P416 Generative-AI-Based Simulation of Electroencephalogram (EEG) to Formulate Personalized Migraine Therapy

Introduction:

Migraine headache is the most common neurological disorder and one of the most common pain conditions. Despite its high prevalence, the basic physiology and underlying factors contributing to the development of migraine headache is still poorly understood. Safe and effective management of migraines requires a personalized approach to treatment, which is fundamentally hampered by the lack of individual migraineurs' data because the current clinical diagnosis does not routinely incorporate specific diagnostic tests/measurements. This creates the vicious cycle where an absence of patient data causes unindividualized suboptimal treatment, which in turn generates more migraine patients. Societal burden incurred due to the mismanagement or suboptimal treatment is substantial.

Objectives:

This project aims to reproduce patient- and context-specific electroencephalogram (EEG) signals, to help more effectively manage migraine, by treating migraine patients with personalized neuromodulation therapy. Specifically, the proposed work aims to:

1) Simulate migraineurs' EEG signals by using an advanced generative-AI model, as well as simultaneous EEG-fMRI multimodal dataset for epilepsy (1 – 8 months): Our use of the epileptic EEG-fMRI data to train for the AI model, instead of migraine EEG, which is practically difficult to obtain, will be justified, and validated against known biomarkers (i.e., EEG signatures and brain coherence changes with migraine) for the completion of this aim.

2) Generate a larger pool of EEG signals reflecting patient- and context-specific information of individual migraine patients: Creating plausible variations in the AI-generated EEG signals is important to later apply to specific patient profiles for predictive signal generation, or to short and low-resolution EEG measurements for signal extrapolation. For clinical validation of the generated pool of EEG signals, this project will use a combination of open-source modules to automatically detect abnormality in EEG signals and let those detected to be reviewed by clinicians for confirmation.

3) Formulate adaptive neuromodulation protocol targeted at each individual patient and his/her own context of migraine episode: It will build an adaptive personalized treatment protocol for electrical neuromodulation, and have it reviewed by clinical experts in terms of patient safety. For a detailed analysis of post-treatment effects on the brain's electric field, a Multiphysics simulation (COMSOL software) will be used.

Clinical trial of the personalized protocol is beyond the scope of this project and will be carried out through the future support of external funding.

Methodology: Our generative-AI model will expand the generative adversarial network (GAN) for EEG with an additional neural network to infer the causal dynamics between electrical activities of neurons and cerebral blood flow in the brain, and the model will be trained using simultaneous multimodal EEG-fMRI data. In addition, the model will be integrated with the adaptive neural-fuzzy network (ANFIS), which will allow fuzzy information as input to the model, to help generate patient-specific variations to the EEG signals. In process, we will keep the validation and sample-generation functions in one loop, to allow clinical experts (or automated anomaly detection algorithm) to examine the causal dynamics of electrical activities and local blood flow, for enhanced explain-ability of our AI architecture. This validation-generation loop will also help extrapolate on insufficient EEG measurements, easing the rigid requirements for research-grade EEG signal collection, which will help improve patient access and disparity issues by permitting fewer-channel and portable options for EEG measurement.

Expected Outcomes:

This project will produce the first, to our knowledge, AI neurovascular research database, which will help formulate adaptive electric brain-stimulation algorithm, as well as identify reliable EEG signatures for precision migraine diagnosis. The neuromodulation protocol is expected to attenuate pain and symptoms across all phases of migraine including prodrome, aura, migraine headache attack, and postdrome. This electro-neuromodulation therapy would adjust brain activity to the interictal level of that specific patient. The incoming signal would interrupt pain perception by somatosensory cortex or, at least, reduce the severity of the attack. For advanced diagnosis, identification of reliable and more specific migraine EEG signature will lead to inexpensive diagnostic tool and treatment-efficiency measuring tool, which would help with treatment choices.

P419 4D Interpolation of Cardiac MRI Imaging Sequences

Situation:

Dynamic obstructions in congenital cardiac conditions are difficult to convey in standard 2D imaging formats. No current technology allows for the acquisition and output of whole stereoscopic 4D beating hearts.

