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The Infrascanner, a handheld device for screening *in situ* for the presence of brain haematomas

JOSE LEON-CARRION[1,2], JOSE MARIA DOMINGUEZ-ROLDAN[3], UMBERTO LEON-DOMINGUEZ[2], & FRANCISCO MURILLO-CABEZAS[3]

[1]*Human Neuropsychology Laboratory, University of Seville, Spain,* [2]*Center for Brain Injury Rehabilitation (C.RE.CER.), Seville, Spain, and* [3]*Intensive Care Unit, Hospital of Traumatology, University Hospital Virgen del Rocio, Seville, Spain*

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Abstract

Purpose: Early identification and treatment of intracranial haematomas in patients sustaining traumatic brain injury is fundamental to successful treatment. This pilot study evaluates the Infrascanner as a handheld medical screening tool for detection, *in situ*, of brain haematomas in patients with head injury.

Methods: This study included 35 TBI patients aged 17–76 ($M = 47.6$), admitted to the neurosurgical intensive care unit and observation unit of a University Hospital in a Level 1 trauma centre. The Infrascanner^{TM} NIRS device uses near infrared light measurements to calculate optical density in brain regions.

Results: Results show Infrascanner sensitivity at 89.5% and specificity at 81.2%. PPV was 85% and NPV 86.7%. The device detected 90% of extra-axial, 88.9% of intra-axial and 93.3% of non-surgical haematomas (less than 25 mL). PPV for this classification was 82.3%; 87.5% sensitivity was found when the Infrascanner exam was performed within 12 hours post-trauma, whereas after 12 hours post-trauma, exams had 90.1% sensitivity.

Conclusions: This study demonstrates that the Infrascanner is useful in initial examinations and screenings of patients with head injury as an adjunct to a CT scan or when it is not available and may allow earlier treatment and reduce secondary injury caused by present and delayed haematomas.

Keywords: *Critical care, emergency, neurotraumatology, traumatic brain injury, near-infrared spectroscopy, head injury*

Introduction

Traumatic brain injury (TBI) is a leading cause of death and disability and a major public health problem in the US, Canada [1–3] and Europe [4, 5]. Main causes of TBI are traffic accidents [6], work and sports-related accidents [7, 8] and violence [9, 10]. Patients with TBI usually show physical and neuropsychological sequelae in the post-acute phase [11–13]. Different studies indicate that early diagnosis, management and care in the acute setting minimizes the impact of secondary injury, one of the most prominent causes of a patient's deteriorating condition [14, 15]. Morbidity and outcome are narrowly associated with the quality of emergency care. Delayed medical attention is the strongest independent predictor of mortality in TBI patients. Quick emergency team activation should be a priority for hospitals operating rapid response systems [16].

Early detection and surgical evacuation of mass-occupying lesions have decreased mortality and improved outcome in these patients. This reduction in mortality and morbidity requires rapid identification of the patient's cerebral and cranial status. A study by Seelig et al. [17] reports on the

Correspondence: Jose Leon-Carrion, Human Neuropsychology Laboratory, Department of Experimental Psychology, C/ Camilo Jose Cela, s/n, University of Seville, Seville – 41018, Spain. Tel: +34954557689. Fax: +34954551784. E-mail: leoncarrion@us.es

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importance of taking action within the first 4 hours post-injury. Any further delay in haematoma evaluation severely increases mortality and worsens functional outcome in patients who survive.

To date, the Computerized Axial Tomography (CT) is the gold standard for identification and localization of haematomas due to TBI. Although rapid initial assessment of a TBI patient is crucial, CT scans are not always available at the moment of trauma or vascular event. In most cases, the patient must wait until arrival at a hospital with a radiology department. Added to this is the difficulty of rescuing certain patients that have suffered a TBI. Consider cases where access to the individual is difficult or more common cases of traffic accidents where the state of the vehicle impedes safe removal of the victim. Any clinical assessment prior to arrival at a hospital must be done *in situ* by emergency personnel. Haematoma assessment within the critical 4-hour period could be achieved by means of an organized system of patient assistance, with two fundamental elements: emergency action protocols and coordination among professionals who care for the patient.

The time devoted to assisting patients who may suffer TBI is usually shorter in accidents that take place in urban or metropolitan areas. Once the person with neurological damage is stabilized, the procedure usually includes a CT scan, followed by neurosurgery, if necessary. However, in emergencies with TBI victims in rural areas or areas with difficult access, such as conflict or natural disaster zones, it is more difficult and will ultimately take longer to determine which persons require neurosurgery. The time between injury and treatment could be reduced if the assessment to detect intracranial haematoma is done *in situ*.

