Assessment of Accuracy, Precision, and Feasibility of a Handheld Near-Infrared Light Device (InfraScanner 2500™) in Detecting Traumatic Intracranial Hemorrhage in Uganda

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1. **Title**

   Assessment of Accuracy, Precision, and Feasibility of a Handheld Near-Infrared Light Device (InfraScanner 2500™) in Detecting Traumatic Intracranial Hemorrhage in Uganda

2. **Study Team**

<u>Duke</u>	
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3. **Purpose of the Study:** The purpose of this study is to determine the sensitivity, specificity, and positive and negative predictive values of the portable near-infrared-based device (portable NIR-based device), the InfraScanner 2500™, to detect intracranial hemorrhage (ICH) secondary to trauma patients presenting to Mbarara Regional Referral Hospital (MRRH) and Mayanja Memorial Hospital (MMH) who have sustained or who are suspected of having sustained head trauma.

4. **Background and Significance:** In 2018, an estimated 69 million individuals sustained traumatic brain injury (TBI), with the majority of cases originating in LMICs.[1,2] With approximately 90% of all injury-related vehicular deaths occurring in LMICs, this already enormous chasm in mortality is expected to only grow wider as obtainability of personal motor vehicles burgeons at rates far exceeding LMIC faculties to build legislatorial, municipal, and medical infrastructure capable of subsiding growing incidence of TBI.[3] Sub-Saharan Africa's unprecedented scarcity of medical resources is especially prominent in neurological care. As of July 2023, there are 0.15 neurosurgeons per 100,000 Africans.[4] This can be contrasted with Europe where, per 100,000 citizens, there exist 17.1 neurological beds, 4.84 neurologists, and 2.43 neurosurgeons – a respective 57, 161, and 16-fold resource disparity between these two continents. Even when compared to global averages, to which Africa and myriad other LMICs contribute, per capita, the world's population benefits from greater than 12 times more neurological beds, 30 times more neurologists, and 56 times more neurosurgeons per capita than the average African.[5]

   In Uganda, a low-income country in East Africa, TBI mortality was estimated to be 9.6%, with mortality rates of 4.7% for patients with mild and moderate TBI and 55% for patients with severe TBI in 2016.[6,7] In Uganda, motorbikes pervade the landscape with motorbike accidents contributing to a majority of the country's TBI. Between 2010 and 2017, Mulago National Referral Hospital saw a doubling of fatal road traffic injuries, from 11.6% to 22.8%.[8] Based upon the limited literature regarding TBI within SSA, Uganda experiences among the highest rates of TBI and TBI-related mortality in the world. Mortality outcomes at MRRH are high, [6]

where as much as 50.4% of deaths at a secondary referral hospital in Uganda were found to be due to trauma, with a 7.4% mortality rate for those admitted. Head trauma, specifically, represented 68% of all trauma deaths and 34.3% of all deaths overall.[9] A recent study conducted in the intensive care unit (ICU) at Mbarara Regional Referral Hospital (MRRH), which serves the Western Region of Uganda, northern Rwanda, eastern Democratic Republic of Congo, and northwestern Tanzania, revealed that head injury accounts for 74% of adult and 69% of pediatric trauma cases, with an overall mortality of 60% for patients admitted to the ICU with head trauma.[6] For comparison, a 2006 UK study showed that in head injury patients requiring intensive care, 77% survived to leave the ICU and 67% survived to leave hospital, an ICU mortality rate nearly three-fold less than that seen in Mbarara.[10] A 2014 Finish study with a similar ICU survivability of 79%, reported an additional 12% mortality in the same population at 6-months. While no long-term TBI survivability data exists for LMICs, granted such significant post-discharge fatality in settings replete with vanguard healthcare resources and armed with robust long-term nursing and rehabilitative capacities. Limited transportation and emergency services infrastructure compound existing challenges to CT accessibility.[11] Unfortunately, CT scanners are currently a modality of considerable financial burdens for both patient and governmental sectors. With the amount of lives lost due to inaccessibility of immediate brain imaging in LMICs, it is imperative to identify and validate cost-effective alternatives to CT scans.

In resource-limited settings, techniques such as ultrasonic measurement of the optic nerve sheaths and latency of the pupillary reflex have been used to infer increased intracranial pressure (ICP). However, these techniques are notably crude as they provide no insight into the location or etiology of the increase in ICP. Optic nerve ultrasound is typically positive only once ICP >30 mmHg (normal 7-15 mmHg)[12] but is notably poor at correlatively quantifying ICPs as they grow emergently high. Optic nerve sheath diameter measurements take up to a day to manifest, long after irreparable brain damage has occurred. Hence, while these modalities can corroborate increased patient ICP, these techniques are inadequate in determining which patients stand to benefit from surgery within a reasonable timeframe and, for those who do, in informing the surgical approach that could save such a patient's life.