This project's hypothesis is that **current, standard of care, cardiac magnetic resonance (CMR) imaging protocols *acquire enough data* to allow for complex *interpolation* in 4 dimensions to allow the creation of a 4D beating heart reviewable in virtual reality (VR).**

Background:

Efforts have only just begun to take existing technologies and create 4D beating hearts. The AIM lab along with Bradley university is currently working on a project focused on a 4D heart from CT titled: *Toward Automation of a 4D Heart From Retrospectively Gated Cardiac CT Scan*. The ability to acquire and export volumetric (3D), time-sequential images of a heart are currently limited to a few imaging modalities, but all struggle to allow interaction in 4D following acquisition. Volumetric ultrasound technology can acquire 4D data but this is limited to small sections of the heart based on imaging windows and stereoscopic 4D views remain experimental. Retrospectively gated CTs can acquire multiple 3D phases of the cardiac cycle, but no tools exist to convert them to 4D beating hearts. CMR can acquire time sequential 3D magnitude data in concert with 4D flow imaging data, but no tool exists to segment and create a 4D beating heart for review. Additionally, from the technology perspective, several key issue to create interactive 4D objects that must be solved are: 1) that standardized formats for 4D objects are limited in software to generate and present them and 2) although individual segmentations of time points are possible from 3D images, to create an animated 4D object requires the calculation of deformations of nodes, edges, and surfaces in the generated 3D objects. Software tools are needed to enable this 4D animation automatically from medical imaging data.

Understanding the standard of care CMR and data acquired:

A standard congenital CMR protocol consists of a series of images obtained over time. These protocols generate 2D cine (movie) clips showing a 2D slice moving through the cardiac cycle. Standard imaging planes are targeted to give a good overview of the heart. Additional sequences focus on 3D anatomy in a static state (usually diastole). A standard procedure usually lasts 1 hour in length, (not including a 4D flow scan which can take 20 minutes to complete.)

Provided the patient does not move out of position during the procedure, each imaging sequence can be related to the other imaging sequences due to preserved 3D coordinates between images. As an example, the bottom left image is of a standard 2 chamber view of the left ventricle (LV), which is labeled as A2; this "A2" plane is represented in the other images from the same study (see Figure 1.) In other words, each image relates in a 3D coordinate space (relative to the physical MRI scanner) to every other image acquired during the same study.