The method normally used to clinically identify intracranial haematomas *in situ* is the neurological evaluation. However, this test is not as sensitive as the CT scan, especially since no observable physical signs exist to assure the presence of an intracranial haematoma. The principle signs recognized by neurological methods are only present in a fraction of patients. For instance, coma is present in 56% of TBI patients without a haematoma [18].

Near-Infrared Spectroscopy (NIRS) could improve existing methods of identification of intracranial haematomas in these patients *in situ*. This instrument is characterized by its small size, portability and overall low cost. A clinical instrument which uses NIRS technology is currently being developed (*Infrascanner*). This device is designed to minimize size and thus increase its portability. The exam lasts 3 minutes and is easy to use in assessment applications as well as data organization and transmission. The Infrascanner provides information that could be useful in initial evaluations of patients with possible brain injury (i.e. at the site of the accident or in emergency rooms where CT scans are not immediately available).

The purpose of this pilot investigation was to evaluate the Infrascanner as a handheld medical screening tool for the detection, *in situ*, of brain haematomas in patients who have sustained a head injury. The validity of the device was studied, particularly its sensitivity and specificity, as well as its positive and negative predictive values as compared to those of CT scans. This study was also designed to evaluate the Infrascanner's classification accuracy in detecting different kinds of haematomas, namely intra-axial and extra-axial haematomas. These usually differ in topographical representation and depth and, hence, a NIRS-based system may vary in detection accuracy. Another aim of this study was to assess the Infrascanner's sensitivity in detecting haematomas that require neurosurgery and smaller haematomas which do not [19, 20], as well as its detection capacity as post-injury time increases, given that within 24 hours haemoglobin starts to metabolize into methaemoglobin and its absorbance characteristics change [21, 22].

Methods

Patients

This study originally included 38 TBI patients. One patient, whose CT scan revealed a spontaneous intracerebral haemorrhage, was discarded from further analysis. Two additional patients were excluded, one due to massive scalp wounds and a second whose CT scan showed frontal mega sinus. The final sample included 29 males and six females, ranging in age from 17–76 ($M = 47.6$). TBI causes included 18 falls, 12 road traffic accidents, two assaults and three additional causes (e.g. animal attack). Glasgow Coma Scale (GCS) was collected at the time of the NIRS exam. Table I shows patients' demographics and clinical characteristics. The mean time between NIRS exam and hospital admission was 12.8 hours (range: 1.97–24.9 hours). The mean time between NIRS exam and CT scan was 5.66 hours (range from 30 minutes to 14.5 hours).

fNIRS algorithm

The Infrascanner^{TM} NIRS device (InfraScan, Inc., Philadelphia, PA) is used for haematoma detection in patients sustaining TBI. The device uses light sensors to contact the scalp surface and calculate optical density in brain regions. This data acquisition protocol consists of eight measurements: four symmetrical

pairs of measurements over frontal, temporal, parietal and occipital locations (see Figure 1). The exam, usually lasting 3 minutes, covers common locations for traumatic haematomas.

Table I. Patients' demographics and clinical variables. GCS = Glasgow Coma Scale.

Characteristic		Subjects
Age (years)	*M*	47.6
	Range	17–76
Sex	Male	29 (82.9%)
	Female	6 (17.2%)
Race	Caucasian	35 (100%)
Skin colour	Light	29 (82.9%)
	Dark	6 (17.1%)
Hair colour	Black	3 (8.6%)
	Brown	15 (42.9%)
	Light	17 (48.6%)
Hair thickness	Thick	5 (14.3%)
	Normal	11 (31.4%)
	Thin	19 (54.3%)
Mechanism of injury	Fall	18 (51.4%)
	Accident	12 (34.3%)
	Assault	2 (5.7%)
	Other	3 (8.6%)
GCS	3–8	3 (8.6%)
	9–12	2 (5.7%)
	13–15	30 (85.7%)

For haematoma detection, NIRS uses the principle that extravascular blood absorbs more NIRS light than intravascular blood since there is a greater concentration (10-fold) of haemoglobin in the acute haematoma than in the brain tissue where blood is contained within vessels. Therefore, the absorbance of NIRS light is greater (and reflected light absorbance is lower) on the side of the brain containing the haematoma.

