INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD)
© 2026 IJNRD | Volume 11, Issue 7, July 2026 | ISSN: 2456-4184 | IJNRD.ORG

Near-Infrared Spectroscopy in Traumatic Brain Injury and Spontaneous Intracranial Haemorrhage: Current Evidence and Future Perspectives

[1]Vikas Kaushik, [2]Padmini Das, [3]Namrata Kahlon

[1]Scientist B, [2]Scientist C (Medical), [3]Professor (Department of Physiology)
[1]Multidisciplinary Research Unit ,
[1]ESIC Medical College & Hospital, Faridabad, India

Abstract : Traumatic brain injury (TBI) and spontaneous intracranial haemorrhage (ICH) remain two of the most pressing neurological emergencies encountered worldwide, contributing heavily to mortality, long-term disability, and healthcare spending [1,5]. Outcomes hinge on how quickly bleeding is recognised, yet definitive neuroimaging is often out of reach in emergency and resource-limited settings. Computed tomography (CT) remains the diagnostic gold standard for intracranial haemorrhage, but its use can be constrained by cost, equipment availability, and the delays that come with transporting an unstable patient.
Near-infrared spectroscopy (NIRS) has developed into a portable optical technique capable of flagging intracranial haemorrhage at the bedside by detecting asymmetries in near-infrared light absorption between the two cerebral hemispheres. Three decades of refinement in optical sensors, signal processing, and device miniaturisation have moved NIRS well beyond its original role as a cerebral-oxygenation monitor [10,13]. A growing body of clinical evidence now points to portable NIRS as a useful point-of-care screening adjunct for patients with suspected traumatic or spontaneous intracranial bleeding, particularly in prehospital care, emergency departments, rural hospitals, and military field settings [14,22,23].

This review sets out the optical principles behind NIRS, weighs the clinical evidence for its diagnostic performance, and considers where the technology is heading, including artificial intelligence–assisted interpretation and wearable optical monitoring. NIRS is not a substitute for CT, but the evidence to date supports its use as a complementary triage tool that can shorten the interval to definitive imaging when a scanner is not immediately at hand.
Larger multicentre validation studies, standardised scanning protocols, and closer integration with digital health platforms will likely determine how large a role portable NIRS ultimately plays in emergency neurology and neurotrauma care.

Keywords: Near-Infrared Spectroscopy; Traumatic Brain Injury; Intracranial Haemorrhage; Stroke; Emergency Medicine; Point-of-Care Diagnostics; Neurotrauma; Optical Imaging.

INTRODUCTION

Traumatic brain injury and spontaneous intracranial haemorrhage continue to sit among the most consequential problems in emergency and critical care medicine. Between them, these two conditions account for a disproportionate share of neurological death and permanent disability - TBI most heavily among young adults injured in trauma, ICH among older patients with cerebrovascular disease. Emergency medicine and neurocritical care have advanced considerably over the past two decades, yet early diagnosis is still probably the single factor that most influences whether a patient survives with meaningful function intact.
Recognising intracranial bleeding quickly matters because it opens the door to timely intervention: neurosurgical evacuation, blood pressure control, reversal of anticoagulation, and transfer to a centre equipped for neurocritical care. Even a delay of a few hours can allow a haematoma to expand and neurological status to deteriorate in ways that are difficult to reverse. It is for this reason that clinical guidelines in most health systems call for immediate neuroimaging whenever intracranial haemorrhage is suspected.
CT remains the backbone of acute haemorrhage diagnosis, valued for its sensitivity, its near-universal clinical familiarity, and its ability to show precisely where and how large a bleed is. The catch is that CT depends on infrastructure that is not evenly distributed. Rural and low-resource facilities frequently lack scanners altogether, and even where CT is available, patient transport, machine availability, and emergency department crowding can introduce delays that matter clinically. These constraints are felt most acutely in low- and middle-income countries, where the burden of neurotrauma and stroke is rising faster than the infrastructure needed to manage it [3,4].
NIRS has drawn growing interest as an alternative first look: a portable, non-ionising optical technology that can be applied at the bedside within minutes. By comparing near-infrared light absorption between the left and right cerebral hemispheres, NIRS devices can flag optical asymmetries consistent with an underlying blood collection. Because the hardware is small and battery-powered, it travels well - into ambulances, emergency departments, intensive care units, military field hospitals, and remote clinics - making it a plausible tool for early triage in settings where imaging is not immediately available.
NIRS began life as a way to monitor cerebral oxygenation [10], but better optical sensors, more capable onboard computation, and, more recently, machine learning have pushed its clinical scope considerably further. These advances have renewed interest in folding NIRS into emergency neurological assessment - not as a replacement for CT, but as an adjunct that can help decide who needs urgent imaging soonest.

What follows is a critical look at the evidence behind NIRS in TBI and spontaneous ICH: the optical principles that make it work, the clinical studies that have tested it, its diagnostic performance relative to CT, where it fits into emergency workflows today, and where the technology - including AI-assisted interpretation, wearable form factors, and precision neurodiagnostics - is likely headed next.

