Enhancing Workflow Analysis in Acute Stroke Patients Using Radiofrequency Identification and Infrared-based Real-Time Location Systems

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In the United States, stroke is the third-leading cause of death in women and the fourth in men [1]. The financial and social burdens are substantial, with annual direct and indirect cost of cerebrovascular disease and stroke in the United States approaching an estimated $312.6 billion [1]. "Time Is Brain" encompasses contemporary philosophies in the management of acute ischemic stroke (AIS) [2]. Approximately 1.9 million neurons die for each second of arterial occlusion [2]. Rapid diagnosis and treatment is integral to preserving brain function, and timely brain imaging is a critical component in the evaluation of potential stroke [3-7]. The American Heart Association and Joint Commission have established guidelines for stroke treatment based on current data. Current guidelines recommend all potential stroke patients to have undergone noncontrast CT of the head within 25 minutes of hospital arrival, with interpretation of CT imaging within 45 minutes of arrival [4]. Treatment for patients considered eligible for thrombolysis is recommended within an hour of patient arrival, reflected within the so-called *door-to-needle time* [4].

Hospitals designated as primary or comprehensive stroke centers by the Joint Commission are required to collect a broad list of clinical and quality improvement–based performance measures [8]. Owing to the complexities and laborious nature of manually extracting data from the health care information system (HIS), radiology information system (RIS), and PACS, compiling data for quality metrics is time-intensive. For example, at our institution, an interdepartmental quality team meets monthly to review stroke metrics and employs three full-time project managers to extract data and organize paper-based reports. The capture latency of the manual data acquisition diminishes the value of information and results in delays in identifying and addressing workflow vulnerabilities [9,10]. To address the growing complexities of gathering data, business intelligence tools have been applied to radiology workflows to monitor and optimize operations [10-12].

WHAT WAS DONE

Real-time location systems (RTLS) and business intelligence are commonly utilized to manage supply chains, improve productivity, and provide real-time decision support systems outside the health care industry [13-15]. Health care has been slow to adopt the use of RTLS; however, early uses include hospital asset tracking [16], medication tracking [17], and outpatient [18], ER [19-22], and pediatric patient tracking [23].

An RTLS consists of a system of fixed readers that receive wireless signals from small identification tags attached to an object or person of interest. The tags transmit their location through a wireless signal such as radiofrequency, infrared (IR), or wireless internet (Wi-Fi). Specialized location engine software then receives the information from the tags and readers to determine the location of tagged entities, and relays the information to a user interface capable of displaying real-time location information of tagged objects/persons [24].

The purpose of this project was to investigate the feasibility of using RTLS to track acute stroke patients and provide workflow data not otherwise captured by hospital and radiology information systems to identify targets for improvement for patient and operational workflow.

For our study, we utilized an asset tracking RTLS installed in a

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large urban hospital, which serves as the region's comprehensive stroke center. The asset tracking RTLS system consisted of RTLS tags attached to the patient's hospital bed, along with a series of RTLS detectors. The RTLS detectors were composed of both wireless signal (Wi-Fi)-enabled detectors and combination radiofrequency identification (RFID)/IR detectors.

Inclusion criteria were patients ≥18 years of age entering the AIS pathway at a large, urban hospital from June 26, 2014 to August 26, 2014. Exclusion criteria were incomplete time stamp recording or lack of RTLS tag on the patient's hospital equipment. A continuous sample of 53 AIS patients from June 26, 2014 to August 26, 2014 were prospectively tracked during the study period throughout the radiology workflow process by a human observer and an RTLS tag attached to the patient's hospital equipment. Nine patients were excluded from the final analysis owing to incomplete time stamp recording and five patients were excluded for lack of RTLS tag on hospital equipment, yielding 39 patients/AIS pathway encounters for the final analysis. Combination RFID/IR detectors documented initial arrival and departure times in a dedicated ER CT scanner. A human observer recorded entrance and arrival time using a wristwatch. The human-observed CT room dwell time, defined as the time the patient is in the scanner room, was compared with RTLS-recorded CT dwell time using a two-sample *t* test. Workflow steps such as CT order time, image acquisition, and preliminary report completion were extracted from the HIS, RIS, and PACS. Workflow analysis maps were created from combined RTLS/HIS/RIS data and summary statistics of workflow steps were calculated.

