SPECIAL REPORT

Improving the Early Detection of Brain Bleeding in Head Trauma Patients

Early Diagnosis of Traumatic Intracranial Hematomas

The Impact of Traumatic Brain Injury on Health Services

How Brain Bleeds Can be Missed

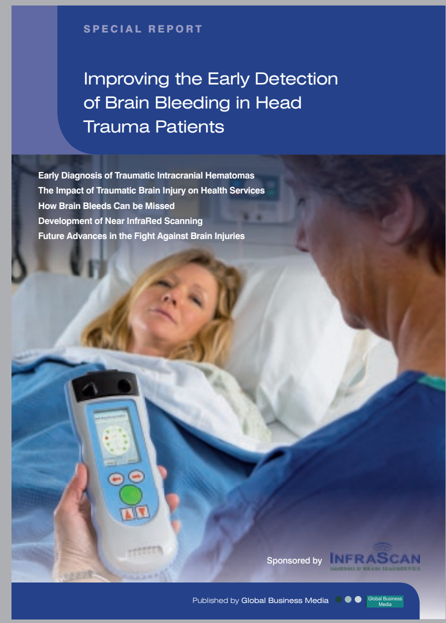
Development of Near InfraRed Scanning

Future Advances in the Fight Against Brain Injuries

Sponsored by INFRASCAN HANDHELD BRAIN DIAGNOSTICS

Published by Global Business Media

Global Business Media



Published by Global Business Media

Global Business Media Limited
62 The Street Ashtead Surrey KT21 1AT
United Kingdom

Switchboard: +44 (0)1737 850 939
Fax: +44 (0)1737 851 952
Email: info@globalbusinessmedia.org
Website: www.globalbusinessmedia.org

Publisher
Kevin Bell

Business Development Director
Marie-Anne Brooks

Editor
Tom Cropper

Senior Project Manager
Steve Banks

Advertising Executives
Michael McCarthy
Abigail Coombes

Production Manager
Paul Davies

For further information visit:
www.globalbusinessmedia.org

Contents

Foreword

BLEEDS ON the brain can be a silent killer. In those moments after an injury, a patient may feel fine, but in reality, the damage has already been done. The sooner those bleeds can be detected, the more likely it is that the patient will go on to enjoy a full recovery.

Unfortunately, many existing detection methods take time, are resource intensive and may not be entirely reliable. Standard CT scans will not necessarily rule out a hematoma and can miss relatively minor issues which can go on to cause complications further down the line.

In our opening article, we hear about how a handheld device using near infrared technology, called the 'Infrascanner', can improve outcomes. This portable device can be used quickly on patients to deliver highly accurate results much more quickly than most conventional assessment methods. It is being used in remote areas and those where using a CT scan may not be possible and giving teams an additional tool to treat traumatic brain injury (TBI) in those critical early stages.

Elsewhere in the Report, Jo Roth will look more closely at the development of the technology underpinning these devices and how it hopes to transform the provision of care to brain injury patients.

Meanwhile, we will look at the impact that brain bleeds and TBIs have on patients and health services. TBIs are a major health issue for health services around the world. Prompt diagnosis and accurate decision making are key to reducing mortality rates.

However, as James Butler discovers, this is not always easy. He looks at problems with the current approach. Concerns over the safety and reliability of CT scans mean health services are looking for less invasive approaches which can deliver a faster and more reliable diagnosis.

Finally, we'll look at developments for the future. Alongside handheld devices, which can deliver point of injury diagnosis, advanced technology, such as artificial intelligence, is helping to improve detection times and avoid human error.

All these advances can improve patient outcomes, but they come back to a key issue – how quickly and accurately can doctors identify the presence of a hematoma? Their success in achieving early diagnosis will help to increase dramatically the chances of survival, while also reducing the strain on resources.

Tom Cropper
Editor

Tom Cropper, has produced articles and reports on various aspects of global business over the past 15 years. He has also worked as a copywriter for some of the largest corporations in the world, including ANZ Bank, ING and KPMG.

Early Diagnosis of Traumatic Intracranial Hematomas

Baruch Ben Dor,[a] Hasan Ayaz,[b] Meltem Izzetoglu,[c] Kurtulus Izzetoglu,[b] Banu Onaral[b]

[a]InfraScan Inc, Philadelphia, PA, 19104
[b]Drexel University, School of Biomedical Engineering, Science and Health Systems, Philadelphia, PA, 19104
[c]Villanova University, Electrical and Computer Engineering, Villanova, PA, 19085

*Address correspondence to Baruch Ben Dor, InfraScan Inc., 3508 Market street, Philadelphia, PA 19104, Tel: (215) 387-6784, Fax: (215) 386-2327, E-mail: bbendor@infrascanner.com, Web: www.infrascanner.com

Abstract

An estimated 1.4 million people experience Traumatic brain injury (TBI) each year in the United States, resulting in 1.1 million hospital visits, 235,000 hospitalizations and 50,000 deaths. TBI is a major public health problem among males ages 15 to 24, who account for two-thirds of childhood and adolescent head trauma patients. In addition, TBI is a severe problem among elderly people (age 75 years and older) of both sexes.

Rapid triage, diagnosis and treatment are critical in minimizing the adverse consequences of the more serious TBI cases. Since many TBI cases occur in clusters and are part of complex, extensive trauma to the individual victim (stemming from automobile accidents, war-zone explosions, etc.), the challenges presented to on-site medical personnel are significant. For patients with moderate-to-severe TBI in particular, diagnosis within the first hour (the "golden" hour) of the traumatic event is critical[1].

InfraScan, Inc. has developed the Infrascanner to provide a rapid evaluation of head trauma patients with possible intracranial hemorrhage. The technology is portable and noninvasive, allowing for repeated monitoring without concern for radiation dose. The Office of Naval Research (ONR) and the United States Marine Corps (USMC) sponsored the development of the Infrascanner.

Brain Injury

A TBI, one of two subsets of acquired brain injury, can result from a closed head injury (whereby the head suddenly and violently hits an object but the skull remains intact) or a penetrating head injury; the other subset of acquired brain injury is non-traumatic brain injury (e.g., stroke, meningitis). A highly individualized injury, TBI severity depends on the nature of the injury, strength of the force, area of the brain affected as well as physical and genetic variations among patients. The damage from TBI can be localized (focal), confined to one area of the brain, or diffuse (typically a concussion), involving more than one area of the brain.