2. Epidemiology and Clinical Burden of Traumatic Brain Injury and Spontaneous Intracranial Haemorrhage

TBI and spontaneous ICH are, on their own, among the most damaging conditions a neurology or emergency department will encounter. Both carry high mortality, both leave a substantial share of survivors with lasting disability, and both impose costs that extend well past the individual patient - into families, health systems, and national economies through prolonged hospital stays, rehabilitation, and lost working years.

2.1 Global Burden of Traumatic Brain Injury

TBI ranks among the leading causes of death and disability worldwide, striking hardest at young, economically active adults. Estimates from the Global Burden of Disease (GBD) study put the number of people living with the after-effects of TBI at more than 55 million, with roughly 27 million new medically treated cases occurring each year [1]. More recent GBD updates suggest that while age-standardised incidence has been gradually declining in many regions, the absolute number of cases continues to rise as populations grow and age [2]. Road traffic collisions, falls, interpersonal violence, occupational injury, and sport-related trauma remain the dominant causes.

The burden falls unevenly. Low- and middle-income countries carry a disproportionate share of it, driven by rapid urbanisation, rising vehicle ownership, road safety enforcement that has not kept pace, and limited access to specialised trauma care [3]. Diagnostic and treatment delays compound the problem further, particularly in regions where neurosurgical services are thin on the ground.

Trauma systems and emergency medical services in wealthier countries have improved survival meaningfully over recent decades. Even so, disability remains common among survivors, who often live with cognitive impairment, behavioural change, post-traumatic epilepsy, and a measurably reduced quality of life.

2.2 Burden of Traumatic Brain Injury in India

India carries one of the largest absolute burdens of TBI in the world. Fast-paced urban growth, a rapidly expanding vehicle fleet, industrial development, and road safety regulation that is often poorly enforced have together driven a marked rise in head injury over the past two decades. Hospital-based epidemiological studies have estimated the incidence of TBI in India at roughly 150-160 cases per 100,000 population annually, with young adults making up the majority of those affected [4]; more recent facility-level series suggest this figure may now be considerably higher in dense urban centres.

Road traffic accidents account for around 60% of severe head injuries in most Indian series, with falls, occupational accidents, and assault-related trauma making up most of the remainder [4]. Alcohol use, low rates of helmet and seatbelt use, delayed transport to definitive care, and limited access to trauma centres all contribute further to poor outcomes.

A shortage of CT scanners outside major cities is a recurring theme in this literature. Patients are often transferred to tertiary centres only after considerable time has passed, narrowing the window for effective neurosurgical intervention. This gap is precisely the kind of problem a rapid, portable screening tool is well positioned to help with - identifying, before referral, which patients most urgently need a scan.

2.3 Spontaneous Intracranial Haemorrhage

Spontaneous intracranial haemorrhage - most often intracerebral haemorrhage (ICH) or aneurysmal subarachnoid haemorrhage - makes up roughly 10-15% of strokes in Western populations, rising to 20-30% in some Asian cohorts, yet accounts for a share of stroke deaths well out of proportion to its frequency [5]. Unlike ischaemic stroke, spontaneous haemorrhage begins with sudden bleeding into the brain parenchyma or surrounding spaces, which raises intracranial pressure, provokes cerebral oedema, and sets off a cascade of secondary neuronal injury.

Hypertension is the single most important modifiable risk factor for spontaneous ICH. Cerebral amyloid angiopathy, vascular malformations, anticoagulant therapy, and coagulation disorders account for a growing share of cases, particularly in older patients. Despite genuine progress in stroke care, case fatality after spontaneous ICH remains stubbornly high - roughly 35-40% within the first month and approaching 50-60% by one year in most population-based series, with a substantial fraction of deaths occurring within the first 48 hours [6,7]. Because of this steep early mortality, prompt neuroimaging matters just as much here as it does in trauma: it is what allows clinicians to act quickly on blood pressure, reverse anticoagulation where relevant, decide on surgical evacuation [8], and route the patient to a stroke unit equipped to manage it.

2.4 Importance of Early Diagnosis

Intracranial haemorrhage is rarely static in its first hours. Haematomas frequently continue to expand in the period immediately after injury or bleeding onset, and that expansion tracks closely with worsening neurological deficits and rising intracranial pressure. Diagnosing the problem early is what allows treatment aimed at limiting this secondary injury to actually begin in time. CT remains the imaging modality of choice because it shows blood collections quickly and with excellent accuracy. But obtaining a scan is not instantaneous - it requires equipment, trained staff, and the physical transport of a patient who may be unstable, and any of these can introduce delay, especially in a crowded emergency department or a resource-constrained hospital.

A reasonably consistent finding across the outcomes literature is that shortening the interval between symptom onset and definitive treatment tends to improve neurological outcome. That is the practical argument for developing portable, non-invasive tools that can help identify, at first contact, which patients need urgent imaging and neurosurgical consultation.

