



Evidence Brief: Near Infrared Spectroscopy for Detecting Brain Hematoma

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PREFACE

The VA Evidence-based Synthesis Program (ESP) was established in 2007 to provide timely and accurate syntheses of targeted healthcare topics of particular importance to clinicians, managers, and policymakers as they work to improve the health and healthcare of Veterans. QUERI provides funding for four ESP Centers, and each Center has an active University affiliation. Center Directors are recognized leaders in the field of evidence synthesis with close ties to the AHRQ Evidence-based Practice Centers. The ESP is governed by a Steering Committee comprised of participants from VHA Policy, Program, and Operations Offices, VISN leadership, field-based investigators, and others as designated appropriate by QUERI/HSR&D.

The ESP Centers generate evidence syntheses on important clinical practice topics. These reports help:

- Develop clinical policies informed by evidence;
- Implement effective services to improve patient outcomes and to support VA clinical practice guidelines and performance measures; and
- Set the direction for future research to address gaps in clinical knowledge.

The ESP disseminates these reports throughout VA and in the published literature; some evidence syntheses have informed the clinical guidelines of large professional organizations.

The ESP Coordinating Center (ESP CC), located in Portland, Oregon, was created in 2009 to expand the capacity of QUERI/HSR&D and is charged with oversight of national ESP program operations, program development and evaluation, and dissemination efforts. The ESP CC establishes standard operating procedures for the production of evidence synthesis reports; facilitates a national topic nomination, prioritization, and selection process; manages the research portfolio of each Center; facilitates editorial review processes; ensures methodological consistency and quality of products; produces “rapid response evidence briefs” at the request of VHA senior leadership; collaborates with HSR&D Center for Information Dissemination and Education Resources (CIDER) to develop a national dissemination strategy for all ESP products; and interfaces with stakeholders to effectively engage the program.

Comments on this evidence report are welcome and can be sent to Nicole Floyd, ESP CC Program Manager, at Nicole.Floyd@va.gov.

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EXECUTIVE SUMMARY

Falls are a common cause of injury among elderly populations, particularly those residing in nursing homes. Most falls in nursing homes occur at the ground level and are low impact. Injuries resulting from these types of falls are variable and range from serious orthopedic and head injury requiring transport to an emergency department (ED) or trauma center to mild injury that can be managed with closer short-term monitoring by nursing staff.¹ The American Medical Directors Association (AMDA) Clinical Practice Guideline recommends that facilities have written policies to guide fall management including initial patient evaluation, monitoring for signs of delayed injuries, determination of the circumstances of the fall, and mitigation of risk factors for future falls.²

Initial patient evaluation after falls involves conducting a physical exam to evaluate the extent of injuries, including impaired consciousness as measured by the Glasgow Coma Scale (GCS), and considering baseline risk factors for intracranial hemorrhage, a potential complication of head injury. Identifying patients with moderate-severe injuries in need of transport and head imaging is usually straightforward. However, determining which patients with mild injuries need further evaluation can be more challenging as many elderly patients have pre-existing dementia or other cognitive disorders that impair the physical exam and GCS assessment, as well as higher baseline risk for intracranial hemorrhage due to use of anticoagulants. A further challenge in evaluating patients with possible head injury after falls is that a subset of patients who initially have a normal exam will develop delayed intracranial hemorrhage and could worsen quickly. For these reasons, guidelines on management of mild head injury including those by the American College of Emergency Physicians/Centers for Disease Control and Prevention commonly recommend head computed tomography (CT) for all patients ≥ 65 years old, even with a normal GCS.³

Despite these guidelines, excessive use of CT and implications for patient safety remains a concern due to radiation exposure.⁴ While the exact rate of normal CT scan findings in nursing home patients presenting after falls is unknown, most patients evaluated for head injury in the ED have normal CTs. A retrospective study using data from the National Hospital Ambulatory Medical Care Survey in the US found that 91% of the approximately 3.9 million head CTs obtained in ED patients to evaluate for head injury in 2009-2010 did not reveal a traumatic intracranial abnormality.⁵

Near infrared spectroscopy (NIRS) is a diagnostic tool that could be used to evaluate patients after falls and aid in decision-making to avoid unnecessary CTs. NIRS is an imaging technique that identifies intracranial hematomas by detecting asymmetry in light absorption over the right and left sides of the head. Handheld NIRS devices offer a portable, noninvasive, and quick

Background

The ESP Coordinating Center is responding to a request from the Office of Community Engagement's Center for Compassionate Innovation for an evidence brief on use of near infrared spectroscopy (NIRS) to evaluate patients in nursing homes including VA Community Living Centers for the presence of brain hematomas after falls. Findings from this evidence brief will be used to inform Subject Matter Experts' consideration of NIRS' clinical use and research, as well as program prioritization, in the nursing home setting.

Methods

To identify studies, we searched MEDLINE®, Cochrane Database of Systematic reviews, Cochrane Central Register of Controlled Trials, and other sources up to June 2017. We used prespecified criteria for study selection, data abstraction, and rating internal validity and strength of the evidence. See our PROSPERO protocol for our full methods.

means of evaluating patients for the presence of a brain hematoma. Infrascanner© 2000 is the only commercially available NIRS device in the US and is currently being used by clinical staff at the VA Pittsburgh's Community Living Center (CLC) to evaluate patients with mild injuries after falls when the clinical suspicion for head injury is low. The aim of this evidence brief was to evaluate the potential impact of NIRS as a diagnostic test for hematomas in nursing home patients after falls by synthesizing the evidence on the performance characteristics of NIRS for detecting brain hematoma, its impact on clinical decision-making, patient outcomes, potential harms, and cost-effectiveness.

Ideally, NIRS use would reduce unnecessary CTs and ED visits among nursing home patients who have mild injuries. This potential benefit must be weighed against the potential harm of a negative NIRS scan in a patient who truly has a brain hematoma in need of further intervention. In general, NIRS is not well-suited to identify bilateral hematomas, small hematomas, and deeply located hematomas with a greater distance from the scalp. Some hematomas that would not be detected by NIRS, but would be identified by CT, are unlikely to cause symptoms or a further change in patient's function. Other small hematomas could expand over time, causing symptoms and functional decline, and these hematomas would be important not to miss. In addition to the potential for missing a clinically important hematoma, there could be other unintended consequences of NIRS use. For example, fewer ED transfers could place additional strain on nursing home staff due to the need to monitor patients more frequently. Fewer ED transfers could also represent missed opportunities to identify reasons for patient falls if they do not undergo more extensive testing. The ideal study of NIRS would aim to capture not only the false positive rate, but these other potential harms.