In 1997, the first ever handheld device that could definitely detect the presence and location of epidural and subdural hematomas was introduced. Initially named the Runman, the device was intended to detect intracranial hematomas in remote and military settings to triage which casualties should be airlifted to medical centers equipped to offer neurosurgery. After numerous iterations, the InfraScanner 1000™ was introduced in the mid-2000s. In 2010, the pivotal five-site double-blinded clinical trial was published and ultimately led to FDA clearance of the InfraScanner 1000™. In the study, the Infrascanner 1000™ measurements were compared to CT scans of 365 patients, 96 of which were hematoma cases of various sizes, depths, and locations. The study demonstrated high sensitivity (88%) in detecting hematomas > 3.5cc in volume and < 2.5 cm from the surface of the brain and a specificity of 91%. Since then, there have been numerous studies that have replicated these results and have substantiated that it is a capable tool for prehospital diagnosis of intracranial hematomas (3-13). While these results are promising, the InfraScanner devices' utility has only been examined through the lens of pre-hospital decision-making.

In 2013, the InfraScanner 2000™ was introduced, prompting our group to validate it in a consecutive series of 500 head injury patients who obtained a head CT scan at Duke University Hospital (DUH). For all patients with CT-proven bleeds (n=104), irrespective of size, initial NIR scans localized the bleed to the appropriate quadrant with a sensitivity of 86% and specificity of 96% compared to a CT scan. For extra-axial bleeds >3.5ml, sensitivity and specificity were 94% and 96%, respectively. For longitudinal serial rescans with the NIR, sensitivity was 89% (<4 days from injury: sensitivity=99%) and specificity was 96%. The device demonstrated 100% sensitivity for all patients requiring craniectomy or craniotomy.

Since the DUH study, our group initiated a study of 684 TBI patients at Mbarara Regional Referral Hospital (MRRH) in Uganda using the InfraScanner 2000™. For all patients with CT-proven bleeds (n=180), irrespective of size, initial NIR scans localized the bleed to the appropriate quadrant with a sensitivity of 89% and specificity of 38% compared to a CT scan. These findings greatly differ from the DUH data set, prompting our team to conduct a secondary analysis of the MRRH data. We found evidence to suggest that skin tone variance, among other patient characteristics, affects the accuracy of the near-infrared-based device.

Previous literature for similar technology, such as pulse oximetry, has suggested an overestimation of SpO2 in dark-skinned individuals.[13–15] In dark-skinned individuals, the skin attenuates near-IR more,[16] and results in more variability in the signal readback. [13] These combined can contribute to a weaker detection by the Infrascanner 2000™ sensor and hence over-estimation of SpO2. In the Infrascanner 2000™, this higher near-IR attenuation due to the dark color of the skin could have been the source of a positive readout. This may account for the amount of false positive results encountered. This study will document and aim to include representation of populations with darker skin tones within medical device development, a matter that extends beyond NIR.[17–20] By addressing racial inequities within device research and developments, we can strengthen their applicability in limited-resource contexts. The sensitivity and specificity of the newer InfraScanner 2500™, with its new algorithms adjusting for skin tone variance, have not been rigorously studied. With these results, the Duke Global Neurosurgery and Neurology (DGNN) proposes to initiate a trial to replicate our DUH findings in an LMIC: using the Infrascanner 2500™ in the background of the current standard of care to quantify the accuracy of the device – the positive and negative predictive values – in diagnosing traumatic ICH relative to CT in the Ugandan setting.

The proposed study addresses the critical need for evaluating and optimizing the handheld near-infrared device's (NIR) performance in diagnosing intracranial bleeds within the diverse skin tone range prevalent in low- and middle-income countries (LMICs), such as Uganda. This research is essential to ensure that NIR can be a highly sensitive, specific, and reproducible tool across all populations, regardless of skin tone. Given the higher prevalence and mortality rates associated with TBI in LMICs,[1,2] coupled with limited healthcare resources and the lack of access to CT scans,[21] the successful adaptation of NIR technology for use in these settings could improve TBI management and inform neurocritical and neurosurgical evidence-based decision making in settings where CT scanning is unavailable or impractical. To work toward this, this study proposes to validate the high sensitivity, specificity, accuracy, and precision of the InfraScanner 2500™ in detecting traumatic intracranial bleeds we have previously demonstrated with InfraScanner 2000™ at DUH, in patients presenting to MRRH and MMH.

If able to detect intracranial hematomas with efficacy similar to CT in the Ugandan patient population, this data can be used to formulate a future trial using the device as a diagnostic tool to inform surgical management for patients in which obtaining CT scans is not feasible.

Aim 1: Determine whether the InfraScanner 2500™ detects intracranial hemorrhage (ICH) with adequate precision relative to CT scans to be used as an effective triage tool to prioritize imaging and need for level of clinical monitoring in an African, LMIC population.

