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RESEARCH ARTICLE

Medical Mobile Application for The Management of Heart-Lung Machine during Cardiac Surgery

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ABSTRACT

The goal of this work is to construct a mobile application device that has a wide variety of functions which has clinical planning and decision making for heart-lung machine controlling and to assess the users' level of satisfaction. The app was constructed according to the steps of design, algorithm, and validation, which is based on the ionic framework. The levels of satisfaction with the developed mobile app among 20 perfusionists were assessed by a questionnaire. The project researchers have officially assigned this medical mobile application with the name is Perfusion Assistant app. that can be accessed and used effectively cross platform on iOS and Android. The application is comprised of 5 main categories which includes: a perfusion calculator, myocardial protection chart, drugs details, priming solution, and parameters values. This finding shown that all cardiovascular parameters did not significant differ from Perfusion Assistant app. when compared to manual calculation. User's satisfaction was at 3.64 ± 0.76 in the first evaluation. After modification with feedback from experts, the satisfaction of this application was evaluated with a 4.13 ± 0.56. Thereby, Perfusion Assistant app. is an application designed in clinical planning and decision of heart-lung machine controlling for perfusionists and medical staff that work in an opened heart surgery arena. Perfusion Assistant app. offers a variety of calculations related to cardiopulmonary bypass including blood flow rate, systemic vascular resistant, priming volume, and predicted hematocrit. Furthermore, Perfusion Assistant app. provides a quick, easy access, and real-time application for cardiopulmonary bypass that user's satisfaction was a good level.

Keywords: Mobile application; Heart and lung machine; Cardiopulmonary bypass

Introduction

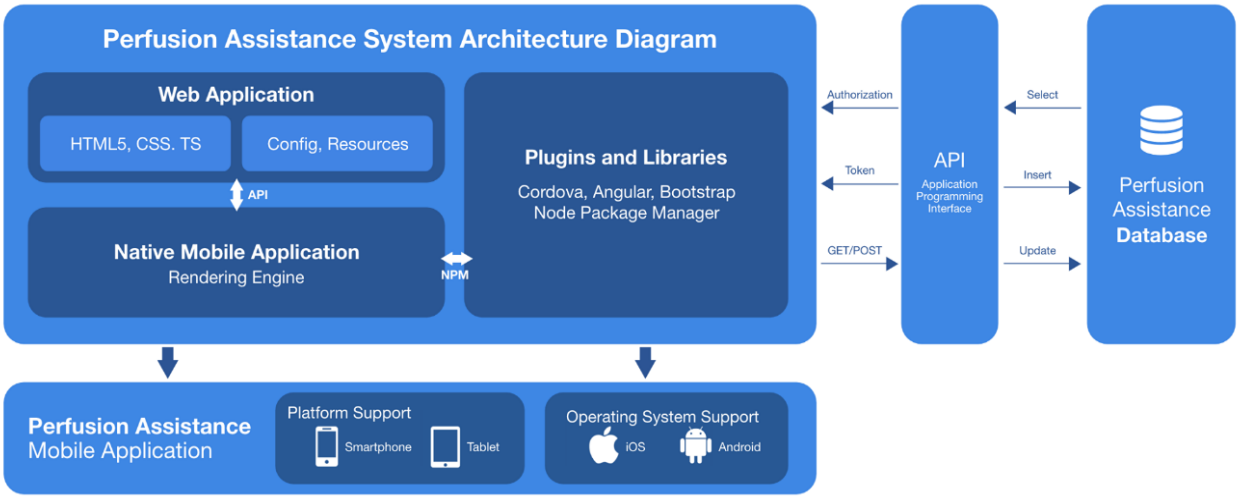
Since John Gibbon construct and develop heart and lung machine (HLM) for cardiopulmonary bypass (CPB), this machine and principal has been used in opened heart surgery over 60 years.[1] HLM controlled by perfusionists mimics the cardiopulmonary function by temporarily taking over their functions during cardiac surgery.[2] However, perfusionists are still required to attentive regarding the monitoring of the blood volume in a venous reservoir of an oxygenator, the mean arterial blood pressures (MAP), and the systemic vascular resistance (SVR) continuously to adjust and maintain the perfusion blood flow rate (BFR) throughout a centrifugal or roller pump in a CPB circuit.[3,4] If perfusionists can be accessed automatically by way of the mobile app for a planned operation, it will be patients' safety; for example: the app can be used to calculate optimal blood flow, SVR, priming volume, and provide a hematocrit prediction to reduce post-operative complications. Furthermore, regulation of pump flow rate dependent SVR to ensure that pump flow is adequate.[5] Moreover, perfusionist need to be considered and calculated into the open-heart surgery procedure several cardiovascular parameters for use of the HLM.[6] Opened heart surgery with CPB is a critical and complex procedure; so, to improve the quality of work, personal digital assistants should develop to help operating room staffs and perfusionists to provide a more accurate system for treating patients.