Types of focal brain injury include bruising of brain tissue (contusion) and rupture of blood vessels inside the skull, thereby resulting in heavy bleeding (intracranial hemorrhage or hematoma). Hemorrhaging can occur inside of the skull but outside of the brain (extra-axial) or within the brain itself (intra-axial). Extra-axial hemorrhages can be further divided into epidural hematoma, subdural hematoma and subarachnoid hemorrhage. Intra-axial bleeding within the brain itself is called an intracerebral hematoma.

Diagnostic and treatment protocols mandate that a patient suffering from head trauma receive immediate medical assessment, including a complete neurological examination. The severity of the head trauma and the responsiveness of the patient in a Glasgow Coma Scale (GCS) evaluation will determine which diagnostic methods will be used for further evaluation. In a GCS evaluation, the patient is scored on his/her ability to open eyes, communicate verbally and demonstrate motor skills. However, the GCS evaluation can be very subjective based upon the individual administering the test and can also be hampered if the patient is under sedation or has restrictions on his/her ability to verbally communicate (i.e., the patient has been intubated). For patients that have demonstrated

InfraScan, Inc. has developed the Infrascanner to provide a rapid evaluation of head trauma patients with possible intracranial hemorrhage

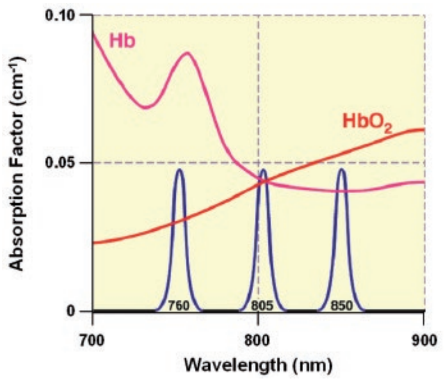
moderate–to-severe TBIs after undergoing a neurological examination, the gold standard imaging test is a computed tomography (CT) scan, which creates a series of cross-sectional X-ray images of the head and brain and can show bone fractures as well as the presence of hemorrhage, hematomas, contusions, brain tissue swelling, and tumors.

An estimated 5.3 million individuals in the United States are living with long-term or life-long disability associated with a TBI that resulted in hospitalization. Unlike most causes of traumatic death, a large percentage of the people killed by brain trauma do not die right away but rather days to weeks after the traumatic event. In addition, rather than improving after being hospitalized, some 40% of TBI patients deteriorate.[2] Primary injury (the damage that occurs at the moment of trauma when tissues and blood vessels are stretched, compressed, and torn) is not adequate to explain this degeneration. Rather, the deterioration is caused by secondary injury resulting from a complex set of biochemical cascades that occur in the minutes to days following the trauma.[3] These biochemical cascades are instigated by brain swelling and inadequate flow of oxygen and blood to the brain resulting from brain compression by the expanding brain hematomas. The aim of the Infrascanner is to catch those hematomas before they are able to do any brain damage and lead to a much earlier intervention to evacuate the expanding brain hemorrhages.

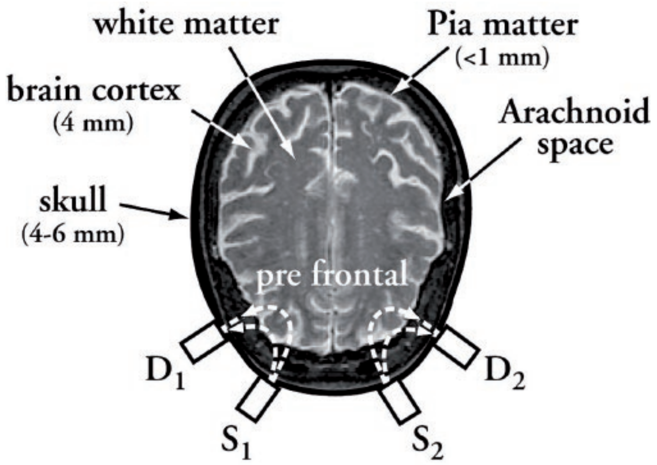
Science and Technology

All biological tissue is, to differing extent, permeable to electromagnetic radiation of different frequencies and intensities. This can also be considered permeability to photons of different energy levels. This permeability to electromagnetic energy is the basis of all imaging based on transmission/scattering characteristics such x-ray, Computed Tomography, and near-infrared, NIR, imaging. From the principles of spectroscopy, it is also known that different molecules absorb different wavelengths of electromagnetic radiation (which is synonymously referred to as light at shorter wavelengths). Similarly, tissue scatters radiation to different degrees. The Infrascanner is concerned with NIR imaging of the hemoglobin molecules. From any light source, photons follow a characteristic path through the target tissue back to a detector on the same approximate plane as the source. While the light is severely attenuated due to the scattering and absorption process, it is nonetheless encoded with the spectroscopic signatures of the molecules encountered en route to the detector.

The principle used in identifying intracranial hematomas with the Infrascanner is that extravascular blood absorbs NIR light more than intravascular blood. This is because there is a greater (usually 10-fold) concentration of hemoglobin in an acute hematoma than in normal brain tissue where blood is contained within vessels. The Infrascanner compares left and right side of the brain in four different areas. The absorbance of NIR light is greater (and therefore the reflected light less) on the side of the brain containing a hematoma, than on the uninjured side. The wavelength of 805nm is sensitive only to blood volume, not to oxygen saturation in the blood, as shown in the figure below.



ABSORPTION OF LIGHT BY OXYGENATED AND DEOXYGENATED HEMOGLOBIN

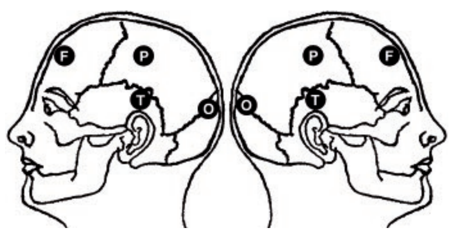


SIMULATED PHOTON DIFFUSION PATH THROUGH BRAIN TISSUE FROM SOURCE TO DETECTOR

The Infrascanner is placed successively in the left and right frontal (F), temporal (T), parietal (P), and occipital (O) areas of the head and the absorbance of light is recorded. The difference in optical density (ΔOD) in each of the four symmetrical areas is calculated on a pair-wise basis from the following formula:

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

where I_N = the intensity of reflected light on the normal side, I_H = the intensity of reflected light on the hematoma side.



