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Anticoagulation Manager: Development of a Clinical Decision Support Mobile Application for Management of Anticoagulants

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Abstract

Patients with certain clotting disorders or conditions have a greater risk of developing arterial or venous clots and downstream embolisms, strokes, and arterial insufficiency. These patients need prescription anticoagulant drugs to reduce the possibility of clot formation. However, historically, the clinical decision making workflow in determining the correct type and dosage of anticoagulant(s) is part science and part art. To address this problem, we developed Anticoagulation Manager, an intelligent clinical decision workflow management system on iOS-based mobile devices to help clinicians effectively choose the most appropriate and helpful follow-up clotting tests for patients with a common clotting profile. The app can provide physicians guidance to prescribe the most appropriate medication for patients in need of anticoagulant drugs. This intelligent app was jointly designed and developed by medical professionals in CDC and engineers at Georgia Tech, and will be evaluated by physicians for ease-of-use, robustness, flexibility, and scalability. Eventually, it will be deployed and shared in both physician community and developer community.

I. Introduction

Approximately four million Americans have a clotting disorder or condition that requires anticoagulation for many years to prevent clot formation and serious consequences [1]. Given a patient with an unknown clotting disorder among many possible types, it is important to determine the best drug that can reduce clotting tendencies, the right dose of drug to avoid under- and over-anticoagulation (patient safety); and to recognize associated conditions that may affect drug metabolism and anticoagulation levels [2]. The correct identification of any particular clotting condition of a patient is largely based on selecting and accurately performing laboratory tests that measure different parts of the clotting cascade [3]. Also, administration of well-selected anticoagulation drugs and their titration to achieve the level of anticoagulation is largely based on laboratory tests. However,

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prescribing proper laboratory test combinations have been challenging for physicians for patients with a clotting disorder.

In 2015, the National Academies of Medicine published recommendations to improve diagnosis in healthcare. The Clinical Laboratory Integration into Healthcare Collaborative (CLIHC™), established by Centers for Disease Control's (CDC) Division of Laboratory Systems (DLS), within the Center for Surveillance, Epidemiology, and Laboratory Services (CSELS), has been addressing some of these recommendations to optimize the ability of practicing clinicians to effectively utilize laboratory services for better patient care. The output has been diagnostic testing algorithms, as well as recommendations to guide clinicians' selection of appropriate laboratory tests based on personalized conditions (e.g., age of the patient, symptoms, medications being used, inpatient or outpatient status).

To assist physicians in making the efficient clinical decision for patients with these chronic conditions, CDC has been devoting efforts in information technologies to expedite the delivery of guidance products for clinical practice. For example, the CLIHC™ has published mobile apps for the selection of laboratory tests in monitoring patients on anticoagulant drugs. The first pilot iOS-based app, called PTT Advisor, was designed to provide a workflow guide for physicians to make the clinical diagnosis of a patient with an abnormally long Partial Thromboplastin Time (PTT) and normal Prothrombin Time (PT) [4, 5].

In this study, we convert the pilot PTT Advisor app into a generalized fast clinical decision workflow management system, nicknamed Anticoagulation Manager, to provide guidance for physicians to prescribe the most appropriate anticoagulant drug and dosage based on laboratory tests when treating patients with the following conditions: (i) long-term anticoagulation of patients with certain mechanical heart valves; (ii) acute heparin-induced thrombocytopenia; (iii) arterial thrombotic events such as a stroke, mini-stroke, or arterial blood clot; and (iv) switching patients from one anticoagulant drug to another. The remaining sections of this article are organized as follows: Section II will introduce the seven main algorithms implemented in Anticoagulation Manager for the selection of anticoagulation lab tests; Section III will present the interface design and the scalability of Anticoagulation Manager; Section IV will describe the ongoing user evaluation and the Technology Acceptance Model; and finally, Section V will conclude this article with future directions.

