Design of a Telestroke System to Optimize Healthcare Delivery for Cerebrovascular Diseases in Colombia

Brenda Ropero, Nicolás Useche
Department of Diagnostic Imaging
University Hospital Fundación Santa Fe de Bogotá
Bogotá, Colombia
e-mail: bv.ropero47@uniandes.edu.co;
jnuseche@gmail.com

Manuel F. Granja
Lyerly Neurosurgery
Baptist Neurological Institute
Jacksonville, Florida, USA
e-mail: mfgranja@gmail.com

Antonio Salazar, Juan Pérez
Laboratory of Telemedicine
University of Los Andes
Bogotá, Colombia
e-mail: ant-sala@uniandes.edu.co;
jc.perez13@uniandes.edu.co

Hernán Bayona, Carlos Martínez
Primary Stroke Center, Neurology Department
University Hospital Fundación Santa Fe de Bogotá
Bogotá, Colombia
e-mail: hernanbayonao@gmail.com;
caferma13@gmail.com

Abstract—**The purpose of this manuscript is to present the design of a software tool that supports clinical decision-making and the early transfer of patients with suspicion of cerebrovascular diseases in Colombia, We designed several clinical algorithms that comply with the latest American Heart Association and American Stroke Association (AHA/ASA) guidelines for the clinical care of a group of cerebrovascular diseases by defining multiple clinical outcomes in three different healthcare settings. Algorithms were reviewed and approved by a group of stroke experts, including a vascular neurologist, a general neurologist, and an interventional neuroradiologist. Patient data, time of symptom onset, and neurological and radiological severity scores were integrated into a comprehensive clinical workflow to increase the diagnostic sensitivity and specificity to select candidates for acute reperfusion therapies. Absolute and relative contraindications for intravenous thrombolysis and mechanical thrombectomy were incorporated to predict the need for an immediate transfer to a specialized stroke unit. These multiple variables contained in the algorithms were entered into a collaborative platform connecting three different healthcare settings with varying degrees of expertise and technological resources for stroke care. A web-based decision aid was obtained for real-time clinical decision-making. This software builds the pillars of a telestroke public-private network for the Emergency Stroke System in Colombia, guiding the clinical identification of a stroke, scoring the magnitude of the neurological deficit, and mainly suggesting whether a determined case may benefit from acute reperfusion therapies.**

Keywords-stroke; telestroke; algorithms; software; collaborative platform.

I. Introduction

Colombia is located in the northern part of South America, with an estimated population of 45.5 million by 2018 [1]. According to the Colombian National Health Observatory, by 2014, strokes were the third leading cause of death after coronary heart disease and interpersonal violence [2]. In the first half of 2018, there were 7,429 deaths attributed to stroke, and approximately 250,000 people in Colombia live with disabilities associated with cerebrovascular diseases [1]. The healthcare system delivery in Colombia is concentrated in urban areas, and access to specialized treatments for acute stroke is distributed inequitably [3]. Hence, patients located in remote areas sometimes lose the opportunity to receive proper treatment in an adequate timeframe, and some patients in urban areas are sent to healthcare facilities with no stroke handling capabilities, thus increasing the probability of permanent sequelae.

In our experience, several efforts have been made to improve the transfer of patients presenting with acute ischemic strokes from rural areas to a certified Primary Stroke Center (PSC) in Bogotá, the capital of Colombia. These experiences have demonstrated that, without a collaborative platform that assists healthcare providers in the decision-making and transfer processes, emergency services became overloaded with patients who were not real candidates, and patients with a potential benefit for acute interventions arrived late, resulting in poorer outcomes.

A system that supports real-time clinical decision-making while evaluating a patient with suspected cerebrovascular disease is not well established in Colombia, particularly for patients with the suspicion of an acute stroke with large vessel occlusion, who may be potential candidates for endovascular therapy in which the recanalization of the occluded cerebral artery results in penumbral salvage if accomplished early [4].