HEAD LOCATION OF INFRASCANNER MEASUREMENTS

Frontal: Left/Right forehead, above the frontal sinus
Temporal: In the Left/Right temporal fossa
Parietal: Above the Left/Right ear, midway between the ear and the midline of the skull
Occipital: Behind the Left/Right ear, midway between the ear and the occipital protuberance

The Infrascanner includes three components: (1) the Scanner, (2) the Disposable Shield and (3) a Cradle. The Scanner includes a safe NIR diode laser and a silicon detector. The light to and from the laser and detector is optically coupled to the patient's head through the disposable shield optical fibers. The optical fibers are long enough to reach through hair and contact the scalp. The use of fiber optics eliminates the need to shave off any hair. And because the fiber optic piece is disposable it prevents cross contamination. Readout of the scan provides information on the severity of a hematoma and identifies the region of the brain bleeding. A higher optical density in the scanned region indicates a larger hematoma.

Military Application

Operational Need

Traumatic brain injury (TBI) has become the defining injury in OIF and OEF (OIF or OPIF – Operation Iraqi Freedom, OEF – Operation Enduring Freedom (the war in Afghanistan). Sixty percent of military service members wounded have sustained blast injuries, and two-thirds of them have TBI; of them 40% have brain hematomas. Rapid triage, diagnosis and treatment are critical in minimizing the adverse consequences of the more serious TBI cases. Current Standard Operating Procedure (SOP) involves an immediate clinical evaluation and neurological examination. Delayed hematomas also occur in significant numbers and may not be diagnosed until significant neurological impairment occurs. A CT scan is the definitive diagnostic modality. A rapid diagnosis, followed by immediate evacuation to a location, which has CT and neurosurgical intervention capability, is paramount to maximizing survivability and minimizing irreversible neurological impairment.

Field evaluations

Infrascanner was field tested by the Level III Fallujah Surgical initially and the Level II Shock Trauma Platoon (STP) of Combat Logistics Battalion 1 commencing February 2008 by CDR Dr. Luis Becerra of the Marines under special permit from Lt. General John Kelly. There were two sites with CT scanners in Iraq, Balad and Baghdad and the use of either required evacuation from Fallujah. Usually air evacuation is accompanied by significant risk and expense. Over 100 Marines and Sailors with closed head injury and concussion have been acutely evaluated with the device:

- About 90 subjects had a mild TBI and were not evacuated (Negative Infrascanners).
- Over one dozen with exposure to IED blasts were referred for CT to Balad and/or Baghdad in spite of negative Infrascanner findings. All CTs confirmed that there were no hematomas.
- Three positive Infrascanner cases were referred to immediate neurosurgical evaluation and treatment, including surgery (All confirmed by a later CT). The positive Infrascanner findings in those patients prompted expedited air evacuations.

INFRASCANNER MODEL 2000

The principle used in identifying intracranial hematomas with the Infrascanner is that extravascular blood absorbs NIR light more than intravascular blood

In 2011 a study by the German Army doctors in Kunduz, Afghanistan[4], evaluated a total of 11 TBI patients (military personnel and local civilians). Kunduz, in the north of Afghanistan, had a level 2 facility, where they used the Infrascanner Model 1000 for triage decisions to Mazar-e-Sharif, 100 miles away, where CT and Neurosurgical team are available. There were no intracranial hematomas in this group, as was confirmed by a later CT scan in Mazar-e-Sharif. The Specificity in this test was 100%. The user evaluation showed that the Infrascanner allows a preliminary estimate of an intracranial hematoma and that Infrascanner is easy to learn and can be repeatedly used even under emergency room conditions.

In 2012 2nd battalion, 4th Marines performed a field evaluation in Helmand Province in Afghanistan of 4 prototypes of Infrascanner Model 2000. The 6-month evaluation ended with 15 helicopter evacuation flights saved (the evacuations were done by vehicles, due to negative Infrascanner reading).

USAARL, the U.S. Army Aeromedical Research Laboratory, at Fort Rucker, AL tested successfully the Infrascanner Model 2000 and gave it AWR (Air Worthiness Rating) for Black Hawk, UH-60.

Clinical Data

The pivotal double blinded clinical study for FDA clearance[5] was carried out in five different clinical sites. Clinical personnel in these five sites collected data using the Infrascanner and Computer Tomography (CT) scans. All the CT scans were read by the expert radiologist from an independent site. The evaluation of the Infrascanner measurements in comparison to the CT scans is based on a total of 431 patient data where 122 of them were hematoma cases of various sizes, depths and places. Consistent with preclinical testing, the Infrascanner demonstrated high sensitivity (88%) in detecting hematomas > 3.5cc in volume and < 2.5 cm from the surface of the brain. Specificity in the Per Protocol population was 91%. The balance between specificity and sensitivity supports the utility of the Infrascanner to prioritize patients with suspected hematomas for CT scan.

An adult population study in Seville, Spain[6], evaluated a total of 35 TBI patients, ages 17-76 years. There were 19 intracranial hematomas, confirmed by a CT scan completed on all subjects within 40 minutes of the Infrascanner test. The Sensitivity in this population was 89.5% and Specificity was 81.2%.

A study in Pittsburgh[7] evaluated in Pediatric ICU 28 patients of 0-14 years who underwent CT as part of the clinical care not necessarily triggered by trauma. There were 12 intracranial hematomas, confirmed by a CT scan completed on all subjects within 24 hours of the Infrascanner test. The Sensitivity in this test was 100% and Specificity was 80%.

