

A Decision-support Algorithm for Self-management of Anticoagulation Therapy Used in a Smartphone Application

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Abstract—Warfarin for anticoagulation therapy is used by patients with specific cardiovascular diseases to control the ability of blood clotting. Traditional ways for self-management of the therapy are based on paper forms and procedures. This paper presents an algorithm developed for the smartphone application “*Warfarin Guide*”, which is a computer-assisted decision-support system used to help patients with self-management of their anticoagulation therapy related to International Normalized Ratio (INR) values. The algorithm was based on clinical guidelines for Warfarin therapy and it was adapted for the software application to address challenges with regular INR checks and adjustments for temporary fluctuations. An evaluation study with 14 participants showed that the patients evaluated the *Warfarin Guide* as useful for self-management of anticoagulation therapy, even though some issues could be improved.

Keywords—international normalized ratio, algorithms, computer-assisted therapy, medical informatics, eHealth

I. INTRODUCTION

The medication Warfarin is prescribed to patients with specific cardiovascular diseases, such as venous thromboembolic disorders, mechanical heart valves, and high-risk groups with atrial fibrillation as a life-long anticoagulation therapy with the aim to control the ability of blood clotting and prevent thromboembolic complications [1]. Measurements and monitoring of the International Normalized Ratio (INR) value are used to guide the Warfarin dosing and the intensity of the anticoagulant therapy [2][3]. Each patient is recommended a management strategy based on the case history with an individual therapeutic range of the INR value. A patient with a low INR has a risk of increased blood clotting and a high INR value indicates an increased risk of bleeding. Patients with increased blood clotting are exposed to a risk of life-threatening conditions such as cerebral infarction or pulmonary embolism. The individual INR values can be influenced by food intake with vitamin K-rich vegetables (i.e. broccoli and spinach) [4], and alcohol consumption [5], but illness, stress and physical exercise may also impact [6]. Patients using anticoagulation therapy can in some cases self-monitor the INR values [7] by a portable

coagulometer device that samples whole blood obtained by a finger prick [8]. Fluctuations outside the therapeutic INR range have been reported in previous studies [9]. These unexpected fluctuations challenge the reliability of regular checks of INR values and the decision-making about anticoagulant medication dose adjustments based on the measured values. This brings to light practical challenges regarding regular checks of the INR values measured at home and decision-making about Warfarin dosing adjustments.

In this context, the project Smartphone Warfarin Guide aimed to develop a software application for self-management of anticoagulation therapy to be used in smartphone or tablet devices. A decision-support algorithm for calculation and recommendation of medication was developed based on the Norwegian national clinical guidelines for Warfarin therapy [10]. This paper reports from the medication calculation algorithm development made in an early project phase.

The following research question was addressed:

What are the benefits and constraints of using a decision-support algorithm in a software application for self-management of anticoagulation therapy with Warfarin?

II. METHODOLOGY

A user-centred design approach was used for the development in the Smartphone Warfarin Guide project [11]. The development was conducted in four phases: 1) co-creation design workshops, 2) iterative development where the algorithm was extracted from the clinical guidelines and implemented to the software application, 3) usability evaluations in laboratory with anticoagulation therapy patients [12] and 4) long-term evaluation through a field test with 14 anticoagulation therapy patients using the smartphone application at home during several months. The research team in the project had a multi-disciplinary background within health informatics, computer science and medicine. The technical development was made by three master students in information and communication technology, under supervision by members of the research team. The Norwegian Centre for Research Data approved the study, with project number 50277 [13].

III. RESULTS

A. The Software Application

Today, patients in Norway that are capable of self-management of anticoagulation therapy manually follow the Noklus clinical guidelines for Warfarin dosage [10]. They have to measure their INR value weekly and keep track of it, remember when to measure the next time, calculate their current weekly medication dosage, and perform calculations of potentially required adjustments to the weekly dosage. In addition, the patients have to remember to take the appropriate dosage on a daily basis.

The developed software application for smartphones or tablet-PC devices instructs and informs those patients about required INR measurements, medication dosage and timely medication intake, see Fig. 1. The application allows for more frequent INR measurements and corresponding adaptation of the daily Warfarin dosage. It removes the need to follow any complex instructions and calculations by the patient, and stores required data as INR values and current medication dosage. Moreover, by transmitting and storing those personal health data to a secure telehealth service for remote monitoring in a health information management infrastructure. The latest data are made available to authorised medical professionals for follow-up and support if needed, and for research and other clinical purposes.

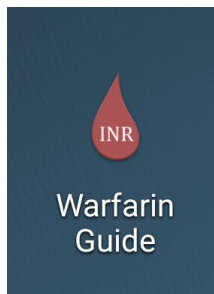


Fig. 1. The start screen of the software application.