2.5 Unmet Clinical Need

Despite real progress in emergency medicine, there is still a meaningful gap between when neurological symptoms begin and when a definitive diagnosis is made. A large proportion of patients first present to primary health centres, community hospitals, ambulances, or remote clinics that simply do not have advanced imaging on site. Clinicians in these settings are often left relying on neurological examination alone, which is an imperfect way to detect intracranial haemorrhage. This is the gap portable technologies such as NIRS are positioned to help close - offering rapid, radiation-free bedside assessment without the infrastructure CT demands. NIRS cannot replace CT, and it should not be asked to, but as a point-of-care screening step it may support earlier referral, more sensible use of scarce imaging resources, and better triage overall, particularly in places where timely neuro imaging is simply not an option [22,23]. Taken together, the scale of the global TBI and ICH burden, and the persistent gaps in access to timely imaging, make a reasonable case for diagnostic approaches that complement rather than compete with existing modalities. Portable optical technologies like NIRS represent one practical step toward faster, more equitable neurodiagnostic care.

3. Principles and Mechanisms of Near-Infrared Spectroscopy

NIRS is a non-invasive optical technique that probes the optical properties of biological tissue using near-infrared light. It began as a method for monitoring cerebral oxygenation [10] and has since evolved into a candidate point-of-care tool for detecting intracranial haemorrhage. At its core, the technique exploits the fact that different tissue components - oxygenated and deoxygenated haemoglobin above all - absorb near-infrared light to differing degrees. Unlike CT or MRI, NIRS does not produce an anatomical image. What it measures instead is a change in light absorption and scattering, which serves as an indirect proxy for tissue composition and haemodynamics. Extravascular blood pooled within the skull changes the optical properties of the tissue it occupies, and this is what allows NIRS devices to flag haemorrhage by comparing corresponding regions on the two sides of the head [11,12].

3.1 Physical Basis of Near-Infrared Spectroscopy

Near-infrared light spans roughly 700-900 nm, a band often called the "optical window" of biological tissue because skin, bone, cerebrospinal fluid, and brain parenchyma are all relatively transparent to it, allowing photons to travel several centimetres beneath the scalp before they are absorbed or scattered away. When light enters the head, photons scatter repeatedly and lose some energy to absorption before a fraction of them make their way back to a detector placed near the source. How much light reaches that detector depends on the optical properties of the tissue the photons passed through along the way. Of everything inside the skull, haemoglobin absorbs near-infrared light most strongly. A pooled collection of blood therefore produces a measurable shift in local optical density - and it is this shift that a NIRS sensor is built to detect.

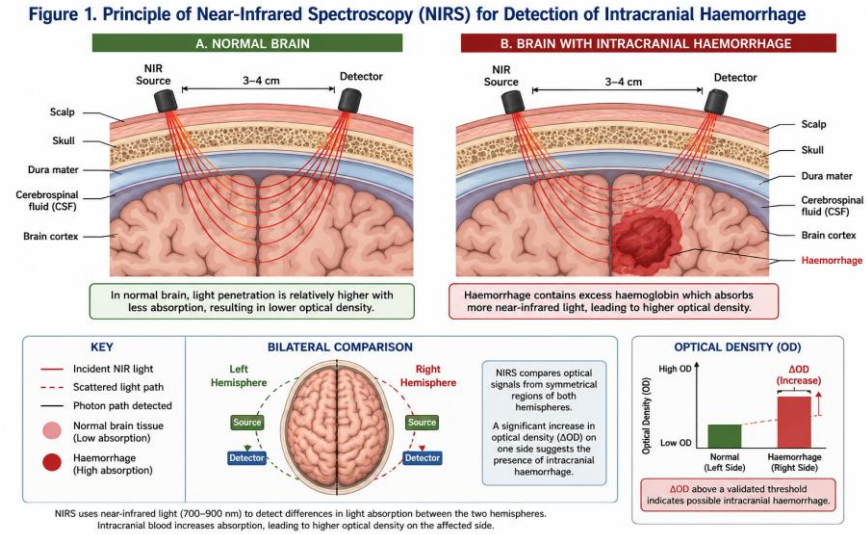

Figure 1. Schematic representation of near-infrared light interacting with intracranial tissue, illustrating differential absorption by haemoglobin-rich blood collections relative to normal brain parenchyma.

3.2 Optical Properties of Brain Tissue

Two optical phenomena govern how near-infrared light moves through tissue: absorption and scattering.

Absorption. Photons hand off their energy to molecules called chromophores as they pass through tissue. In the brain, the principal chromophores are:

- Oxygenated haemoglobin (HbO_2)
- Deoxygenated haemoglobin (Hb)
- Water
- Lipids
- Cytochrome-c oxidase
- Melanin, within superficial tissue layers

Haemoglobin dominates this list in terms of how much it absorbs. Because intracranial haemorrhage is, in effect, a localised concentration of haemoglobin-rich blood, the affected hemisphere absorbs noticeably more near-infrared light than the uninjured side.

Scattering. Photons also collide with microscopic structures - cell membranes, collagen fibres, organelles, extracellular matrix - which redirects their path without necessarily absorbing them. Repeated scattering events trace out the characteristic "banana-shaped" arc that light follows between the emitter and the detector. Absorption and scattering together determine how much light ultimately makes it back to the sensor.