A collaborative platform integrating multiple clinical variables, clinical scales and scores and outcome predictors seems to be a feasible solution to increase health coverage in a country with healthcare budget constraints [5]. Considering the constantly emerging improvements in cerebrovascular disease protocols and evidence-based practices, we have developed a web-based software named Telestroke-RU (Emergency Network, which is the English translation of the Spanish "*Red de Urgencias*"), based on the latest diagnostic and therapeutic recommendations by the American Heart Association and American Stroke Association (AHA/ASA) [6]. The purpose of this software is to guide the clinical decision-making processes step-by-step when non-expert clinicians have doubts in patient management, thus serving as a communication tool with stroke experts in the context of patients presenting with a broad spectrum of cerebrovascular diseases such as ischemic stroke, hemorrhagic stroke, and transient ischemic attack (TIA). The software is available on the website https://telestroke.uniandes.academy.

This paper is organized as follows: Section II defines the three healthcare settings and describes the algorithm design process. Section III describes related work in the healthcare sector and introduces the software development. Section IV describes the results of the web-based collaborative platform. Finally, Section V presents our conclusions, future work and acknowledgements.

II. Healthcare Settings and Algorithm Designs

The software algorithms were designed according to the human and technological resources available at healthcare facilities in which a patient with a cerebrovascular disease may arrive.

A. *Healthcare settings*

We define three clinical settings as follows:

Primary Healthcare Setting (PHS): a basic level of healthcare delivery, where diagnostic tools are limited to the anamnesis and physical exam performed by a primary care physician and where basic blood tests are available. The purpose of this setting is to make an accurate diagnosis and to facilitate timely transfers, as shown in Figure 1. The clinical workflow designed for this setting has 10 different pathways resulting in different final possible outcomes, including priority or urgent transfer to an Intermediate or an Advanced Healthcare Setting, as shown in Figure 2.

Intermediate Healthcare Setting (IHS): intermediate level of healthcare delivery capable of performing computed tomography scans (CT scans), computed tomography angiography (CTA), and intravenous thrombolysis. Although IHS provides neurologists and radiologists, they are not available 24 hours/7 days a week to make critical decisions. The purpose of this setting is to make an accurate diagnosis of a stroke with a large vessel occlusion and optimize the early transfer of patients who are candidates for endovascular therapy. The clinical workflow designed for this setting has 39 different pathways resulting in different possible outcomes, including urgent transfer to an Advanced Healthcare Setting (AHS), referral to the Intensive Care Unit (ICU) after the administration of intravenous thrombolysis, neurosurgery referral, hospitalization or ambulatory care. Although the complete IHS algorithm is not shown due to its extensiveness, Figure 3 shows an example of one module of ischemic stroke requiring intravenous thrombolysis.

Advanced healthcare setting (AHS): an advanced level of healthcare delivery. AHS includes specialized human and technological resources available 24 hours/7 days a week for the healthcare delivery of a patient presenting with a cerebrovascular disease. These specialized human and technological resources include vascular neurologists, neuroradiologists, the ability to perform CT scans, CTAs, magnetic resonance imaging (MRI), magnetic resonance angiography (MRA), and the capacity for intravenous thrombolysis and endovascular therapy, as well as stroke ICUs. This setting can receive transfers from PHS and IHS. The clinical workflow for this setting has 1,162 different pathways, and because interfacility transfers are not necessary, it results in the following final possible outcomes: ICU referral after administration of intravenous thrombolysis or endovascular therapy, neurosurgery referral, hospitalization, or ambulatory care. Although the complete IHS algorithm is not shown due to its extensiveness, Figure 4 shows an example of one module for ischemic stroke with large vessel occlusion requiring endovascular therapy.