Aim 2: Use these findings to evaluate the InfraScanner 2500™s ability to accurately detect intracranial hemorrhages in darker-skinned populations within LMICs.

Setting: In Uganda, as of 2019 there are 55 ICU beds making up a ratio of 1.3 ICU beds per million population.[22] 12 government neurosurgeons,[23] and 11 trained neurologists to serve, [24] not accounting for the significant international referrals received from neighboring countries, the entire population of 47.2 million people.[25] Mbarara Regional Referral Hospital (MRRH) is a government owned referral and teaching hospital for Mbarara University of Science and Technology medical school with a bed capacity of 600. Mayanja Memorial Hospital (MMH) is a private, not-for-profit hospital with 100 bed capacity in Mbarara, Uganda.

5. **Design, Procedures, and Methods:**

A prospective cohort study is to be conducted at the MRRH Division of Neurosurgery and Mayanja Memorial Hospital (MMH) from May 2024 until May 2025 or until our sample size has been met. Prior to the study, approval from the following institutions and administrations will occur; Duke University IRB approval, Mbarara University of Science and Technology (MUST) IRB approval, Uganda National Council for Science and Technology (UNCST) approval, and administrative approval from both hospitals will be collected.

Methods & Procedures

When applicable (conscious patient and/or family or legally authorized representative (LAR), the study will be introduced to the patient and relevant parties before the research team approaches the patient. While head trauma frequently results in impaired cognition and/or consciousness, and due to the urgency of these circumstances, patients are often not accompanied by kin, whenever appropriate, the purpose of the research and the procedure will be explained in detail using an IRB-approved verbal consent "script", with all questions answered to the patient's and/or representative's satisfaction.

Upon presentation to the casualty unit at MRRH or MMH and/or within 30 minutes prior to or following a CT scan, the study team will approach the patient or the patient's LAR for permission to scan the patient's cranium with the InfraScanner 2500™ (Image A). If permission is granted, the study team member will sequentially measure the optical absorption for each of the 8 quadrants of the scalp (frontal, temporal, parietal, and occipital bilaterally) (**Image B**). The device is engineered such that the light emitter and receiver are spaced 4 cm apart, allowing the light's intensity to be measured between adjacent light guides (**Image C**). Parting combs will be used to help access the scalp on patients with hair that prevents the fiberoptic tips from direct contact with the scalp. A laminated swatch displaying Monk Skin Tone Orbs will be used for later analysis of skin tone on the Monk Skin Tone Scale (**Image**

D).[26] This entire procedure, including greeting, scanning the patient, should take <10 minutes. Basic demographics, neuro exam, and InfraScanner 2500™ data will be entered into REDCap (Appendix A).

The collection period for each research subject concludes within 30 days following his or her initial consent, patient or LAR decision to withdraw from further participation, hospital discharge, or patient death, whichever occurs first.

6. **Eligibility:** Any patient aged 12 and up who presents to Mbarara Regional Referral Hospital (MRRH) or Mayanja Memorial Hospital (MMH) with suspected head trauma, who is able to or who has a LAR who is able to consent in English, Runyankole, or Luganda will be considered for this study. After being made aware of the study by a physician directly caring for the patient and agreeing to hear more about the study, the prospective participant and/or the participant's LAR will be approached.

7. **Exclusion:** Patients for which wounds to their head are too large to properly use the InfraScanner 2500™ will be excluded from this study. Patients will also be excluded if hair cannot be appropriately parted to allow for the fiberoptic tips of the device to make direct contact with the scalp. Patients for whom it is not possible to obtain an Infrascan within 30 minutes of their CT imaging will also be excluded from the study.

8. **Subject Recruitment and Compensation:** Potential research participants will be approached by the research team only if given permission by the physician in charge of the patient's care after he or she has informed the patient and/or the patient's LAR of the research and received a verbal agreement from the patient and/or LAR to hear more about the research study. Each participant will be compensated UGX 15,000 ($4) for participation in this study. The study personnel will be trained in the consent process and will make it abundantly clear that agreement or refusal to participate in the study will not influence the patient's care in any way.

9. **Consent Process:** After being made aware of the study by a physician directly caring for the patient and agreeing to hear more about the study, the prospective participant and/or the participant's LAR will be approached. Upon admission to MRRH for suspected head trauma, the patient's physician will introduce the patient or the patient's legally authorized representative to the presence of the study. If the consenting party agrees to hear about the study, the study coordinator or research assistant will greet the patient and speak with the patient and/or legally authorized representative, thoroughly describing the protocol and reason for the study. All consenting study personnel will be trained in the consent process and will provide ample reassurance to the patient or consenting party that the decision to participate will not, in any way, affect his/her medical care. Care will be taken to thoroughly answer all questions prior to obtaining final consent. The patient and/or legally authorized representative will be clearly informed that the research protocol is completely optional, that participation will not affect the treatment they receive, and that, should they give consent, they are free to withdraw from the study at any time. Participants will have the opportunity to decide on their involvement in the study up until they receive their first CT scan at either hospital, provided this decision is made before the end of the 30-minute post-scan window. If they do not consent

before their first CT scan and outside this 30-minute timeframe, they will be ineligible for inclusion in the study. Participants will be afforded time to withdraw from the study up until 30 days following initial consent or are discharged from medical care. The consent process will occur in the casualty unit at MRRH and MMH or the MRRH intensive care unit (ICU). The study team will be readily available to the patient, legally authorized representative, and/or patient's relatives throughout the study for any questions or concerns they may have.