Unfortunately, studies of NIRS to date have almost exclusively focused on demonstrating the technical feasibility of the device and its diagnostic accuracy in series of patients who are referred for a CT scan. These studies therefore provide little insight on how use of NIRS impacts clinical decision-making, patient outcomes, and healthcare utilization. Moreover, it is unknown how NIRS performs in older nursing home patients with mild injury after falls because this type of use has not been studied. Only one study of Infrascanner© 2000 has been conducted in patients with mostly mild injuries, and in that observational study of 85 patients presenting to a neurosurgical center with predominantly mild head injury (85% with GCS 12-15), Infrascanner© 2000 failed to identify 2 hematomas among 43 patients with hematomas on CT.⁶ Patients had a mean age of 48, high prevalence of hematomas (53%), and unreported baseline risk factors. The findings of this study are not necessarily predictive of how NIRS would perform in nursing homes with a different makeup of patients and overall lower prevalence of hematomas.

Given concerns about overuse of CT and the potential benefits of NIRS as a diagnostic tool in nursing home patients with mild injuries after falls, it would be reasonable to consider implementation of a NIRS protocol in a pilot study among VA CLCs. A pilot could provide reliable estimates of CTs and ED transfers averted. However, because positive CT scans are rare in this situation, a much larger study (or decision modeling) would be needed to assess the frequency and clinical consequences of false negative NIRS scans.

EVIDENCE BRIEF

INTRODUCTION

PURPOSE

The ESP Coordinating Center (ESP CC) is responding to a request from the Office of Community Engagement's (OCE) Center for Compassionate Innovation (CCI) for an evidence brief on use of near infrared spectroscopy (NIRS) to evaluate patients in nursing homes including VA Community Living Centers (CLCs) for the presence of brain hematomas after falls. Findings from this evidence brief will be used to inform Subject Matter Experts' consideration of NIRS' clinical use and research, as well as program prioritization, in the nursing home setting.

BACKGROUND

Falls are a common cause of injury among elderly populations, particularly those residing in nursing homes. More than 60% of nursing home residents experience at least one fall per year, making a reduction in falls a focus of prevention efforts.¹ Most falls in nursing homes occur at the ground level and are low impact. A prospective study of fall rates and characteristics among 528 nursing homes in Germany found that 41% of falls occurred during transfers and 36% occurred while walking.⁷ Injuries resulting from these types of falls are variable and range from serious orthopedic and head injury requiring transport to an emergency department (ED) or trauma center to mild injury that can be managed with closer short-term monitoring by nursing staff.¹ The American Medical Directors Association (AMDA) Clinical Practice Guideline recommends that facilities have written policies to guide fall management including initial patient evaluation, monitoring for signs of delayed injuries, determination of the circumstances of the fall, and mitigation of risk factors for future falls.²

Management of moderate-severe injuries after falls is usually straightforward and most patients will be transported to an ED or trauma center. Management can be more challenging in patients who have mild injuries, particularly when the circumstances of the fall are unknown and patients cannot provide additional history or participate in the physical exam due to pre-existing dementia or other cognitive disorders. Clinicians may struggle with deciding which patients are appropriate to monitor and which patients are at risk of serious head injury and need to be transported to an ED to undergo head imaging with computed tomography (CT). A further challenge in evaluating patients with possible head injury after falls is that subset of patients who initially have a normal exam will develop delayed intracranial injuries and could worsen quickly. Intracranial hemorrhage, bleeding in the layers of tissue between the skull and the brain or within the brain itself, can occur at the time of injury or may be delayed by several hours or days.

Since CT came into widespread use, uncertainty has existed regarding which patients with mild head injury should undergo imaging, and this uncertainty led to efforts to define which clinical findings predict intracranial lesions.⁸ The Glasgow Coma Scale (GCS) is a widely used measure of impaired consciousness based on eye opening and verbal and motor responses that is used to assess the extent of traumatic brain injury (TBI) and is included in most decision-making tools regarding CT use in patients with head injury. Patients are classified as having mild injury (GCS ≥ 13), moderate injury (GCS 9-12), or severe injury (GCS 3-8). In an observational study of patients with minor head injury and normal GCS, Haydel et al⁸ found that patients with

headache, vomiting, age \geq 60 years, drug or alcohol intoxication, deficits in short-term memory, physical evidence of trauma above the clavicles, and seizure should undergo head CT, as these clinical findings predicted intracranial lesions. According to guidelines regarding CT use in patients with mild TBI, including guidelines by the American College of Emergency Physicians/Centers for Disease Control and Prevention, patients age \geq 65 years should undergo CT even with a normal GCS.³

However, development of guidelines has not settled the controversy regarding which patients with mild head injury should undergo CT. Concern still exists regarding excessive use of CT and implications for patient safety due to radiation exposure.⁴ The radiation exposure associated with a head CT is equivalent to the radiation dose of 30 chest x-rays.⁹ While the exact rate of normal CT scan findings (and therefore unnecessary radiation exposure) in nursing home patients presenting after falls is unknown, the majority of patients evaluated for all types of TBI in the ED have normal CTs. A retrospective study using data from the National Hospital Ambulatory Medical Care Survey in the US found that 91% of the approximately 3.9 million head CTs obtained in ED patients to evaluate for TBI in 2009-2010 did not reveal a traumatic intracranial abnormality.⁵ A retrospective study of patients \geq 75 years old with mostly normal GCS (95%) who underwent CTs in an ED in Poland found that 97.4% of 116 patients with low-energy accidents (mostly ground-level falls) had negative CT scans.¹⁰

Several new technologies are being developed to aid in decisions regarding which patients with mild head injuries should have CT scans. For example, the US Army has evaluated the BrainScope One, a handheld, non-invasive electroencephalogram-based device, which has been incorporated into a decision aid that pairs clinical risk factors with test results to predict the likelihood of intracranial injuries visible on CT.¹¹ Developers of BrainScope One reported that use of this tool would have led to a 33% reduction in unnecessary CTs based on retrospective analysis of 564 patients with mild TBI.¹¹ In this study, BrainScope One was negative in 7.7% of cases in which CT was positive, but Huff et al¹¹ note that none of these patients developed worsening symptoms or required neurosurgical intervention.¹ Other emerging diagnostic tools include protein S100B, thought to be a biomarker for neurologic injury,¹² and artificial neural networks, mathematical models theorized to predict CT findings in older patients with mild TBI.¹³

Near infrared spectroscopy (NIRS) is another example of a tool that could be used to reduce unnecessary CTs. NIRS is an imaging technique that identifies intracranial hematomas based on the different light-absorbing properties of hemoglobin in extravascular compared to intravascular blood. When more extravascular blood is present, as in the case of a hematoma, the local concentration of hemoglobin is greater and leads to higher light absorption.¹⁴ NIRS works by comparing light absorption over the right and left sides of the head, with asymmetric findings suggesting the presence of a hematoma (measured as the change in optical density). Handheld NIRS devices provide results within minutes, require minimal staff training, and do not expose patients to radiation. Because they are portable, handheld NIRS devices can be used in multiple settings, including nursing homes, and can be used repeatedly to monitor patients after falls without harms associated with the scan itself. Proponents of NIRS suggest that it could be integrated into patient assessment after falls in the case of mild injuries when the clinical

¹ Note that Huff et al reported a false negative rate of 7.7% in the text, but Figure 2 supports a lower rate of 3.96%. We contacted the authors for clarification, but they did not respond by the publication date of this report.

suspicion for a hematoma is low to provide reassurance to patients and clinicians that a hematoma is not present and thereby prevent unnecessary ED visits and CTs. NIRS has not been intended to be used as a substitute for clinical judgement or in nursing home patients with moderate-severe injuries who require transport for acute management.