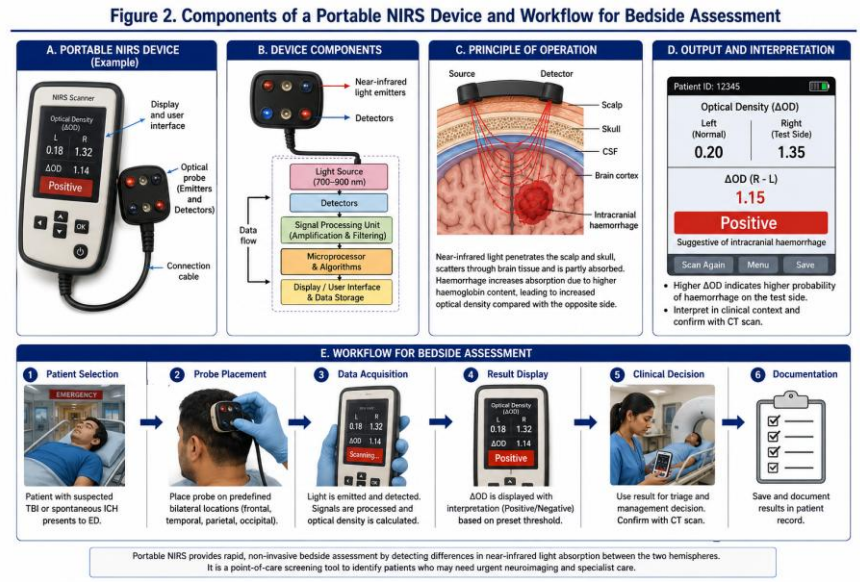

Figure 2. Photon migration path ("banana-shaped"trajectory) through scalp, skull, and cortical tissue between the near-infrared light source and detector.

3.3 Mechanism of Intracranial Haemorrhage Detection

Portable NIRS devices detect haemorrhage through bilateral comparison. Readings are taken in sequence from matching points on the left and right sides of the head - typically the frontal, temporal, parietal, and occipital regions.

In a healthy brain, corresponding regions on either side should have nearly identical optical properties. When a haemorrhage develops on one side, the extra haemoglobin raises local absorption, and that produces a measurable gap - expressed as a change in optical density (ΔOD) - relative to the opposite side. A sufficiently large ΔOD is taken as evidence of an underlying blood collection. Because the method relies entirely on left-right comparison, it works best for haemorrhages that are asymmetric: unilateral epidural, subdural, and superficial intracerebral haematomas. Bilateral, symmetric bleeds, or lesions sitting close to the midline, tend to produce little interhemispheric difference and are correspondingly harder for NIRS to pick up.

3.4 Instrumentation

Today's portable NIRS systems are compact, battery-powered units built for rapid bedside use. Designs differ somewhat between manufacturers, but most share four core components:

- Near-infrared light source - usually laser diodes or LEDs emitting within the 700-900 nm range
- Optical detectors - photodiodes sensitive enough to register reflected or transmitted light intensity
- Signal processing unit - onboard software that converts raw optical signal into a quantitative optical density measurement
- User interface - a handheld display or tablet that presents the result to the operator in real time

Most contemporary devices can complete a full cranial survey in under five minutes, which is short enough to be practical in emergency departments, ambulances, intensive care units, and remote clinics.

3.5 Factors Influencing Diagnostic Performance

NIRS has clear practical advantages, but its accuracy is shaped by several patient- and device-related variables. Light penetration is limited to roughly 2.5-3.5 cm beneath the scalp, which means superficial haematomas are detected far more reliably than deep bleeds involving structures such as the basal ganglia or brainstem [15]. Scalp lacerations, subgaleal haematomas, skull fractures, thick or dark hair, prior cranial surgery, and cranial implants can all interfere with light transmission and distort the signal. Patient movement during scanning is another source of artefact, particularly in the prehospital setting where conditions are rarely ideal.

Technical factors - sensor placement, detector sensitivity, ambient lighting, and calibration - add further variability to diagnostic performance. Ongoing refinements in sensor design and signal processing are aimed squarely at reducing these sources of error.

3.6 Advances in Optical Signal Processing

Computational methods have done a great deal to extend what NIRS can achieve clinically. Modern devices increasingly rely on algorithms that filter out motion artefact, correct for tissue heterogeneity, and improve signal-to-noise ratio before a reading is even shown to the operator.

Machine learning is an increasingly important part of this picture. By analysing absorption patterns across multiple scan sites at once, AI-based systems may help pick up subtler haemorrhages, reduce how much the result depends on operator skill, and standardise interpretation across different clinical settings [26,27].

Cloud-based data analysis and telemedicine integration add a further layer of value, enabling remote expert review of NIRS readings - a feature that could matter a great deal for rural facilities and emergency medical services operating without on-site specialist support. Near-infrared spectroscopy rests on well-understood optical principles - the differential absorption of near-infrared light by haemoglobin - and applies them to detect intracranial blood collections without radiation or an anatomical scan. It is best suited, at present, to superficial and unilateral haemorrhages, but the sections that follow examine how well this holds up against clinical evidence, and where ongoing advances in sensor design, computation, and artificial intelligence are likely to take the technology next.