10. **Subject's Capacity to Give Legally Effective Consent:** We expect that most of the subjects will be neurologically and/or cognitively impaired due to the extent of head injury, multisystem trauma, and/or medical treatments. Since this is a minimal-risk study, we will offer study participation to subjects with diminished abilities if they have a legally authorized representative. For patients with less severe injuries and those who are later hospitalized with resolving injuries, we expect subjects to be cognitively intact and capable of autonomously making decisions about their routine medical care. For such patients, they can consent without the need for a legally authorized representative. The study will also be offered to patients 12 years of age and older. For patients younger than 18 years, we will obtain assent from the subject, when he or she is cognitively able, and consent from their legal representatives or parents.

11. **Study Interventions:** As described above, within 30 minutes of each CT scan, the study team will scan the study subject's cranium with the InfraScanner 2500™. The previous model, InfraScanner 2000™ (**Image A**), shows the size of the noninvasive fiberoptic tips that make contact with the scalp. The InfraScanner 2500™ has an improved algorithm embedded in the new software, while the hardware mechanisms of detection remain unchanged between the InfraScanner 2000™ and InfraScanner 2500™ models. The study team member will use the device to sequentially emit light through fiber optic light guides rested upon the patient's scalp so that near-infrared light can be emitted in each of the quadrants (**Image B**). The device is engineered such that the light emitter and receiver are spaced 4 cm apart, allowing the light's intensity to be measured between adjacent light guides (**Image C**). This entire procedure should take <10 minutes.

12. **Device Description/Mechanism:** The following description is adapted from the InfraScanner White Paper [27] : All biological tissue is, to a 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 as X-ray, CT, 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 (**Image C**).

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 the left and right sides 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. With specified wavelength ranges, optical light source(s) or emitter(s) and a photodetector are placed at a distance, allowing proper NIRS absorption measurements in a desired tissue volume. The wavelength of 805 nm is sensitive only to blood volume, not oxygen saturation (**Image E**).

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. Specifically, the placement is as follows:

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 (Image B).

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 IN = the intensity of reflected light on the normal side, IH = the intensity of reflected light on the hematoma side.

In summary: 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 optical fibers are placed 4 cm apart, allowing optimal detection of hematomas. The extended fiber optics eliminates the need to shave off any hair. And because the fiber optic piece is disposable, it prevents cross-contamination. The detected light passes through an optical NIR band-pass filter in order to minimize background light interference. Electronic circuitry is included to control laser power and the detector signal amplifier gain. The detector signal is digitized and analyzed by a single board computer, SBC, in the Scanner. The SBC receives the data from the detector and automatically adjusts the settings of the Scanner to ensure good data quality. The data is further processed by the SBC, and the results are displayed on the screen. A 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. [27]

13. **Risk/Benefit Assessment:** There are no known health risks associated with the use of NIR. All data obtained with the Infrascanner 2500™ will be blinded from physicians participating in the care of study patients to ensure there is no deviation from the standard of care. While there are neither any specific direct clinical benefits to the research participant through participation in this study, the involvement may provide significant future benefits to the community and enhance TBI care in Uganda and LMICs globally. This contribution to advancing medical knowledge and improving TBI management strategies underscores the importance of participation. Participants will be compensated approximately UGX 15,000 ($4 USD) for their contribution to this valuable research effort.

14. **Costs to the Subject:** No additional costs to the patient will be incurred as a result of this add-on research protocol.

15. **Statistical Considerations:** Objectives: The primary objective of this study is to estimate the test characteristics (sensitivity, specificity, and the false positive and false negative rates) of the portable NIR-based device (InfraScanner 2500™) in the identification of any size hematoma among patients hospitalized at MRRH or MMH who have sustained or who are suspected of having sustained head trauma. CT scan results will serve as the gold standard. The sensitivity, specificity, and false positive and false negative rates will be estimated. Continuous variables will be summarized with means/medians, standard deviations, and ranges, and will be analyzed using one-way analysis of variance (ANOVA). Categorical variables will be summarized with frequency counts and percentages and analyzed using the χ^2 test or Fisher's exact test where appropriate. Sensitivity, specificity, false-positive, and false-negative values will be calculated for InfraScanner 2500™ versus CT as a gold standard, with an estimated 95% confidence interval (CI). Receiver operating characteristic (ROC) curves and area under the curve (AUC) with 95% CI will be plotted. Logistic regression will be fit to examine the association between InfraScanner 2500™ results (conditioned on CT results) and potential confounders such as age, sex, skin color, hair length, hairstyle, skull fracture, scalp laceration, polytrauma, and scalp hematoma. Minimum blood volume detected as positive by InfraScanner 2500 (minimum resolution) will be reported. All statistical tests will be two-sided, and significance will be assessed at $\alpha = 0.05$. Analyses will be performed using R (Boston, MA).