Infrascanner© 2000 (developed by Infrascan Inc. with sponsorship from the US Office of Naval Research and the US Marine Corps) is the only commercially available handheld NIRS device in the US and obtained Food and Drug Administration (FDA) clearance as a Class II medical device in 2012.¹⁵ Infrascanner© 1000, an earlier model of Infrascanner© 2000, obtained FDA clearance in 2010. Infrascanner© 2000 is also marketed and sold in Europe. The cost of the device, as noted by Dr. Oldershaw (phone conversation, August 2017), may vary by health system, but is approximately \$9500 (including the device itself and a set of disposable shields that form contact with the patient). A second handheld NIRS device, Crainscan© (developed by BYTech Inc.) is also commercially available in Europe. The devices work by the same principle with some differences in methods. Specifically, Infrascanner© 2000 and Crainscan© emit slightly different wavelengths of near infrared light (both are close to the ideal 805 nanometer wavelength to detect blood) and use different types of sensors placed at the scalp.¹⁶ Infrascanner© uses two 1.6mm optical fibers that form narrow contact with the scalp after maneuvering around hair follicles, while Crainscan© uses a wider detector that is placed directly over hair.^{16,17} No studies have compared the effectiveness of the 2 devices. Additional NIRS devices that have been developed for detection of brain hematomas include the Runman, which was an earlier prototype of Infrascanner©, Smartscan, and a research device developed by Francis et al.¹⁸

Currently available NIRS devices have inherent limitations in their ability to detect brain hematomas due to the nature of the technology itself. Because NIRS works by comparing light absorption of blood on the 2 sides of the head, results can be falsely negative in patients with bilateral hematomas. NIRS results may also be falsely negative in the cases of chronic subdural hematomas, because the absorption properties of blood change over time and can become less detectable by NIRS.¹⁴ The NIRS signal is also susceptible to confounding from structures that alter the path of light such as hair, scalp, and bone.^{16,19} Improving accuracy in this regard has been the focus of NIRS device development over time, and it is the rationale behind some of the differences in detection methods between Infrascanner© and Crainscan©. Specifically, Infrascan Inc. states that its design reduces the effect of hair color on scan results.¹⁶ The presence of scalp hematomas may lead to false positive results, although in many cases scalp hematomas may be detected by physical exam and avoided so that they do not interfere with NIRS measurements.²⁰ In general, NIRS is best suited to detect larger hematomas and those closer to the brain surface. Infrascanner© can detect hematomas ≥ 3.5 ml and within 2.5 cm of the brain surface.¹⁴

Despite these limitations, Infrascanner© 2000 and Crainscan© are already being used in clinical practice in the US and Europe. In addition to use as an initial diagnostic test for brain hematomas after TBI, serial NIRS scans have been used to monitor for the development of delayed hematomas in hospitalized TBI patients. Other types of NIRS devices are used to monitor cerebral autoregulation and oxygenation in the hospital setting.¹⁹ Infrascanner© 2000 is currently being used by clinical staff at the VA Pittsburgh's CLC to evaluate patients with mild injuries after falls when the suspicion for head injury is low. In a comparison of patient fall rates and ED transfers in July 2014 and July 2015, 41% fewer patients were transferred after falls (19 out of 33 in July 2014 compared to 5 out of 30 in July 2015) with use of Infrascanner©, according to Dr.

Oldershaw (phone conversation, August 2017). However, in interpreting these results, it is important to keep in mind that reduced ED use (and presumably reduced CT use) does not take into account the frequency or consequences of false negative NIRS test results. The false negative rate cannot be calculated from this experience because patients who had negative NIRS results did not get CT scans or receive long-term follow-up.²

An ideal study of NIRS would observe nursing home patients with mild injuries and evaluate how use of NIRS changes clinical decision-making. Specifically, it would measure the positive effects (fewer ED visits and CT scans) as well as the negative effects (missed hematomas and their consequences). Unfortunately, no study has evaluated the use of NIRS in this population and setting or examined its effect on decisions. For this reason, we posed broad key questions and included studies in other settings. While these studies may have some useful information, it is critical to keep in mind the limitations of generalizing the results of these studies to a different population and setting.

The aim of this evidence brief is to evaluate the potential impact of NIRS use among nursing home patients after falls by describing the technical feasibility of NIRS for detecting brain hematomas and synthesizing the evidence on the performance characteristics of NIRS, and its impact on diagnostic and therapeutic decision-making, patient outcomes, potential harms, and cost-effectiveness.

KEY QUESTIONS

- KQ1: What are the performance characteristics of NIRS as a diagnostic test for patients with mild TBI suspected of having a brain hematoma or with risk factors for brain hematoma?
- KQ2: What is the evidence that use of NIRS impacts diagnostic and/or therapeutic decision-making for patients suspected of having a brain hematoma or with risk factors for brain hematoma?
- KQ3: What is the evidence that use of NIRS to detect brain hematomas impacts patient outcomes?
- KQ4: What are potential adverse effects and unintended consequences of using NIRS for detection of brain hematoma?
- KQ5: What is the cost-effectiveness of using NIRS for detecting brain hematoma?
- KQ6: Do the effects of NIRS vary by patient population or setting?

² Mathematically, when the chance of a positive CT scan is low, a very inaccurate test could appear to be useful unless false negatives are considered. For example, assume that 50 patients undergo a test and that 1 of them has a hematoma. If our “test” is a coin flip, about 25 patients would have a negative test (“tails”) and the number of CT scans would be reduced by 50%. If the one patient with a hematoma either had “heads” (and had a CT) or had “tails” but was not followed up, we would believe the coin toss was a very useful test.

ELIGIBILITY CRITERIA

The ESP included studies that met the following criteria:

- **Population:** Adults (≥ 18 years)
- **Intervention:** Near infrared spectroscopy (NIRS) device
- **Comparator:** Any (CT scan, MRI scan, etc)
- **Outcomes:**
 - ***Diagnostic test performance:*** Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV)
 - ***Diagnostic impact:*** Earlier diagnosis or reduced need for additional diagnostic tests
 - ***Therapeutic impact:*** Improved triage or earlier treatment
 - ***Patient outcome impact:*** Morbidity, mortality, patient satisfaction, healthcare utilization, or quality of life
 - ***Adverse effects or unintended consequences:*** Any
 - ***Cost-effectiveness:*** Any
- **Timing:** Any
- **Setting:** Any

METHODS

To identify articles relevant to the key questions, our research associate searched MEDLINE®, Cochrane Database of Systematic reviews, Cochrane Central Register of Controlled Trials, PsycINFO, Health Technology Assessment, Database of Abstracts of Reviews of Effects, NHS Economic Evaluation Database, CINAHL, Military & Government Collection, and Scopus up to 6/30/2017, using terms for hematoma, hemorrhage, brain injury, near infrared, and spectroscopy; additional citations were identified from grey literature sources, hand-searching reference lists, and consultation with content experts (see Supplemental Materials Appendix A for complete search strategies). We limited the search to published and indexed articles involving human subjects available in the English language. We also contacted Infrascan, Inc. and BYTech Inc. with requests for scientific information. Study selection was based on eligibility criteria described above. Titles, abstracts, and full-text articles were sequentially reviewed by 2 investigators and checked by a third. All disagreements were resolved by consensus.