A study in Padua and Treviso, Italy,[8] evaluated 110 children at intermediate or high risk for intracranial injury according to the PECARN rules (GCS 14 and 15). There was only one brain hematoma case in this group (it was successfully detected). The Specificity in this test was 93% and the NPV was 100 %. The use of Infrascanner would have led to avoid ten CT scan, reducing the CT scan rate by 58.8 %

A study in Lublin, Poland,[9] evaluated 94 children with mild TBI (GCS 14 and 15). The Sensitivity in this test was 86.7 % and Specificity was 90 %. The aim of the study is to propose a new protocol of screening patients using Infrascanner as a complement to repeated neurological examination and medical history review. The results of this study led to the adoption of the Infrascanner as part of the standard of pediatric care in Poland.[10]

A study in Moscow, Russia[11] evaluated Infrascanner ability to detect ICH among 95 children having experienced mild traumatic head trauma. 42 children with associated medium-high risk (GCS 13-14) received an evaluation by neurosurgeon, Infrascanner scan, and had a CT. 53 children with associated low risk (GCS 15) received a scan with the Infrascanner and were clinically monitored for 72 hours. Among the medium-high risk category the sensitivity was 100% and the specificity was 91.2%. In the low risk group, the specificity was 91.7%.

A study in Beijing, China[12] evaluated a total of 85 TBI patients, ages 8-89 years. There were 45 intracranial hematomas, confirmed by a CT scan completed on all subjects within 30 minutes of the Infrascanner test. The Sensitivity in this population was 95.6% and Specificity was 92.5%.

A study in a physician-staffed helicopter Emergency Medical Service (HEMS) in Nijmegen, Netherlands[13] evaluated a total of 25 TBI patients. There were 15 intracranial hematomas, confirmed by a CT scan completed on all subjects upon arrival to a trauma center. The Sensitivity in this population was 93.3% and Specificity was 78.6%.

A study in General Military Hospital in Beijing, China[14] evaluated a total of 102 TBI patients. There were 24 intracranial hematomas, confirmed by a CT scan completed on all subjects within 30 minutes of the Infrascanner test. The Sensitivity in this population was 100% and Specificity was 93.6%. Blood contained within scalp hematomas was found to be a major cause of false positive results with this technology.

References:

1. Seelig JM, Becker DP, Miller DP, et al. (1985). Traumatic acute subdural hematoma: major mortality reduction in comatose patients treated within four hours. N Engl J Med 304:1511-1518.
2. Narayan RK, Michel ME, Ansell B, Baethmann A, Biegon A, Bracken MB, Bullock MR, Choi SC, Clifton GL, Contant CF, Coplin WM, Dietrich WD, Ghajar J, Grady SM, Grossman RG, Hall ED, Heetderks W, Hovda DA, Jallo J, Katz RL, Knoller N, Kochanek PM, Maas AI, Majde J, Marion DW, Marmarou A, Marshall LF, McIntosh TK, Miller E, Mohberg N, Muizelaar JP, Pitts LH, Quinn P, Riesenfeld G, Robertson CS, Strauss KI, Teasdale G, Temkin N, Tuma R, Wade C, Walker MD, Weinrich M, Whyte J, Wilberger J, Young AB, Yurkewicz L. 2002. Clinical trials in head injury. Journal of Neurotrauma, Volume 19, Issue 5, Pages 503-557.
3. Xiong Y, Lee CP, and Peterson PL. 2001. Mitochondrial dysfunction following traumatic brain injury. In Head Trauma: Basic, Preclinical, and Clinical Directions. Miller LP and Hayes RL, eds. Co-edited by Newcomb JK. 2001, John Wiley and Sons, Inc. New York. Pages 257-280
4. T. Braun, U. Kunz, C. Schulz, A. Lieber, C. Willy, "Near-infrared spectroscopy for the detection of traumatic intracranial hemorrhage. Feasibility study in a German army field hospital in Afghanistan", Der Unfallchirurg, Jan 2014: 1-8.
5. Robertson, C., Zager, E., Narayan, R., Handly, N., Sharma, A., Hanley, D., Garza, H., Maloney-Wilensky, E., Plaum, J., and Koenig, C., 2010, "Clinical Evaluation of a Portable Near-Infrared Device for Detection of Traumatic Intracranial Hematomas," Journal of Neurotrauma, 27(9), pp. 1597-1604.
6. Jose Leon-Carrion, Jose Maria Dominguez-Roldan, Umberto Leon-Dominguez, Francisco Muril-lo-Cabezas, "The Infrascanner, a handheld device for screening in situ for the presence of brain haematomas", Brain Injury. September 2010, Vol. 24, No. 10: 1193-1201.
7. R. Salonia, M.J. Bell, PM. Kochanek, R.P. Berger, "The Utility of Near Infrared Spectroscopy in Detecting Intracranial Hemorrhage in Children", Journal of Neurotrauma. April 2012, Vol. 29, No. 6: 1047–1053.
8. S. Bressan, M. Daverio, F. Martinolli, D. Dona', F. Mario, I.P. Steiner, Liviana Da Dalto, "The use of handheld near-infrared device (Infrascanner) for detecting intracranial haemorrhages in children with minor head injury", Childs Nerv Syst, Nov 2013.
9. Bartłomiej Tyzo, Tomasz Trojanowski, Dariusz Szczepanek, Radosław Rola, "Algorithm of initial management of mild head injury using the portable near-infrared spectroscope", Neu-rologia Praktyczna, Feb 2014: 13-20.
10. Grażyna Skotnicka-Klonowicz, Jan Godziński, Adam Hermanowicz, Jan Wendland, Erwin Strzesak, Krzysztof Strzyżewski, Piotr Czauderna, "Management of minor to moderate head trauma in children - Guidelines of the Polish Association of Pediatric Surgeons", Standardy Medyczne/ Problemy Chirurgii Dziecięcej, 2014, vol. 4: 42-50.
11. Semenova, AH., Marshintev, V., Melnikov.V., Meshcheryakov, V., Adayev, R., Lukyanov, VI. Infrascanner in the Diagnosis of Intracranial damage in Children with traumatic brain Injuries. Brain Injury 2016 30(1):18-22.
12. Long Xu, Xiaogang Tao, Weiming Liu, Yanong Li, Jun Ma, Te Lu, Bo Han, Baiyun Liu, Yuanli Zhao, Jingsheng Li, Jizong Zhao, Portable near-infrared rapid detection of intracranial hemor-rhage in Chinese population, J Clin Neurosci (2017), http://dx.doi.org/10.1016/j.jocn.2017.02.056
13. Peters J, Van Wageningen B, Hoogerwerf N, Tan E. Near-infrared spectroscopy: a promising prehospital tool for management of traumatic brain injury. Prehosp Disaster Med. 2017;32(3):1-5.
14. Chun-yang Liang, Yang Yang, Chun-sen Shen, Hai-jiang Wang, Nai-Ming Liu, Zhi-wen Wang, Feng-lei Zhu, Ru-xiang Xu, Chinese military evaluation of a portable near-infrared detector of traumatic intracranial hematomas, Military Medicine (2018), https://doi.org/10.1093/milmed/usx088