B. *Algorithm designs*

Six people were involved in the design of the telestroke system as described below. The algorithms were reviewed in weekly sessions by a group of experts working in a Joint Commission International (JCI)-certified PSC and included a vascular neurologist, a general neurologist and a neuroradiologist. Preliminary drafts of the algorithms were made with further discussions and edits for approximately two months focusing on the best and most proper way to manage patients in each setting. The group of experts finally approved the three algorithms in consensus following the latest evidence-based 2018 AHA/ASA guideline recommendations [6] and adapting them to the latest version of the national stroke guidelines of Colombia [7]. The performance of the final version of the algorithms was tested using simulated cases and dissecting the workflows into modules by a group that consisted of a physician and two engineers who were involved in developing the software. For the ease of the collection of data of clinical variables, neurological state and radiological findings, and considering the degree of expertise and technological resources for stroke holistic care of the three healthcare settings, the clinical algorithms were organized into common basic modules, as shown in Table I. The scales and predictors used in these modules, which allow assessing the severity of the event, the neurological state of the patient, and other factors which allow determining the treatment, either in situ, or the referral to a higher level service are shown in Table II. Each clinical workflow guides the diagnosis of a spectrum of cerebrovascular diseases, including ischemic stroke, hemorrhagic stroke, and TIA, allowing us to rule out conditions presenting similarly to a stroke, denoted as stroke mimics.

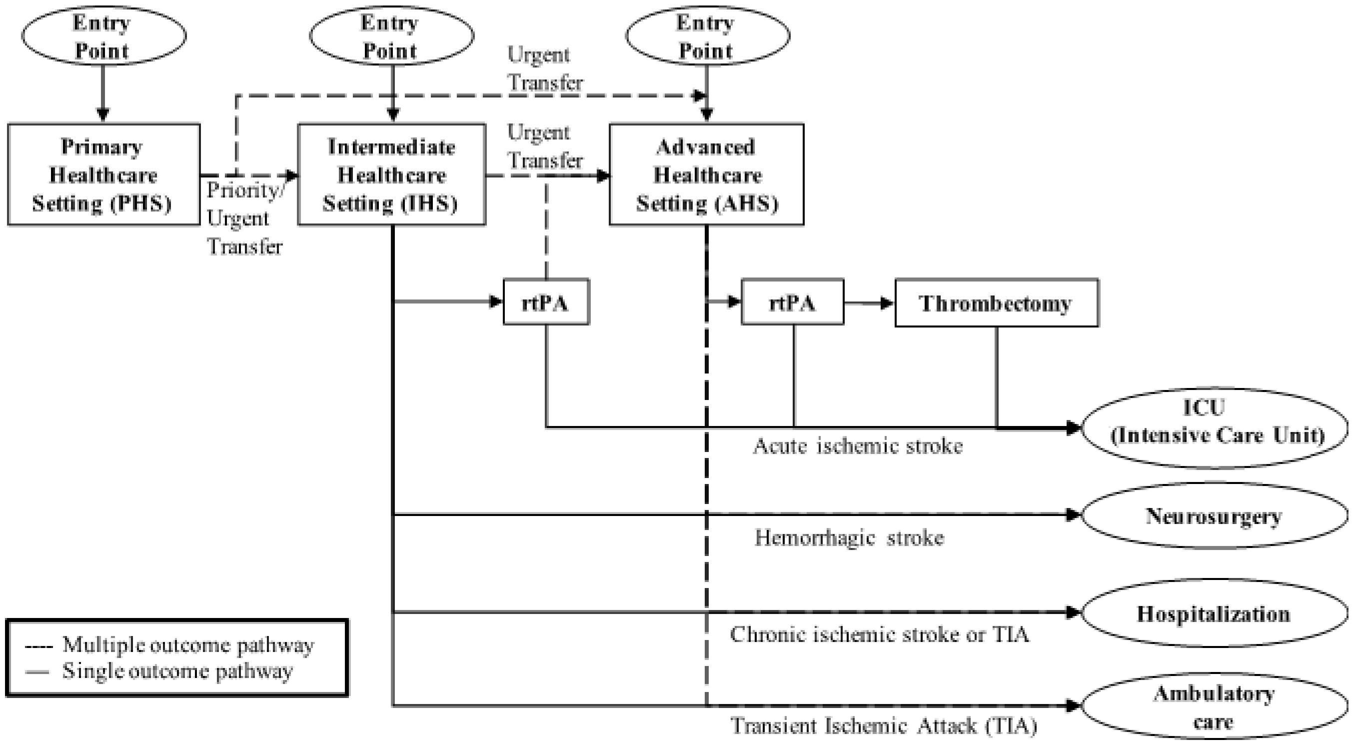

Figure 1. Interaction between the three healthcare settings and final possible diagnosis and referrals. rtPA= Recombinant tissue plasminogen activator.