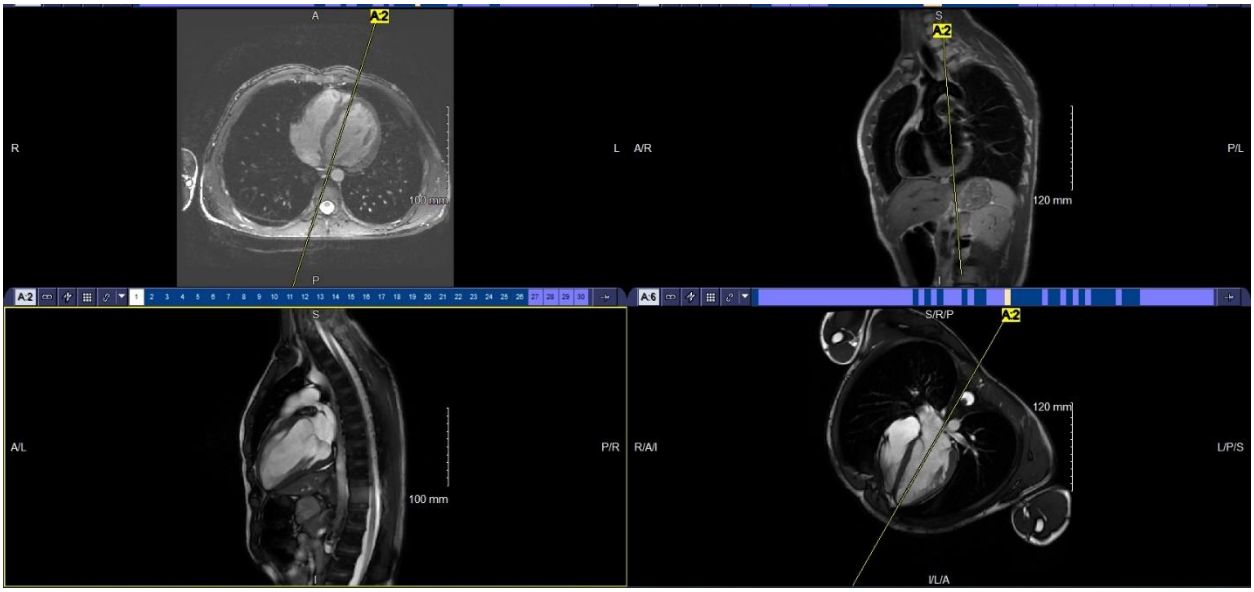

Figure 1

This lab currently has the capability to automate segmentation of the myocardium from the 3D imaging sequence in diastole. Considering that the scanner acquires each 2D cine gated to the cardiac cycle, the time and space location of the diastolic image is known.

Therefore, it should be feasible to take the automated segmentation data – as seen represented in the top left 3D imaging dataset in Figure 2 – and apply those same masks to each 2D cine image during end-diastole. The other three images in Figure 2 represent how the same mask should apply to each image.

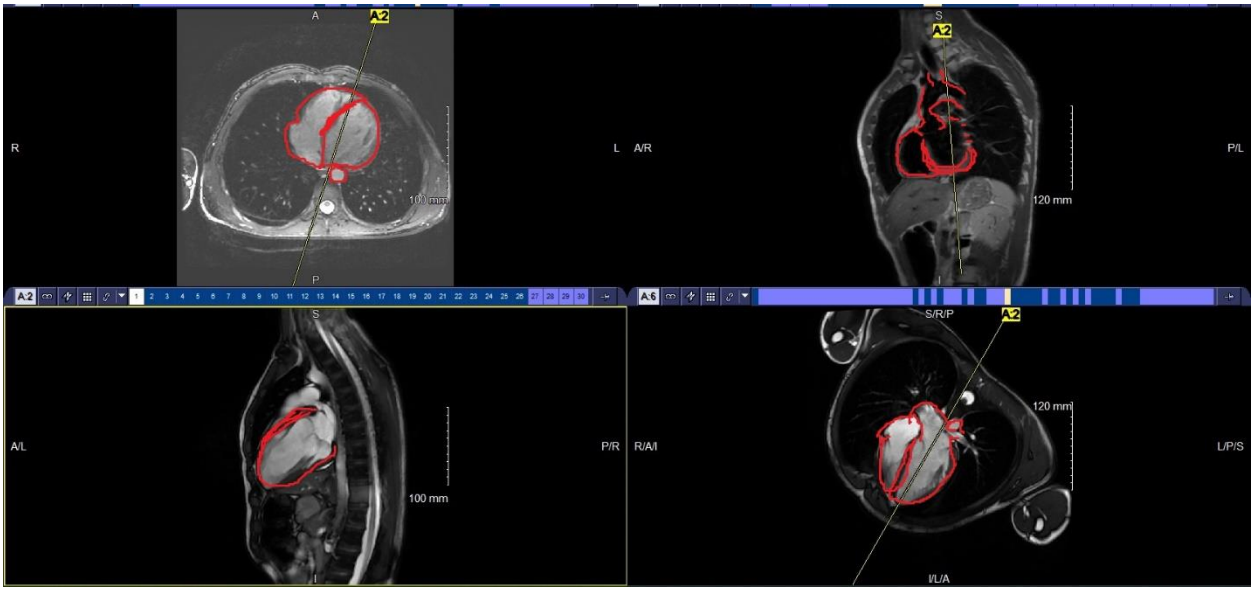

Figure 2

Once a starting point of myocardial segmentation has been applied to each cine loop, standard pixel tracking and warp field analysis should be able to maintain myocardial masked definition

throughout the cardiac cycle. Figure 3 demonstrates the same 3D diastolic dataset with 2D cines at end-systole.

