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Research article

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Smartphones for evaluation of computerized tomography scan of patients with suspected skull fractures and intracranial hemorrhage in emergency medicine

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Ethics Committee Approval
The Acibadem Mehmet Ali Aydinlar University Ethics Committee approved the study protocol on 5.5.2015 with approval number 2015/6.
All procedures in this study involving human participants were performed in accordance with the 1964 Helsinki Declaration and its later amendments.

Conflict of Interest
No conflict of interest was declared by the authors.

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Abstract

Background/Aim: It is generally not probable to employ a radiologist or an experienced physician for interpreting radiological images at emergency services**.** The importance of telemedicine has grown, especially during the coronavirus 2019 pandemic. There are a few studies on cranial tomography image transfer and correct evaluation rate with smartphones in the literature. This study aims to evaluate the effectiveness of smartphones for diagnosing mortal pathologies such as skull fractures and intracranial hemorrhages compared to the original images on LED displays of radiology terminals.
Methods: This methodological study was designed to validate smartphones' usefulness in assessing cranial computerized tomography scans in emergency cases. Four sets of CT scans, each containing 10 case samples in four diagnostic groups, subarachnoid hemorrhage, subdural hemorrhage, epidural hemorrhage, and bone fractures, and a set of 10 non-pathological CT scans were evaluated first on 6.1-inches smartphone display for 1 minute, and then on the 17-inches LED display again for 1 minute. The internal camera of the smartphone was used to capture the image before assessments.
Results: A total of 12 neurosurgeons evaluated 50 CT scan images both on smartphones and LED displays. The overall accuracy between both methods ranged between 80%-100% for subarachnoid and epidural hemorrhage and bone fractures, and between 90%-100% for subarachnoid hemorrhage and non-pathological CT scans. The individual kappa coefficients of neurosurgeons ranged between 0.725 to 1.0 (P<0.001).
Conclusion: The overall accuracy of smartphone CT readings with computer LED displays was satisfactory. Our results showed that smartphones are useful for rapid communication between neurosurgeons and emergency department doctors, contributing to timely and accurate patient management in emergency situations.

Keywords: Smartphone, Computerized tomography, Intracranial hemorrhages, Emergency medicine, Telemedicine, Teleradiology

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Introduction

Intracranial hemorrhage is a significant medical emergency with an estimated incidence of 25 per 100,000 person-years [1]. The underlying pathology may vary widely, including but not limited to trauma, hypertension, aneurysms, thrombosis, and other causes [2]. Particularly traumatic intracranial injuries are significant public health problems that affect millions of people worldwide annually, which cause significant mortality and morbidity that can affect all domains of human life [3-5].

The admissions due to cranial injuries also possess a significant burden on emergency health services. The assessment of a patient with a suspected intracranial event includes appropriate imaging modalities, which are indispensable for the initial management of such a patient at the emergency room. The imaging studies contribute both to the diagnosis and the treatment [6]. Nevertheless, it is generally not probable to employ a radiologist or an experienced physician for interpreting radiological images at emergency services. An accurate and timely diagnosis of intracranial status is essential for reducing mortality, and mobile health, or telemedicine, in other words, may aid emergency service staff in such conditions.

The World Health Organization defines the concept of telemedicine as the communication or consultation between health professionals about patients using voice, text, data, imaging or video functions of a mobile device [7]. The time and lifesaving access to expert advice by using any means of technology draw attention in recent years, and numerous studies are being conducted to evaluate the different methods for such purposes. Smartphones and tablets helped assess radiological images for diagnosing fractures remotely in several recent studies [8-12].

The importance of this issue has grown during the coronavirus 2019 pandemic [13]. A unique advantage of telemedicine is that during the pandemic, even quarantined doctors can continue to provide teleconsultations.

Besides its advantages, the accuracy of the remote assessments is strictly associated with the quality of the images transferred. Nevertheless, there might not always be a chance to transmit high-quality radiological images, particularly the sequential sections like computerized tomography (CT) images. A quick way of image transfer is taking a photograph of the image on the computer screen and sending it to an expert over messaging applications, which may significantly affect the expert's decision.

Based on this background, this study aimed to evaluate the usefulness of CT images captured by smartphones compared to the original images on LED displays of computers for diagnosing skull fractures and intracranial hemorrhages, which are a significant burden of mortality and morbidity at the emergency rooms.

Materials and methods

This prospective study was performed between May 2018 and September 2018 with the radiology unit of a university hospital and 12 neurosurgeons working in İstanbul. The local institutional ethics board approved the study protocol on 5.5.2015 with the approval number 2015/6. The STROBE checklist was used in the study design and drafting of the manuscript [14].