III. Related Work and Software Development

This section describes previous work in the topic and the development details of our software.

A. *Related Work*

In our country, there are no systems in the health sector that support decisions for stroke care. Worldwide, the few existing systems are designed in different practical front-ends in the form of applications available for smartphones, tablets and web-based tools [8]-[11], or software integrated into medical records [12]. These systems rely on measurements of clinical scales or radiological scores but rarely rely on a combination of both. These are also designed mostly for acute ischemic stroke care, excluding other conditions within the spectrum of cerebrovascular diseases. Some are used for acute care, while others are used for follow-up during hospitalization or for outpatient care.

Furthermore, most existing systems use the same algorithm independent of the different levels of expertise and the technological resources of health facilities within a country. Since in real clinical scenarios the eligibility criteria for reperfusion therapies are based on a combination of clinical and radiological variables, a combination of these criteria is suggested to improve the efficiency in management and quality of care. Nevertheless, many studies implementing this type of system show a reduction of morbidity, mortality, inpatient length of stay as well as better functional outcomes [13].

B. *Software development*

The final version of the algorithms was arranged into a software presented in a simple and friendly interface for both administrative and healthcare provider users in the form of a collaborative platform. Access to the software was possible with the previous activation of an account by creating a username and a password. Privileges for interaction with a determined module of the software were assigned depending on the user expertise and capacity to make special contributions for the different scales and scores. Considering that in Colombia, a patient can interact with administrative staff, paramedics, triage staff, nurses, general physicians, emergency physicians, neurologists and neuroradiologists, user privileges were given depending on the role of the professional. A relational model was implemented with the following final diagnosis outcomes: ischemic stroke within the therapeutic window (acute or subacute compromising middle cerebral artery (MCA), anterior cerebral artery (ACA) and/or posterior cerebral artery (PCA) territories), chronic ischemic stroke, hemorrhagic stroke, TIA and stroke mimics.

Software code was made using PHP (Hypertext Preprocessor) and JavaScript languages. Data were stored using the MySQL 5.1.40 database (Oracle Corporation, Redwood City, CA, USA), which was created and administered by MySQL Administrator 1.1.9. The software is executed in different web browsers, such as Mozilla Firefox, Google Chrome, Safari and Microsoft Edge, so that it can be used on a computer, a tablet or a smartphone. The application is available at https://telestroke.uniandes.academy.