II. Algorithms of Anticoagulation Laboratory Test Selection

As mentioned in Section I, the first version of PTT Advisor covered only one algorithm (i.e., prolonged PTT with normal PT tests). Since 2013, CDC has been developing seven more workflow algorithms to address the comprehensive and appropriate selection of alternative anticoagulation therapies for patients with other conditions. These algorithms, developed following published guidelines and released after being reviewed ("vetted") by a group of national coagulation experts, provide step-by-step, clinical decision workflows to assist in management of patients who need anticoagulant drug therapy and have one of the below conditions. As illustrated in Fig. 1, a physician has to determine a patient's condition so as to continue one of the following algorithms:

1. *Venous thromboembolism (VTE) or pulmonary embolism (PE)*: VTE is the formation of blood clots in the vein. PE is a blockage in one of the pulmonary arteries in lungs [6, 7].
2. *Nonvalvular atrial fibrillation (NVAF)*: NVAF is used to describe cases where rhythm disturbance is not associated with valvular problems [8].
3. *Current or history of heparin induced thrombocytopenia (HIT)*: HIT is the development of thrombocytopenia (a low platelet count) due to the administration of various forms of heparin, an anticoagulant [9].
4. *Mechanical heart valve (MHV):* Clot-risks are higher for people with mechanical valves [10].
5. *Risk of fetal loss (FL)*: FL refers to the spontaneous intrauterine death of a fetus at any time during pregnancy.
6. *Patent foramen ovale (PFO) or atrial septal defect (ASD*): PFO is defined as a foramen ovale that does not seal.
7. *Switching*: History of being on anticoagulant drugs and desire to switch from one to another.

All of the algorithms are integrated into one decision tree that starts from the top node as shown in Fig. 1. A diamond note represents an inquiry followed by its possible consequences represented as branches in which a branch connects to a next-level inquiry. Based on a patient's conditions, a physician starts from the top node and iteratively responds to inquires until a final square-shaped leaf (i.e., suggested anticoagulant lab test(s)) has been reached without any further inquires. Fig. 2 illustrates an iterative inquiry example for a patient with the following three conditions: (1) *pulmonary embolism (PE)*, (2) *hemodynamically stable*, and (2) *not safe of using anticoagulation therapy*. Following the tree by responding these three conditions, the decision tree finally suggests: "*Consider IVC filter if the patient requires anticoagulation*".

III. Design of Anticoagulation manager

A. Main Operation Screen

As we mentioned in Section II, a physician needs to follow the integrated decision tree and iteratively respond a patient's conditions until final suggested anticoagulant laboratory test(s) has been obtained. The main purpose of the Anticoagulation Manager was to improve the efficacy of the process so that the physician can reach the final suggestion by just a few clicks on a phone screen. As shown in Fig. 3, the main operation screen consists of three parts: the inquiry (top), possible options (middle), and operation buttons (bottom). For example, at the top node of the decision tree (i.e., the first question) shown in Fig. 3(a), the question is "*Select one of the following types of anti-coagulation*," and two possible options are "*Start a patient on anti-coagulation*" and "*Switch a patient's anticoagulation*." The user can click on the desired option, and the screen is updated to the next inquiry (i.e., from Fig

3(a) to Fig. 3(b)). The physician continues responding to inquiries by clicking corresponding conditions until the final suggestion has been obtained (i.e., from Fig. 3(b) to 3(f)). The option list can be scrolled if it is longer than the displayed range.

Anticoagulation Manager provides the "Evaluation Review" feature that is accessible at any time and allows the user to review all the selected steps in the algorithm. The feature also allows the user to change any previously completed step in the algorithm, or if no change is necessary, the user can return to the current step. This feature is implemented by four operation buttons, *Back, Next, Go to last*, and *Restart*, via the buttons at the bottom of the screen. Buttons may be disabled (i.e., shaded) if the operation is currently not available. For example, the *Back* button is disabled in Fig. 3(a) because the user cannot go back in the first question. The user can open the help screen (Fig. 4) for the descriptions of these four buttons. Thus, the innovative Evaluation Review feature ensures very efficient use of the clinician's time, obviating the need to start over if a mistake is made. To protect patient privacy, the information is not stored and cannot be associated with any specific patient.

B. Scalability

The current decision tree of the seven main algorithms was implemented using a JSON (JavaScript Object Notation) format which is a lightweight data-interchange format. JSON is easy for humans to read and write and easy for machines to parse and generate. For each algorithm node, its question, the corresponding options, and consequences, are coded as an array object in the JSON file. In the future, we can easily include other tree-based algorithms by adding new nodes into the current JSON file, without changing any existing nodes. It makes the app capable of storing unlimited number of algorithms.

The current JSON file is stored in the local memory. During the launch phase, the app updates the JSON file from the online server. Therefore, whenever the JSON file is updated (e.g., adding nodes for a new algorithm), the content of the decision tree can be a seamless, automatic, update without the need to republish the app and require the user to update the app frequently. Keeping a copy of the JSON file in local memory also provides the capability of offline mode, which can avoid situations from Internet connection problems.