We used predefined criteria to rate the internal validity of all included studies. We used the Cochrane ROBIS tool to rate the internal validity of systematic reviews.²¹ We used QUADAS-2 tool to rate the internal validity of diagnostic accuracy studies.²² We abstracted data from all studies for prespecified study and patient characteristics of interest and results for each included outcome. For studies that did not report NIRS performance characteristics, we calculated sensitivity, specificity, PPV, and NPV when data on NIRS and CT results were available. For studies that reported NIRS performance characteristics for a subset of hematoma types, we performed additional calculations for all hematoma types when possible. All data abstraction and internal validity ratings were sequentially reviewed by 2 investigators and checked by a third. All disagreements were resolved by consensus.

We graded the strength of the evidence for Infrascanner© 2000 and Crainscan© (the 2 NIRS handheld devices that are currently commercially available) sensitivity and specificity based on the AHRQ Methods Guide for Comparative Effectiveness Reviews.²³ This approach incorporates 4 key domains: risk of bias (includes study design and aggregate quality), consistency, directness, and precision of the evidence. It also considers other optional domains that may be relevant for some scenarios, such as a dose-response association, plausible confounding that would decrease the observed effect, strength of association (magnitude of effect), and publication bias. Strength of evidence is graded for each key outcome measure and ratings range from high to insufficient, reflecting our confidence that the evidence reflects the true effect.

Where studies were appropriately homogenous, we synthesized outcome data quantitatively Microsoft® Excel® for Windows (2016) to estimate pooled effects. Where meta-analysis was not suitable due to limited data or heterogeneity, we synthesized the evidence qualitatively.

A draft version of this report was reviewed by technical experts selected to represent relevant specialties including radiology, NIRS device development, and systematic review methodology. Their comments and our responses are available in Appendix F in the supplemental materials.

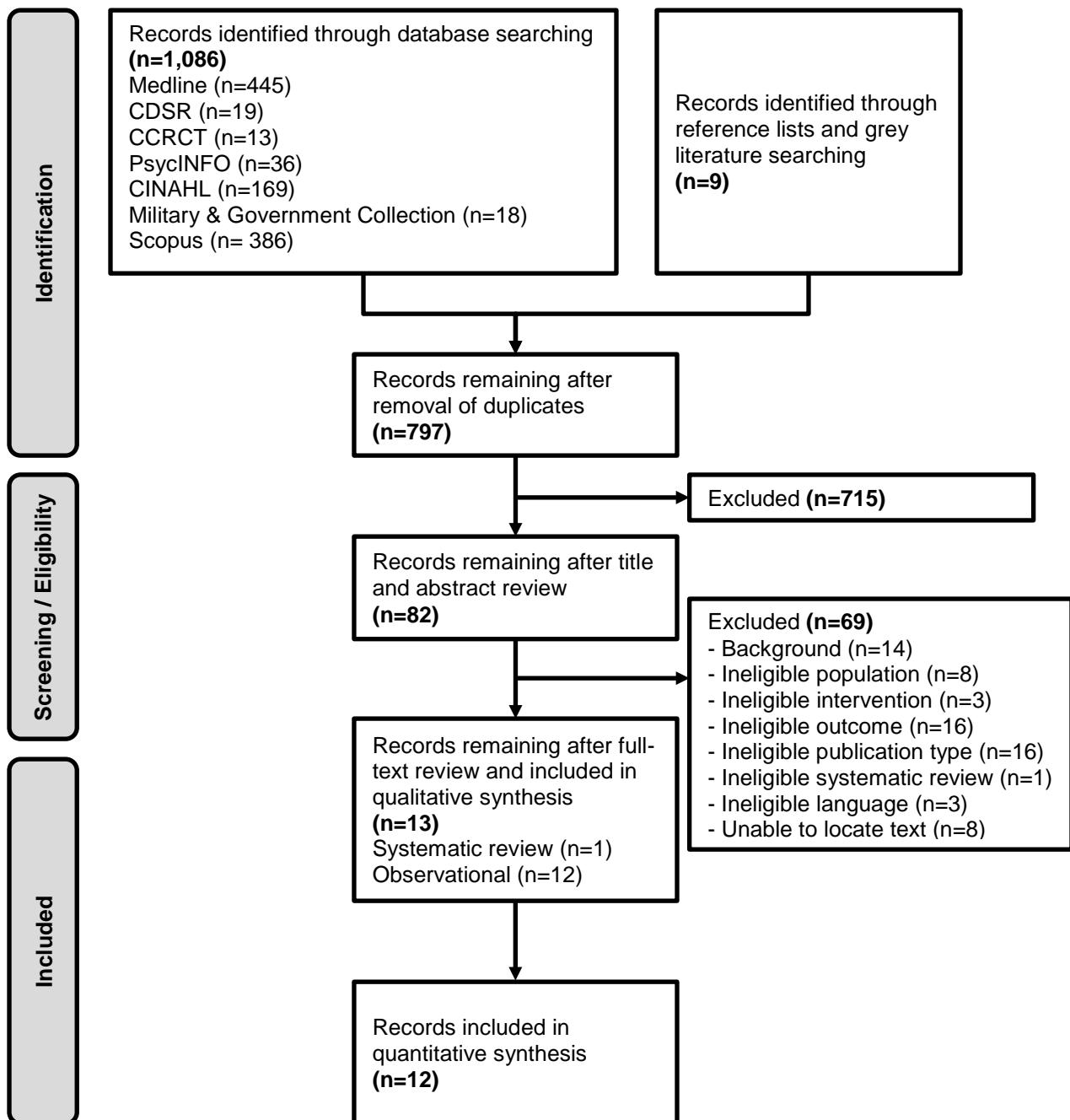
The complete description of our full methods can be found on the PROSPERO international prospective register of systematic reviews (<http://www.crd.york.ac.uk/PROSPERO/>; registration number CRD42017071444).

RESULTS

The literature flow diagram (Figure 1) summarizes the results of the search and study selection processes.

LITERATURE FLOW

Figure 1: Literature Flowchart



LITERATURE OVERVIEW

Searches resulted in 797 unique potentially relevant articles. We included 12 observational diagnostic accuracy studies (see Supplemental Materials Appendix B for list of excluded studies),^{6,14,18,20,24-31} with a median sample size of 89 (range 19-365) and a total population of 1,364 individuals. We identified a 2017 systematic review by Brogan et al¹⁶ that included 8 diagnostic accuracy studies on NIRS. Brogan et al¹⁶ included only 6 (50%) of the studies included in our review.^{14,18,20,26,29,30} Notably, the review by Brogan et al.¹⁶ did not include the newest studies of Infrascanner© 2000^{6,31} and Infrascanner© 1000²⁴ that were published after their search end date of 1/1/2015. Also, the review by Brogan et al¹⁶ included 2 additional studies in pediatric populations^{32,33} that were outside our scope. We received a scientific information packet from Infrascan, Inc. which did not include studies that we had not otherwise identified in our search.