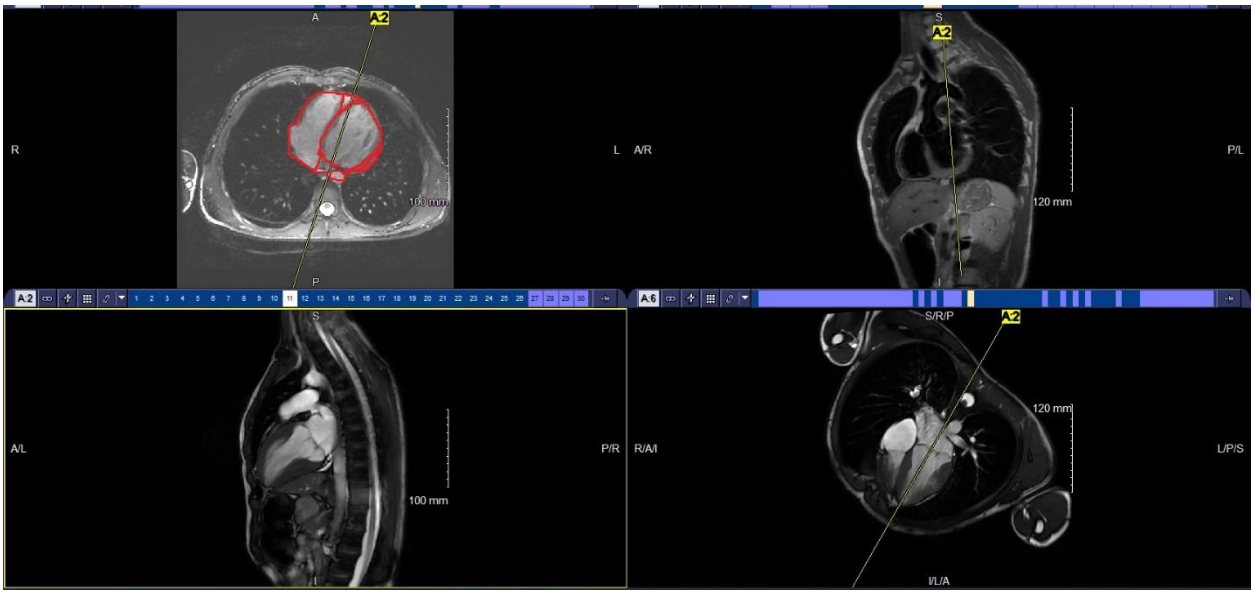

Figure 3

But if the pixel tracking and warp field are successful, then each end-systolic (and each stepped phase image) can then be automatically segmented as seen in Figure 4 with the green highlights marking the predicted segmentation elements.