    A secondary objective is to estimate the test characteristics of the InfraScanner 2500™ in the identification of hematomas within its detection limits (volume >3.5 mL and depth <2.5 cm) compared to CT scan results as the gold standard.

    Exploratory objectives include:

    1. Examining the impact of factors such as hematoma type, location, patient age, and skin tone on test characteristics of the InfraScanner 2500™
    2. Determining the minimum resolution detectable by the InfraScanner 2500™
    3. Analyzing the effects of extracranial hematomas, lacerations, and swelling on the device's performance characteristics
    4. Estimating Receiver Operating Characteristic (ROC) curves

    Study Design:

a) Eligibility:
Any patient aged 12 and up who presents to MRRH or MMH with a suspected head trauma scan will be considered for this study. Based on previously reported data, we expect that true hematoma will be present in approximately 46% of participants overall.[28]

b) Standard of comparison:
All patients entered into the trial will have undergone one cranial CT scan prior to enrollment and will be consented for the study. All patients enrolled will undergo one cranial scan using the InfraScanner 2500™ within 30 minutes of the CT scan. Patients and care providers will be blinded to the results of InfraScanner 2500™. The standard for comparison will be determined as follows. A CT result that is positive for hematoma will be considered a true positive, and a CT result that is negative for hematoma will be considered a true negative.

Definitions of Sensitivity, Specificity, False Positive, False Negative:
Let T^+ denote the event that the test is positive for hematoma, and D^+ denote the event that a hematoma is present. Sensitivity, $P(T^+/D^+)$, will be defined for each patient's InfraScanner results as the probability that a true hematoma, as determined by a CT scan, will be detected. Similarly, let T^- denote the event that the test is negative for hematoma and D^- denote the event that a hematoma is not present.[29] Specificity, $P(T^-/D^-)$, will be defined as the probability of being negative for a hematoma on the InfraScanner 2500™ scan within 30 minutes of CT given the patient has no hematoma present.

The false positive rate will be defined as $P_{F+} = P(D^-/T^+) = P(T^+/D^-)[1-P(D^+)]/P(T^+)$. Similarly, the false negative rate will be defined as $P_{F-} = P(D^+/T^-) = [1-P(T^+/D^+)]P(D^+)/[1-P(T^+)]$. Estimates for the false positive and false negative rates will be provided for a range of values for the prevalence of hematomas.

c) Sample Size
Computation of the required number of patients is based on estimating the sensitivity of each method to within at most +/- 0.099 with 95% confidence. The 95% confidence interval for the sensitivity based on previous findings,[28] and the sample size calculator provided.[29,30]

With 84 patients with positive findings of hematoma (i.e. CT-proven ICH), sensitivity can be estimated to be within at most +/- 0.099 with 95% confidence. [31] Assuming 46% of patients have true hematomas detected, [28] 171 patients who obtain CT scans must be accrued. Accounting for this, and allowing for a 5% dropout rate the required sample size for this trial is **180** total subjects.[29,30] We estimate that 50% of TBI patients will obtain CT scans, thus approximately 360 TBI patients will present to MRRH and/or MMH to reach our desired sample size.

d) Recruitment and Retention

It is anticipated that of all participants >12 years of age that present with suspected TBI, at least 40 patients per month will be accrued . Study enrollment should thus be completed within approximately 10 months. The collection period for each research subject concludes within 30 days following their initial consent, patient or LAR decision to withdraw from further participation, hospital discharge, or patient death; whichever occurs first.

16. **Data and Safety Monitoring:** Patients will be under continuous supervision during the entirety of each data collection period. Outside the ~10-minute window of the data collection period, the patient is not subjected to any research intervention or influenced by the research in any way. As part of their treatment, patients will be under hospital care for the diagnoses for which they were admitted, and the research team will be in continual contact with the team regarding their clinical status and enrollment in the study.

    The PI will be responsible for securing and monitoring the data, including a quarterly review of data storage procedures.

17. **Privacy, Data Storage, and Confidentiality:** Patients will be numbered as experimental subjects. Data will be stored in a secure database. For analysis, data will be fully de-identified. Experimenters' notes will be stored in a locked cabinet in the PI's office in the Department of Neurosurgery and in digital form on the DHTS-maintained server.