A rapid diagnosis, followed by immediate evacuation to a location, which has CT and neurosurgical intervention capability, is paramount to maximizing survivability and minimizing irreversible neurological impairment

The Impact of Traumatic Brain Injury on Health Services

Tom Cropper, *Editor*

Millions of people around the world suffer traumatic brain injuries every year. Their chances of survival and living a good quality life depend on how quickly they are diagnosed and treated.

The longer a brain bleed goes undetected the greater the risk of mortality or serious long-term complications. Despite numerus advances in technology and our understanding of brain injuries, these rates remain persistently high

EVERY DAY, 153 people in the USA die from traumatic brain injuries (TBIs). It's the leading cause of death among younger people and causes 30% of deaths from all injuries in the USA[a]. It has an enormous impact on the resources of health services and can leave survivors with debilitating injuries and requiring long-term care. Reducing the dangers of TBIs is a major public health priority, but despite considerable advances in technologies and treatment, death rates remain high.

Hidden Brain Bleeds

A key issue is the difficulty of discovering brain bleeds early enough. Unless treated promptly, a brain bleed can quickly build up, compressing the brain, which prevents oxygen- rich blood getting where it needs to go within the brain. This lack of oxygen causes swelling which can further exacerbate the bleeding. As the swelling grows the brain can be forced down into the small hole at the base of the cranium known as the 'foramen magnum'. Parts of the brain which come into contact with the bone around this opening will cease to work and, because these parts often deal with critical functions such as the heart and breathing, a bleed – if left untreated – can have a serious risk of mortality.

It is, then, a race against time. The longer a brain bleed goes undetected the greater the risk of mortality or serious long-term complications. Despite numerus advances in technology and our understanding of brain injuries, these rates remain persistently high. Brain injury is the number one cause of death and disability among people under the age of 40 according to figures from NICE[b].

A paper by the *Journal of Neurosurgery* estimates that 69 million people suffer from TBI from all causes every year with South East Asia and Western Pacific regions experiencing the highest rates[c].

Mortality rates are a concern, but so too are the number of people living with a disability as a result of a TBI. These can be anything from relatively mild complications in which people living with the condition experience cognitive problems, to more severe cases which require ongoing medical treatment. A 2012 study revealed that the true incidence of people living with TBI is up to six times higher than official estimates from organizations such as the World Health Organisation. The study was the first to include milder forms of brain injury which are not treated by hospitals. It found that there were between 2.2 to 3.6 million people worldwide who sustained moderate or severe injuries. The implication of the report is that the impact on health services and the wellbeing of individuals could be significantly higher than previously believed[d].

The Burden on Health Services

The burden of providing care to people living with brain injuries is considerable. They are a major cause of admissions to emergency departments with most sufferers requiring further treatment and hospitalization. With these departments already struggling under the strain, improving the timeliness and efficacy of head injury treatment will be vital if these departments are to keep up with the demands being placed upon them.

Long term care can be expensive. Unlike other conditions, in which people might be expected to improve as time goes on, brain injury patients can often deteriorate requiring increasingly extensive interventions and care. In many cases, it is a losing battle but developments in technology ensure that it's a battle which can continue for much longer than before.

Rising Healthcare Costs

That might be good news for patients. More people are surviving brain injuries or at least finding a way to live with brain damage, but ongoing care is expensive. It follows a wider trend in which health services are having to cater for more complex and longer-term conditions.

INFRASCANNING OF A PATIENT IN A HOSPITAL BED

Improved technology and an aging population put resources under strain. Innovations expand the scope of what health services can do, but these come at a price. Delivering gold standard care is becoming increasingly expensive and society's success in extending life means health services are spending more money providing complex care to people for longer.

Older people are also at greater risk of suffering brain bleeds, particularly those which can be difficult to detect such as a subdural hematoma. The brain is wrapped in a protective tissue called the dura which is connected to the brain by a network of veins. As people age, the brain shrinks and pulls away from the dura, but the veins cling onto the brain. As the brain pulls away from the dura, these veins can be exposed and vulnerable.

The result is that even a small blow to the head could be fatal. Symptoms could include headaches, dizziness and slower cognitive functions, but these are all too easy to ignore because the impact to the head might not have been serious. Indeed, if it was a light bump, it's easy to forget it happened at all which means brain injury will be the last thing patients consider.

The skull becomes more fragile and the risk of injury greater. Research into traumatic brain injuries among older people found that falls at home increased the risk of traumatic injury. TBI represented 45% of all trauma cases among older people with falls at home being the most common.

Medications and ongoing conditions can also increase the risk of bleeds. Studies suggest that people who take blood thinning drugs could be at an increased risk of brain bleeds and will be less likely to survive a stroke[e]. A study of veterans over the age of 75 who were using warfarin to thin the blood found that a third of patients suffered a bleed – much higher than previously thought[f].

Promoting Early Detection

Brain bleeds should therefore be seen as a serious public health issue – not just for the risk posed to life and the long-term health of patients, but also because of the drain on healthcare resources. There is, though, a clear way to address both at the same time, and that is to identify problems at a much earlier stage.

For that to happen, much work must be done in the identification of bleeds and this is one area where there is considerable room for improvement. The standard procedure for dealing with a suspected brain bleed would be to look for symptoms and, if necessary, schedule a CT or MRI scan. However, this process is far from infallible and can only happen once the patient has been admitted to hospital.

The real breakthrough will come with methods which can identify bleeds at the earliest possible moment – ideally before symptoms have even manifested themselves. Doing so sets off a positive chain of events. It allows prompt treatment to be delivered before hospitalization, it minimizes the damage done, improves survival rates and reduces the risk of more serious complications. More patients will survive brain injuries and more of them will live healthy and fulfilling lives.

