Need Assessment and Development of a Mobile-based Medication Dosage Calculation Application for ICU nurses

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Abstract

Background

Medication dosage calculation errors are among the most common errors of nurses in intensive care unit (ICU). Information technologies, particularly mobile devices, can advance drug dosage calculation processes. The objective of this study was to develop a medication dosage calculation application for nurses in intensive care units.

Methods

This study was performed in the ICUs of teaching hospitals in Kerman University of Medical Sciences in 2018. First, a need assessment survey of nurses was conducted to determine the required features of the application. As well two specialists were interviewed to determine the medications used in the ICUs. Second, a medication dosage calculation application was developed using formative usability testing.

Results

Overall, 80% of the participants (n=120) answered the need assessment questionnaire. Of 29 features determined in the needs assessment, 19 were selected to develop the application. Moreover, 25 medications were selected by specialists and participants for the development of the application and its prototype. The usability test of the prototype found 15 problems. After fixing these problems 2 problems were identified, which were fixed in the final version.

Conclusion

According to the participants, development of the medication dosage calculation application increases the accuracy of drug dosage and reduces the errors. The user-identified features were developed in-app. User-centered usability testing in this study improved development based on needs of users. The method used in this study can be used by developers of health applications to develop applications which are consistent with user needs.

Background

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] have 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 is 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 administrating 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.

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].

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.

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. Formal and content validity of the questionnaire were confirmed by three medical informatics specialists, one health information management specialist and one ICU expert. Reliability of the questionnaire was confirmed by calculating internal consistency with Cronbach's alpha of 93%. This questionnaire consisted of four sections: 1) Demographic information of the participants, including age, gender, education, work experience, as well as two questions about user experience with health applications and people's views on usefulness of the application in patient care processes; 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) on 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.

Phase II: Development and usability test

In this phase, the standard formula for obtaining 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. Finally, the application was developed in the Android programming language. At each stage of development, the specialists were consulted and the developed application was evaluated. After receiving feedback and modifications to the application, the prototype was developed. In this phase, usability of the application was evaluated by think aloud method [34] using AB Screen recorder software. In this method, all the work done by users is recorded and observed and analysed by the evaluator. Participants were asked to perform the following 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. At least 5–8 participants are sufficient for think aloud method(35); thus, 8 participants evaluated the application at each time of usability test. After reviewing the video recordings of the participants by two evaluators, usability problems of the prototype were identified and used to modify and develop the final version of the Drug Dosage Calculator application.

Table 1
Description of scenarios used in usability test

Drug	Scenarios
Dopamine	Dopamine 10 μg/kg/min was prescribed for a 60 kg patient. Obtain the number of drops per min with micro set and serum set and the number of cc per h or pump syringe for IV administration of 200 mg dopamine dissolved in 50 cc normal saline.
Streptokinase	2000 unit/min streptokinase was administered for coronary artery disease. Determine the number of drops of microst and macrost (serum set) per min for IV administration of streptokinase at a dose of 750000 units and 100 cc. Calculate the rate of drug administration (cc/h) for the same syringe and 20 cc pump syringe.
Propofol	For sedating a woman weighing 80 kg, 0.1 mg/kg/min propofol was required. Calculate the number of drops per min with microset and serum set if 200 mg propofol is reached to 100 cc using serum. Calculate the number of cc per h if pump syringe and 50 cc syringe is used.
Lidocaine	For a patient weighing 75 kg, 1 mg/kg lidocaine in the form of bolus in 2–3 min and 3 mg/min in the form of infusion are requested by the physician. For 2% lidocaine, calculate the number of cc lidocaine administered as bolus. For three 2% lidocaine ampoules in a 5 cc ampoule (15 cc total) and 100 cc serum, calculate the number of drops per min with serum set and microset. For pump syringe and 50 cc syringe, calculate cc per hour.

Data analysis

In the first part of the questionnaire (demographic information) for analysis of the 5-point question related to usefulness of the application in patient care processes, the respondents chose the points low, very low and average for uselessness of the application and high and very high for usefulness of the application. For analysis of the 5-point questions of the second part of the need assessment questionnaire (the necessity of drug dosage calculator application), the respondents chose the points low, very low and average for low necessity and high and very high for 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. Linear regression was also used to examine the relationship between demographic information and necessity of the application. To determine the features required in the application, total percentage of features existing in the questionnaire was obtained. EM (Expectation Maximization) algorithm was used to eliminate missing data.