18. **Limitation of study**
    This study will not include patients whose injuries impede the use of the device onto the scalp which may exclude TBI cases of greater severity, potentially biasing results towards less severe TBI cases.

ABBREVIATIONS LIST

MRRH - Mbarara Regional Referral Hospital

MMH - Mayanja Memorial Hospital
TBI - Traumatic Brain Injury
LMIC - Low- and Middle-Income Country
SSA- Sub-Saharan Africa
DUH - Duke University Hospital
DHTS - Duke Health Technology Solutions
CT - Computer Tomography
SpO2 - Oxygen Saturation
SBC - single board computer
LAR - family or legally authorized representative

Image A - Display of Infrascanner device with example of fiber-optic tips making contact with scalp. 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 optical fibers are placed 4 cm apart

Image B - Head location of Infrascanner Measurements. 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.

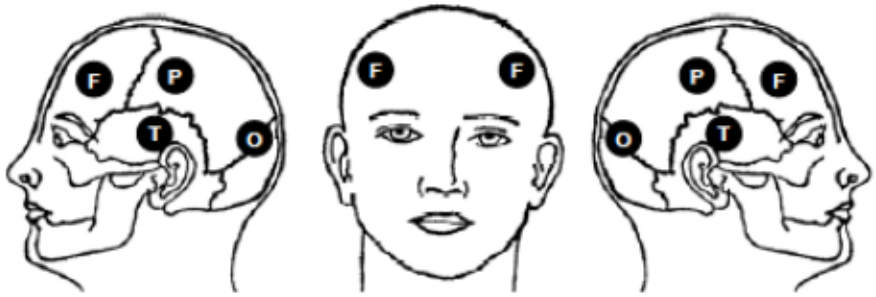
Image C - Depiction of light path from fiber optic source through the scalp intermediate tissue and through the fiber optic detector. From any light source, photons follow a characteristic path through the target tissue back to a detector on the same approximate plane as the source. While the light is 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.

Image D - The scale skin tone will be measured against with 1 being the lightest and 10 being the darkest

Image E - The blue line depicts the detected NIR wavelength at 805 nm and the absorption factor is displayed to be sensitive only to blood volume at 805 nm.

Image A

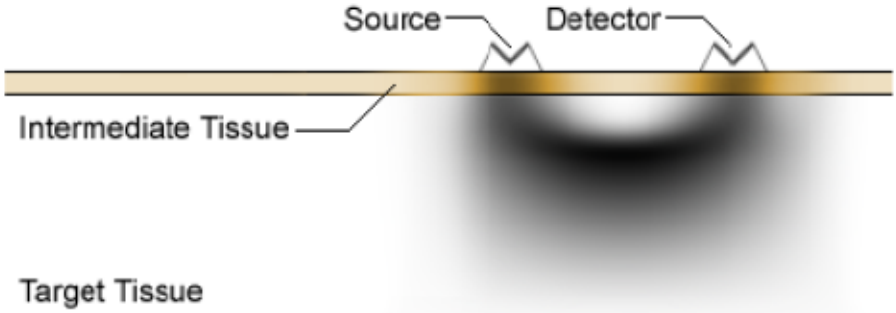
Image B



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

Image C



Simulated photon diffusion path through target tissue from source to detector.