After installing the application in a device, a first-time-configuration has to be carried out. The user must enter a code provided by a medical professional. With that code, the newly created user profile of the software application is linked to the individual patient profile in the telehealth service in the health information management infrastructure. As part of that user profile configuration, the INR-range is set to either “2.0-3.0” or to “2.5-3.5”, the patient’s initial medication dosage is set, and the secure data communication with the telehealth service is configured.

After successful configuration, the main user interfaces of the application, include the following visible and functional elements (see Fig. 2 for examples):

1. Patient’s latest dosage status.
2. Patient’s most recent INR measurement.
3. Due date for next INR measurement.
4. Button to register new INR measurement.
5. Button to access past “history” of measurements and medication dosages.
6. “Help” button to gain access to application’s documentation.
7. “Settings” button to gain access to settings and configuration of application.

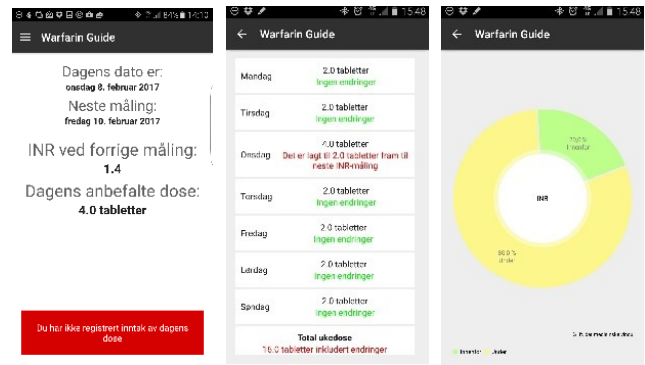


Fig. 2. The last measurement and today’s recommended dosage (left), the recommended dosage for a whole week (middle), and duration the INR value has been within the therapeutic range (green segment on right).

B. The Medication Calculation Algorithm

The Noklus clinical guidelines is a description for manual adjustments of the weekly Warfarin medication dosage by the patients, with the help of a portable INR measurement device. The following changes have been made for the medication calculation algorithm in the software application compared to the original guidelines:

- A low INR value (0.0-1.6 or 0.0-1.9) used to have a choice whether or not to increase the weekly dose (low-molecular weight heparin injection should also be considered if $INR < 1.5$). In the software application it is increased only if the last INR measurement was low.
- “Take an extra daily dose divided into 1-2 days” is “take one extra daily dose today” in the software application.
- If the answer to the question “Have you been sick, started on a new drug or been on holiday overseas” is “Yes”, the patient should do a measurement after 3-4 days and that has been changed to 3 days.

A flow chart of the resulting medication calculation algorithm including the changes and adaptations made for the software application is shown in Figure 3. This algorithm is used by the application every time a user is prompted to do a new measurement from the home screen.

The INR ranges displayed under the label “INR 2.5” is for users with the therapeutic range “2.0-3.0”. The INR ranges displayed under the label “INR 3.0” is for users with the therapeutic range “2.5-3.5”. That means that if two users with different therapeutic ranges measured the same INR values, it is not certain they would trigger the same logic. E.g. if “INR 2.5” users measure 2.0, it leads to no changes; if “INR 3.0” users measure 2.0, pills need to be added to the weekly dosage.

C. The Field Test

A field test for long-term evaluation of the smartphone application and the medication calculation algorithm was run with 14 participants, that all were anticoagulation therapy patients recruited from a local hospital. They used the smartphone application at home for four months. After two months they were requested to fill in a questionnaire on user experience regarding the design and functionality. After four months, there was a meeting was organized at the hospital for evaluation of the long-term experiences.