How Brain Bleeds Can be Missed

James Butler, *Staff Writer*

Traumatic brain injury is a major and growing health concern, but all too often symptoms are missed and injuries can be misdiagnosed. How can these Figures be changed?

While methods of detection have improved significantly, there is still plenty of room for improvement. CT scans cannot conclusively rule out the existence of a hematoma and may well fail to pick up a more moderate incidence

THE TREATMENT of people with brain injuries has advanced dramatically over the past few decades, but it is still far from perfect. Bleeds on the brain can be missed, scans can take too long and, in some cases, can even cause additional health problems. The search is on for alternative methods which are faster, healthier and more reliable.

Assessing Brain Injuries

Diagnosis starts with an initial assessment. Doctors will first look for patients who exhibit symptoms such as lethargy, decreased alertness, sudden or severe headaches, tingling, numbness, changes in vision or seizures (especially if there is no previous history). If there is a suspicion of a brain injury the patient may undergo a CT or MRI scan to identify the presence of a bleed.

However, this process has a number of flaws. Firstly, it can be imprecise. Initial assessment of patients and of CT scans may depend on the judgement of the doctor at that time. Not every patient presents with the classical signs of a brain injury. It could also be caused by a host of other factors such as high blood pressure or blood thinning drugs. It is all too easy for a doctor to make a mistake. Doctors and insurance companies will take their lead from the radiologist's assessment and, while most are highly professional and capable, mistakes can happen.

Errors with documentation, for example, can cause misdiagnosis such as the case of a woman who was wrongly given the all clear after her CT scans were lost. She collapsed at work after an aneurysm burst. The hospital was forced to apologize and admit that a correct diagnosis would, in all probability, have avoided the hemorrhage[g].

Missed diagnosis not only places patients at risk, but also exposes the hospital to legal action. As a result, when in doubt, clinicians may choose to err on the side of caution and commission a CT scan. However, these are not without their problems. The use of CT scans has increased dramatically over the past 20 years. They have become a standard part of detecting brain bleeds. But these can be costly, expose patients to doses of radiation and may not pick up smaller hematomas.

A study published in 2012 suggested MRI scans might pick up brain injuries which had been missed by the standard CT scanners[h]. UCSF/SFGH Researchers studied 135 patients with mild traumatic brain injuries who had received CT scans when they were first admitted. They were given MRIs about a week later. Most had no detectable signs of injury on a CT scan but more than a quarter of those who had 'normal' CT scans also had detectable spots on their MRI scans called focal lesions, which are a sign of a microscopic brain bleed. The study suggested that MRI scans may be effective at identifying bleeds which might be missed by a CT scan.

CT scans can be relatively bad at identifying soft tissue injuries, which is why they might miss 10-20% of instances which would be picked up by MRI scans. Less severe TBIs can take time to truly develop on a physical level. Microscopic brain bleeds might not appear on a CT scan for hours or even days after an injury.

MRI scans are not fool-proof either. Much depends on the quality of the machine being used, with newer and more advanced MRIs being more capable of detecting the true extent of a brain injury than older models. However, not every hospital will have the latest equipment.

A Risk of Cancer?

Some reports have also suggested CT scans could lead to a small but significant increase in the risk of developing brain cancer. A report in the *Journal of the National Cancer Institute* focused on a nationwide study of 168,394 Dutch children who had received one or more CT scans between 1979 and 2012[i]. It found that overall cancer incidence was 1.5 times higher than they would have expected. Relative risks increased by two to four times for the highest dose category.

INFRASCANNING OF A PATIENT IN A HOSPITAL BED

The researchers did advise that these findings should be treated with caution because the incidence of brain tumors was higher in this grouping than in the general population, but it adds to concern about the use of CT scans.

High Cost of CT Scans

While safety is the primary concern, reducing CT scans may potentially save money. Each scan is costly and running them as a standard part of the diagnosis process will result in a significantly increased burden on health service budgets. Reducing the need for CT scans, therefore, could result in considerable savings.

Researchers in the US have been looking at whether a blood test could potentially reduce or eliminate the need for a CT scan . A study of a new high sensitivity blood test suggests it could accurately and reliably determine whether a CT scan is truly necessary in patients with a suspected brain injury.

Researchers studied 2,000 patients who visited the ER with an ongoing suspicion of TBI. They had a head CT and blood was collected within 12 hours of the brain injury. The blood was checked for the presence of two biomarker proteins released into the bloodstream after a TBI: C-terminal hydrolase-L1 (UCH-L1) and glial fibrillary acidic protein (GFAP).

The results showed that in 97% of cases the blood tests eliminated the risk of a TBI as backed up by the CT scan. According to the researchers, the tests could reduce the number of CT scans required by a third resulting in significant time and money savings for busy emergency departments. According to the report's authors, TBI leads to more than 25 million ER visits every year and these, in turn, lead to 20 million CT scans. However, CT scans only detect 10% of cases of mild TBI.

Early and Continuous Monitoring

While methods of detection have improved significantly, there is still plenty of room for improvement. CT scans cannot conclusively rule out the existence of a hematoma and may well fail to pick up a more moderate incidence.

It is perfectly possible for a patient to be given the all clear and sent home with an undetected brain bleed. Continuous monitoring and prompt, accurate diagnosis, therefore, will be crucial to ensuring patient safety as well as reducing the burden on health services.

This heightens demand for devices which can be taken to the patients rather than requiring the patients to come to them. The development of small handheld scanners enables clinicians to perform diagnosis immediately after an injury before arrival at hospital, enabling them to perform quick assessments at bedsides or in the home. This can be crucial in providing effective assessments of those patients who are still undergoing observation.

The use of CT scans has increased dramatically over the past 20 years. They have become a standard part of detecting brain bleeds. But these can be costly, expose patients to doses of radiation and may not pick up smaller hematomas

Development of Near InfraRed Scanning

Jo Roth, *Staff Writer*

Near Infrared scanning technology has long held out the possibility of delivering early and non-invasive identification of brain bleeds, but new technology is finally making it a reality.