Mobile applications have been able to help improve one's efficiency and knowledgebase when faced with challenges.[7,8] They are fundamental benefits that make life easier and help streamline job responsibilities.[9,10,11] Moreover, the advantages of a medical mobile application improve access to medical literature and clinical work plan.[12,13,14] Another contribution of this work is that previous studies have shown that mobile application on smartphones on iOS and Android are popularly used among physicians and professional medical staffs for the past decade.[15] Therefore, the goal of this work is to construct a mobile application device that has a wide variety of functions which has clinical planning and decision making for HLM controlling and to assess the users' level of satisfaction.

Materials and methods

This smartphone app was constructed and developed based on an ionic framework. (ionicframework, AngularJS, Cordova, HTML5, JavaScript), which are unique algorithms used in the operation of HLM. This study was approved by the Naresuan University Institutional Review Board with certificate approval number 0471/2018. The app was constructed and developed utilizing the following phases: design, algorithm, validation, and evaluation user's satisfaction. Overall, the Perfusion Assistance system architecture platforms are as shown in Figure 1.

Figure 1. Assistance system architecture diagram



1. Mobile application design phase

The scope of the discussion process to create a workable HLM application was principle of cardiopulmonary bypass.[16] The researchers were able to go through a brainstorming to determine the steps necessary to fill the knowledge gap that would make the HLM process more reliable and practical for perfusionists and operating room staffs.

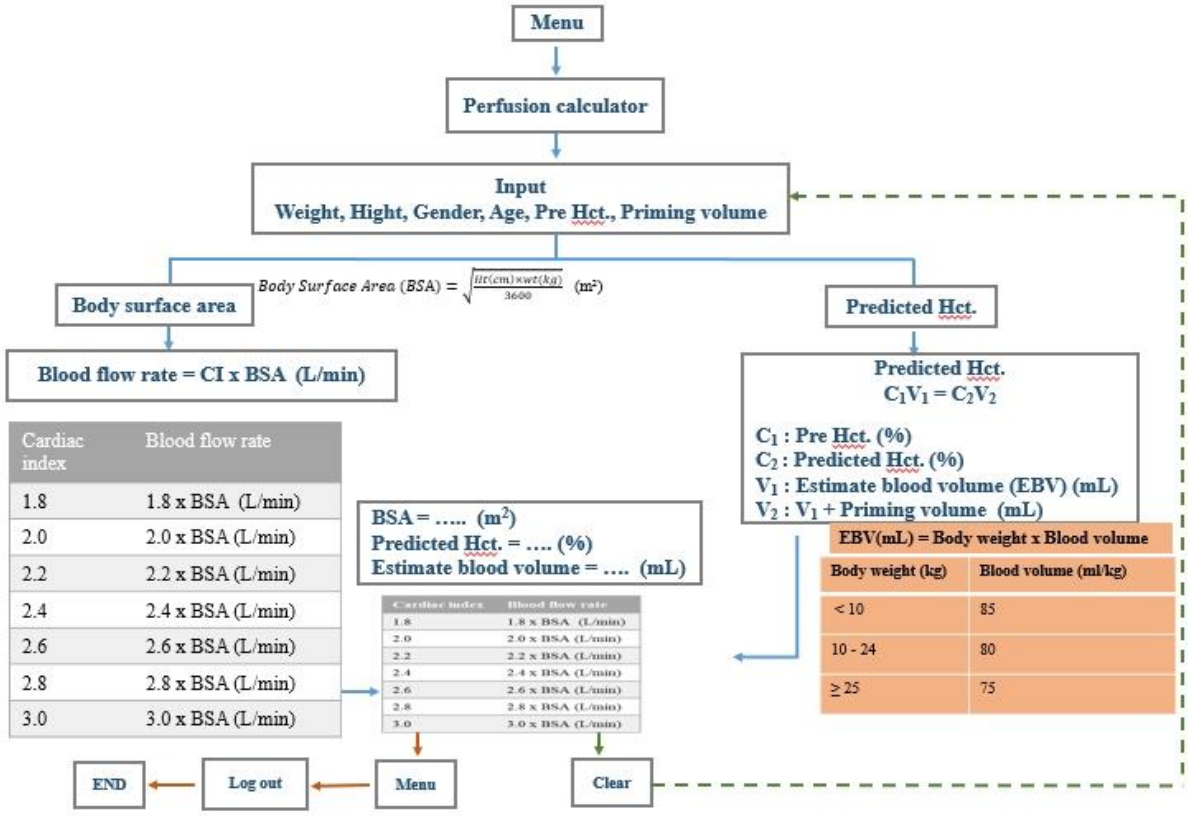
This medical mobile application which is referred to as the Perfusion Assistant app. has 5 typically categories of concerns that most perfusionists are interested when using an application program that relates toothier professional responsibilities. Application functions such as perfusion calculator, myocardial protection, drugs, priming solution, parameters values, location and about us icon (Figure 2).