IV. User Evaluation

After receiving approval from the Federal Office of Information Collection and Regulatory Affairs, we will recruit nine care providers to evaluate Anticoagulation Manager usability. Each provider will be asked to search most appropriate anticoagulant drug and dosage in laboratory tests given a variety of patient conditions. Based on their performance and feedback, improvements for the interface design will be made.

In addition to performance, end-user acceptability of Anticoagulation Manager will be evaluated based on the Technology Acceptance Model (TAM) [11]. TAM is one of the most established models on technology acceptance and has been suggested in evaluating many new mobile information technologies [12–14]. TAM proposes that when users are presented with a new system, technology, or software package, a number of factors (especially perceptions and attitudes of one's behaviors) affect their decision about how and when they

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will use it. In our study, the three variables examined will be perceived ease of use (PEOU), perceived usefulness (PU), and final behavioral intention (BI) to use Anticoagulation Manager: (Fig. 5). PEOU measures the degree to which a physician perceives that use of the app to be free of effort. PU is defined as the probability that a physician finds the app valuable to their future practice. Lastly, BI determines a physician's final willingness to use Anticoagulation Manager. After collecting measures of these three variables, the TAM model will assess how users come to identify, accept, and use Anticoagulation Manager.

V. Conclusion

In this study, we designed and developed Anticoagulation Manager, an intelligent clinical decision workflow management system on iOS-based mobile devices to assist physicians in providing personalized care for patients with one of seven common conditions requiring anticoagulants. The app will allow physicians to select the most appropriate laboratory test(s) that will point to the best anticoagulant drug, determine its proper dose and formulation adjusted for other existing conditions, and monitor the anticoagulation effect of the drug in the patients. Anticoagulation Manager was designed with scalability that can quickly include new anticoagulant algorithms without changing the interface and republishing the app to users. The ongoing user evaluation will test the app's usability by comparing the performance and user acceptance to paper- and computer-based operations.

While the current design of Anticoagulation Manager is promising, we still plan to make improvement in the following three directions. First, currently the Anticoagulation Manager only supports iOS devices. In the future we hope to extend its capabilities to other mobile platforms, such as Android and Windows Phone, or develop a web-based interface without constraint of mobile platforms. Second, we will continuously improve Anticoagulation Manager and finally publish the app on Apple iTunes, and other platforms, as funding and time allows. Third, after completing the first phase user evaluation, we will continue recruiting more physicians to improve the reliability of results and pursue a more robust evaluation study to compare the performance of the Anticoagulation Manager to paper- and desktop-based operations.

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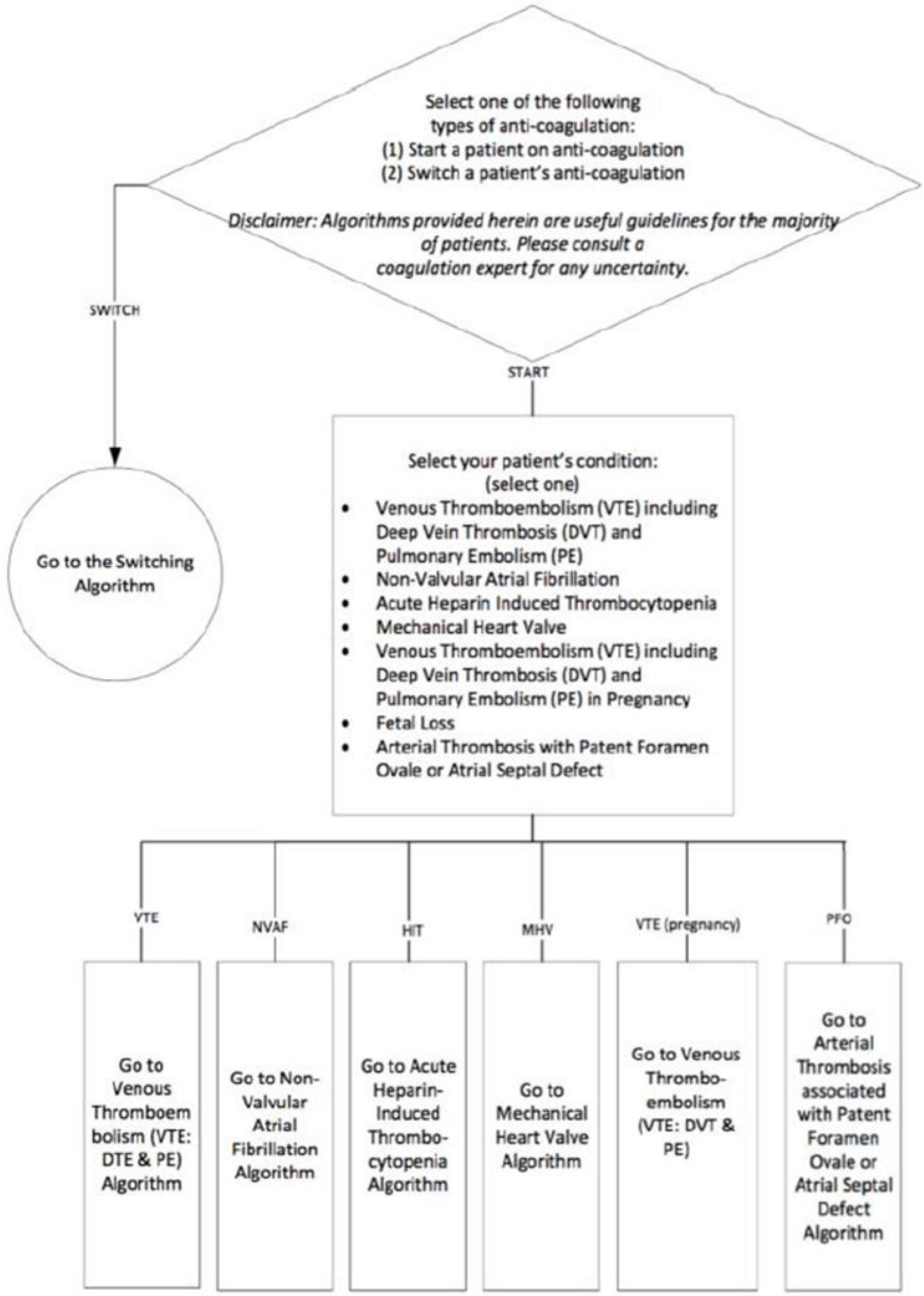