OUTCOMES

A series of 39 AIS patients were tracked throughout the radiology workflow and the time lapse at various steps calculated (Fig. 1). CT room dwell time differences between human observer and RTLS demonstrated no significant differences ($P = .99$). As measured by RTLS, mean CT dwell time was 14.7 minutes (standard deviation [SD] 7.1 minutes) and mean CT entrance to CT scout acquisition was 7.5 minutes (SD 4.5 minutes).

Additionally, using RTLS and RIS data, we found mean CT order placed to CT order received time to be 8.4 minutes (SD 20.1 minutes). Mean time from CT arrival to initial image acquisition was 6.0 minutes (SD 2.6 minutes) when the CT order was acknowledged by the CT technician before the patient arrived in the CT room (23 of 39 patients). When patients arrived in the CT room before CT order acknowledgment, mean CT arrival to initial image acquisition increased to 9.4 minutes (SD 5.8 minutes, 16 of 39 patients). The difference in CT arrival time and initial image acquisition between the two groups is statistically significant (two-sample *t* test, SD_1 5.8 minutes; SD_2 2.6 minutes; $P = .02$).

Based on RIS/PACS and HIS data, mean CT image acquisition time was 8.5 minutes (SD 8.4

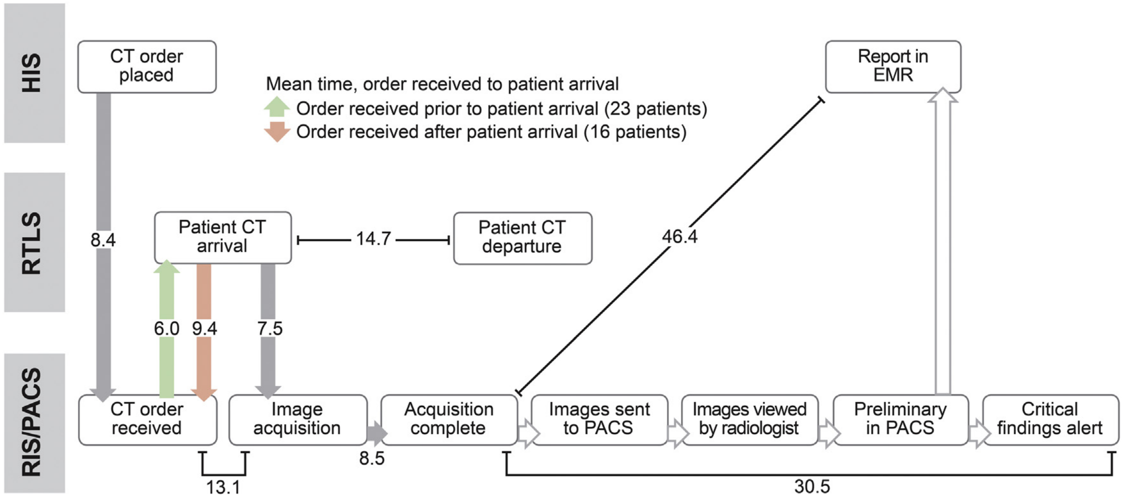

Fig 1. Mean time lapse in minutes based on Hospital Information System (HIS), Real-Time Location System (RTLS), Radiology Information System/PACS (RIS/PACS), and Electronic Medical Record (EMR) data for 39 acute stroke patients at a large urban hospital. *Solid arrows* represent tracked steps. The *green arrow* indicates tracking instances where the CT order was received before patient arrival, whereas the *red arrow* represents tracking instances where the order was received after the patient had arrived at the scanner.