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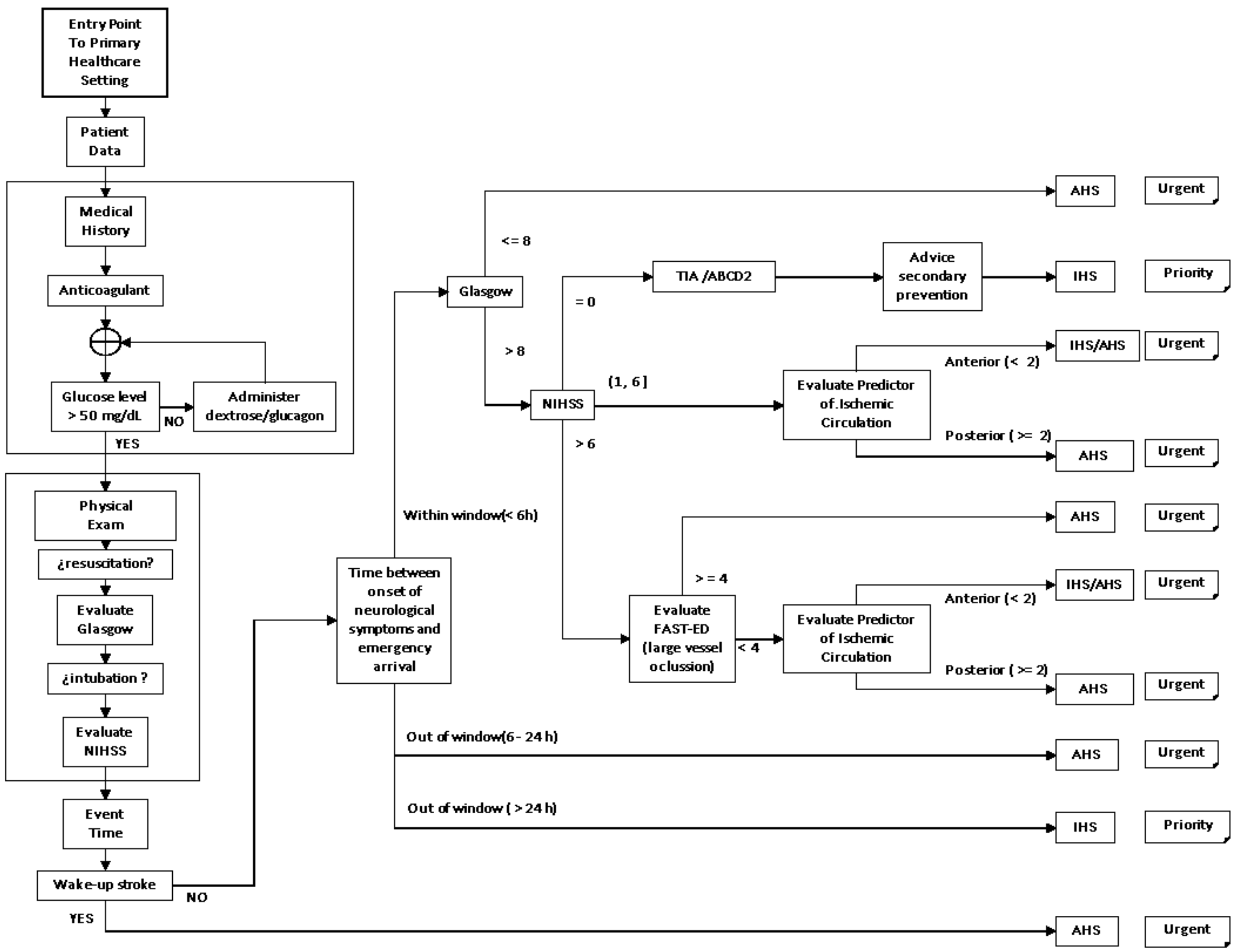

Figure 2. Detailed clinical workflow for the Primary Healthcare Setting. Algorithm results in 10 different pathways and final possible outcomes.

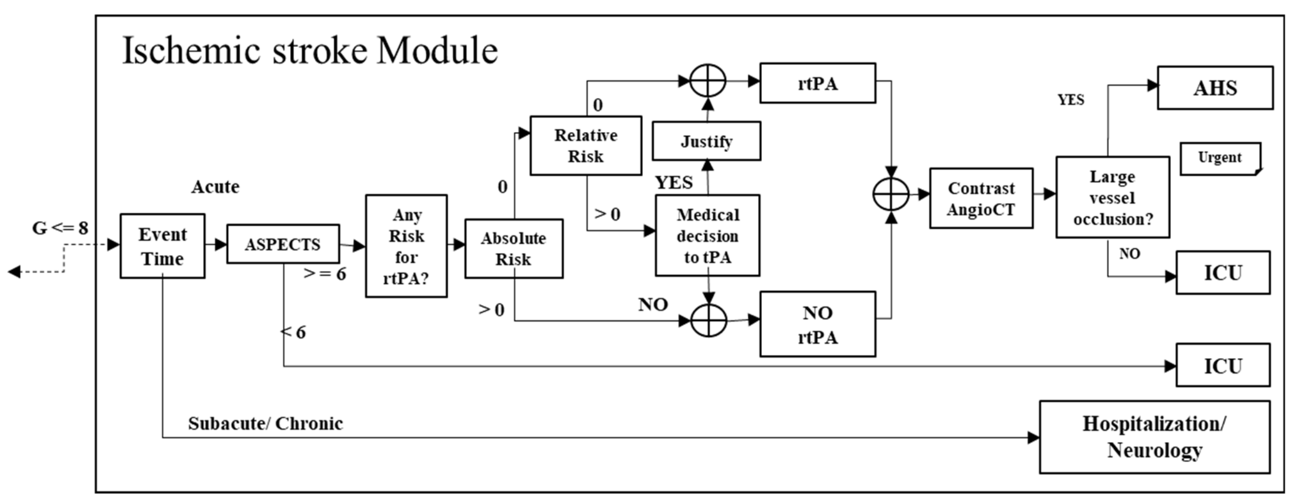

Figure 3. Ischemic stroke module showing one arm of the Intermediate Healthcare Setting algorithm. Due to its extensiveness resulting in 39 different pathways, the complete workflow is not shown. This is a case of a patient with ischemic stroke requiring intravenous thrombolysis. rtPA= Recombinant tissue plasminogen activator. --- = Intermediate pathways.