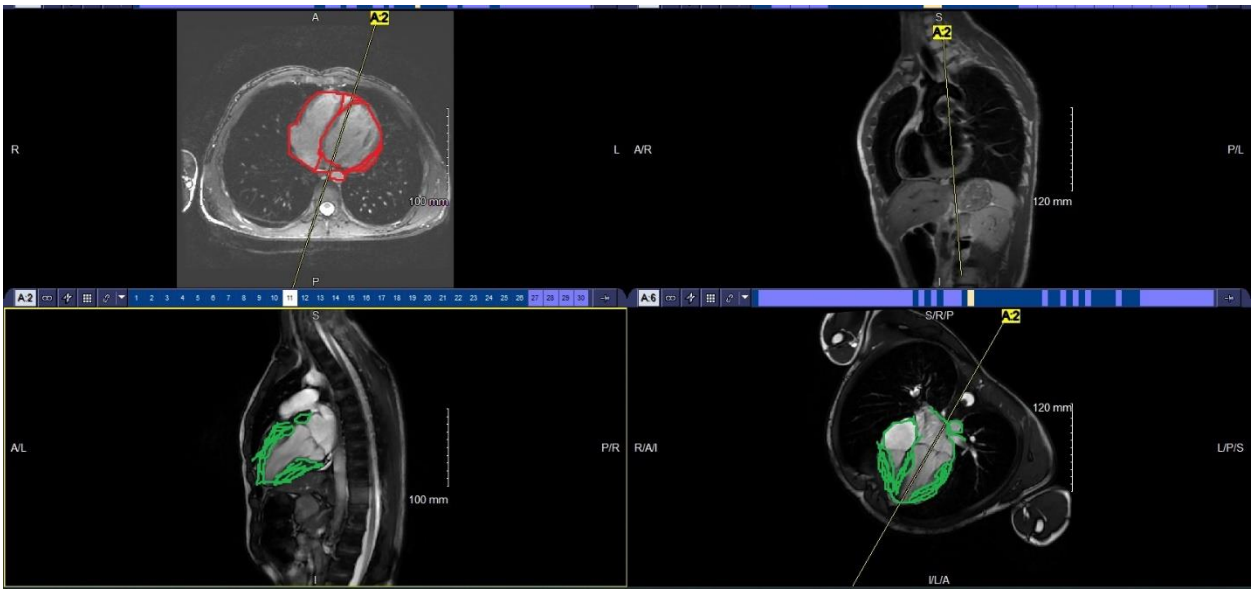

Figure 4

When one considers that 2D cines are acquired in many imaging planes, then it becomes feasible to translate each of these 2D segmented regions over time as source data to allow for standard image interpolation/super resolution techniques to fill in the gap in 4 dimensions. The ultimate result would be a fully segmented beating heart generated from standard of care CMR data.

A stretch goal could be the addition of cardiac valve motion, which is frequently captured on 2D imaging slices, but not 3D. This complex 4D interpolation could unlock valve imaging in MR, not to mention more standard automated analysis of ventricular volumes and ejection. This likely will require segmentation of valves from individual images and separate warping along time frames.

Assessment:

Automated assessment of cardiac function from medical imaging represents a billion dollar industry segment by 2031. Current standard of care analytical tools focus on automated analysis of standard 2D imaging formats. For example, echocardiography obtains standard 2D parasternal long axis imaging planes which are utilized to generate automated surrogates of cardiac function. Similarly, cardiac MRI acquires stacks of short axis images which are also subjugated to automated segmentation of each 2D slice to generate surrogates of cardiac size and function.

Rather than developing analytical tools based on standard 2D imaging planes, this project seeks to reinvent cardiac analytics by acknowledging the 4D nature of a beating heart and developing tools to recreate personalized medical representations which can then be analyzed from a 4D perspective.

The first step in this 4D transformation is to take existing, standard of care medical imaging protocols and interpolate (in time and space) the beating heart. Utilizing standard of care cardiac magnetic resonance (CMR) images, we aim to generate an accurate representation of patient specific 4D hearts. Once interpolation criteria are determined for creation of the 4D heart, then reverse engineering can begin to challenge standard of care imaging protocols to decrease the burden of source data needed to accurately generate a patient specific 4D heart.

This goal of a 4D heart also opens up simplified analytics regarding cardiac size and function; with volumetric source data, the complex geometries of the right versus left ventricles become neutralized allowing for automated analysis to occur regardless of the complex geometry. Where current 2D segmentations fail due to highly variable 2D imaging contours of a right ventricle (or other non-mathematically modeled segments like the LV) the 3D geometry becomes more predictable and therefore, more amenable to automated analysis.

This project's complex 4D interpolation will unlock many automated analytical tools that 2D cannot attain.

P420 Tailored Diabetic Wound Care Educational Tool

The overarching goal of this project is to develop a personalized educational tool/guide for diabetes patients in outpatient and home care settings, with a specific focus on comprehensive wound care, including packing, identification, and positioning. The long-term objective is to advance patient care, self-care, and clinical practices in diabetes care by addressing the crucial educational needs of patients during their recovery process at home. The project's specific aims are 1) identifying the pain points of proper wound care at home and patients' preferred methods for education delivery, 2) design and develop personalized educational material to address patient needs, accessed through their preferred platform, and 3) conduct an evaluation of prototype educational tools and usability studies. This project will utilize a patient-centered approach to design personalized educational/guidance for home-based wound care. Proposed research activities include stakeholder interviews for design requirements ,participatory design, prototype development, iteration based on feedback, and evaluation of the platform/tool. Phase 2 funding will be sought to scale up the developed tool and integrate into rural care practice. The project aligns with Jump ARCHES goals by integrating technology and education to improve patient outcomes in non-tertiary care settings in Illinois, addressing gaps in current practices. The proposed work aims to set new standards in diabetes education and contribute valuable insights to the broader healthcare community, promoting innovation and advancements in patient care beyond specialized centers.

P421 Mixed Reality Simulator for Neonatal Needle Thoracentesis

Approximately 10-20% of infants born each year will require resuscitation in the delivery room. In 1% of these cases, advanced resuscitation is needed, which may include high risk and invasive procedures, to survive. In community hospitals, this care typically falls to general practitioners or emergency department providers who have no additional training in neonatal procedures. The important procedures they may be called on to perform can be few and far between, leading to new graduates lacking competence in these procedures and leaving seasoned practitioners at risk for skill atrophy [1]– [4]. Community providers need a way to maintain skills in neonatal procedures without having to travel great distances to attend simulation workshops in academic centers.