Figure 1.
Link of seven main anticoagulation algorithms.

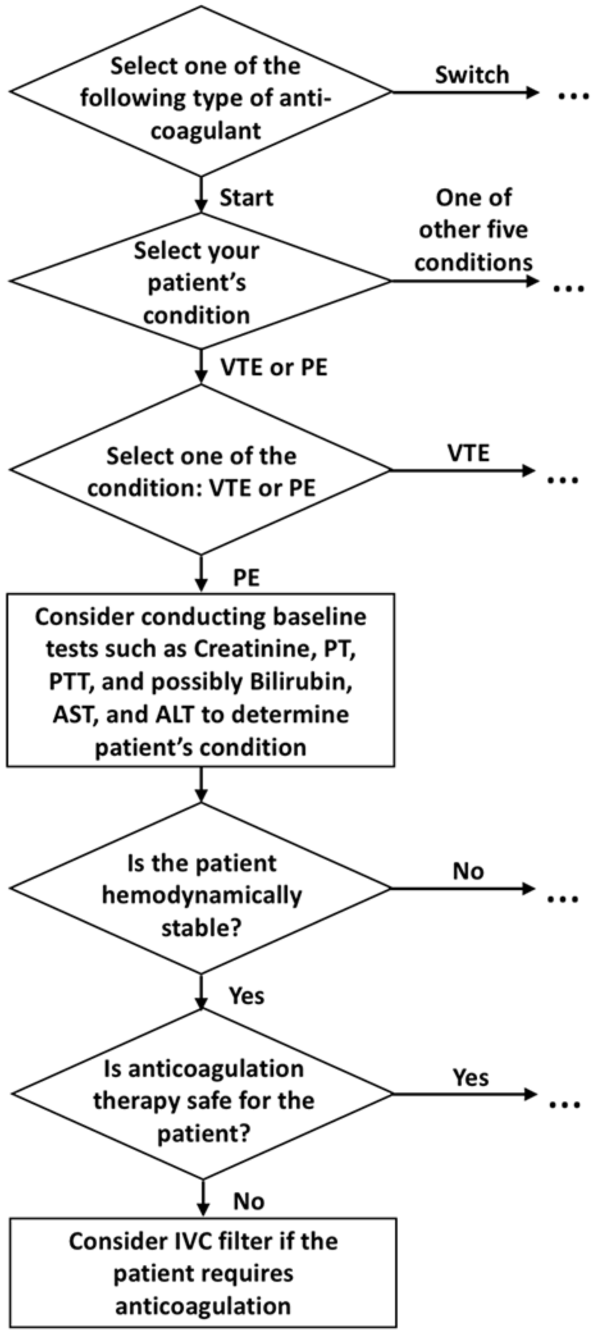

Figure 2.