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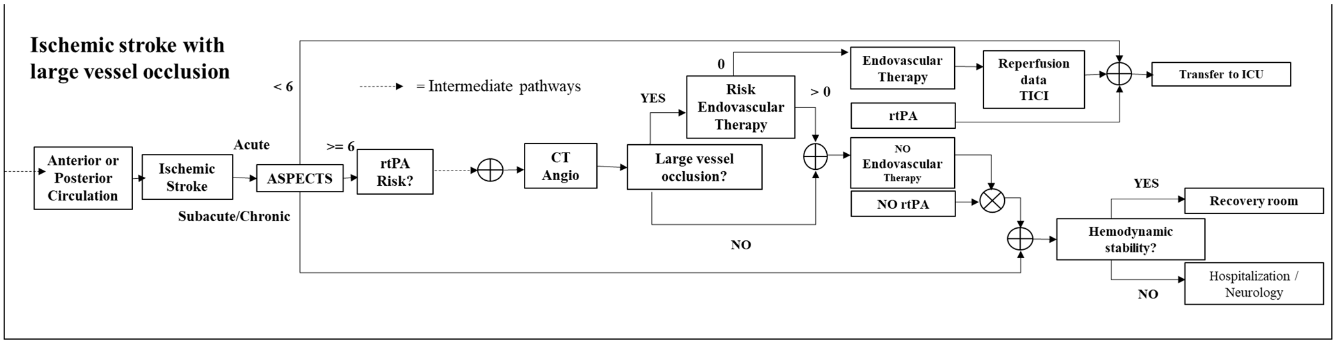

Figure 4. Ischemic stroke Module showing one arm of the Advanced Healthcare Setting. Due to its extensiveness resulting in 1,162 pathways, the complete workflow is not shown. This is a case of a patient with ischemic stroke requiring endovascular therapy. rtPA= Recombinant tissue plasminogen activator.

Tests on all the units of the workflows were run to ensure that the implementation of each unit correctly modeled the intended behavior of the diagram shown in Figure 1.

For each healthcare setting, a clinical workflow was established. Figure 2 shows an example of the algorithm implemented for the PHS, which is the most straightforward setting. The performance of the workflows for each setting was tested using simulated cases to guarantee that each unit worked.

Over 1,211 tests were run to reproduce all possible pathways among the three settings. Additional tests were run considering the frequent error of users: trying to select multiple options in single-option menus, changing a selection at the beginning of the workflow when at the end of the workflow, mistakenly selecting an option that is not possible in the current state, etc.

These tests, while not capable of modeling all possible errors, were diverse enough to detect flaws in the system so that the appropriate corrections could be made.

TABLE I. BASIC SOFTWARE MODULES

Module #	Content of modules	
	Description	***Data***
Module 1	Identification data	Name, age, sex, identification number
Module 2	Time of onset of symptoms	Day, month, year and hour
Module 3	Neurological deficit, past relevant illnesses	e.g., Left hemiparesis, global aphasia. Past Diabetes Mellitus
Module 4	Use of anticoagulant medications	e.g., Use of oral warfarin for atrial fibrillation.
Module 5	Physical exam	Heart Rate, Blood Pressure, Respiratory Rate, Weight, Laterality, rest of physical exam.
Module 6	Imaging	Compromised Cerebral territory, infarct volume, etc.
Module 7	Laboratory	Complete Blood Count, creatinine, clotting times, etc.
Module 8	Interventional procedures	Door to needle time, door to inguinal puncture, etc.