The difference in optical density (ΔOD) in the different areas is calculated using the following formula:

$$\Delta OD = \log_{10}\left(\frac{I_N}{I_H}\right)$$

where I_N = the intensity of reflected light on the normal side and I_H = the intensity of reflected light on the haematoma side.

This system includes two main components: a NIRS-based sensor and a wireless personal digital assistant (PDA). The sensor includes a safe Class I NIRS diode laser, optically coupled to the patient's head by means of two disposable light guides in a 'hairbrush' like configuration. This configuration allows the sensor to contact the skin of the scalp. The 4.0 cm separation between light source and detector allows NIRS absorbance measurement in tissue volume with ~2 cm of

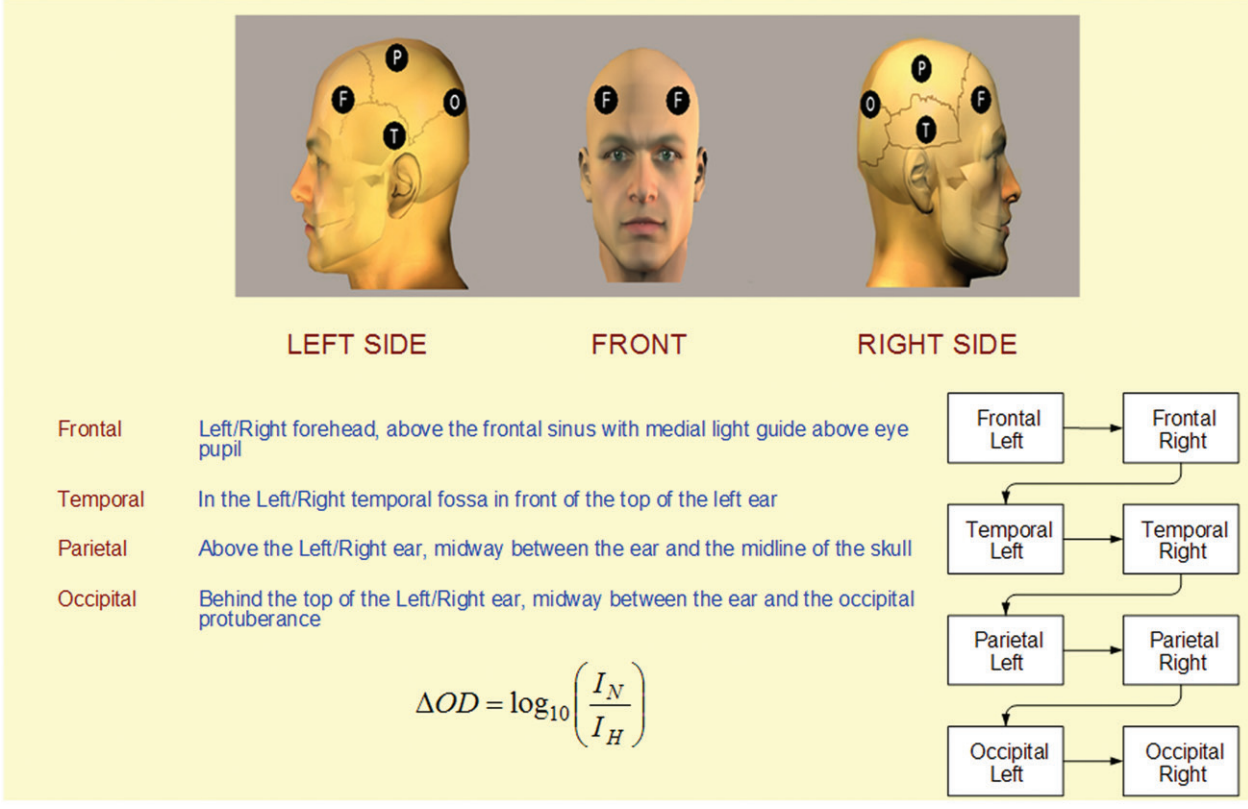

Figure 1. Location and procedure for Infrascanner data acquisition in patients with suspected brain injury.