Five sets of CT scans, each containing ten image sets, were randomly selected from the radiological repository of the hospital. The image sets included non-pathological radiological views, plus CT images of patients in four diagnostic groups, namely, subarachnoid hemorrhage, subdural hemorrhage, epidural hemorrhage, and skull fractures only. The CT scans were already assessed and diagnosed by the radiologists before the study.

A total of 12 neurosurgeons participated in the study. The participants were not informed about which pathologies were included. In addition, it was ensured that the participants did not know about the other participants participating in the study. Before the participants' assessments, the CT images were initially captured using the internal camera of a smartphone (6.1 inches display and 828x1792 pixels display resolution, and 12 MP camera) from a 30 cm distance of the 17-inches LED display (1920x1080 pixels of screen resolution). Each participant assessed the same CT images first on a 6.1-inches smartphone display for 1 minute and then on the 17-inches LED display again for 1 minute. The participants' diagnoses were recorded after assessing of each image, and evaluated by the authors based on the radiologists' reports as correct or not.

Statistical analysis

The descriptive analyses were presented as percentages throughout the study. During the analyses, first, the accuracy of the assessments was evaluated for each diagnostic group and each participant. The overall accuracy for each diagnostic group was defined as the proportion of the total number of correct and wrong diagnoses in both smartphone and LED displays divided by the total assessments (calculated as (A+D)/10; Table 1). Second, the level of agreement between smartphone and LED display assessments was analyzed using Kappa statistics for each participant. The results were interpreted considering the distribution range of the agreement levels. Third, the proportion of only correct diagnoses was calculated for each sample image and diagnostic subgroup (calculated as A/10; Figure 1). SPSS21 software (IBM Inc., Armonk, NY, USA) was used to build the tables and statistical analyses of the study. A value of $P<0.05$ was considered statistically significant.

Results

A total of 12 neurosurgeons evaluated 50 CT scan images both on smartphones and LED displays. The overall accuracy of the assessments and the kappa coefficients of agreement were presented in Table 2. If a participant made the correct diagnosis or made the same mistake on the same image on both displays, this was recorded as an accurate answer. Accordingly, the overall accuracy ranged between 80%-100% for subarachnoid and epidural hemorrhage and bone fractures, and between 90%-100% for subarachnoid hemorrhage and non-pathological CT scans. The individual kappa coefficients of agreement between the smartphone and LED display assessments of each participant ranged between 0.725 to 1.0. All were significant ($P<0.001$) and corresponded to good to very good agreement between both methods.

Table 1: Formulation of the accuracy analyses

		LED display Correct	False	
Smartphone display	Correct	A	B	∑ correct on smartphone display
	False	C	D	∑ false on smartphone display
		∑ correct on LED display	∑ false on LED display	∑ images assessed (10 images per diagnostic group)

Table 2: Overall accuracy of CT image assessments

Participants	Subarachnoid hemorrhage %	Subdural hemorrhage %	Epidural hemorrhage %	Bone fractures %	Normal CT scan %	Overall kappa (Tel-LED)	*P*-value
#1	90	90	100	100	100	0.905	<0.001
#2	90	100	100	100	90	0.947	<0.001
#3	100	100	100	100	100	1.000	<0.001
#4	100	100	100	100	100	1.000	<0.001
#5	100	90	80	100	100	0.848	<0.001
#6	100	100	80	100	100	0.875	<0.001
#7	90	90	100	80	100	0.817	<0.001
#8	100	90	100	100	100	0.940	<0.001
#9	100	100	100	100	100	1.000	<0.001
#10	100	100	90	90	100	0.905	<0.001
#11	90	100	100	100	90	0.891	<0.001
#12	80	90	90	90	90	0.725	<0.001

The correct diagnosis rates were presented in Table 3. The assessments revealed that the lowest levels of correct diagnoses were 80% for subarachnoid hemorrhage, 87.5% for subdural and epidural hemorrhage, 83.3% for bone fractures, and 88.9% for non-pathological CT scans.