Table 1 presents the characteristics of the 12 primary studies (see Supplemental Materials Appendix C for full evidence tables). Mean patient age for all studies was \leq 60 years old. Most studies (67%) did not report on gender, but those that did included 51-83% male patients. Although skin and hair color are potential confounders of the NIRS signal, most studies (67%) did not report this information. Most patients had a history of TBI or suspected TBI and had been referred for CT scan. In Hennes et al,²⁸ patients were already diagnosed with a subdural hematoma and in Kahraman et al,²⁹ patients were already diagnosed with an epidural or subdural hematoma.^{28,29} 2 studies included a control population of healthy individuals or those with minor injuries.^{6,29} Aside from Hennes et al,²⁸ which only included patients with diagnosed hematomas, the prevalence of any type of hematoma ranged from 5-59%.

Severity of signs and symptoms at presentation was reported in 50% of studies. In 5 of the 6 studies that reported severity measures at presentation, most patients had a GCS score close to or \geq 13, consistent with mild injury.^{6,14,20,24,30} In contrast, patients included in Peters et al³¹ had a mean GCS of 6.9, consistent with severe injury.

Studies varied in the type of handheld NIRS device used. Six studies used Infrascanner© 1000 or 2000 and 2 additional studies used the RunMan device.^{6,14,20,24,25,27,28,31} Three studies used Crainscan© or Smartscan.^{26,29,30} One study used a device developed by the study authors.¹⁸

No studies were conducted in elderly nursing homes patients with low clinical suspicion for hematoma after a fall. Only one study was conducted in the US (multicenter study conducted in the US and India by Robertson et al¹⁴). Most studies (83%) occurred in the emergency department or hospital setting. One study was conducted in the pre-hospital setting.³¹ Most studies (83%) were single-center.

Table 1: Characteristics of Included Studies

Author Year N	Setting Time Frame Country	NIRS Device Comparator	Mean Age (Range)	Percent Male	Inclusion Criteria	Mechanism of Injury	GCS Score	Other Reported Outcomes
Hennes 1997 ²⁷ N= 212	ED 2 years Germany	Runman CT	NR	NR	Patients with clinical diagnosis of intracranial pathology possibly associated with head trauma or stroke	NR	NR	NR
Hennes 1999 ²⁸ N= 19	ED NR Germany	Runman CT	NR	NR	Patients with CT diagnosis of subdural hematoma	NR	NR	NR
Francis 2005 ¹⁸ N= 65	CT Facility NR India	Developed by authors CT	NR	NR	Patients aged 17 years and older, referred for brain CT scan	NR	NR	NR
Kahraman 2006 ²⁹ N= 60*	ED/ICU NR Turkey	Smartscan CT	59.73 (4-103)	80%	Patients with traumatic epidural or subdural hematomas (control=minor trauma patients with no intracranial hematoma by CT scan)	Falls= 23.3% MVC= 20.0% Other= 56.7%	NR	NR
Kessel 2007 ³⁰ N= 110	Trauma Unit [†] 1 year Israel	CrainScan CT	56.2	NR	Adult trauma patients with possible brain injury mandating head CT scan	NR	Mean=12.6 Range= 3-15	NR
Ghalenoui 2008 ²⁶ N= 148 [‡]	ED NR Iran	CrainScan CT	36.8 (11-78)	63.5	Patients with closed head injuries requiring CT scan	Falls= 16.9% Other= 83%	NR	NR
Coskun 2010 ²⁵ N= 92	ED 5 days Turkey	Infrascanner 1000 [‡] CT	NR	NR	Patients of any age with TBI	NR	NR	NR

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Leon-Carrion 2010 ²⁰ N= 35 [‡]	ED/ICU NR Spain	Infrascanner 1000 CT	47.6 (17-76)	83	Patients with TBI admitted to neurosurgical ICU or emergency room observational unit	Falls= 51.4% MVC= 34.3% Other= 14.3%	3-8= 8.6% 9-12= 5.7% 13-15= 85.7%	Hematoma prevalence (<12 hours post-trauma vs >12 hours post-trauma) Mean time between NIRS exam and CT scan
Robertson 2010 ¹⁴ N= 365 [¶]	ED [†] 2 years 3 months USA/India	Infrascanner 1000 CT	36.7 (1-88)	NR	Patients of any age undergoing CT scan within 12 hours of a blunt or penetrating head injury	Falls=43.8% MVC= 41.9% Other=14.2%	3-8= 24.4% 9-12= 8.8% 13-15= 66.8%	NR
Akyol 2016 ²⁴ N= 151	ED 3 months Turkey	Infrascanner 1000 CT	49.9 (18-94)	51	Adult patients (age>18 years) with minor head trauma (loss of consciousness, disorientation, amnesia, and GCS > 13) and CT scan	Falls= 51% MVC= 21.8% Other=27.2%	≥13 = 100%	Patient discharge; Hospital admittance; Average time spent in ED
Peters 2017 ³¹ N= 22 [¶]	HEMS NR Netherlands	Infrascanner 2000 CT	54 (7-79)	NR	Patients of any age with suspected neurocranial trauma, TBI included unless other treatment priorities prevented scan	MVC= 36% Falls =24% Other= 40%	Mean= 6.9 Median= 3.0	Physician-reported ease of use
Xu 2017 ⁶ N= 85 [‡]	Neurosurgery Center 1 year 2 months China	Infrascanner 2000 CT or MRI	48.3 (8-89)	NR	Patients of any age undergoing a CT scan within 12 h of a blunt or penetrating head injury	NR	3-8= 6% 9-12= 9% 13-15=85%	NR

* Study included few (≤ 3) people <18 years who were included in the patient and injury characteristics data, as well as the test performance data

† Multi-site

‡ Study included unreported number of people <18 years who were included in the patient and injury characteristics data, as well as the test performance data

