Need assessment and development of a mobile-based medication dosage calculation application for ICU nurses

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Abstract
Medication dosage calculation errors are among the most common errors of nurses in intensive care unit (ICU). Mobile devices can advance drug dosage calculation processes. This study aimed to develop a medication dosage calculation application for nurses in ICUs. This study was performed in teaching hospitals of Kerman University of Medical Sciences in 2018. The required features was determined in a need assessment survey of nurses. As well, two specialists were interviewed to determine the medications used in the ICUs. Then, the application was developed using formative usability testing. Overall, 80% of the participants (n = 120) answered the survey. Nineteen out of 29 features determined in the survey, and 25 medications selected by the specialists and participants were used to develop the application. The usability test of the prototype found 15 problems. After fixing, 2 problems were identified and fixed in the final version. According to the participants, the medication dosage calculation application increases the accuracy of drug dosage and reduces errors. The user-identified features were developed in-app. User-centered usability testing in this study improved development based on the users’ needs. The method used in this study can be used to develop health applications which conform to user needs.

Keywords Needs Assessment · Design · Evaluation · Mobile health application · Drug dosage calculations

1 Introduction
Patient safety is a serious public health issue worldwide [1]. Patient safety is referred to as prevention of error and injury to patients [2]. Despite the effect of patient safety on people health medical errors in health care continue to occur [3]. One of the most common medical errors is medication errors [4]. These errors occur due to patient misuse of medication or wrong administration of medication by health care providers and can lead to failure in treatment process and injury to the patient [5–7]. One of the most common medication errors is the error caused by drug dosage calculations [8]. As previous studies [9–11] has shown, there is a great deal of error in the calculation of drug doses.

Various studies [12–16] have shown that information and communication technology, particularly mobile devices, is used in all areas of health care, including drug dosage calculations. Currently, many people of different medical professions are using different mobile health applications and these have a positive effect on their activities and performance [15, 17]. Mobile devices can provide easy and timely access to information and these tools has replaced traditional models [18, 19]. These tools can reduce medical errors, particularly human errors [12]. Poor skill to perform medication calculations leads to medication error in hospitalized patients [20]. Therefore, computational errors are the main cause of error in hospitalized patients [21]. Intensive care unit (IC) in hospitals is one of the wards that...
are important due to severity of disease and high need of patients to receive patient safety health care [21]. Nurses play an important role in patient safety, as nurses are responsible for administering medication to patients admitted to the ward [22]. In addition to understanding the use and consequences of each drug, they must also calculate drug dosage correctly [23]. A study on medical errors in the intensive care unit showed that each patient was exposed to error 1.7 times a day, and drug errors accounts for 78% of medical errors in ICU [24].

As ICU nurses are on the shift when administrating medication to the patient, they need a tool that can provide information quickly and easily. Studies which have used information and communication technology for drug dosage calculations involve anesthesiologists using mobile health applications [13], mobile health application for calculating drugs in pediatric cardiovascular resuscitation [25], and CPOE implementation [26, 27]. There are no studies to date on the use of mobile health applications for drug dosage calculation by ICU nurses. Development of this application can accelerate and increase the accuracy in calculating the correct dosage of medications, reduce medication error by nurses, and prevent adverse effects. The objective of this study was need assessment and development of a drug dosage calculation application for ICU nurses.

2 Methods

Participatory design [28, 29] was used to develop the Drug Dosage Calculator application.

Participatory design is an iterative process that is performed at various stages including user needs assessment, design and participatory development of prototype, testing, retesting, and evaluation. Technologies developed by participatory design projects are often more successful because users are involved in the process of identifying needs in design and development [30].

2.1 Research design

This study was conducted in two phases. Phase I involved needs assessment of nurses and Phase II involved development and usability test of the Drug Dosage Calculator application. This study was approved by the Ethics Committee of Kerman University of Medical Sciences under code IR.KMU.REC.1398.190.