Results

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 30–40 40–50 > 50 years	48(40.0) 51(42.5) 7(5.8) 1(.8)
Gender	Male Female	18(15.0) 102(85.0)
Experience in ICU	< 5 5–10 10–15 15–20 > 20	46(38.3) 42(35.0) 22(18.3) 4(3.3) 2(1.7)
Education	Associates' Bachelor's Master's and above	4(3.3) 106(88.3) 10(8.3)
Experience with health application	No Yes	35(29.2) 85(70.8)
Usefulness	Very low Low Average High Very high	5(4.2) 7(5.8) 41(34.2) 53(44.2) 14(11.7)

Table 3 illustrates people's views on necessity of a drug dosage calculator mobile health application. About 53% of participants claimed that they needed the mobile health 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 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.

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		

Table 4 shows the relationship between demographic information and necessity of mobile health application. Of demographic information, there was only a significant relationship between usefulness of mobile health application in patient care processes and necessity of mobile health application ($P < 0.05$). In response to usefulness of mobile health application in the field of health, necessity of drug dosage calculator mobile health application increases by 0.22, on average, per increase in each level on Likert scale.

Table 4
The relationship between demographics and necessity of mobile health application

Demographics		Mean ± Sd	Regression Coefficient(95%CI)
Gender	Female Male	1.85(0.35)	0.08 (-0.46,0.63)
Education	Associate's Bachelor's Master's and above	2.05(0.33)	-0.93(-2.15,0.27) -0.33(-0.98,0.36)
Experience with application	Yes No	1.71(0.45)	-0.04(-0.04,0.36)
Age			0.02(-0.01,0.06)
Experience in ICU			-0.01(-0.05,0.03)
Usefulness of application *			0.22(0.027,0.42)
*p value < 0.05			

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 (Table 5). Moreover, 9 medications by ICU specialists and 16 medications in response to open questions by participants 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) (figur1).

Table 5
Identified features for development of drug dosage calculator mobile health application

	Sum of high and very high N(%)
Choose the drug	76(63.4)
Search the drug	82(68.4)
Display default name when searching	75(62.5)
Display generic name when calculating dosage	75(62.5)
Display commercial name when calculating dosage	64(53.3)
Display both generic and commercial names when calculating dosage	65(54.2)
Insert username when signing in	48(40)
Insert password when signing in	35(29.1)
Display unit of each input data	68(56.6)
Display the result of dosage calculation	90(75)
Clear the result	56(46.7)
Register the nurse profile when calculating dosage	45(27.5)
Display the nurse profile when calculating dosage	38(31.7)
Register the patient profile when calculating dosage	52(43.3)
Display the patient profile when calculating dosage	56(46.6)
Report if the patient or the nurse profile is registered	56(46.7)
Display minimum dosage	81(67.5)
Display maximum dosage	85(70.8)
Help for calculating dosage	90(75)
Link to scientific references related to dosage calculation	73(60.8)
Display drug dosage calculation formula	82(68)
Personalize the application (font, color, …)	59(49.2)
Help for using the application	88(73.3)
Contact the developer	58(48.4)
Move the selected drugs to list of favorites	62(51.6)

	Sum of high and very high N(%)
Introduce the references used in the application	64(53.3)
Provide general explanations about the application	62(51.7)
Update the application	82(68.3)
Choose weight in calculating dosage	88(73.3)
The bold features were used for development	

Of 16 participants in two stages of usability test, 14 were women and the mean of their age was 31 (22–51 years). In evaluation of prototype, 15 usability problem were identified by two evaluators. 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 6).

Table 6
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	

Discussion

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. However, since more than half of people felt the need to have an mobile health application to perform drug dose calculations, the reason for people not reporting errors may be the difference between abstract ideas and their actual performance.

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[52]. In the present study, the identified drugs 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[53]. 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[54–57] 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. [55] 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[56] showed that appropriate labeling for items can improve the ease of use of the mobile health application. In addition, Klingberg et al. [57] found that changes in button design were effective in improving their performance.

Limitations

This study had Three limitations. First, 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. Second, 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. Third, 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[58].

Application of findings

The results of this study can be used for hospital presidents 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.

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.