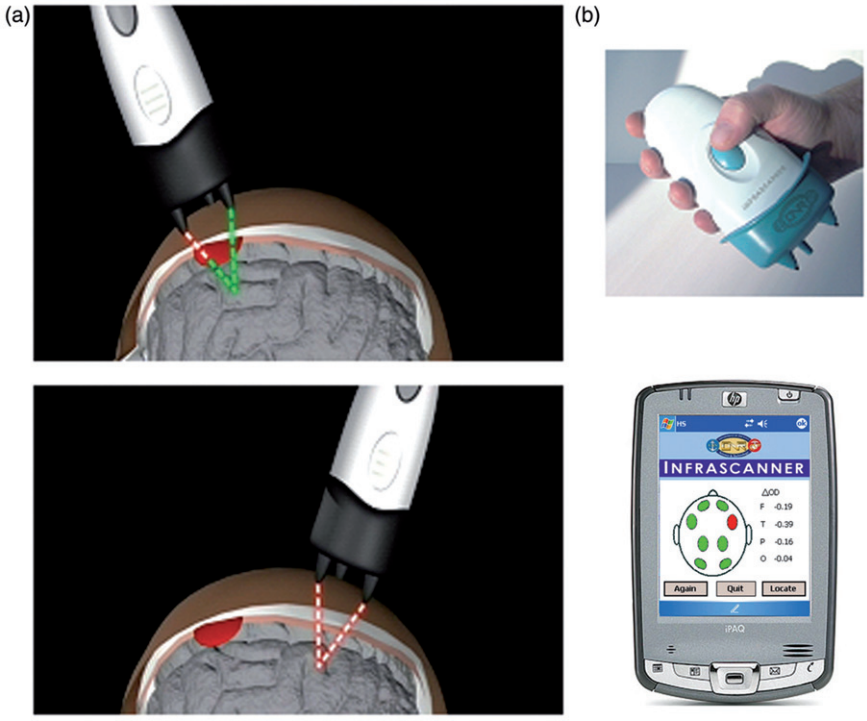

Figure 2. Scanning sequence for brain haematoma. (a) The NIRS Sensor has two components: a 808 nm diode laser and a silicon detector. The NIRS light source emits a light that penetrates the brain and is registered by the NIRS detector connected to the scalp through two optical fibres. The light intensity determines approximately how much blood volume is present. The Infrascanner performs symmetrical readings in the four main brain lobes: frontal, temporal, parietal and occipital. Haematoma detection derives from the difference in optical density between left and right readings for each brain lobe. (b) The detected signal is digitized and transmitted to a Bluetooth wireless personal digital assistant (PDA) that displays the results on the screen.

width and 2–3 cm of depth. The light source uses an 808 nm wavelength. The detector is covered by a band pass filter to minimize interference from background light. Electric circuitry is also included to control laser power and detector signal amplifier gain. Signals acquired from the detector are digitized and transmitted by a wireless link to the PDA. This link is also used to receive and set the sensor's hardware parameters. The PDA receives the data from the sensor and automatically adjusts its settings to ensure good data quality. The data is further processed and the results are displayed on the PDA screen (Figure 2).

Intracranial haematoma detection was established when a $\Delta OD > 0.2$ units occurred in a particular pair of bilateral measurements. When a measurement indicated a difference of ± 0.2 OD or greater, the measurement pair was repeated twice to confirm the presence of a haematoma. A $\Delta OD \leq 0.2$ units was considered a negative exam. The 0.2 cut-off for the Infrascanner was set following a previous study on haematoma detection using NIRS [23]. This study showed that the ΔOD range varies among different types of haematomas. For instance, the ΔOD range for intracerebral haematomas was 0.1–0.8, with a maximal sensitivity of 0.3. However, 40% of these haematomas showed ΔOD below 0.3 (only 13% fell below 0.2). ΔOD range for epidural haematomas was 0.6–1.6, with a maximal sensitivity of 1.3. Maximal sensitivity for subdural haematomas was 0.7 (range 0.5–1.6). Based on these results, >85% of intracranial haematomas can be detected using a 0.2 cut-off.

Procedure

This study was performed on patients admitted to the Neurosurgical ICU (22 beds) and the Emergency Room Observation Unit (42 beds) at the Virgen del Rocio University Hospital, Seville, Spain (a Level 1 trauma centre). The Hospital Institutional Review Board approved this study and all procedures were in accordance with the Declaration of Helsinki guidelines.