2.2 Phase I: need assessment

This study was conducted in the fall of 2018 in general intensive care units of teaching hospitals of the Kerman University of Medical Sciences (Shafa, Afzalipour, Shahid Bahonar). The studied population consisted of all nurses in the general intensive care unit of all three hospitals who were enrolled by census. Questionnaires were used for data collection. Three medical informatics specialists, one health information management specialist and one ICU expert confirmed formal and content validity of the questionnaire. The reliability of each construct of the questionnaire was confirmed by Cronbach’s alpha and the weighted average of 86% was obtained. This questionnaire consisted of the following four sections: (1) Demographic information of the participants, including age, gender, education, work experience (2) Determining the necessity of a drug dosage calculator application (6 questions on a 5-point Likert scale ranging from the lowest to the highest necessity); (3) Content and features required in app development (29 closed questions on a 5-point Likert scale ranging from the lowest necessity to the highest necessity and one open question to add other features needed by nurses; these features were determined by reviewing pharmaceutical applications as well as expert suggestions when validating the questionnaire); (4) An open question to determine drugs that nurses need to calculate. In order to collect the data, the researcher referred to the studied hospitals in person, provided explanations about the purpose of the study, received verbal consent of the nurses to participate in the study, and finally distributed need assessment questionnaires.

In addition to assessing the needs of nurses for administrating medications, the researcher identified important drugs used in this ward by conducting two interviews with two ICU specialists to use in development of the application.

2.3 Phase II: development and usability test

In this phase, the standard formula for calculating drug dosage was identified by reviewing scientific references and guidelines [31–33] and approved by two ICU specialists to be used in the Drug Dosage Calculator application. In addition, all the features for which more than 50% of participants chose ‘high’ and ‘very high’ in the needs assessment phase were selected for developing the application. In order to verify the accuracy of drug dose calculations, the two specialists were consulted at each stage of the development and the developed application was evaluated. The prototype of the application was developed in the Android programming language. During the development, the usability of the application was evaluated by think aloud method [34] in two round. In this method, we used AB Screen recorder to record videos from the mobile screen. Since at least 5–8 participants are sufficient for think aloud method [35], at each round of the usability test, eight- of the nurses who participated in the needs assessment phase were asked to perform
Participants’ view on necessity of drug dosage calculator mobile health application

3 Results

3.1 Phase I: need assessment

Of 150 nurses, 120 (80%) responded to the questionnaires; 85% of the participants were women and more than 82% were younger than 40 years. The majority of participants (73%) had a work experience of less than 10 years and about 88% had a bachelor’s degree. Approximately 71% of participants had no experience of using applications in the field of health, and more than half (56%) found it useful to use mobile applications in their patient care processes (Table 2).

Table 2 Demographic information of participants

| Demographics | N(%) |
|--------------|------|
| Age          |      |
| <30 years    | 48(40.0) |
| 30–40        | 51(42.5) |
| 40–50        | 7(5.8)  |
| >50 years    | 1(0.8)  |
| Gender       |      |
| Male         | 18(15.0) |
| Female       | 102(85.0) |
| Experience in ICU |    |
| <5           | 46(38.3) |
| 5–10         | 42(35.0) |
| 10–15        | 22(18.3) |
| 15–20        | 4(3.3)  |
| >20          | 2(1.7)  |
| Education    |      |
| Associates’  | 4(3.3)  |
| Bachelor’s   | 106(88.3) |
| Master’s and above | 10(8.3) |
| Experience with health application | |
| No           | 35(29.2) |
| Yes          | 85(70.8) |

Table 3 Participants’ view on necessity of drug dosage calculator mobile health application

| Participants’ view | Average and lower N(%) | High and very high N(%) |
|--------------------|-------------------------|-------------------------|
| Error in calculation of dosage by nurse * | 111 (92.5) | 9 (7.5) |
| Error in calculation of dosage by colleagues | 104(86.7) | 16(13.3) |
| Damaging error in calculation of dosage for the patient * | 9(7.5) | 111(92.5) |
| Need for mobile health application for calculating dosage | 56(46.7) | 64(53.3) |
| Save time for calculation of dosage by mobile health application * | 35(29.2) | 85(70.8) |
| Higher accuracy of drug dosage calculations by mobile health application * | 31(25.8) | 89(74.2) |

*p value <0.05

For analysis of the 5-point questions of the second part of the need assessment questionnaire (the necessity of drug dosage calculator application), the low, very low and average responses to each questions were considered as low necessity and high and very high responses as high necessity of drug dosage calculator application. Chi square test was used to compare the ratio between the responses related to necessity and non-necessity of the application. To determine the features required in the design of the application, we analysed the responses of the participants to the third part of the questionnaire. The features that were given high and very high priority by more than 50% of participants were used in software design. Expectation Maximization algorithm (EM) was used to eliminate missing data.