4. Clinical Evidence

4.1 Foundational Studies in Traumatic Brain Injury

The clinical case for NIRS in intracranial haemorrhage detection rests on work going back to the early 1990s. Gopinath and colleagues were among the first to show that NIRS could localise intracranial haematomas by comparing optical density across the two hemispheres [11], and a follow-up study demonstrated that the technique could detect delayed traumatic haematomas that developed hours after the initial injury - haemorrhages that are easy to miss on a single early CT scan [12]. Robertson and colleagues subsequently formalised this approach into a device-based protocol and reported that NIRS could identify traumatic intracranial haematomas with a sensitivity approaching that of early CT in appropriately selected patients [13], later validating a portable version of the device in a multicentre cohort [14].

Kahraman and colleagues assessed the accuracy of NIRS specifically for subdural and epidural haematomas and found the technique performed well for superficial collections, though its accuracy fell for haematomas located deeper within the cranium - a limitation consistent with the physical depth constraints described in Section 3.5 [15]. An earlier Indian study by Francis and colleagues reported similarly encouraging results in a small preliminary cohort of patients with unilateral intracranial abnormalities [16].

4.2 Diagnostic Accuracy Across Studies

Systematic review evidence gives the clearest overall picture of how NIRS performs. Brogan and colleagues pooled data across multiple studies of traumatic intracranial haematoma and reported sensitivity and specificity figures that, while respectable, fell short of CT - underscoring that NIRS functions best as a triage adjunct rather than a diagnostic replacement [25]. Later meta-analyses focused specifically on the Infrascanner platform have reported pooled sensitivity in the region of 0.85-0.90 and specificity closer to 0.75-0.80, with performance improving further when the analysis is restricted to studies using a standardised ΔOD cut-off of 0.2.

A consistent theme across this literature is the trade-off between sensitivity and specificity: NIRS tends to catch a high proportion of true haemorrhages but also generates a non-trivial rate of false positives, particularly in unselected or low-prevalence populations. This pattern matters for how the technology should be used clinically - as a rule-in tool that prompts urgent imaging, not a rule-out test that overrides clinical judgement.

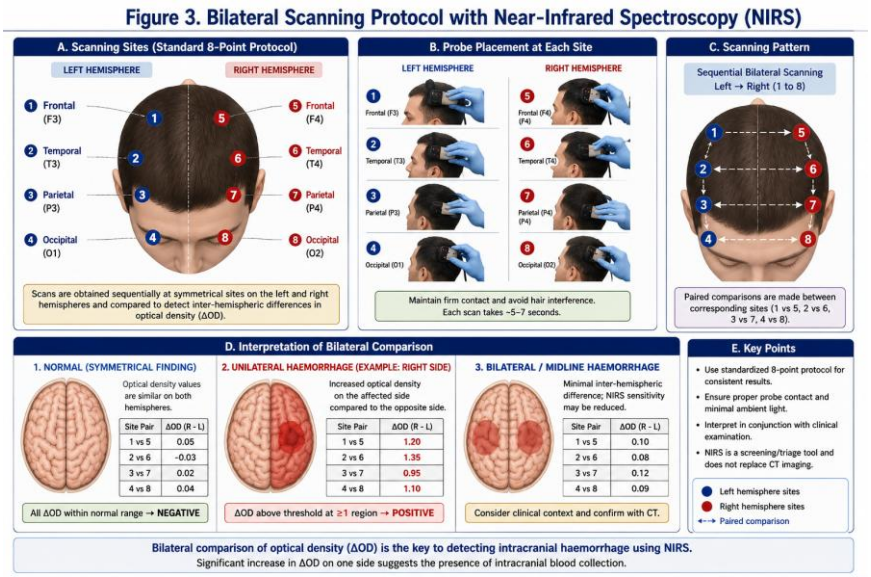

Figure 3. Representative diagnostic performance metrics (sensitivity and specificity) reported across portable NIRS studies in suspected intracranial haemorrhage.

4.3 Evidence in Paediatric Populations

Children pose a particular challenge for NIRS, given thinner cranial bone but also a lower baseline prevalence of clinically significant haemorrhage. Salonia and colleagues reported that NIRS could detect intracranial haemorrhage in children with reasonable accuracy, though performance varied by haematoma size and location [18]. A subsequent multicentre validation study by Kirschen and colleagues, conducted across three academic paediatric emergency departments, found a sensitivity of 81% and specificity of 67% for haematomas within the device's stated detection limits, concluding that the technology could serve as an adjunct to existing paediatric head-injury decision rules rather than a stand-alone diagnostic tool [24]. Bressan and colleagues reported broadly similar findings in a European paediatric cohort with minor head injury [21].

4.4 Prehospital and Military Settings

Because NIRS devices are small and quick to use, they have attracted particular interest for prehospital and military applications, where CT is rarely an option. Peters and colleagues reviewed the evidence for NIRS as a prehospital tool and concluded that, despite meaningful limitations, it could plausibly support earlier triage decisions in trauma systems [22]. Schober and colleagues tested a portable NIRS device in a European helicopter emergency medical service, finding the approach broadly feasible but also documenting a notable rate of false-positive readings in a healthy volunteer cohort - a reminder that field conditions introduce variability not always captured in controlled hospital studies [23]. Braun and colleagues reported comparable feasibility data from a German army field hospital deployment in Afghanistan, one of the more direct tests of NIRS under genuinely austere conditions [20].