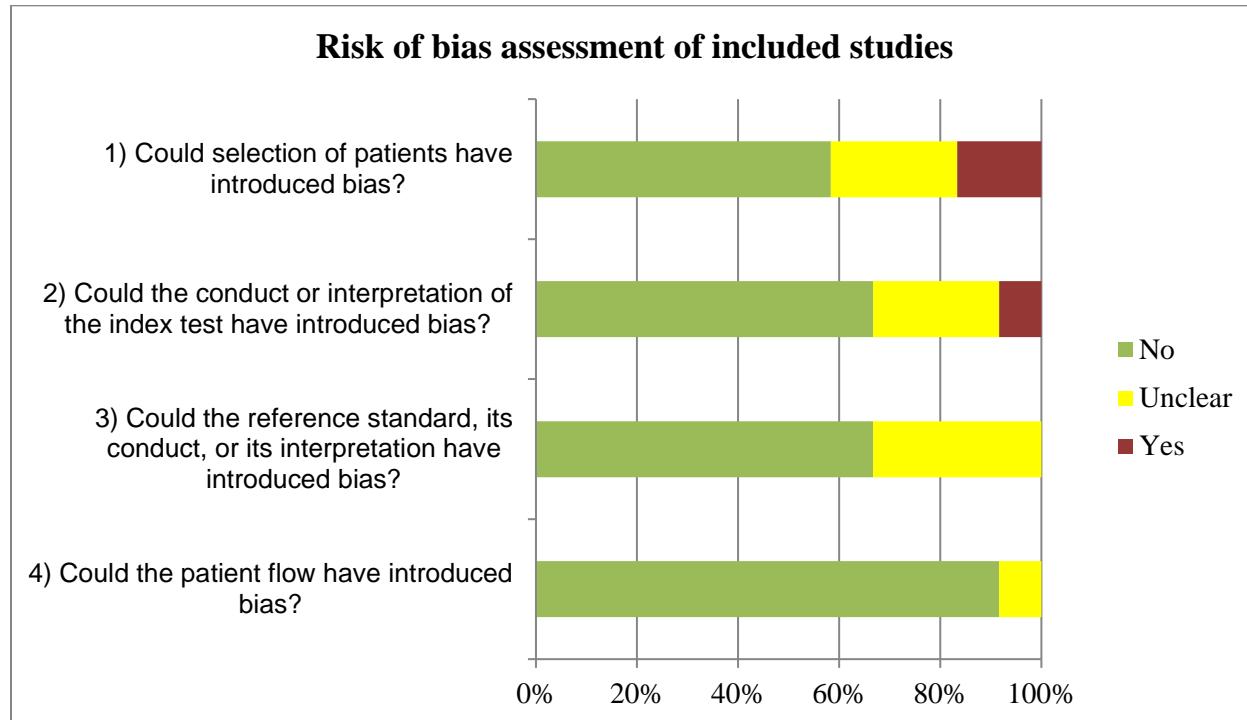
§ Model not reported, but is assumed to be the Infrascanner 1000 because it was the only model available at the time of the study

¶ Study included people <18 years who were included in the patient and injury characteristics data, but not in the test performance data

Abbreviations: CT= computed tomography; ED= emergency department; GCS= Glasgow Coma Score; ICU= intensive care unit; MRI= magnetic resonance imaging; MVC= motor vehicle crash; TBI= traumatic brain injury

Risk of bias was unclear in the majority of studies (67%) due to uncertainty regarding how patient selection was conducted and whether radiologists interpreting CTs were blinded to NIRS results. Risk of bias was low in the remainder of studies. Figure 2 shows the details of the risk of bias assessment.

Figure 2: Summary of QUADAS-2 Assessment



KQ1: What are the performance characteristics of NIRS as a diagnostic test for patients suspected of having a brain hematoma or with risk factors for brain hematoma?

Performance characteristics are shown by study in Table 2 and by device in Figures 3 and 4 (see Supplemental Materials Appendices D and E for full details). 2 studies of Infrascanner© 2000,^{4,5} have the most practical application because Infrascanner© 2000 is the only commercially available NIRS handheld device in the US. In patients with predominantly mild TBI referred to a neurosurgery center, Infrascanner© 2000 correctly identified hematomas in 96% of patients (sensitivity) and correctly ruled out hematomas in 93% (specificity).⁶ Infrascanner© 2000 failed to identify 2 hematomas among 43 patients with hematomas on CT scans (false negatives).⁶ But, given that patients in this study had a mean age of 48, high prevalence of hematomas (53%), and unreported baseline risk factors, findings of this study are not necessarily predictive of how NIRS would perform in nursing homes with a different makeup of patients and overall lower prevalence of hematomas. When used in patients with predominantly mild TBI, CrainScan©³⁰ and Infrascanner© 1000^{14,20,24} correctly identified and ruled out hematomas at rates ranging from 68% to 89% (sensitivity) and 67% to 95% (specificity), respectively. NIRS' accuracy in correctly identifying and ruling out hematomas also ranged widely in patients with severe TBI³¹ and when used in patients already diagnosed with hematoma²⁸. Collectively, these findings provide little insight on how NIRS would perform in elderly nursing home patients with mild injuries.

Across studies, reasons cited for false negatives included bilateral hematomas, small hematomas below the NIRS detection threshold, deeply located hematomas with greater distance from the scalp, patient agitation or motion, and difficulty completing NIRS examination in transport.^{14,18,20,27-31}

Table 2: Performance Characteristics

Author Year N	NIRS Device Hematoma Type	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)	Prevalence (95% CI)
Hennes 1997 ²⁷ N= 212	Runman Type: Intracranial hemorrhage including SDH	.96 (.91-.99)	.29 (.20-.39)	.65 (.61-.68)	.84 (.68-.93)	.58 (.51-.64)
Hennes 1999 ^{28†} N= 19	Runman Type: SDH	.84 (.60-.97)	NA*	NA*	NA*	1.00 (.82-1.00)
Francis 2005 ^{18‡} N= 71	Developed by authors Type: Any	.82 (.48-.98)	.88 (.77-.95)	.56 (.38-.73)	.96 (.88-.99)	.15 (.08-.26)
Kahraman 2006 ²⁹ N= 60	Smartscan Type: EDH, SDH	.87 (.69-.96)	1.00 (.88-1.00)	1.00 (1.00-1.00)	.88 (.75-.95)	.50 (.37-.63)
Kessel 2007 ^{30§} N= 110	CrainScan Type: Any	.68 (.48-.84)	.95 (.88-.99)	.83 (.64-.93)	.90 (.83-.94)	.25 (.18-.35)
Ghalenoui 2008 ²⁶ N= 148	CrainScan Type: Any	.89 (.77-.96)	.78 (.68-.86)	.70 (.61-.77)	.92 (.85-.96)	.36 (.29-.45)
Coskun 2010 ²⁵ N= 92	Infrascanner 1000† Type: Any	.88 (.47-1.00)	.38 (.28-.49)	.12 (.09-.16)	.97 (.83-1.00)	.09 (.04-.16)
Leon-Carrion 2010 ²⁰ N= 35	Infrascanner 1000 Type: Any	.89 (.67-.99)	.81 (.54-.96)	.85 (.67-.94)	.87 (.63-.96)	.54 (.37-.71)
Robertson 2010 ¹⁴ N= 365	Infrascanner 1000 Type: Any	.69 (.58-.78)	.91 (.87-.94)	.73 (.64-.80)	.89 (.86-.92)	.26 (.22-.31)
Akyol 2016 ²⁴ N= 151	Infrascanner 1000 Type: SAH, EDH, SDH	.86 (.42-1.00)	.67 (.58-.74)	.11 (.08-.15)	.99 (.94-.94)	.05 (.02-.09)
Peters 2017 ^{31§} N= 22	Infrascanner 2000 Type: Any	.85 (.55-0.98)	.78 (.40-.97)	.85 (.61-.95)	.78 (.48-.93)	.59 (.36-.79)
Xu 2017 ⁶ N= 85	Infrascanner 2000 Type: Any >3.5ml and <2.5cm from brain surface	.96 (.85-.99)	.93 (.80-.98)	.93 (.83-.98)	.95 (.83-.99)	.53 (.41-.64)