Example of decision path for a patient with conditions: (1) pulmonary embolism (PE), (2) hemodynamically stable, and (2) not safe of using anticoagulation therapy.

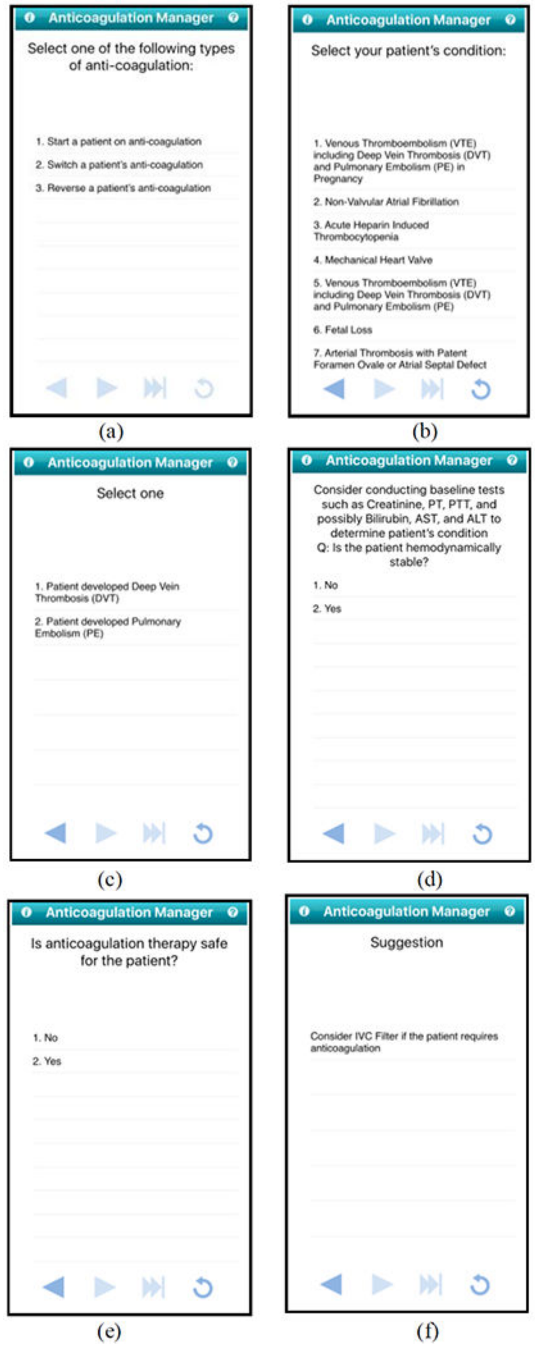

Figure 3.

Screenshots of Anticoagulation Manager: operations for a patient with the three conditions as illustrated in Fig. 2.