Figure 3 shows the study's inclusion protocol for patients with TBI. Briefly, after admitting a patient suspected of having an intracranial haematoma, emergency doctors requested a CT scan and an Infrascanner exam. In some cases, the Infrascanner exam was performed after the CT scan for medical reasons. An experienced neuroradiologist, blind to the study goals and NIRS data, evaluated the

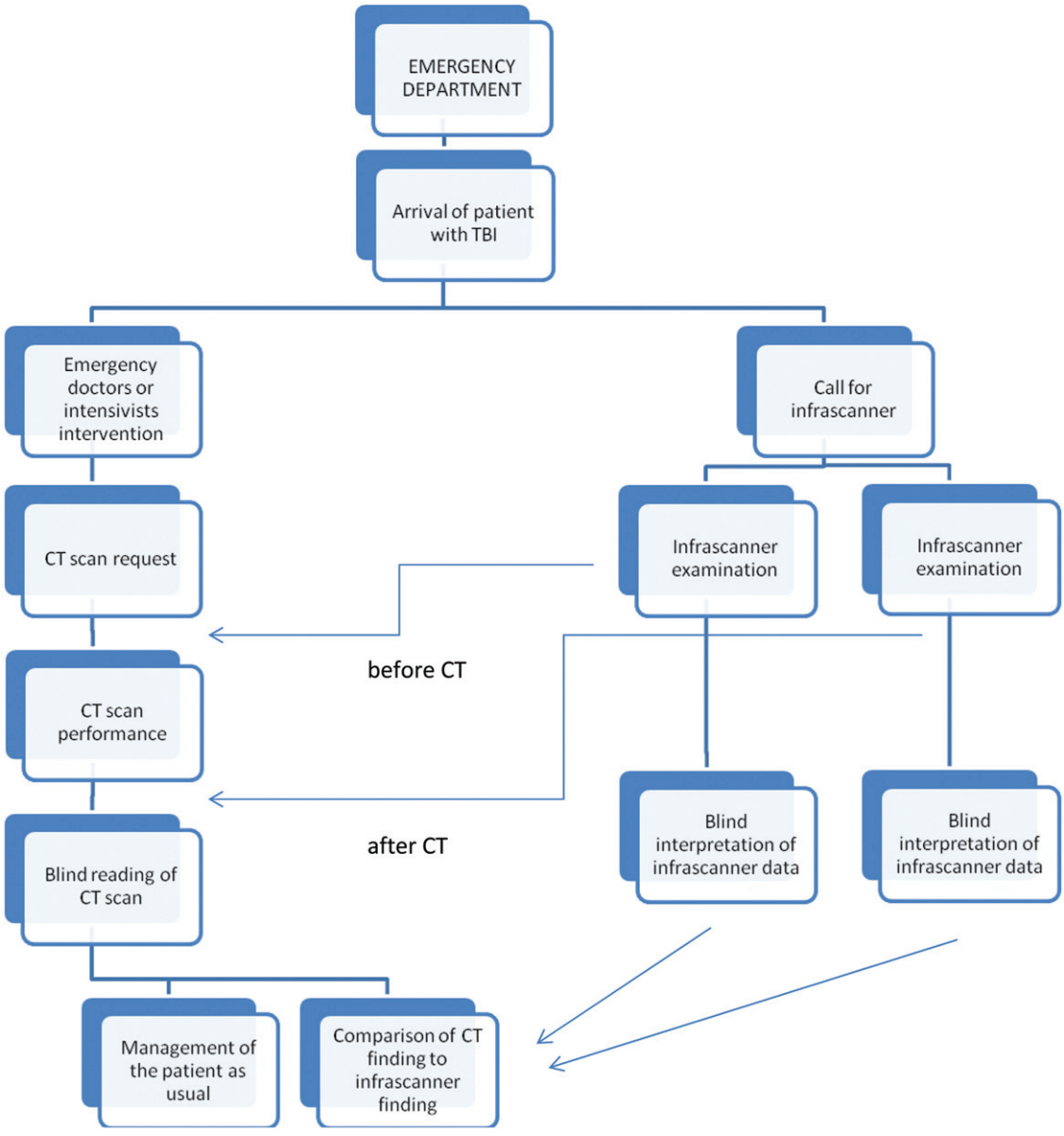

Figure 3. Flowchart on patient admissions and inclusion in NIRS exam.

CT scans. NIRS exams were performed by trained hospital personnel, also blind to CT scan results. Finally, all patients were managed according to Brain Trauma Foundation guidelines and local protocols.

Haematoma characteristics, including type, volume (gauged in mL) and distance from brain surface, were also recorded. The GCS score was collected at baseline and during each NIRS assessment. NIRS accuracy indexes in haematoma detection were first calculated using CT scan results as the comparative gold standard. A CT scan with hyperdense images was considered pathological.