Trehan and colleagues evaluated NIRS as a screening tool in an Indian military hospital setting and reported findings broadly consistent with the wider literature, reinforcing that the technology's performance characteristics travel reasonably well across different health systems and patient populations [19].

4.5 Evidence in Spontaneous Intracranial Haemorrhage and Stroke

Most of the published NIRS literature concerns traumatic haemorrhage, but interest in applying the same principles to spontaneous ICH and stroke triage has grown. Cerebral oximetry-based NIRS measurements have been explored as an early screening step in emergency department patients presenting with headache, with some studies reporting that a sufficiently large interhemispheric difference in regional oxygen saturation correlates with an underlying haemorrhage. While this evidence base remains smaller than that for TBI, it points toward a plausible role for NIRS in flagging spontaneous ICH earlier in the emergency workflow, particularly in settings where stroke patients might otherwise wait longest for imaging.

5. Clinical Applications and Emerging Technologies

5.1 Point-of-Care Triage

The clearest current application of NIRS is triage: helping decide, at first contact, which head-injured or stroke-suspected patients need imaging most urgently. In settings where CT is available but access is delayed by transport or scheduling, a positive

NIRS reading can help justify prioritising a patient for the next available scan slot. In settings where CT is not available on site at all, NIRS can inform the decision to transfer a patient to a higher level of care sooner rather than later.

This application depends on NIRS being used as intended - as a screening adjunct integrated into an existing clinical pathway, alongside history, examination, and validated decision rules, rather than as a stand-alone diagnostic test.

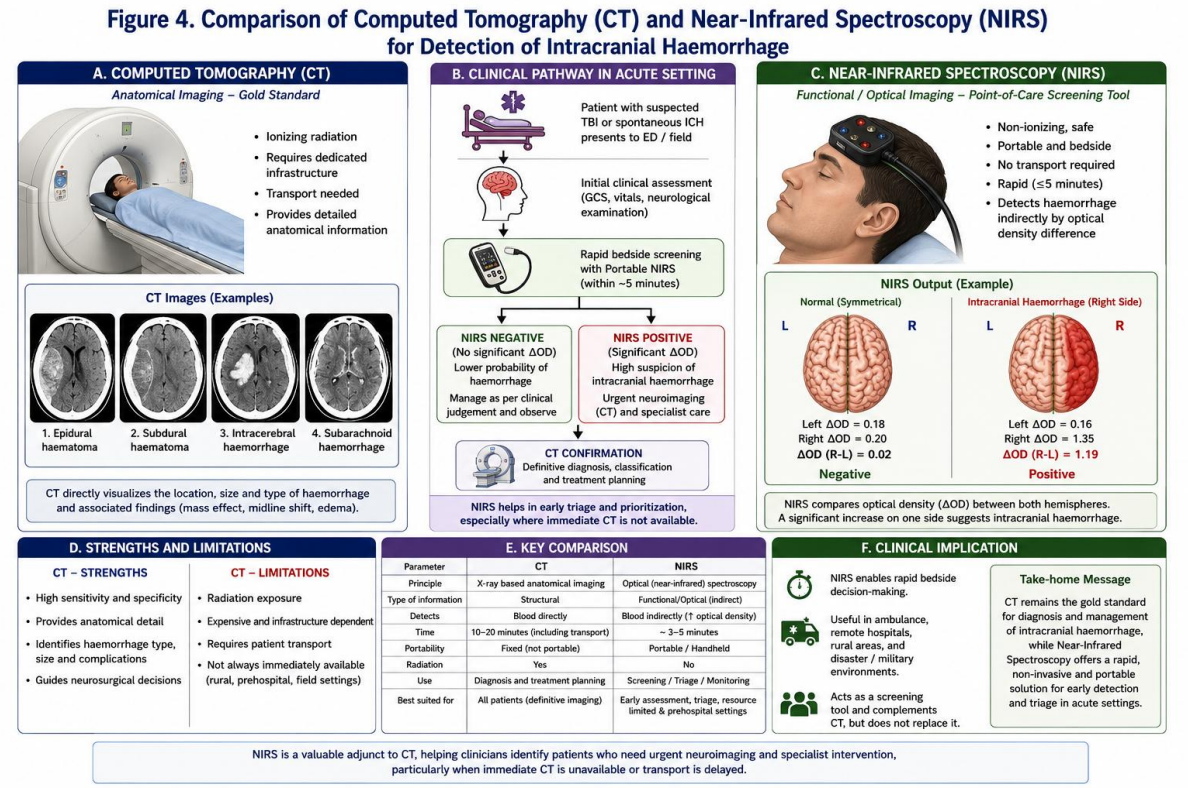

Figure 4. Illustrative deployment settings for portable NIRS devices, including prehospital, emergency department, and remote healthcare environments.

5.2 Artificial Intelligence and Machine Learning

AI-assisted interpretation is one of the more active areas of development in this field, though most of the published deep learning literature to date addresses CT-based haemorrhage detection rather than NIRS signals directly [26,27]. The broader lesson from that CT-focused work - that machine learning models can match or exceed human-level accuracy at detecting intracranial haemorrhage when trained on sufficiently large datasets - has motivated efforts to apply similar approaches to NIRS waveform data, with the goal of reducing operator dependency and improving consistency across different users and settings [28]. Early human-factors and usability studies on point-of-care NIRS devices suggest that standardising the interface and automating the interpretation step could meaningfully reduce variability introduced by less experienced operators [28].