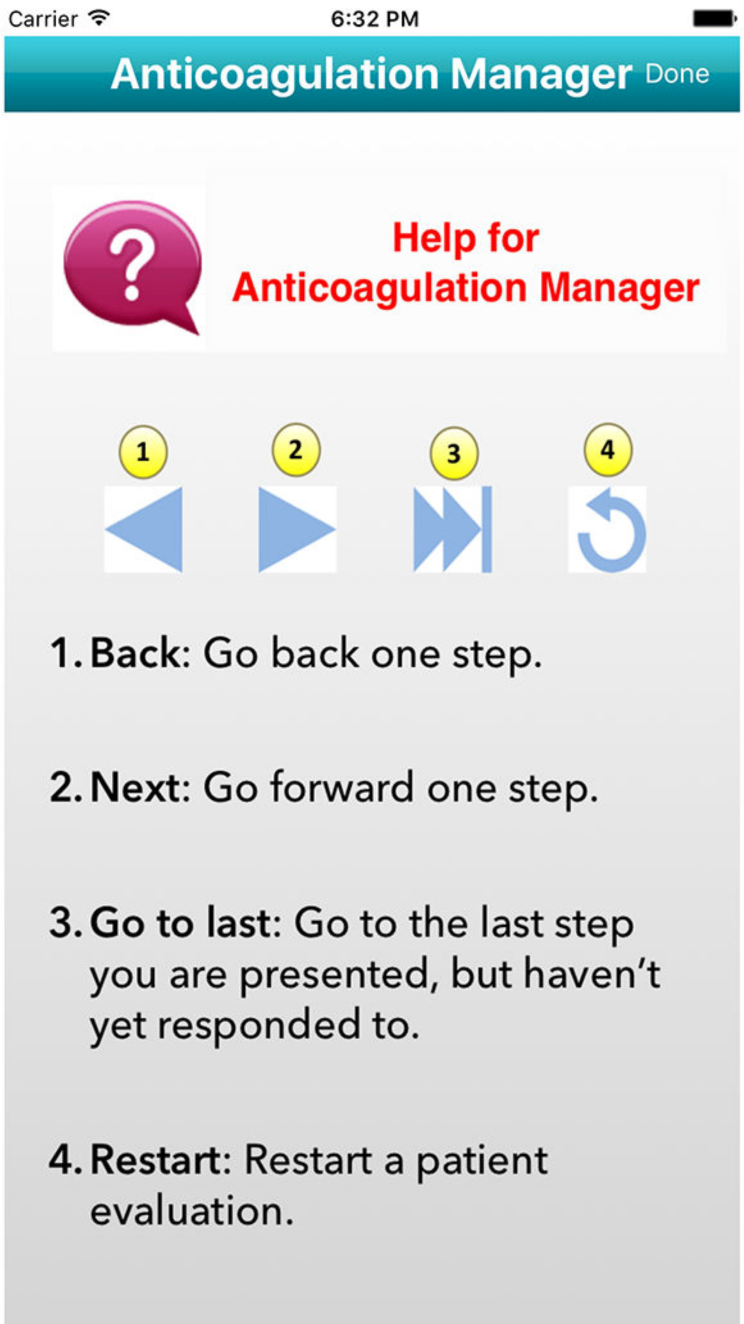

Figure 4.
The screen of description of four user operations in the feature of Evaluation Review.

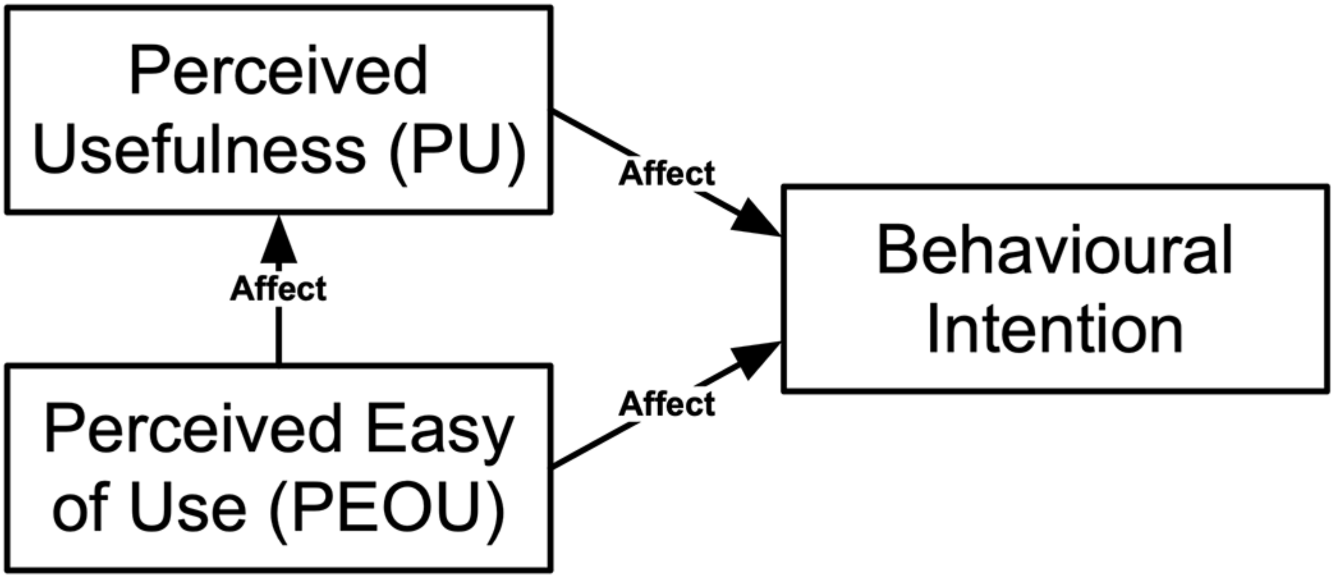

Figure 5.
Conceptual framework pertaining the acceptance of Anticoagulation Manager