Table 3: Correct diagnosis proportions

	Subarachnoid hemorrhage %	Subdural hemorrhage %	Epidural hemorrhage %	Bone fractures %	Normal CT scan %
Image #1	100	100	100	83.3	100
Image #2	80	87.5	100	100	100
Image #3	100	100	100	100	100
Image #4	100	100	100	100	100
Image #5	87.5	100	91.7	100	100
Image #6	100	100	87.5	100	88.9
Image #7	100	100	100	100	88.9
Image #8	91.7	87.5	100	100	100
Image #9	100	100	90.9	100	100
Image #10	100	100	100	100	100

Discussion

In this study, we evaluated the usability of smartphones for assessing CT images to diagnose skull fractures and intracranial hemorrhages. Our analyses revealed that the images captured by an internal smartphone camera could provide adequate quality to a neurosurgeon on a 6.1-inch display for accurate diagnosis of a skull fracture or intracranial injury. Accuracy of diagnoses on a smartphone display compared to computer LED screen was satisfactory, and both displays showed significant overall accordance to aid neurosurgeons in diagnosing the correct pathology.

Today, physicians' consulting the radiological images over mobile messaging applications became a common practice [15]. This is particularly important in emergency medicine, since accurate and timely diagnosis and appropriate interventions are lifesaving in this vulnerable patient group. Unfortunately, there is limited availability of experienced health professionals to evaluate the radiological images in most emergency services. At this point, a practical solution is consulting the images over messaging applications [16]. To date, several studies evaluated the usability of smartphones for the diagnosis of musculoskeletal traumas and bone fractures over radiological images and reported that this was a safe and accurate way for skeletal trauma consultation that can significantly decrease the lags in emergency services [8, 17].

One of the very first reports about using mobile devices for CT evaluation was published by Yamamoto and Williams [18] in 2000, which reported that a wireless pocket computer can download the CT scan images from a wireless modem in 4 to 6 minutes and provide adequate quality for reviewing on display. Three years later, another study by Yaghmai et al. [19] evaluated the feasibility of a personal digital assistant (PDA) device for interpreting the cranial CT scans of trauma patients, which were directly transferred into the device from a picture archiving and communications system (PACS). The authors reported that this handheld device can reliably interpret the CT scans of patients with suspected intracranial hemorrhage. In a recent study from Sakai et al. [20], using a telemedicine application to transfer images on smartphone, there was a high degree of inter-device and inter-rater agreement in terms of the vascular neurologists' neuroimaging findings between the smartphone and the desktop PC monitor in patients with acute stroke. Unlike this study, we used manually captured images by the smartphone, which made the quality of the images more dependent on the manual capturing and the technical specifications of the smartphone. Nevertheless, we confirmed the accuracy of the manually captured images.

Another study by Waran et al. [21] evaluated the utility of sending short video clips of an entire scan series between junior and senior doctors in a neurosurgery unit after office hours and reported that this method is very effective for emergency consultations, which should otherwise only depend on verbal descriptions, which is more susceptible to errors. In our study, we did not send images as video clips because the resolution of photos taken with the smartphone is higher than the resolution of the video clips.

In 2013, Shivapathasundram et al. [22] evaluated the utility of transferring entire series of patient neuroimaging using the video application of the smartphones to the consultant neurosurgeons over only one patient's three video recordings. They reported that this was a valuable and rapid way to communicate with the neurosurgeons in emergency situations. Mobile devices were evaluated in numerous studies for radiological assessment in many situations other than traumatic emergencies. In one of those, Park et al. [23] evaluated the diagnostic performance of smartphones in the assessment of coronary CT angiography of patients with acute chest pain in the emergency services. The authors reported that smartphone readings by the cardiac radiologist were more similar to the angiography results and in-house radiologists' reports than the reading of on-call residents, which was considered a promising result for further evaluations of the real-time mobile consultations to achieve an improved diagnostic competency. Unlike Park et al.'s study, in our study, the same physicians evaluated the images from smartphones and LED displays.

As currently available evidence in the literature suggests, mobile technologies are becoming more integrated in healthcare practice, especially in situations in which rapid communications with colleagues are most needed. Traumatic injuries are examples of these emergencies. Our results also confirmed the previous reports on this topic and showed that smartphones are useful for consulting the CT scans of patients with a probable skull fracture, intracranial injury, and hemorrhage with off-site neurosurgeons.

There are some limitations in our study. Monitoring of the same CT image by the participants right after the first evaluation may cause them to look more carefully at the suspicious place in the initial assessment. Another limitation is that clinicians are likely to use phones with different resolutions and sizes in real life. In the future, the minimum phone features that can be used to evaluate images correctly can be determined with comprehensive studies to be carried out with phones with different resolutions and sizes.

Conclusions

This study showed that the overall accuracy of smartphone CT readings with computer LED displays was satisfactory, suggesting that CT images captured with smartphones can provide an adequate quality to the neurosurgeons for accurate diagnosis. This rapid communication between the neurosurgeons and the emergency department doctors can contribute much to patient management in emergency situations.

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