While these devices will not be used to replace CT scans, they can be useful for reducing the number of scans needed and delivering treatment to places where CT scans would not be available, such as in remote areas, sporting events or military field stations

THE INITIAL hours after a severe traumatic brain injury are crucial. Ischemic injuries are common during the first post-trauma hours and these can have a dramatically negative impact on long-term outcomes. Improving care immediately after brain injury – before arrival at the hospital – can significantly improve outcomes.

Long Awaited Developments

For some time, near infrared (NIR) spectroscopy has been viewed as a promising technology which can allow for significantly earlier commencement of monitoring with minimal operator variability than has previously been the case. It could be applied at the very earliest stage of brain injury treatment – namely in the immediate aftermath of an injury before hospital treatment.

NIR measures how IR light penetrates through different types of tissue. Extra vascular blood absorbs light at a different rate to intravascular blood. This is because there is a greater concentration of hemoglobin than in normal brain tissue which contains blood vessels. This will allow it to highlight the presence of a bleed at a much earlier stage.

Most current methods would require hospital admissions. If the head injury is serious, a hematoma can cause serious damage in this time, even if symptoms are not immediately apparent. In cases of severe brain bleeds, this could be the difference between life and death.

They also allow room for operator variability. Symptoms may be interpreted differently by doctors, and details in scans may be missed. One doctor may interpret images in one way while others may see them differently. More moderate bleeds may not be detectable by a CT scan in the early hours and days after an injury, which means patients may be mistakenly given the all clear.

Advantages of NIR

A pilot study of a handheld IR device, the Infrascanner, found that it demonstrated high sensitivity and specificity in identifying intra and extra axial hemorrhagic hematomas. It was also highly effective at identifying small hematomas in the first 24-hours after injury – something which is often missed by CT scans – and at identifying problems on site. In addition, it showed positive results in spotting hematomas after 12 hours, which also suggested it could be used as an adjunct tool for continual monitoring of patients after discharge[k].

A study into the effectiveness of NIR for children found that the technology could be used to detect ICH without any of the additional risks associated with CT scans. The time needed to complete tests was no more than 15 minutes and it offered a good way for checking children with non-specific symptoms who exhibited a normal reading on the Glasgow Coma Scale (GCS). When signs of injury were found, patients could then be scheduled for a CT scan to confirm those initial findings[l].

While these devices will not be used to replace CT scans, they can be useful for reducing the number of scans needed and delivering treatment to places where CT scans would not be available, such as in remote areas, sporting events or military field stations.

What Stands in the Way?

For all this potential, though, there have always been uncertainties about its value. The most serious of these, according to a report published by the NCBI, has been problems of extracerebral contamination of the NIR signal from the scalp and skull[m]. NIR light is not just absorbed by the target chromophores but also by light scattering. Bone, hair and differences in areas of subarachnoid space contribute to the variation of the underlying tissue being analyzed. This could result in non-linear relationships between absorption and attenuation change.

Earlier iterations of the technology were also unable to prove conclusively their accuracy and clinical viability. The report highlights a number of studies in which it had been used for intracerebral hematoma detection in areas where CT scans were not readily available. One study in Iran found that 46.6% of the patients had possible intracranial hematoma. A CT scan determined that the true number was 36.5%. The figure was not an exact match but was enough to demonstrate that the technology could offer value in those situations where CT scans were not readily available, such as remote areas or for use by the military.

FIELD INFRASCANNING OF MILITARY PATIENT

How Technology is Improving

Since then, though, the technology has steadily improved and several devices are coming to market which can deliver early identification. The leading model, the InfraScanner 2000, has refined all the advances of IR technology into an easy to use handheld device. It has received FDA clearance in the US and the CE Mark in Europe and is being used in a range of settings.

Some of these are areas in which conventional treatment would be difficult, such as the military. More than 200 devices have been deployed in battlefield stations as part of their standard aid kits. These are used for rapid assessment of casualties in the field to make a decision about whether to evacuate.

The device is also ideal for remote areas, enabling doctors to make a more informed decision about whether a patient can be treated in a local hospital or should be moved to a specialist trauma center. Ambulance services are using it to enable fast triage of patients at the scene of an accident. It is being deployed at the bedside and home settings and can be used with children where the GCS is not reliable. In many different settings, it is giving care teams more critical information to make decisions about treatment.

The makers stress that this is not a replacement for conventional approaches, but it is an additional tool which can address many of the gaps left by current treatment. It enables teams to treat patients more promptly, make better care decisions, and spot smaller bleeds. By doing so, it has the potential to save an enormous number of lives now and into the future.

Future Advances in the Fight Against Brain Injuries

Tom Cropper, *Editor*

Death rates from traumatic bring injuries remain worryingly high. However, a number of advances offer hope for the future.

New technologies and solutions hold the key to identifying problems at an earlier stage and reducing the mistakes which can put the lives of patients at risk

TRAUMATIC BRAIN injury causes millions of deaths around the world. However, with earlier identification, better assessment and more precise surgical techniques, many of those lives could be saved. Existing approaches mean many people slip through the net. Serious injuries are not identified quickly enough, and errors can happen throughout the process. New technologies and solutions hold the key to identifying problems at an earlier stage and reducing the mistakes which can put the lives of patients at risk.

The Human Element

A common weakness comes from the human element. Although the risk may be small, doctors can misread scans or fail to spot problems. For example, in 2010 doctors mistakenly told a woman that she had cancer when in fact the shadows were bleeds all over her brain. She had been told she had five months to live and was preparing to move out of her home when doctors told her of the mistake. The bleeds were in fact down to a condition called multiple cavernomas and, while her life was still in danger, there was every chance she would continue living for many years[n].

There are many reasons why doctors may make a mistake. Scans may be unclear. Workloads may be heavy, and it is possible for them to miss details in scans or, as in the case above, they may misinterpret the images.

Many experts believe the solution could lie in artificial intelligence (AI). Researchers claim that a deep learning system designed to detect acute Intracerebral Hemorrhage (ICH) and classify 5 ICH subtypes from unenhanced head computer tomography scans can replicate the performance of professional radiologists. A study tested the system on 200 retrospective scans and a prospective set of 196 scans. The study found the system had comparable results to expert radiologists in two data sets.