2.4 Data analysis

For analysis of the 5-point questions of the second part of the need assessment questionnaire (the necessity of drug dosage calculator application), the low, very low and average responses to each questions were considered as low necessity and high and very high responses as high necessity of drug dosage calculator application. Chi square test was used to compare the ratio between the responses related to necessity and non-necessity of the application. To determine the features required in the design of the application, we analysed the responses of the participants to the third part of the questionnaire. The features that were given high and very high priority by more than 50% of participants were used in predetermined scenarios using the prototype and express what they think when performing the scenarios (Table 1). These scenarios were developed through consultation with ICU specialists and were intended to cover almost all activities of the Drug Dosage Calculator application. The video recordings of the participants at each round were reviewed by two evaluators and the usability problems of the prototype were identified. The results were used to modify and develop the final version of the Drug Dosage Calculator application.
did not make mistakes in calculation of dosage and 87% claimed that their colleagues also did not make mistakes in calculations. About 92% of the participants believed that error in calculating dosage was harmful for the patient.

Our analysis showed no significant relationship between participant’s demographics and the necessity of using mobile health applications ($P > 0.05$).

### 3.2 Phase II: development and usability test

Of 29 features listed in need assessment questionnaire, the sum of 19 features was more than 50%, which were selected for development of the mobile health application (Table 4).

In addition, analysis of open questions of the needs assessment questionnaire (part 3) identified conversion of unit (g to mg, etc.) as feature. Moreover, 9 medications by ICU specialists and 16 medications in response to open questions by nurses were identified to be used for development of the mobile health application. Based on the list of identified drugs, 15 drugs were individually included in the mobile health application. Other identified drugs were included in the mobile health application in two categories based on similarity of the computational formula to calculate serum volume (micro set and macro set) and 3 categories to calculate a specific dose of drug (weight-based drugs, unit-based drugs, and percent-based drugs) (Fig. 1).

Of 16 participants in two stages of usability test, 14 were women and the mean of their age was 31 (22–51 years). Two evaluators identified 15 usability problems in the prototype. Usability problems were categorized into 5 categories and other problems such as small font size, writing problems, inability to enter decimal numbers when calculating drug dosage, and other features which confused the user were categorized as other. After fixing these problem and redevelopment, the application was evaluated and this time two usability problems were identified and the application was modified (Table 5).

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**Table 4** Identified features for development of drug dosage calculator mobile health application

| Feature                                           | Sum of high and very high N(%) |
|---------------------------------------------------|---------------------------------|
| Display the result of dosage calculation          | 90(75)                          |
| Help for calculating dosage                       | 90(75)                          |
| Help for using the application                    | 88(73.3)                       |
| Choose weight in calculating dosage               | 88(73.3)                       |
| Display maximum dosage                            | 85(70.8)                       |
| Update the application                            | 82(68.3)                       |
| Display drug dosage calculation formula            | 82(68.4)                       |
| Search the drug                                   | 82(68.4)                       |
| Display minimum dosage                            | 81(67.5)                       |
| Choose the drug                                   | 76(63.4)                       |
| Display default name when searching               | 75(62.5)                       |
| Display generic name when calculating dosage      | 75(62.5)                       |
| Link to scientific references related to dosage calculation | 73(60.8)                       |
| Display unit of each input data                   | 68(56.6)                       |
| Display both generic and commercial names when calculating dosage | 65(54.2)                       |
| Display commercial name when calculating dosage   | 64(53.3)                       |
| Introduce the references used in the application  | 64(53.3)                       |
| Move the selected drugs to list of favorites      | 62(51.6)                       |
| Provide general explanations about the application| 62(51.7)                       |
| Personalize the application (font, color, …)      | 59(49.2)                       |
| Contact the developer                             | 58(48.4)                       |
| Display the patient profile when calculating dosage | 56(46.7)                       |
| Report if the patient or the nurse profile is registered | 56(46.7)                       |
| Clear the result                                  | 56(46.7)                       |
| Register the patient profile when calculating dosage | 52(43.3)                       |
| Insert username when signing in                   | 52(43.3)                       |
| Register the nurse profile when calculating dosage | 45(27.5)                       |
| Display the nurse profile when calculating dosage | 38(21.7)                       |
| Insert password when signing in                   | 35(29.1)                       |