After corrections, the implementation accurately models the algorithms of the three settings. To facilitate the user experience, the interface was designed to be explicit in each question to avoid ambiguities. Furthermore, a simple manual was designed to show, step-by-step, the actions that must be followed to carry out common procedures so that the user can learn the overall mechanism of the system.

IV. RESULTS

A web-based decision aid was obtained for real-time clinical decision making using a computer, a tablet or a smartphone in Colombia. The software organizes the information contained in the algorithms into eight different basic modules as shown in Table I. A total of 11 clinical scales and radiological scores were integrated into its corresponding module to increase the sensitivity and specificity of each possible diagnosis. The privileges for the different professionals participating in stroke code responses to fill the data are shown in Table II. To ensure the safe selection of candidates for reperfusion therapies, relative and absolute contraindications for both intravenous thrombolysis and mechanical thrombectomy were also integrated into the software in different modules [14].

Three phases were planned for the validation of the performance of the Telestroke system. The first phase was initiated by one physician and two engineers who simulated a number of different cases based on a 5-year stroke database from 2014 to 2018. They collected approximately 610 past real cerebrovascular disease cases from our institution containing most of the variables shown in Tables I and II. The second phase is in progress at this moment and is intended for the training and validation of the software with neurology residents involved in daily stroke code responses. Once modifications in the software from the second phase are made, the third phase will be performed in real clinical scenarios in a network between pilot hospitals.

Depending on the patient point of entry at the Emergency System, the software guides clinical decision-making and supports early interfacility transfer for patients with a high suspicion of cerebrovascular diseases. Administrative and healthcare users can simultaneously feed the modules through directed steps entering patient data, thus beginning to solve the clinical case that models a specific pathway.

The first phase of the software validation was made by simulating diverse clinical cases. For example, a pathway simulating the diagnosis of acute stroke within the therapeutic window yields the following decision processes:

If a healthcare provider working in a PHS suspects a patient is presenting an acute stroke, the software guides the diagnosis using the Glasgow Coma Scale (GCS) [15] and the NIHSS scale [16] and supports the decision of interfacility transfer for candidates to reperfusion therapies using the time of symptom onset, the Field Assessment Stroke Triage for Emergency Destination (FAST-ED) score [17], and the relative and absolute contraindications for reperfusion therapies.

The combination of these results inside the system will determine the severity of the neurological deficit and, in this case, the decision to transfer the patient to an IHS or an AHS based on the presence of a clinically large vessel occlusion. In this case, the main purpose is to accurately diagnose a stroke and clinically evaluate the compromised cerebral territory and large vessel occlusion. The complete workflow for the PHS considering the various diagnoses and therapeutic decisions is shown in Figure 2.

TABLE II. CLINICAL SCALES AND RADIOLOGICAL SCORES USED IN THE BASIC MODULES

Module #	Content		
	Scale/Score	***Description***	***Responsible Professionals***
Module 3	ABCD^2 score [18]	Predictor of stroke risk after TIA [19]	General physician, emergency physician or neurologist
Module 5	Cincinnati scale [20]	Evaluation of potential stroke before physician evaluation	Pre-hospital staff, nurses, general physician
	Glasgow Coma Scale [15]	Level of consciousness	General physician or emergency physician
	NIHSS [16]	Quantify impairment caused by stroke	General physician, emergency physician, neurologist
	Posterior circulation predictor [21]	Score predicting posterior circulation involvement	Neurologist
	FAST-ED [17]	Detection of large vessel occlusion	General physician, emergency physician, neurologist
	WFNS score [22]	Grades the severity of subarachnoid hemorrhage	Neurologist or neurosurgeon
Module 6	ASPECTS [23], FISHER [24] and ICH [25]	Radiological scores for ischemic and hemorrhagic stroke	Radiologist, neurologist and/or neurosurgeon
Module 7	TICI score [26]	Thrombolysis reperfusion	Interventionist

If a healthcare provider working in an IHS suspects a patient is presenting an acute stroke, the software guides the diagnosis using the Glasgow Coma Scale (GCS) [15] and the NIHSS scale [16] and supports the decision of interfacility transfer for candidates to endovascular therapy using the time of symptom onset, the Alberta Stroke Program Computed Tomography (ASPECTS) score [23] for compromised anterior and/or posterior cerebral circulations, and the relative and absolute contraindications for endovascular therapy. The combination of these results inside the system will determine the severity of the neurological deficit and, in this case, the decision to transfer the patient to an AHS based on the presence of a radiological large vessel occlusion. If the criteria for reperfusion therapies are met, the software recommends administering intravenous thrombolysis and initiating a prompt transfer to an AHS to perform endovascular therapy and the corresponding referral to a specialized stroke ICU. Due to its extensiveness, the complete workflows for the IHS and AHS are not shown because it is not possible to appreciate the details.