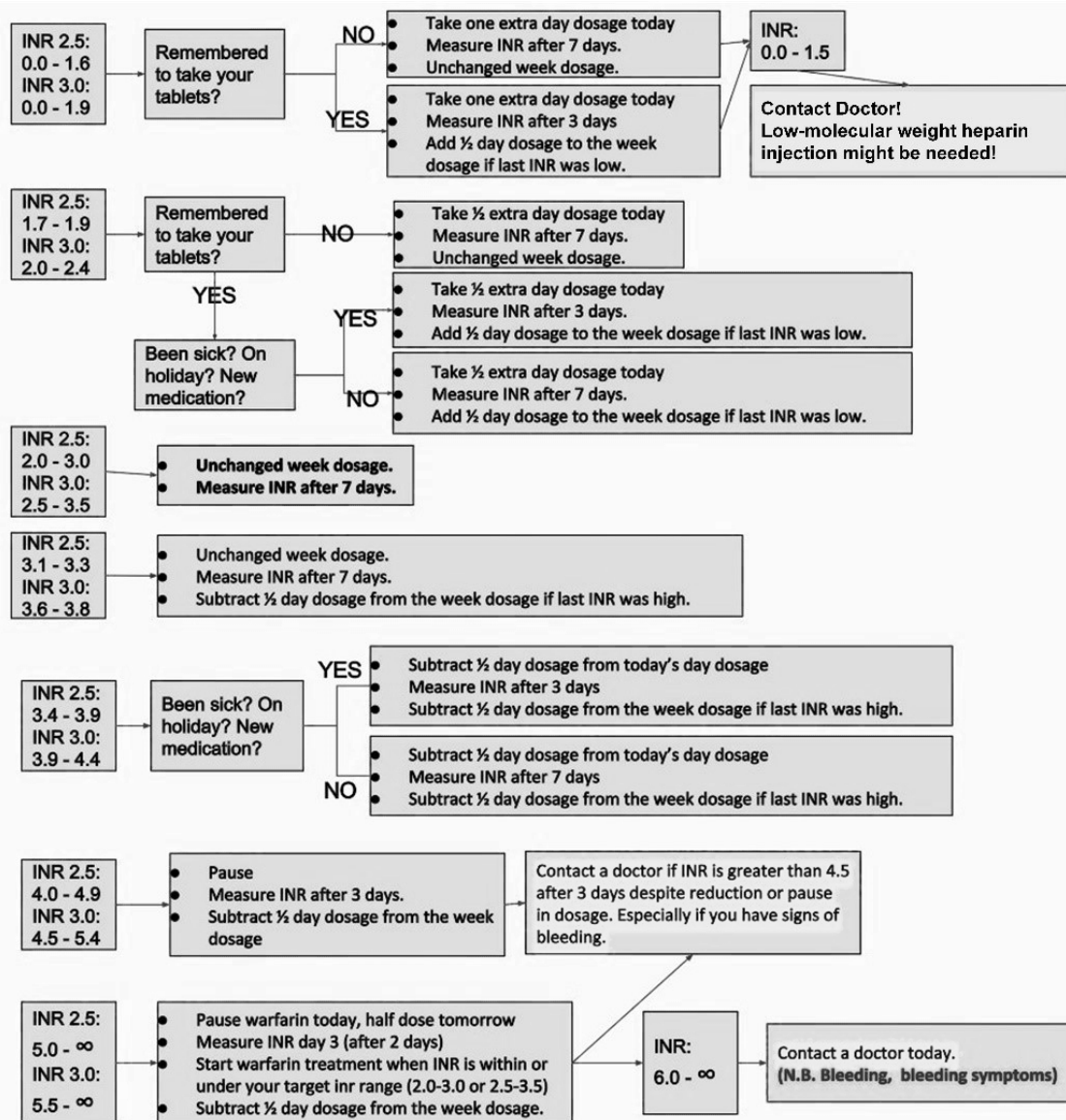


Fig. 3. Flowchart of the medication calculation algorithm with changes to adapt for the software application.

The paper-based clinical guidelines were used in conjunction with the smartphone application to identify inconsistencies. The design suggestions from the field test targeted adaption for all types of smartphones as the application was only compatible with Android devices. A function for manual change of the measurement's day was suggested and also transfer of the data to a personal computer for backup. During the field test, two discrepancies were found between the recommended week dose of the smartphone application compared to the clinical guidelines.

IV. DISCUSSION AND CONCLUSION

This paper has presented the medication calculation algorithm development for self-management of INR measurements and Warfarin dosing, that was implemented in the Smartphone application Warfarin Guide. With this application the manual process of medication determination

based on a printed tabular guideline has been transformed into an application-based workflow.

The field test with the anticoagulation therapy patients confirmed advantages of the application for the management of INR measurement dates, the information about the current daily and weekly medication dose, required temporary adjustments, as well as a log of previous INR values and taken medication doses.

The algorithm allowed the adaptation of the medication dose to a continuous time-series of INR measurements, but it faced the challenge that the recommended daily dose (i.e. the total number of tablets in the weekly dose divided on seven days) can require the division of tablets. As solution, the algorithm rounded the dose to the nearest half tablet. This can explain some inconsistencies between the dosage recommended by the Noklus clinical guidelines and the dosage recommended from the smartphone application based

on the algorithm. Further testing and validation of the algorithm under clinical supervision according to regulations for medical software [14] is required.

The study carried out so far had some limitations, such as the limited number of participants included in the field trial for testing the medication calculation algorithm. Nevertheless, the study included real patients using anticoagulation therapy and they had a background that meaningfully represented the target end-user group. Future work would include implementation of Bluetooth transmission from the measurements' device to the smartphone application to reduce the potential for errors due to the manual transfer of INR measurement results. Further, a randomised controlled trial (RCT) is under preparation, where a comparison between using the standardised paper-based clinical guidelines and the smartphone application for data-driven decision support will be made. The patients' trust in the technology would also be an important topic to study further.

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