Overall sensitivity and specificity analyses were performed, using comparisons between NIRS and CT scan results. True positives, false positives, true negatives and false negatives were counted and used to estimate both sensitivity (true positives/true positives + false negatives) and specificity (true negative/false positive + true negative). Positive predictive values (PPV = true positive/true positive + false positive), negative predictive values (NPV = true negative/true negative + false negatives) and their respective 95% confidence intervals (CI) were also calculated. Subsequent analysis included estimating NIRS classification accuracy indexes for intra-axial haematomas (intraparenchymal and intraventricular haematomas), extra-axial haematomas (subdural, epidural and subarachnoid haemorrhages), non-surgical intracranial haematomas (volume < 25 mL) and NIRS exams taken before and after 12 hours post-TBI.

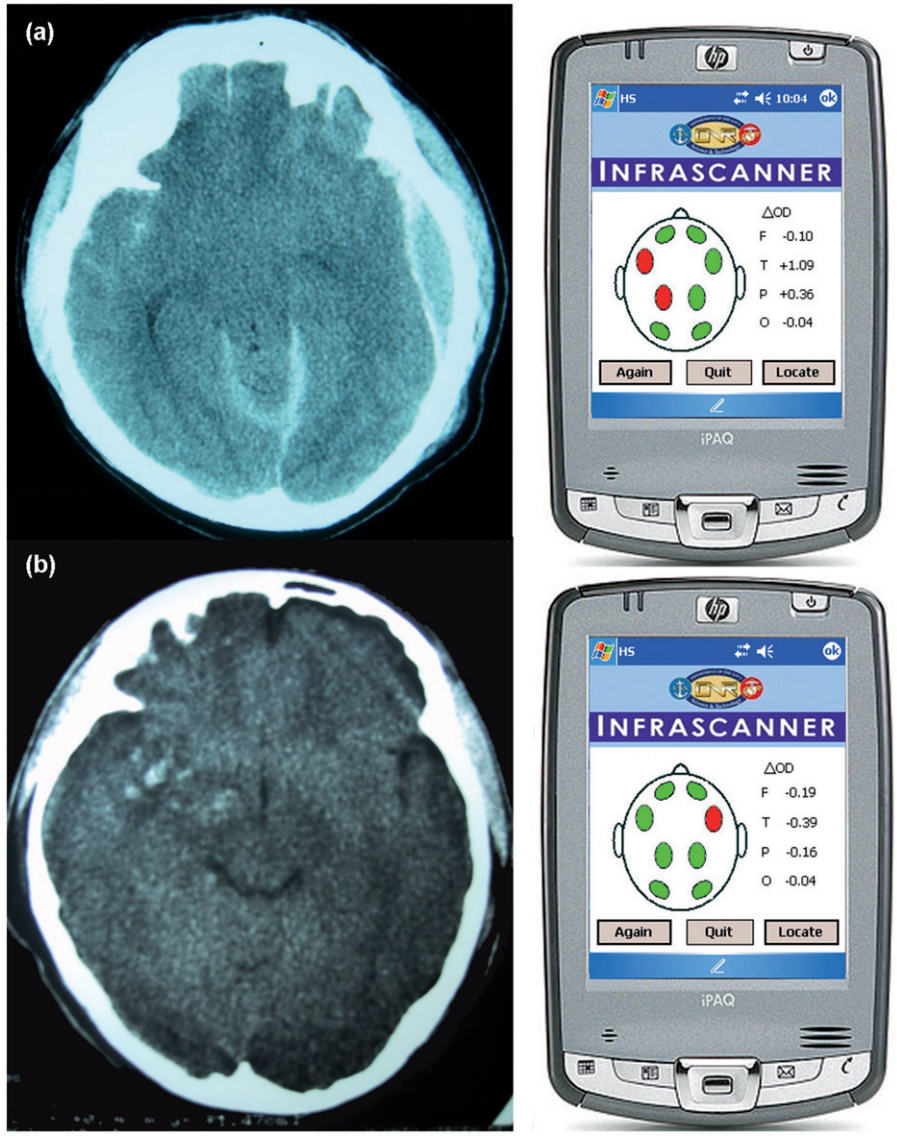

Figure 4. Examples of pathological CT scans and Infrascanner detections. Images on the left show CT scan results. Images on the right show corresponding haematoma detection by the Infrascanner exam. (a) CT showing left temporal and parietal epidural haematoma and its detection by the Infrascanner. (b) CT showing small intraparenchymal contusions and their detection by the Infrascanner.