Figure 2. Main and additional information icon of Perfusion Assistant app

2. Algorithm mobile application phase

The algorithm phase is used to identify the multiple concepts, steps, and application's flow mapping. During this phase, the programmer converts the appropriate and complex data and information into an algorithm. Once the formatting of the basic algorithms was completed, we to evaluate mobile application by cardiothoracic surgeons and perfusionists. Afterwards, comments were reviewed, and the suggestions were received on how to improve the unique algorithms. The researchers then reconstruct the arrays into the final Perfusion Assistant app. For example, the unique algorithm used for the perfusion calculator is shown in Figures 3.

Figure 3. Algorithm of Perfusion Calculator



3. Validation mobile application phase

After development mobile application, the accuracy of Perfusion Assistant app. final version was examined. The medical information contents were reviewed by 5 professional perfusionists and 5 cardiothoracic surgeons. Moreover, the completeness of medical contents was checked for any inconsistencies or mistakes in the text; in addition, the language format and usage in the applications were edited and corrected by a native English language expertise at the Language Center, Naresuan University (LCNU). Every aspect of the perfusion calculator formats and formulas received approval. Then cardiopulmonary bypass parameters were compared between manual calculator and Perfusion Assistant app.

4. Evaluation user's satisfaction phase

After validation completion, a team of experts were assembled. To evaluate application user's satisfaction, 10 clinical perfusionists were asked

to use the new revision of the "Perfusion Assistant app." and provide the researchers with an updated evaluation. Afterwards, the level of satisfaction of 10 clinical perfusionists in second evaluation was examined. The application user's satisfaction questionnaire was scored based on a 5-point Likert scale.

Statistical Analysis

Descriptive data was expressed as mean ± standard deviation (SD), frequencies, or as an absolute number and percentages when appropriate. The normal distribution of the data was examined using the Kolmogorov-Smirnov test. Differences between manual calculator and Perfusion Assistant app. of continuous variables were analyzed by independent t-test. The SPSS software version 17 (SPSS Inc, Chicago, IL, USA) was used for all our analysis. P values < 0.05 were statistically significant.

Results

We were able to construct and develop the medical mobile app to provide the Perfusionist a more suitable working load. The Perfusion Assistant app., a mobile application, can be accessed effectively cross platform both on iOS and Android. This smartphone app was designed to be easy to use. Tapping the startup screen makes the main menu appear; once the startup screen disappears, the 5 main sections which are presented by icons, perfusion calculator, drugs, myocardial protection, priming solution, and parameters value appear, on the screen. The startup screen and home menu, along with the contents of the main menu are shown in Figures 2.

The result illustrated that body surface area (BSA), blood flow rate (BFR), predicted Hct, systemic vascular resistance (SVR), arterial oxygen content (CaO_2), mixed venous oxygen content (CvO_2), oxygen delivery (DO_2) and oxygen consumption (VO_2) did not significant differ from Perfusion Assistant app. when compared to manual calculations. The variables related to the perfusion data collection and analysis of data between manual format and the Perfusion Assistant app. are presented in Table 1.