In addition to the workflows for each healthcare setting, this software serves as a reference network tool. Hence, the information on the state of the patient and the results of blood tests, imaging evaluations, and procedures are available online for all health services involved in patient care.

In summary, 10, 39 and 1,162 different pathways resulting in different final possible outcomes were obtained for the Primary, Intermediate and Advanced Healthcare Settings, respectively.

V. CONCLUSION AND FUTURE WORK

The software presented here is an early step in a long-term process to strengthen the stroke emergency network between hospitals with different healthcare levels in urban and rural regions in Colombia. This novel tool can guide healthcare provider decision-making through a collaborative platform, using up-to-date clinical workflows and coordinating the consultation of stroke experts, not only for acute stroke cases but also for a broad spectrum of cerebrovascular diseases. The main goal is to identify acute phase ischemic strokes within the therapeutic window that are susceptible to acute reperfusion interventions with the intention to decrease the high number of people with resulting stroke disabilities. The collaborative platform also contributes to minimizing errors and promoting safer, quicker and high-quality clinical care. This tool is currently being implemented in simulated clinical cases with neurology residents in our institution with the objective to calibrate the software and make further updates and improvements in the interface before it is implemented in real scenarios, so the results of this phase are not shown yet. Its impact will be evaluated in a third validation phase inside a network of pilot hospitals. Once all phases are concluded, the real performance of the software will be determined in terms of comparing its impact on the timing of task completion for time-consuming processes before and after the implementation of the software, door to needle times, quality of care, connectivity, clinical outcomes at discharge, 30 days and 90 days after the event using the modified Rankin scale [27] and its performance as a learning tool platform to simulate clinical cases for healthcare providers in training participating in stroke code responses.

Considering the underreporting of stroke cases and the inconsistency between studies showing different prevalence and incidence measures across the country [28], other possible uses of this software include the collection of epidemiological data that are not currently centralized for future analyses and studies concerning cerebrovascular diseases. The implementation of this tool in an AHS may serve as a self-assessment instrument for measuring the fulfillment and adherence to the latest standards of care inside dedicated stroke units, thus contributing to providing the best care available and improving outcomes. A challenge along the way is to continually update the algorithms that feed the software, considering the ever-changing evidence-based medicine. This can be resolved with periodical reviews between stroke experts and software developers. This online collaborative platform is currently in the second phase of the aforementioned three phase-process of validation, and future work needs to be done to incorporate the real-time transmission of CT scans and the geolocation of the nearest advanced healthcare facilities based on the patient point of entry. Some possible limitations in the implementation of this software that can arise in the future might include a limited internet connection in remote areas and issues related to the articulation with ambulance transportation systems.

To our knowledge, there are no similar software tools in Colombia incorporating specific algorithms for different healthcare levels that consider the varying degree of resources and infrastructure for approaching patients with a suspicion of cerebrovascular disease regardless of the site of case occurrence. Its usability for other countries, especially for Spanish-speaking countries, is one we have not explored and depends on the completion of the three validation phases inside our country. However, we suspect it can become a tool for accomplishing accreditation requirements for stroke centers desiring a certification by an international organization once the definition of an AHS is fulfilled. The extrapolation of this system to other countries requires extensive resource investment, especially for non-Spanish speaking countries, considering the differences in healthcare system articulation and health policies. This software begins to build the pillars of a public-private stroke network initiative that guides the clinical identification of a stroke, the magnitude of the neurological deficit and, particularly, whether a determined case can benefit from an acute intervention, narrowing the times of interfacility transfers.

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