The bold features were used for development and application to do their dosage calculations and 71% claimed that the mobile health application would save time. Approximately 74% of them believed that the drug dosage calculator mobile health application would increase accuracy in calculation; 92.5% of the participants claimed that they

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**Fig. 1** Screenshots of the Drug Dosage Calculator application (A: Home page of the mobile health application, B: Submenu of “Drug Dosage Calculation” menu, C: Submenu of “IV rate calculation”, D: Calcium Gluconate rate calculation page.)
Table 5  Describing usability problems in think aloud usability test

| Usability problem                                      | Prototype evaluation | Application evaluation |
|--------------------------------------------------------|----------------------|------------------------|
| Some buttons are hidden                                | 2                    | 1                      |
| Some buttons are hidden                                | 2                    |                        |
| Function of some buttons is vague                      | 2                    |                        |
| There is mistake in displayed formula                  | 3                    |                        |
| The name of some buttons are vague                     | 2                    | 1                      |
| Other                                                   | 4                    |                        |

4 Discussion

4.1 Principal findings

Most participants claimed that they needed an mobile health application for drug dosage calculations and that this application would save time and increase accuracy in calculations. Based on needs assessment of nurses, features such as choosing and searching the drug name, calculation result display, application user help, update and formula display were selected to develop prototype of the mobile health application. Think aloud usability test identified the prototype usability problems; after redevelopment based on usability results; usability problems of the mobile health application were significantly reduced. Then these problems were fixed in development of the final version.

More than half of the participants found it useful to use the mobile health application in patient care. Martinez et al. [36] also found that mobile health interventions were often helpful. This could be due to the ease of use, mobility and cost-effectiveness of mobile health applications [37]. These mobile health applications can also be useful for a number of reasons, such as enhancing user skills, motivation, and trust as well as supporting clinical staff activities [37–39].

Contrary to previous studies [20, 25, 40] that show drug calculation error in actual performance of nurses, in the present study more than half of nurses believed that they rarely made mistake in drug dosage calculations. This might be due to the difference in the perception of the participants in a self-report process with their actual performance. However, since more than half of participants felt the need to have a mobile health application to perform drug dose calculations, they may need it for saving their times when calculating dosage.

The majority of participants in this study believed that error in calculating drug dosage is harmful to patients. Various studies [13, 15, 41] have shown that drug dosage calculation mobile health application has been able to prevent drug error by people. Mobile health Applications for drug dosage calculation can be used to maintain patient safety and prevent drug errors. Most nurses participating in this study believed that development of a drug dosage calculation mobile health application could increase accuracy of drug dosage calculations. This finding is consistent with a previous study [42], which pointed to improved accuracy and reduced error in patient care using medication calculation tools.

Studies [43, 44] have shown that if a technology is not useful, users are less likely to use it. Therefore, it is better to utilize the features desired by users in technology development [45]. Using a user-centered design approach in mobile health application development can meet the needs of users and lead to creation of a user-friendly interface [46]. Implementing user needs tailored to their level of technical literacy also facilitates successful access to and acceptance of mobile health [47].

At the request of more than half of the nurses, references used and links to scientific references related to drug dosage were used in mobile health application development. In this regard, Ownby et al. [48] showed that mobile health application can contribute to improvement of knowledge about health of people. Since access to scientific references leads to greater knowledge acquisition by users, linking to scientific references can remind nurses of the knowledge they had learned a long time ago. In addition, these features can be useful in lifelong learning to update clinical information to prevent errors in medical system and to improve the quality of patient care. Most of the nurses participating in this study found it necessary to use the mobile health application help. In this regard, Khajouei et al. [49] reported that users were dissatisfied with the lack of help in the system. This may be because help provides a description of how to use it and allows for answers to important user questions. Many nurses consider the ability to update the mobile health application an important feature in app development. In their study, Seed et al. [50] showed that failure to update medical application can lead to information being deprecated and consequently misuse of the application. With the advances in knowledge and the possibility of adding new drugs with sophisticated pharmaceutical computing in this area, the mobile health application seems to be able to cover this new information. In this study, personalization was one of the features that lesser proportion of nurses needed to have in the mobile health application. Anastasiadou [51] showed that patients have different needs and characteristics and that mobile health applications need to be personalized. Contrary to Anastasiadou’s findings, the reason that fewer nurses request this feature in the present study could be the relative similarity of nursing activities in the intensive care unit. Since user participation in provision of information content provides immediate and rapid access to this information by users, this study conducted a need assessment to list the needed medications. User need assessment not only identifies information needs; it can also be effective in
determining how this information is displayed in the system based on user needs. In the present study, the medications, which were required by nurses and ICU specialists, were classified according to the formula as well as the medication form in the application and approved by the experts when developing the prototype.