Image D - **MONK SKIN TONE SCALE (1-10)**

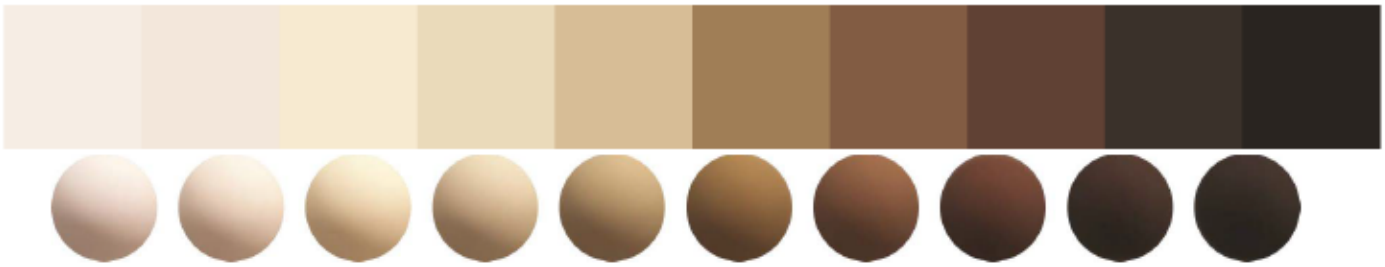
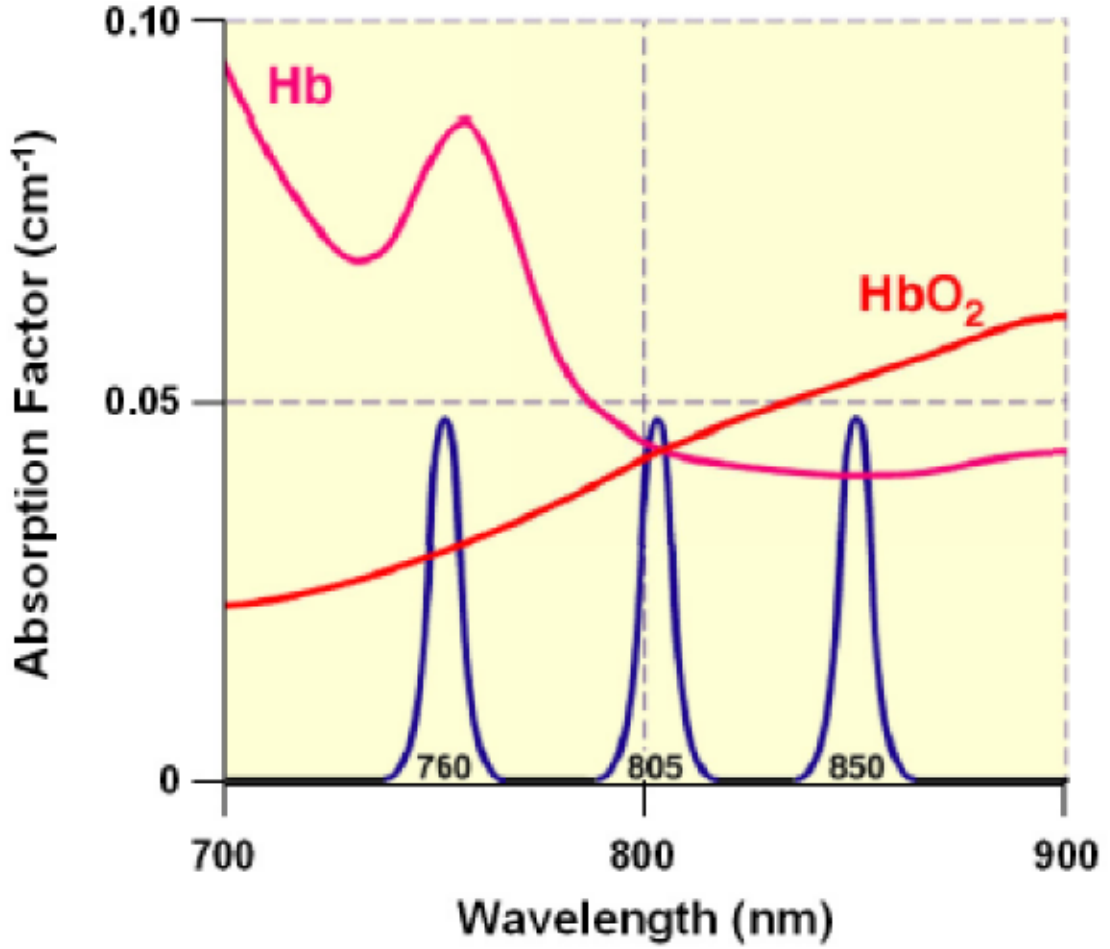


Image E



Absorption of light by oxygenated and deoxygenated hemoglobin

Appendix A

Variable	Type	Description	FITBR Harmonization-Variable Name
finished	T/F	Details if the survey was completed	
ra	Text Entry	Name of Research Assistant completing the survey	
name	Text Entry	Name of patient	
id	Text Entry	Study ID number of patient	SubjectIDNum
age	Numeric	Age of patient	AgeYrs
sex	M/F	Sex of patient	GenderTyp
skin tone	Numeric	Monk Skin Tone Scale (1-10)	
region	Dropdown	Region of Uganda where patient lives	CntryResdnceName
district	Dropdown	District of Uganda where patient lives	
country_other	Text Entry	Country of residence if not Uganda	CntryResdnceName
study_site	Dropdown	Name of site where patient enrolled	SiteName
admit_month	Dropdown	Month of admission	VisitDate
admit_day	Dropdown	Day of the month of admission	VisitDate
admit_year	Dropdown	Year of admission	VisitDate
admit_hours	Numeric	Hour of admission (using 24 hour timing)	ScreenVisitDateTime
admit_mins	Numeric	Minute of the hour of admission (up to 59 mins)	ScreenVisitDateTime
temp	Numeric	Temperature on admission	
admit_eye	Numeric	Admit GCS eye opening	GCSEyeRespnsScale
admit_verbal	Numeric	Admit GCS verbal	GCSVerbalRspnsScale
admit_motor	Numeric	Admit GCS motor	GCSMotorRespnsScale
admit_gcs	Numeric	Admit GCS total	GCSTotalScore
neuro_month	Dropdown	Month of neuro exam	
neuro_day	Dropdown	Day of the month of neuro exam	
neuro_year	Dropdown	Year of neuro exam	
neuro_hours	Numeric	Hour of neuro exam (using 24 hour timing)	
neuro_mins	Numeric	Minute of the hour of neuro exam (up to 59 mins)	