5.3 Wearable and Telemedicine-Integrated Devices

A further direction under active exploration is continuous or semi-continuous NIRS monitoring using wearable form factors, rather than a single spot-check reading. Such devices could, in principle, track trends in interhemispheric optical asymmetry over time - potentially useful for detecting a haematoma that develops gradually, as delayed traumatic haemorrhages often do [12]. Pairing these devices with telemedicine platforms would allow a remote specialist to review readings in real time, which is particularly relevant for rural facilities and emergency medical services that lack on-site neurosurgical expertise.

6. Limitations and Challenges

NIRS has genuine, well-documented limitations that any clinical use has to account for.

- Depth of detection: light penetration of roughly 2.5-3.5 cm means deep haemorrhages, including many involving the basal ganglia, thalamus, or brainstem, fall largely outside its reach [15].
- Bilateral or midline lesions: because the method relies on left-right comparison, symmetric or midline haemorrhages produce little or no detectable signal.
- False positives: scalp haematomas, lacerations, and skull fractures can mimic the optical signature of an intracranial bleed, and field studies have reported meaningful false-positive rates even in healthy volunteers [23].

- Operator and technical variability: sensor placement, ambient light, calibration, and patient movement all introduce variability that is harder to control outside a research setting.
- Limited evidence base for spontaneous ICH: most validation studies have focused on trauma populations, and evidence specific to spontaneous haemorrhage and stroke triage remains comparatively thin.

None of these limitations disqualify NIRS from clinical use, but they do define its role clearly: an adjunct that supports triage decisions, not a technology that can substitute for definitive neuroimaging.

7. Future Directions

Several developments are likely to shape where NIRS goes from here. Larger, prospective, multicentre studies - designed with standardised scanning protocols and blinded, independent CT correlation - would go a long way toward resolving the considerable variability seen across the current literature. Consistent reporting of ΔOD thresholds and hematoma-size cut-offs, in particular, would make it far easier to compare results between studies and settings.

On the technology side, continued refinement of sensor design and signal processing should help address some of the false-positive and depth limitations described above, while AI-assisted interpretation may reduce the operator dependency that has affected performance in field studies [26,27,28]. Wearable, continuous-monitoring form factors integrated with telemedicine platforms represent a plausible next step for extending NIRS beyond a single-timepoint screening test toward ongoing surveillance in high-risk patients.

Finally, closing the evidence gap for spontaneous ICH and stroke triage - an area currently underrepresented relative to trauma - would help clarify how much value NIRS can add outside the setting in which it has been most extensively studied.

8. Conclusion

Near-infrared spectroscopy offers a genuinely useful, if imperfect, answer to a real clinical problem: how to screen for intracranial haemorrhage quickly, safely, and without the infrastructure CT requires. The evidence base, built up over three decades and spanning trauma centres, paediatric emergency departments, helicopter transport services, and military field hospitals, supports its use as a point-of-care triage adjunct, particularly where definitive imaging is delayed or unavailable. It is not, and is unlikely to become, a replacement for CT. What it can do is help identify, sooner, which patients most need that scan - and in settings where minutes matter, that may be enough to change an outcome. Continued investment in larger validation studies, standardised protocols, and AI-assisted interpretation should help define more precisely how large a role portable NIRS will ultimately play in emergency neurology and neurotrauma care.

Acknowledgment

The authors gratefully acknowledge the Multidisciplinary Research Unit (MRU), ESIC Medical College & Hospital, Faridabad, for providing the academic environment, institutional support, and resources that facilitated the preparation of this review article.

References

1. James SL, Theadom A, Ellenbogen RG, Bannick MS, Montjoy-Venning W, Lucchesi LR, et al. Global, regional, and national burden of traumatic brain injury and spinal cord injury, 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016. Lancet Neurol. 2019;18(1):56-87.
2. Global Burden of Traumatic Brain Injury in 204 Countries and Territories From 1990 to 2021: a systematic analysis for the Global Burden of Disease Study 2021. Am J Prev Med. 2025 (online ahead of print).
3. Hyder AA, Wunderlich CA, Puvanachandra P, Gururaj G, Kobusingye OC. The impact of traumatic brain injuries: a global perspective. NeuroRehabilitation. 2007;22(5):341-353.
4. Gururaj G. Epidemiology of traumatic brain injuries: Indian scenario. Neurol Res. 2002;24(1):24-28.
5. Qureshi AI, Tuhrim S, Broderick JP, Batjer HH, Hondo H, Hanley DF. Spontaneous intracerebral hemorrhage. N Engl J Med. 2001;344(19):1450-1460.
6. van Asch CJ, Luitse MJ, Rinkel GJ, van der Tweel I, Algra A, Klijn CJ. Incidence, case fatality, and functional outcome of intracerebral haemorrhage over time, according to age, sex, and ethnic origin: a systematic review and meta-analysis. Lancet Neurol. 2010;9(2):167-176.
7. An SJ, Kim TJ, Yoon BW. Epidemiology, risk factors, and clinical features of intracerebral hemorrhage: an update. J Stroke. 2017;19(1):3-10.
8. Mendelow AD, Gregson BA, Rowan EN, Murray GD, Gholkar A, Mitchell PM; STICH II Investigators. Early surgery versus initial conservative treatment in patients with spontaneous supratentorial lobar intracerebral haematomas (STICH II): a randomised trial. Lancet. 2013;382(9890):397-408.