Table 1. Manual compared to Perfusion Assistant app data calculations per variable.

Variable	Manual	Perfusion Assistant app.	p - value
BSA	1.65±0.075	1.65±0.075	0.083
Minimum BFR	3.297±0.150	3.299±0.150	0.093
Optimum BFR	3.958±0.181	3.959±0.181	0.065
Maximum BFR	4.947±0.226	4.949±0.226	0.223
Predicted Hct	31.206±0.997	31.206±0.997	0.651
SVR	1,323.520±45.970	1,323.52±45.970	0.157
CaO_2	16.840±0.320	16.840±0.320	0.404
CvO_2	12.690±0.260	12.690±0.260	0.317
DO_2	663.841±18.689	663.841±18.689	1.00
VO_2	157.984±8.199	157.984±8.199	0.317

BSA: Body surface area; BFR: Blood flow rate; Hct: Hematocrit; SVR: Systemic vascular resistance; CaO_2: Arterial oxygen content; CvO_2: Mixed venous oxygen content; DO_2: Oxygen delivery; VO_2 oxygen consumption.

To evaluate the Perfusion Assistant app. users' satisfaction, 20 perfusionists were asked to use the app and then assess and provide their personal level of satisfaction so that the researchers can identify the appropriateness and usefulness of the app. All perfusionists were members of the Society of Cardio- Thoracic Technologist of Thailand. The mean age of users was 34.16 years (range, 26-63 years); 5 (25%) were male and 15 (25%) were female; 95% were cardiothoracic technologist that are practicing perfusionists, while (85%) were bachelor's degree, and (15%) were master degree. The mean regarding the duration of work as a perfusionist was 9.83 years as shown in Table 2.

Table 2. The characteristics of participants.

Characteristics of participants	Value (n = 20)
Age (years)	34.16 (26-63)
Male, % (n)	25% (5)
Duration of work as perfusionist (years)	9.83
Major academic Cardiothoracic technology % (n) Nursing % (n)	 95% (19) 5% (1)
Study level Bachelor's degree % (n) Master's degree % (n)	 85% (17) 15% (3)

User satisfaction was at 3.64 ± 0.76 in the first evaluation. Based on their feedback, the app required slightly modification. User's satisfaction was at a good level; however, in the second evaluation the application performed at a higher level, 4.13 ± 0.56. Nevertheless, based on user's comments, the programmer modified the string of arrays used in the app. The mean values of user satisfaction according to the data presented in the ten items listed in the questionnaire are shown in Table 3.

Table 3. User's satisfaction on "Perfusion Assistant" mobile application.

Category	First evaluation (n=10)	Second evaluation (n=10)	p - value
1. Usability	3.90±0.56	4.05±0.60	0.403
2. Designed to be user-friendly	3.60±0.84	4.20±0.52	0.841
3. Content is properly related to design objectives	4.00±0.81	4.25±0.44	0.398
4. Provides clarity of content usage	3.40±0.51	4.20±0.52	0.598
5. Prevents potential faults	3.10±0.73	3.70±0.73	0.085
6. The processing speed of the application	3.90±0.87	4.35±0.48	0.572

7. The reliability of the application	3.50±0.84	4.05±0.51	0.585
8. Font size, design, and screen color are appropriate	3.70±1.05	4.10±0.64	0.264
9. Language usage	3.60±0.51	4.15±0.58	0.435
10. Appropriateness of screen size	3.70±0.82	4.25±0.55	0.414
Average Mean ± S.D.	**3.64±0.76**	**4.13±0.56**	**0.401**

Value is shown as mean ± Standard deviation.
Five-point Likert scale used.