Results

CT lesions were represented as follows (*n*): negative CT (16), intraparenchimal haematoma (7), subdural haematoma (4), epidural haematoma (2), subarachnoid haemorrhage (3), subarachnoid haemorrhage + subdural haematoma (2), intraparenchimal haematoma + epidural haematoma (1). Figure 4 shows four pathological CTs of intracranial haematomas detected by Infrascanner in the study sample.

Overall accuracy indexes obtained from the TBI patient group showed that the Infrascanner achieved 89.5% sensitivity and 81.2% specificity. PPV was 85% and NPV was 86.7%. The Infrascanner could detect 90% of extra-axial haematomas and 88.9% of intra-axial haematomas (Table II).

The Infrascanner exam detected 93.3% of existing non-surgical haematomas ($n = 15$). PPV for this classification was 82.3% (Table III).

Finally, 87.5% sensitivity was found when the Infrascanner exam was performed within the first 12 hours post-trauma, whereas exams taken after 12 hours post-trauma showed 90.1% sensitivity (Table IV).

Discussion

The most significant results of this pilot study are that the handheld near-infrared Infrascanner demonstrates high sensitivity and specificity in detecting intra- and extra-axial hemorrhagic haematomas and,

Table II. Classification accuracy of pathological findings in CT scans. Overall analyses and sub-classification analyses based on type of haematoma are provided. Extra-axial (epidural, subdural and subarachnoid), intra-axial haematomas (intraparenchymal) and CT without pathological findings are shown. CT = Computerized tomography. CI = Confidence Intervals.

	All intracranial haematomas	No haematomas in CT	Extra-axial haematomas in CT	Intra-axial haematomas in CT
True Positive	17	0	9	8
True Negative	13	13	0	13
False Positive	3	3	0	3
False Negative	2	0	1	1
Prevalence	54.28%	45.7%	28.6%	25.7%
Sensitivity (95%CI)	89.47% (65.5–98.1)	89.47% (65.5–98.1)	90% (54.1–99.5)	88.89% (50.7–99.4)
Specificity (95%CI)	81.25% (53.7–95.0)	81.25% (53.7–95.0)	81.25% (53.7–95.0)	81.25% (53.7–95.0)
Positive Predictive Value (95%CI)	85% (61.1–96.0)	0% (0.0–69.0)	75% (43.8–93.3)	72.72% (39.3–92.7)
Negative Predictive Value (95%CI)	86.67% (58.4–97.6)	100% (71.6–100)	92.85% (64.1–99.6)	92.85% (64.1–99.6)

Table III. Sensitivity analysis for non-surgical intracranial haematomas with volume <25 ml.

	Haematomas volume <25 mL
True Positive	14
True Negative	13
False Positive	3
False Negative	1
Prevalence	31.4%
Sensitivity (95%CI)	93.3% (66.0–99.6)
Specificity (95%CI)	81.2% (53.7–95.0)
Positive Predictive Value (95%CI)	82.3% (55.8–95.3)
Negative Predictive Value (95%CI)	92.8% (64.2–99.6)

Table IV. Haematoma sensitivity analysis within the first 12 hours post-injury and after 12 hours post-injury.

	NIRS measure <12 hours	NIRS measure ≥12 hours
M (hours)	7.4	18.2
Range (hours)	1.97–11.6	13.7–24.9
True Positive	7	10
True Negative	13	13
False Positive	3	2
False Negative	1	1
Prevalence	25.7%	31.4%
Sensitivity (95%CI)	87.5% (46.7–99.3)	90.1% (57.1–99.5)
Specificity (95%CI)	81.25 (53.7–95.0)	81.25 (53.7–95.0)
Positive Predictive Value (95%CI)	70% (35.3–91.9)	83.33% (50.88–97.1)
Negative Predictive Value (95%CI)	92.85% (64.7–99.7)	92.85% (64.1–99.6)

even more importantly, it is able to detect small haematomas (<25 mL) within the first 24 hours following injury. Data shows that the Infrascanner achieves 89.5% sensitivity when used on patients with TBI. Its on-site capacity to identify patients that have suffered an intracranial haematoma may be considered very high. The Infrascanner also shows excellent specificity (81.2%) or the capacity to detect true negatives, identifying patients with TBI that have not suffered an intracranial haematoma. When compared to gold standard CT scans, its probability of positive predictive value is 85% and 86.7% for negative predictive value. This means that the Infrascanner is very accurate when confirming the presence or the absence of a haematoma.