A user-friendly mobile health application can also improve the health outcomes of people [52]. Therefore, this study developed the mobile health application based on user needs and evaluated usability of the mobile health application. Among the methods used to evaluate system usability, the methods that involve present users in the real world provide a better understanding of system usability. Previous studies [53–56] have shown that think aloud method identifies many problems related to usability and identifies the root cause of the problems. Thus, this study used think aloud method to evaluate the application and the identified usability problems were solved. According to usability test results, participants had difficulty selecting some options because of the small font size in the mobile health application. In this regard, Moradian et al. [54] showed that a larger font size in the system could attract more attention to screen elements. There was also some ambiguity in the name and performance of some buttons, which was identified in the usability test. In this regard, Ehrler et al. [55] showed that appropriate labeling for items can improve the ease of use of the mobile health application. In addition, Klingberg et al. [56] found that changes in button design were effective in improving their performance.

4.2 Limitations

This study had three limitations. First, the focus of this study was on developing and usability evaluation of a mobile application for calculating medication dosage. In this study the perception of users concerning the usefulness and necessity of such an application was studied, however, the effect of the application on reducing medication errors by nurses was not investigated. Future studies can address this issue in order to identify the true value of these applications. Second, the questionnaire was distributed only to all nurses working in General ICUs in three teaching hospitals in Kerman. Future studies could provide more accurate results in a broader context, including other intensive care units such as trauma, stroke, intoxication, heart and surgery. However, given that the medications used in all ICUs are often the same, the study in other wards seems to achieve the same results. Third, some of the user needs may not be covered due to the use of questionnaire in determining user needs. In each case, different features were compiled for this questionnaire by reviewing different mobile health applications and expert opinions, and an open question was added to add those that were not considered. Fourth following the U.S. sanctions against Iran and an embargo on iOS products, apple removed Iranian apps from its app store. Hence, in this study we could develop the application only for Android. However, most people use the Android operating system [57].

4.3 Application of findings

The results of this study can be used for hospital authorities and policymakers to plan for the use of drug calculator applications in different wards. Drug Dosage Calculator application can be used as a template for developing similar applications for all nursing groups to increase accuracy and reduce error in drug dosage calculation and ultimately patient safety. Moreover, the method used in this study can be used by health program developers to produce usable mobile health applications with appropriate information content and in accordance with needs of their users.

5 Conclusion

According to participants, mobile health applications of drug dosage calculations can increase accuracy and reduce error in drug dosage calculations. In this study, the features required in the mobile health application were developed based on user needs. Since applying user needs according to their level of technical literacy will lead to better acceptance of mobile health and improve the health outcomes of patients, the features required in the mobile health application were developed based on user needs. User-centred usability testing in this study improved the development according to user needs.

The method used to determine user needs and improve usability of the mobile health application in this study can be used by developers of mobile health applications in the field of health. In addition, the mobile health application developed in this study is a model for developing similar mobile health applications for use by other nurses in different wards of the hospital. Since this study was conducted only in the general ICU, future studies could provide more accurate information with regard to other intensive care units.

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Authors’ contributions FA, RK, MA and FR contributed to the conception and design of the study, acquisition and interpretation of the data, and drafting the paper. Y.J. was primarily responsible for the statistical analysis of the data. All 5 authors read and approved the final version of the article submitted.
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**Declarations**

**Conflict of interest** The authors declare that there is no conflict of interest in this study.

**Ethical considerations** The study (Proposal code: 97000670) was approved by the ethics committee of the Kerman University of Medical Sciences. All participants gave written informed consent. The methods applied in this study performed in accordance with the Declaration of Helsinki and approved by research ethics committee of Kerman University of Medical Sciences (Ethics code: IR.KMU.REC. 1398.190).

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