Discussion

Our Perfusion Assistant app. is written in JavaScript, using ionic framework version 2 for the mobile application design, and can be used on any mobile devices (phones or tablets) that use an Android and iOS platform.[17] The most challenging phase of the process of developing the clinical planning and decision regarding the HLM controlling smartphone app was designing the scope and algorithm for the mobile app. In this study, the scope of function and algorithm link were determined in collaborations with all involved researchers. Furthermore, we edited and developed of scope and algorithm based on suggestion from experts who participated in the first evaluation. In the first Perfusion Assistant app. design, there were seven categories, which also included a blood gas interpretation. However, blood gas interpretations for this study require the storage of a much larger number of contents; consequently, the configuration of the algorithms caused the program to be not unstable once engaged, for smartphones possess an insufficient capability to store large amounts of contents. In addition, some specifications in blood gas function are not able to interpretation the data correctly. Therefore, we decide to temporarily remove the blood gas interpretation from this app. Nevertheless, blood gas interpretation is considered a very important variable for HLM controlling.[18] However, the perfusionist who have used the app have provided us with suggestions that will require additional development of the blood gas interpretation mode. Therefore, blood gas interpretation mode should be further developed.

The perfusion calculator mode has three sub mode which include: BFR, SVR, and oxygen content and consumption. The Mosteller equation, BSA= Square root of (Bw x Ht)/3600 regarding body surface area, was applied to determine the following validation of BSA value when comparing the manual calculations with formulas and this mobile app. showed no significant difference.[19] Concerning myocardial protection, the priming solution and the parameter values mode were for learning content only. Therefore, this app has grabbed the user' attention and to motivate learners. This work should have contained diverse videos as well as many photos and pictures. However, the researchers did not include videos in the app; for according to the app producer, video downloads on a smartphone require a large capacity memory. Moreover, app development can be a difficult process because of limited funds and the amount of technological support.

Inadequate tissue perfusion during CPB can lead to metabolic acidosis, organ damage, and

dysfunction.[20,21] Determination of the BFR with HLM is difficult because blood flow during CPB does not mean anything in isolation judgment. During CPB requires the amount of delivered oxygen to the tissues organs depends on the blood flow rate and the oxygen content. Moreover, the adjustment of the flow rate of HLM during CPB, if patients have vasoplegia condition, characterized by significantly decreased SVR and low MAP that they are usually necessary to administer a continuous vasopressor infusion.[22] On the contrary, if patients have high MAP with dramatically increased SVR. In this situation, perfusionists may decide on a reduced blood flow rate of HLM to reduce complications of open-heart surgery.[16] Therefore, this app is very beneficial to solve inadequate tissue perfusion during CPB.

The user satisfaction survey of the "Perfusion Assistant app." revealed good-quality subjective level of satisfaction. They showed a high satisfaction with the design, content, and usability of the program; therefore, there is a high anticipation that perfusionists will use this app for planning and making decision to assist in controlling HLM during opened heart surgery. The contents and features were organized by a considerable of cardiothoracic surgeons and professional perfusionists based on the easy and broad choice that this application assists with clinical practice to control HLM of the menu. We brought all first suggestions from participants to revise the final version. For example, all content was created in a way that can be viewed comfortably by allowing users to enlarge the font size and improvisation to the text and background colors on the screen. Moreover, regarding the algorithm of this application, users can easily key a few data to input in this application that it can process various essential data to control HLM that is suitable for both iOS and Android operating systems. Therefore, the final version of this application has high participant satisfaction. However, this application focus on calculating the important parameter of the entire contents to plan and make the decision to control HLM; therefore, there is a need for the future to develop this application link with the patient monitor during cardiac surgery. Furthermore, this smartphone app educationally for cardiothoracic surgeons, anesthesiologist, scrub nurse, and medical staff. However, only a small number of participated in this survey. They suggested that having full knowledge of principle of CPB; therefore, there is a need for future work aimed add and focusing in detail on the learning content.

According to recent years, many medical companies have launched a variety of new generation of HLM. Nonetheless, this price is more expensive. Several developed countries are making efforts for providing improved a semi-automated or automated circulation system for the HLM.[23,24] We hope as part of algorithm mobile application in this work may are fundamental data for biomedical engineer to develop automatic control of the HLM in next step of opened heart surgery arena.

Conclusions

Perfusion Assistant app. is a medical application designed in clinical planning and decision of HLM controlling for perfusionists and medical staffs that work in the opened heart surgery arena. Perfusion Assistant app. offers a variety of calculations related to cardiopulmonary bypass including BFR, SVR, priming volume and predicted hematocrit. Furthermore, this

mobile app provides quick, easy access and real-time to the knowledge of cardiopulmonary bypass that user's satisfaction was a good level.

Conflict of Interest Statement:

The authors have no conflicts of interest to declare.

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