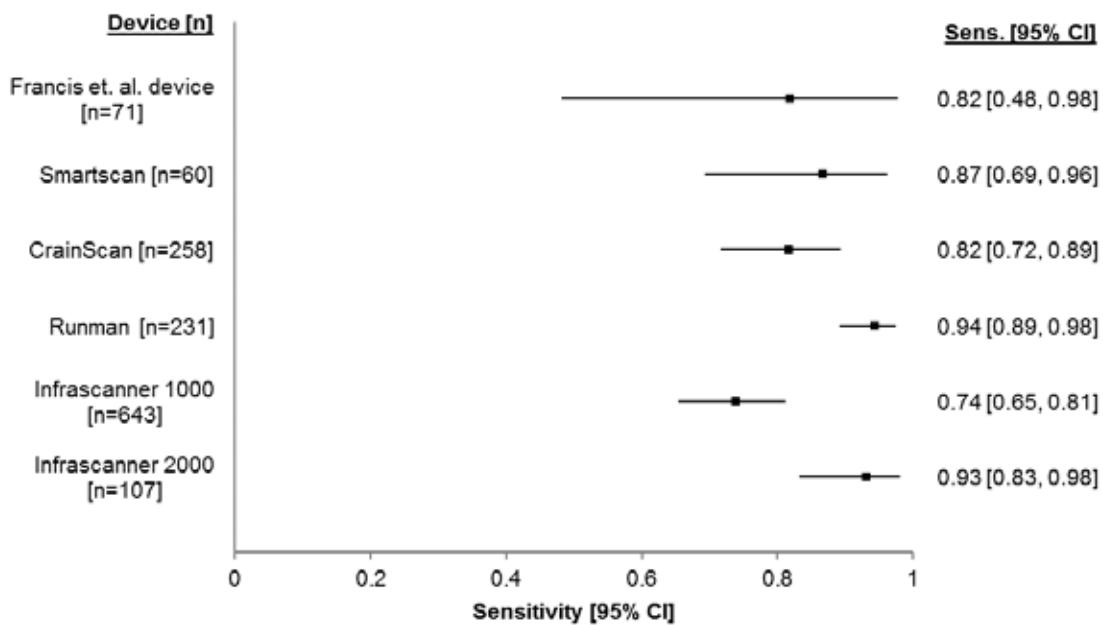
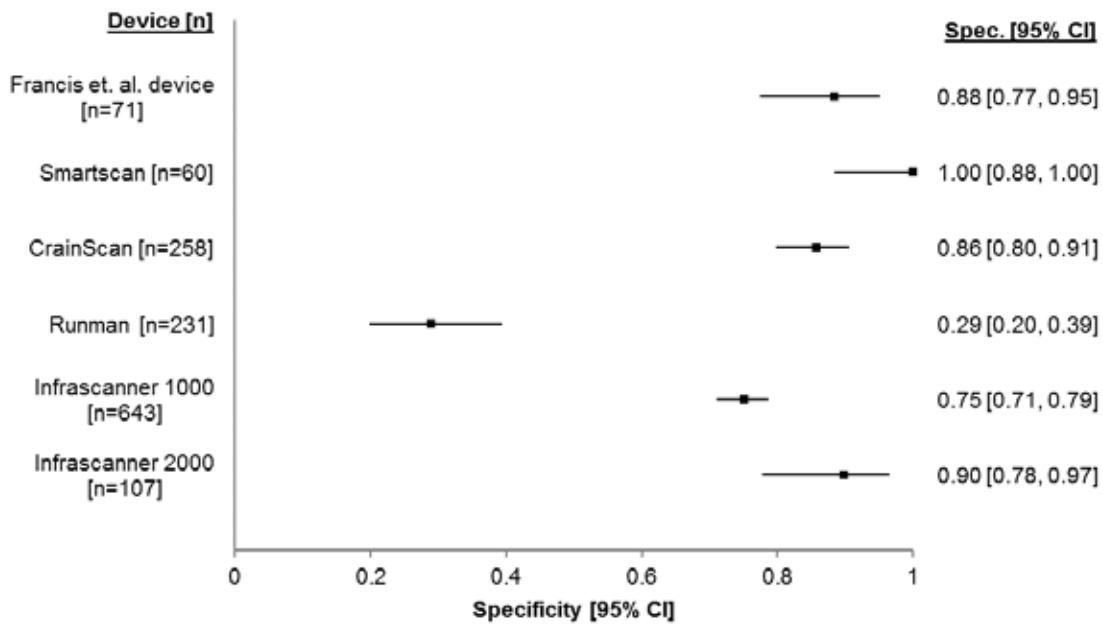
Abbreviation: NA= not applicable; cm= centimeter; ml= milliliter; SDH= subdural hematoma; EDH= epidural hematoma; SAH= subarachnoid hematoma

*This study only tested a population of patients with hematoma

†Model not reported, but is assumed to be the Infrascanner 1000 because it was the only model available at the time of the study

‡ESP calculated values from study data

§ESP calculated values differed from reported values (ESP calculated values are shown)

Figure 3: NIRS Sensitivity by Device**Figure 4: NIRS Specificity by Device**

KQ2: What is the evidence that use of NIRS impacts diagnostic and/or therapeutic decision-making for patients suspected of having a brain hematoma or with risk factors for brain hematoma?

The majority of studies (92%) did not report the impact of NIRS on clinical decisions. In one study of patients with severe injuries (mean GCS 6.9) evaluated in the pre-hospital setting, one patient received 10% hypertonic saline as an addition to initial treatment based on the results of a NIRS scan.³¹ In this study, patients underwent NIRS prior to or during transport to the hospital and use of NIRS did not lead to decisions to transport any patient to a different location than was originally intended.

KQ3: What is the evidence that use of NIRS to detect brain hematomas impacts patient outcomes?

The majority of studies (92%) did not report the impact of NIRS on patient outcomes. One study of Infrascanner© 1000 use in ED patients with mild TBI (GCS ≥ 13) in Turkey found that in-hospital outcome was not significantly related to use of NIRS ($p = 0.905$).²⁴

KQ4: What are potential adverse effects and unintended consequences of using NIRS for detection of brain hematoma?

No studies identified harms associated with the process of undergoing a NIRS scan. The scan itself is noninvasive and relatively quick to perform. Reported times to complete NIRS scans ranged from 2-4 minutes in studies of Infrascanner© 1000 and 2000 and did not interfere with delivery of usual care.^{14,24,31} Potential adverse effects of using NIRS are related to the possibility of false negative and false positive results as a function of the performance characteristics discussed above, as well as potential unintended consequences of transporting fewer patients to EDs.