Abbreviations

ICU: Intensive care unit; IV: Intravenous; EM: Expectation Maximization algorithm; CPOE: Computerized physician order entry

Declarations

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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. YJ. 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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Availability of data and materials

The data generated and analyzed during this study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Verbal consent was obtained from the participants and the procedure was approved by ethics committee of Kerman University of Medical Sciences (approval number: IR.kmu. REC. 1398.190).

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Figures

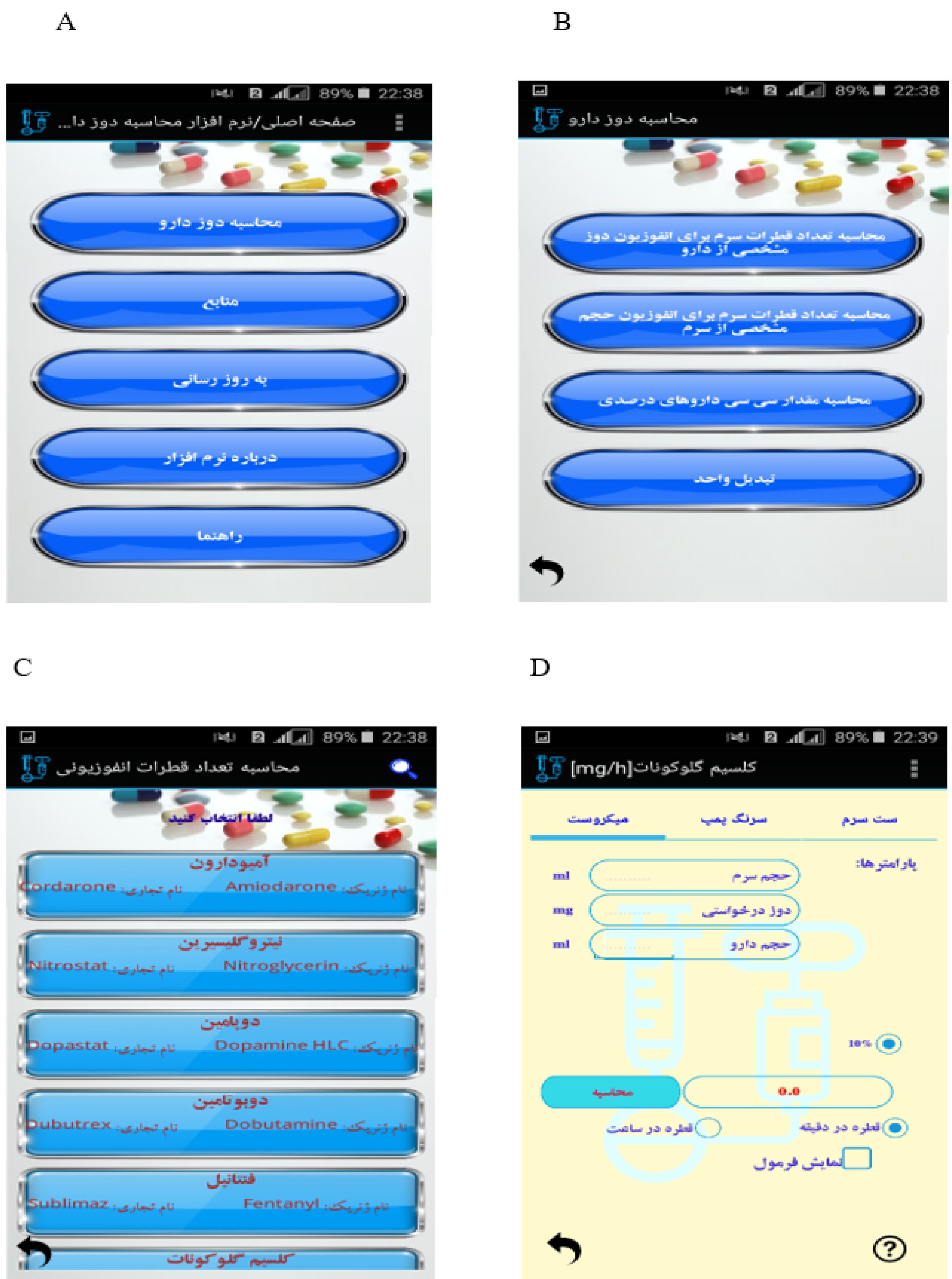

Figure 1

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.)