9. Hemphill JC 3rd, Bonovich DC, Besmertis L, Manley GT, Johnston SC. The ICH score: a simple, reliable grading scale for intracerebral hemorrhage. Stroke. 2001;32(4):891-897.

10. Jöbsis FF. Noninvasive infrared monitoring of cerebral and myocardial oxygen sufficiency and circulatory parameters. Science. 1977;198(4323):1264-1267.

11. Gopinath SP, Robertson CS, Grossman RG, Chance B. Near-infrared spectroscopic localization of intracranial hematomas. J Neurosurg. 1993;79(1):43-47.

12. Gopinath SP, Robertson CS, Contant CF, Narayan RK, Grossman RG, Chance B. Early detection of delayed traumatic intracranial hematomas using near-infrared spectroscopy. J Neurosurg. 1995;83(3):438-444.

13. Robertson CS, Gopinath SP, Chance B. Use of near-infrared spectroscopy to identify traumatic intracranial hematomas. J Biomed Opt. 1997;2(1):31-41.

14. Robertson CS, Zager EL, Narayan RK, Handly N, Sharma A, Hanley DF, et al. Clinical evaluation of a portable near-infrared device for detection of traumatic intracranial hematomas. J Neurotrauma. 2010;27(9):1597-1604.

15. Kahraman S, Kayali H, Atabey C, Acar F, Gocmen S. The accuracy of near-infrared spectroscopy in detection of subdural and epidural hematomas. J Trauma. 2006;61(6):1480-1483.

16. Francis SV, Ravindran G, Visvanathan K, Ganapathy K. Screening for unilateral intracranial abnormalities using near-infrared spectroscopy: a preliminary report. J Clin Neurosci. 2005;12(3):291-295.

17. Leon-Carrion J, Dominguez-Roldan JM, Leon-Dominguez U, Murillo-Cabezas F. The Infrascanner, a handheld device for screening in situ for the presence of brain haematomas. Brain Inj. 2010;24(10):1193-1201.

18. Salonia R, Bell MJ, Kochanek PM, Berger RP. The utility of near-infrared spectroscopy in detecting intracranial hemorrhage in children. J Neurotrauma. 2012;29(6):1047-1053.

19. Trehan V, Maheshwari V, Kulkarni SV, Kapoor S, Gupta A. Evaluation of near infrared spectroscopy as screening tool for detecting intracranial hematomas in patients with traumatic brain injury. Med J Armed Forces India. 2018;74(2):139-142.

20. Braun T, Kunz U, Schulz C, Lieber A, Willy C. Near-infrared spectroscopy for the detection of traumatic intracranial hemorrhage: feasibility study in a German army field hospital in Afghanistan. Unfallchirurg. 2015;118(8):693-700.

21. Bressan S, Daverio M, Martinolli F, Dona D, Mario F, Steiner IP, et al. The use of handheld near-infrared device (Infrascanner) for detecting intracranial haemorrhages in children with minor head injury. Childs Nerv Syst. 2014;30(3):477-484.

22. 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(4):414-418.

23. Schober P, Bossers SM, Schwarte LA, Ristori D, Boer C. Intracranial hematoma detection by near infrared spectroscopy in a helicopter emergency medical service: practical experience. Biomed Res Int. 2017;2017:1846830.

24. Kirschen MP, Myers SR, Neuman MI, Grubenhoff JA, Mannix R, Stence N, et al. Intracranial traumatic hematoma detection in children using a portable near-infrared spectroscopy device. West J Emerg Med. 2021;22(4):782-791.

25. Brogan RJ, Kontojannis V, Garara B, Marcus HJ, Wilson MH. Near-infrared spectroscopy (NIRS) to detect traumatic intracranial haematoma: a systematic review and meta-analysis. Brain Inj. 2017;31(5):581-588.

26. Sen AN, Gopinath SP, Robertson CS. Clinical application of near-infrared spectroscopy in patients with traumatic brain injury: a review of the progress of the field. Neurophotonics. 2016;3(3):031409.

27. Arbabshirani MR, Fornwalt BK, Mongelluzzo GJ, Suever JD, Geise BD, Patel AA, Moore GJ. Advanced machine learning in action: identification of intracranial hemorrhage on computed tomography scans of the head with clinical workflow integration. NPJ Digit Med. 2018;1:9.

28. Shah J, Vithalapara K, Malik S, Lavania A, Solanki S, Adhvaryu NS. Human factor engineering of point-of-care near-infrared spectroscopy device for intracranial hemorrhage detection in traumatic brain injury: a multi-center comparative study using a hybrid methodology. Int J Med Inform. 2024;184:105367.