The data also illustrates the Infrascanner's excellent capacity to identify both intra-axial and extra-axial haematomas. Its sensitivity for extra-axial haematomas was 90% and 88.9% for intra-axial haematomas. The Infrascanner was excellent at detecting extra-axial (epidural, subdural and sub-arachnoid haemorrhage) as well as intra-axial haematomas during the acute phase of TBI. The predictive values were very accurate, given that the prevalence of intracranial haematomas in this sample was 54.3% and well distributed between intra-axial (25.7%) and extra-axial (28.6%). In some cases, the Infrascanner detected intra-axial haematomas over 3 cm deep. This is unusual, given that the distance between the Infrascanner's light source and detectors should limit detection to a depth of 3 cm. Some authors [24] suggest that oedematous tissue between the haematoma and the NIRS light source and detectors could make the optical density measure surpass 0.2.

The volume of a haematoma is the single strongest predictor of outcome. Thus, it is relevant to report that the Infrascanner is highly sensitive (93.3%) to small haematomas (<25 mL). It would be of great interest to provide accuracy results for large haematomas (>25 mL). However, in this sample, the prevalence of haematomas this large was too low (11.42%) for valid accuracy analyses with representative data.

The Infrascanner, while not designed to substitute CT scans, may be useful in places or situations

where CT scans are not available. This is especially important given that suspicion of early progressive haemorrhage occurs in almost 50% of patients with head injury who undergo CT scanning within 2 hours of injury, particularly those with cerebral contusions [25].

The Infrascanner was also able to detect brain haematomas in this patient sample after 12 hours post-injury. Recent evidence shows that haematoma expansion is associated with early neurological deterioration [26]; 38% of patients suffer intracerebral haematoma growth during this time period and it has been related to a worse prognosis. The Infrascanner may be an adjunct tool for quick, periodic monitoring of patients with suspected brain lesions.

A limitation to the present study could be the Infrascanner's current configuration. The location of the haematoma must be precisely determined and, to obtain accurate measurements, the Infrascanner's fibre-optic light guides must be carefully positioned on the scalp. Since scalp haematomas may cause false positive NIRS readings, the head scanning protocol avoids measurements through scalp haematomas, measuring near, but not in, scalp injuries. In this study, sub-galeal haematomas, easily detected in a physical examination, were not problematic, given that with the 3 cm separation between light source and detector, superficial blood on the scalp did not absorb as much light as did deeper intracranial blood.

These results included two false negatives. The first was a 26-year-old male admitted to the ICU with a GCS of 14. A CT scan revealed a traumatic right fronto-temporal haematoma, causing a mass effect and a volume of 33 cm^3. The patient also suffered a small left frontal hemorrhagic contusion. During the Infrascanner exam, the patient was very agitated and tended to move his head, which could distort the measure. The other patient, a 62-year-old female, was admitted to the ICU with a GCS of 15 after hitting her head on the floor during a fainting spell. A CT scan revealed a small subarachnoid haematoma in the occipital lobe, which had penetrated the cerebral falx. The location of the haematoma and its small size could have made it difficult for Infrascanner detection. In any case, studies have reported that in some cases ($\sim$10%), the optical signal of NIRS methods is insufficient, due to various, mostly anatomical, reasons [27]. This could be the case in these false negative results.

This study demonstrates that the Infrascanner is a useful tool in the initial examination and screening of patients with head injury. It has proven utility as an adjunct to CT scans or as a preliminary exam given within 24 hours post-injury, when a CT scan is not available. The Infrascanner's high specificity and high NPV suggest that the device could supplement clinical information, such as neurological status, mechanism of injury and hemodynamic stability, all of which are used in the field to triage patients to a trauma centre and in the emergency unit to determine the urgency and/or need for subsequent imaging studies. The Infrascanner is not designed to substitute a CT scan, nor can the NIRS technology replace CT scanning when it is readily available. However, a positive NIRS exam could give higher priority for imaging, even in an otherwise low risk patient, particularly in cases where the detection is made prior to hospitalization.

In conclusion, the data show that the Infrascanner is a sound portable device for detecting pre-operative intracranial subdural, epidural and subarachnoid haematomas in intensive care fields and emergency care units. It could aid paramedics, emergency room physicians and hospital staff, permitting earlier treatment and reducing secondary injury caused by present and delayed haematomas. It would be interesting to test the Infrascanner in the ICU to determine if periodic NIRS measures can be used to monitor the post-operative development of intracranial haematomas.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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