The researchers said that this could provide a quick virtual second opinion or alert testers to the presence of a hemorrhage and trigger appropriate follow up tests. It reduces the risk of error and also accelerates the testing and analysis process[o].

Meanwhile, MaxQ AI announced that its intercranial hemorrhage software had received 510k clearance from the US Food and Drug Administration (FDA), paving the way for clinicians in acute care settings to have access to the software. Earlier this year, it also achieved the CE Mark for use within the European Union. The software leverages AI technology to analyze non-contrast head CT images without a workflow impact on the reader[p].

Handheld Scanners

Handheld infra-scanners are also increasingly being used to detect brain bleeds at the point of injury. The British and Irish Boxing Association (BIBA) recently announced that it had approved the use of handheld infra-scanners at its professionally sanctioned events. These scanners can detect brain bleeds with an accuracy rate of 90% before any symptoms such as headaches had manifested themselves[q].

The decision came in the wake of two major head injury events including the death of Mike Towell at a boxing event in Glasgow. He suffered a technical knockout (TKO) and was transferred to hospital where doctors discovered a bleed on the brain. Even though this did not happen at a BIBA sanctioned event, the organization decided to investigate ways in which injuries such as these could be detected as quickly as possible.

They hope that these devices will dramatically accelerate identification of brain bleeds and allow patients to receive appropriate treatment in the shortest amount of time possible. The devices may mean that patients will be receiving crucial life-saving interventions even before they get to the hospital or before symptoms set in.

Similar scanners were also approved for use in Mixed Martial Arts in 2016 in the wake of a series of incidents similar to the death of Mike Towell. In all these cases, fighters had initially felt fine before slipping into unconsciousness. This initial lucid period may delay identification of a hematoma with lethal consequences. Handheld devices promise to enable diagnosis during this period and improve survivability for military personnel.

As this technology continues to prove its value, it is being cleared for use in a wider range of situations from military operations, to emergency teams and in-home assessments. It takes much less time to set up and makes it possible to deliver on the spot targeted treatment in that crucial interval immediately after an injury.

Advances in Surgery

One of the main reasons for failure of surgery for ICH has been secondary damage caused by an invasive procedure. However, recent tests suggest a less invasive and gentler procedure might have better results. A study of the new gentle approach to removing stable clot material after a hemorrhage found that there was no overall difference in results, but when the operation achieved complete or near complete removal of the clot, results were much more promising. The 58% of patients who were left with less than 15ml of clot material – the goal of the procedure – did experience significant surgical benefits. The results, although not as good as they had hoped, were enough to suggest this therapy could save lives[r].

INFRASCANNER MODEL 2000 IN CHARGING CRADLE

Technology has an important role to play. It can improve processes, deliver more accurate scans and enable more appropriate treatment at an earlier stage. Many of the people who die from brain injuries could be saved with earlier interventions. Whether health services can deliver these will be the critical component in the ongoing battle against traumatic brain injuries.

One of the main reasons for failure of surgery for ICH has been secondary damage caused by an invasive procedure. However, recent tests suggest a less invasive and gentler procedure might have better results

References:

[a] Facts about Traumatic Brain Injury: https://www.brainline.org/article/facts-about-traumatic-brain-injury

[b] NICE Head injury briefing paper: https://www.nice.org.uk/guidance/qs74/documents/head-injury-briefing-paper2

[c] Estimating the Global Incidence of Traumatic Brain Injury: https://thejns.org/view/journals/j-neurosurg/aop/article-10.3171-2017.10.JNS17352.xml

[d] Global Traumatic Brain Injury Incidence Six Times Higher: https://www.thejournal.ie/global-traumatic-brain-injury-rates-could-be-six-times-higher-than-thought-study-683302-Nov2012/

[e] Blood Thinning Drug Linked to Increased Brain Bleeds: https://www.aan.com/PressRoom/Home/PressRelease/659

[f] Warfarin Brain Bleed Risk: Higher Than Thought: https://www.webmd.com/heart-disease/atrial-fibrillation/news/20160309/brain-bleed-risk-from-warfarin-may-be-higher-than-thought#1

[g] Mother Suffers Brain Haemorrhage: https://www.dailymail.co.uk/health/article-2640429/Hospital-wrongly-gave-patient-clear-brain-scan-results-MISSING-suffered-brain-haemorrhage.html

[h] MRI Scans Reveal Signs of Brain Injury Not Revealed by CT Scans: https://www.ucsf.edu/news/2012/12/13326/mris-reveal-signs-brain-injuries-not-seen-ct-scans

[i] CT Scans May Increase Risk of Brain Cancer: https://www.sciencedaily.com/releases/2018/07/180719085337.htm

[j] Blood test Could Predict the Need for a CT Scan: https://www.forbes.com/sites/robertglatter/2018/07/28/blood-test-may-be-able-to-predict-need-for-ct-scan-after-a-head-injury/#4fff20fd63d2

[k] The Infrascanner, a Handheld Device for Screening In-Situ for the Presence of Brain Haematomas: https://www.researchgate.net/publication/45693925_The_Infrascanner_a_handheld_device_for_screening_in_situ_for_the_presence_of_brain_haematomas

[l] The Utility of Near Infrared Spectroscopy in Detecting Intracranial Haemorrhage in Children: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3325547/

[m] Clinical application of near-infrared spectroscopy in patients with traumatic brain injury: a review of the progress of the field: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4874161/

[n] Grandmother Diagnosed with Cancer Told Doctors Had Made a Mistake: https://www.telegraph.co.uk/news/health/news/6951189/Grandmother-diagnosed-with-brain-cancer-was-later-told-doctors-had-made-a-mistake.html

[0] AI Can Detect and Classify Acute Brain Bleeds: https://www.empr.com/home/news/artificial-intelligence-can-detect-classify-acute-brain-bleeds/

[p] Max IQ Received FDA Clearance: http://bit.ly/2UFQFyp

[q] Handheld Infra-Scanners That Detect Brain Bleeds Introduced by BIBA: http://www.boxbiba.com/?p=2230

[r] For Brain Bleeds Gentle But Thorough Removal May Boost Outcomes: https://www.medpagetoday.com/meetingcoverage/isc/77898