) Confident. (n = 7)

iii) Neither confident nor nervous. (n = 0)

iv) A little nervous. (n = 0)

v) Very nervous. (n = 0)

### 3.4 Future Prospects

Self-diagnosis and self-management are important treatment options for patients with RA, and has been previously investigated [21]. Significant benefits have been observed if self-management programs are maintained for > 8 years [22], and previous studies have demonstrated the utility of online self-management systems for patients with RA [23] and touchscreen questionnaire systems for patient data collection [24]. Smartphones may be useful self-management devices for patients with RA due to their telecommunication facilities, and the fact that they are now ubiquitous and have multiple features. Using a combination of smartphone devices and our self-assessment system, the availability of web-based interventions to support the self-management of patients with RA should be further investigated in a study similar to the previous feasibility study for patients with diabetes [25].

The predictive model in the present study may play an important role for patients with RA in self-diagnosis and self-management of their disease activity on a daily basis because it offers several benefits. First, the application does not include invasive measurements like blood testing, but daily measurements (joint symptoms, ADL, and gait parameters) that can be made using a smartphone. Second, disease activity can be represented objectively by the gait measurements in the predictive model. Third, medical staff and patients may be able to share information regarding the patient’s condition at home in real time using the functions of the smartphone. As a consequence, patients can receive timely advice from their medical providers and seek interventions before acute exacerbation of symptoms. The daily assessment may not be useful for the patients to cure the acute flare-up, but may be useful to monitor their symptom and prevent the progression of the disease because RA is a chronic progressive inflammatory disease. A previous study indicated that RA patients are willing to use smartphone application for their self-management [5]. The need of the self-management system seems high. However, from this study, we cannot indicate that the self-assessment system has the potential to alter treatment. Thus, more research is required ranging from the step of self-diagnosis to the intervention for improving self-assessed disease activity using the smartphone application in clinical practice.

![Figure 3](image-url)
There were several limitations to this study. First, the findings in this feasibility study should be considered preliminary owing to the small sample size and distribution (eight out of nine subjects were females), which may introduce some error of inference, reduce the power of analysis, and limit generalization. Second, the observation duration was relatively short, and we should observe longer duration. Third, the questionnaires lacked some interesting factors (e.g., user behavior when using the smartphone application). Forth, we could compare DAS28 and DAS28 predictive model only once a month because we could not frequently do blood testing. Fifth, we did not take varying walking speed into account in the present study. It is an important issue because walking speed can affect the degree of balance. Finally, the correlation of DAS28 with DAS28 predictive model was weak when subjects had a high DAS28-CRP. We should investigate the way to improve the accuracy of measuring their self-assessed disease activity.

4. Conclusions

The results of this feasibility study indicated that the DAS28 predictive model can longitudinally predict DAS28 and may be an acceptable and useful tool for assessment of RA disease activity for both patients and healthcare providers. The need of the self-management and self-diagnosis system seems high. Thus, more research is required ranging from the step of self-diagnosis to the intervention for improving self-assessed disease activity using the smartphone application in clinical practice.

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Disclosure Statement


References

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Appendix

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