KQ5: What is the cost-effectiveness of using NIRS for detecting brain hematoma?

No studies reported on the cost-effectiveness of NIRS. Several studies described NIRS as low cost, but did not include actual cost information.^{18,24,26}

KQ6: Do the effects of NIRS vary by patient population or setting?

The available evidence does not demonstrate whether the effects of NIRS vary by patient population due to limited reporting of patient baseline characteristics and injury severity. Most studies took place in the ED or hospital setting, limiting comparisons of NIRS across settings.

SUMMARY AND CLINICAL IMPLICATIONS

We found no studies that evaluated the use of NIRS among nursing home patients after falls to avoid unnecessary CTs. Instead, studies of NIRS have almost exclusively focused on demonstrating the technical feasibility of the device and its performance characteristics, providing little insight on how the use of NIRS impacts clinical decision-making, patient outcomes, and healthcare utilization. Moreover, studies of NIRS have mostly been in patients ≤60 years old in the ED or hospital setting, with largely unreported disease severity and baseline risk factors for intracranial hemorrhage, thereby limiting applicability of findings to older patients in nursing homes.

Given that the nominator's highest priority was to evaluate the clinical impact of NIRS in nursing home patients after falls, we acknowledge that we excluded studies on the development of NIRS as a diagnostic test that were not designed to evaluate NIRS performance characteristics or other clinical outcomes. While the earliest studies of NIRS have value in terms of understanding the principles of NIRS and how NIRS measurements (change in optical density) compare to CT findings, studies that did not define when a NIRS scan was considered positive or negative (*i.e.*, state a cut-off point for the change in optical density that indicates a positive scan) or report performance characteristics have lower clinical relevance.

Early studies³⁴⁻³⁸ on RunMan are examples in which the authors did not state how they defined a positive NIRS scan, thereby limiting the conclusions that can be drawn from these studies about the performance characteristics of NIRS as a diagnostic test. Given more time, we could request and analyze raw individual patient data from these studies³⁴⁻³⁸ to derive additional sensitivity and specificity data based on published detection thresholds for Crainscan/Smartscale and Infrascanner. However, additional data on performance characteristics would still not address the most significant limitation of the current literature base – the lack of outcomes related to the impact of NIRS on clinical decision-making and healthcare utilization including use of CT.

We also acknowledge that we excluded studies³⁵⁻³⁸ evaluating the use of serial NIRS scans in hospitalized TBI patients in order to detect late-onset hematomas. However, using serial NIRS to monitor patients who are hospitalized for head injury and/or have already been diagnosed with a hematoma or undergone surgery is a distinct clinical scenario with different reference tests (such as intracranial pressure monitoring) that has limited applicability to the nominator's priority population.

Potential harms of NIRS as a test for hematomas in nursing home patients after falls are primarily related to the possibility of obtaining a negative NIRS scan in a patient who truly has a hematoma in need of further intervention. Across studies, reasons cited for false negative results reflect known limitations of NIRS as an imaging technique. In general, currently available NIRS devices are not well-suited to identify bilateral hematomas, small hematomas, and deeply located hematomas with a greater distance from the scalp. It is unknown how many patients could be harmed by a false negative NIRS scan if NIRS is used to evaluate nursing home patients with mild injury after falls. Some small hematomas that would not be detected by NIRS, but would be identified by CT, are unlikely to cause symptoms or a further change in patient's function. Other small hematomas could expand over time causing symptoms and functional decline, and these hematomas would be important not to miss. In addition, there could be unintended consequences of fewer ED transfers, including strain on nursing home staff due to more frequent monitoring of

patients as well as missed opportunities to identify reasons for patient falls if they do not undergo more extensive testing in the ED.

LIMITATIONS

The evidence base included in this review has several important limitations. First, inconsistent reporting of patients' baseline characteristics and disease severity at presentation limits conclusions regarding NIRS performance among different patient populations. Second, mean patient age for all studies was \leq 60 years old and findings could therefore have limited applicability for elderly populations. Third, most studies were conducted in the ED or hospital settings rather than in a nursing home or other pre-hospital settings. Fourth, while the use of serial NIRS scans has been evaluated in hospitalized TBI patients including those who have already been diagnosed with hematomas or undergone surgery, the use of serial NIRS scans has not been evaluated in patients with mild injuries in the pre-hospital setting. Finally, the most significant limitation of the current literature base is a lack of outcomes related to clinical decision-making and impact of NIRS on healthcare utilization including use of CT.

In terms of our review methods, limitations include our literature search with exclusion of non-English studies, our use of second-reviewer checking in lieu of dual independent review, and our scope. Given our focus on use of NIRS among nursing home patients after falls, our results may have limited applicability to the use of NIRS in other patient populations and clinical scenarios.

FUTURE RESEARCH

Given concerns about overuse of CT and the potential benefits of NIRS as a diagnostic tool in nursing home patients with mild injuries after falls, it would be reasonable to consider implementation of a NIRS protocol in a pilot study among VA CLCs. A pilot could provide reliable estimates of CTs and ED transfers averted. However, because positive CT scans are rare in this situation, a much larger study (or decision modeling) would be needed to assess the frequency and clinical consequences of false negative NIRS scans.³ In addition to evaluating the use of a single NIRS scan as diagnostic tool at the time of injury, future studies should evaluate the performance of serial NIRS scans for monitoring nursing home patients after falls who are not transferred to the ED. NIRS can be performed repeatedly on the same patient without exposure to radiation or harms associated with the scan itself and results from a series of scans may prove to be more clinically useful than a single scan. VA Pittsburgh's experience using Infrascanner[©] 2000 could provide guidance for other facilities to develop clinical policies regarding NIRS.

To avoid some of the methodologic limitations of existing studies of NIRS, future studies should: a) report patients' baseline characteristics including age, risk factors for intracranial hemorrhage including use of anticoagulants, and degree of injury after falls including GCS scores, b) ensure blinding of radiologists reading CTs to NIRS results, and c) include only completed NIRS scans in results (thereby limiting the potential for over-reporting of false negatives).

Another gap in the literature is better characterization of how many elderly patients with mild injuries after falls undergo CTs that are negative and therefore could have been avoided.

³ For example, it would take a sample size of 811 to demonstrate 95% sensitivity and 95% specificity in a population with a hematoma prevalence of 9%, alpha =0.05, power= 0.80, and a margin of error of 5%.

Quantifying the rate of unnecessary CT use could strengthen the rationale for the use of NIRS as a tool to aid clinical decision-making for nursing home patients after falls.

CONCLUSIONS

Handheld NIRS devices offer a portable, noninvasive, and quick means of evaluating patients for the presence or absence of a brain hematoma with certain caveats, including the inability of NIRS to detect bilateral findings. NIRS has the potential to aid clinical decision-making in nursing home patients after falls when the need for head imaging is unclear. However, studies of NIRS to date have not been designed to evaluate the impact of NIRS in this clinical scenario.

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