infra_eye	Numeric	Infrascanner GCS eye opening	GCSEyeRespnsScale
infra_verbal	Numeric	Infrascanner GCS verbal	GCSVerbalRspnsScale
infra_motor	Numeric	Infrascanner GCS motor	GCSMotorRespnsScale
infra_gcs	Numeric	Infrascanner GCS total	GCSTotalScore
injury_month	Dropdown	Month of TBI	InjDateTime
injury_day	Dropdown	Day of the month of TBI	InjDateTime
injury_year	Dropdown	Year of TBI	InjDateTime
injury_hours	Numeric	Hour of neuro exam (using 24 hour timing)	
injury_mins	Numeric	Minute of the hour of neuro exam (up to 59 mins)	
hair_scalp_access	Y/N	hair status occuldes access to scalp	
hair_scalp_access_reason	Text Entry	Text entry if hair status did not allow for access to scalp	
trauma	Dropdown	Cause of trauma	
trauma_other	Text Entry	Text entry if cause of trauma was not listed	
polytrauma	Y/N	Polytrauma present	
rta	Dropdown	Cause of road traffic accident	
rta_other	Text Entry	Text entry if cause of RTA was not listed	
scalp	Y/N	Scalp or face hematoma present	
scalp_text	Text Entry	Location of scalp or facial hematoma	
facial_bleed	Multi-select	Bleeding from eyes, ears, or nose present	
skull	Y/N	Skull fracture present	
skull_bones	Multi-select	Location of skull fracture	
scalp_injury	Y/N	Open scalp injury present	
surgery_planned	Y/N	A surgery was planned	
surgery	Y/N	A surgery was completed	
surgery_month	Dropdown	Month of surgery	
surgery_day	Dropdown	Day of the month of surgery	
surgery_year	Dropdown	Year of surgery	
surgery_type	Multi-select	Type of surgery performed	
surgery_type_other	Text Entry	Text entry if surgery type not listed	

ct	Y/N	A CT was completed	
ct_month	Dropdown	Month of CT	
ct_day	Dropdown	Day of the month of CT	
ct_year	Dropdown	Year of CT	
ct_hours	Numeric	Hour of CT (using 24 hour timing)	
ct_mins	Numeric	Minute of the hour of CT (up to 59 mins)	
ct_no	Multi-select	Details why a CT was not completed	
ct_no_other	Text Entry	Text entry for no CT if not listed	
infra_1_month	Dropdown	Month of first infrascanner	
infra_1_day	Dropdown	Day of the month of first infrascanner	
infra_1_year	Dropdown	Year of first infrascanner	
infra_1_hours	Numeric	Hour of first infrascanner (using 24 hour timing)	
infra_1_mins	Numeric	Minute of the hour of first infrascanner (up to 59 mins)	
infra_1_positive	Y/N	First infrascanner with a positive result	
infra_1_frontal	Numeric	First infrascanner numeric result in frontal area	
infra_1_parietal	Numeric	First infrascanner numeric result in parietal area	
infra_1_temporal	Numeric	First infrascanner numeric result in temporal area	
infra_1_occipital	Numeric	First infrascanner numeric result in occipital area	
outcome_month	Dropdown	Month of outcome	
outcome_day	Dropdown	Day of the month of outcome	
outcome_year	Dropdown	Year of outcome	
outcome	Dropdown	Outcome of patient	
disc_eye	Numeric	Discharge GCS eye opening	GCSEyeRespnsScale
disc_verbal	Numeric	Discharge GCS verbal	GCSVerbalRspnsScale
disc_motor	Numeric	Discharge GCS motor	GCSMotorRespnsScale
disc_gcs	Numeric	Discharge GCS total	GCSTotalScore

gose	Numeric	GOSE on discharge	GlasgowOutcomeScalExtScore
ct_pos	Y/N	CT with positive findings	
ct_fl	Dropdown	Type of bleed on CT frontal left	
ct_fr	Dropdown	Type of bleed on CT frontal right	
ct_pl	Dropdown	Type of bleed on CT parietal left	
ct_pr	Dropdown	Type of bleed on CT parietal right	
ct_tl	Dropdown	Type of bleed on CT temporal left	
ct_tr	Dropdown	Type of bleed on CT temporal right	
ct_ol	Dropdown	Type of bleed on CT occipital left	
ct_or	Dropdown	Type of bleed on CT occipital right	
ct_loc	Dropdown	Location of bleed on CT	
ct_sz	Y/N	Size within device limits	
ct_depth	Y/N	Depth within device limits	

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