Currently, high-stake and life-saving medical procedures are largely taught on physical mannequins. However, these mannequins require expertise to guide and evaluate performance. Digital solutions to train these procedures have been explored in the form of Virtual Reality (VR) simulations [5], [6]. Mixed Reality (MR) is an emerging technology that allows users to interact with virtual and physical environments at the same time. The use of this technology allows learners to have the haptic feedback of physical mannequins, while simultaneously receiving instructions and feedback from the MR headset overlaid on the physical environment [7].

We aim to develop an innovative MR platform (using the Microsoft HoloLens 2) to provide simulation training for various neonatal procedures. This platform would benefit trainees in pediatrics, family medicine, OB GYN, and emergency medicine as well as provide a platform to prevent skill atrophy in current practitioners. This platform could be further expanded in the future to include any procedure across any specialty.

We will start by developing an MR simulation for needle thoracentesis which is a procedure to aspirate pneumothorax. Pneumothorax is the presence of air in the pleural space and is a serious condition in newborns. This procedure was chosen because neonates with pneumothorax are at high risk of mortality (>40%) and because a physical simulator for this procedure already exists [8].

In Phase 0 of our project which was funded by Jump Arches in 2023, we successfully developed a guided Simulator for needle thoracentesis training, leveraging the Microsoft HoloLens 2 platform (video attached). In phase1, we will evaluate the usability and engagement of our guided MR simulator by enrolling experts in needle thoracentesis to test the simulation. Additionally, newer devices such as the Quest pro/Quest 3 have come to market and provide a lower cost headset. We will modify the developed guided simulator for these headsets and have our experts determine the preferred device for this simulation.

Our final goal of this phase 1 is to create a video database of neonatal procedures. In our phase 0, we explored the possibility of a real-time instrument tracking and guidance-based MR simulator. Through the research in phase 0, we realized that the marker system poses a significant problem for use on small one time use instruments that are frequently used in neonatal procedures. The long-term solution to this problem includes transitioning from marker-based tracking to a marker-free system to enhance applicability and accuracy in real clinical settings, ensuring a seamless and realistic training environment for healthcare providers. To meet that goal, in Phase 1 we will focus on collecting data for Computer Vision and ML based object detection, tracking and guidance system.

P423 Empowering the Diagnosis of Rare Diseases in Primary Care Settings

Undiagnosed rare diseases pose a significant challenge in healthcare, often leading to delayed treatment andpoorer patient outcomes. The integration of machine learning and knowledge graphs presents a transformativeopportunity to detect these diseases from electronic medical records (EMRs). This project aims to develop aninnovative system that leverages these technologies to identify patterns and correlations within EMRs, enablingearly detection of rare diseases. This aligns with the goals of the Jump ARCHES program, which supports projectsthat design, implement, and evaluate innovative solutions to health system operational challenges. By harnessingmachine learning and knowledge graphs, this project aims to address the critical issue of undiagnosed rarediseases, enhancing diagnostic precision and improving patient outcomes.

P426 Development of an active wheelchair seat cushion to address pressure ulcers

Pressure ulcers are a prevalent problem in individuals with limited mobility, e.g., caused by advanced-stage ALS, frailty due to aging, obesity, injury, or surgery (Theaker et al., 2000). Amyotrophic Lateral Sclerosis (ALS) is a progressive neurodegenerative disease, which results in muscle weakness and eventually complete inability to control voluntary muscles. It is estimated that per year, approximately 3 million people are diagnosed with pressure ulcer, and over 500,000 of these patients need extended hospital stays for treatment (Lyder & Ayello,2008). There are over 100 risk factors associated with disease, including low body mass index, limited mobility, and prolonged seated positions (Raju et al., 2015). Pressure ulcers can be avenues to infection and other complications, some of which can lead to permanent wounds and loss of life. It is estimated that 8% of deaths of paraplegic individuals are a direct result of a pressure ulcer (Scovil et al., 2012). This project will address the limited seat cushion options for prevention and treatment of pressure ulcers in wheelchair users. To mitigate the development of pressure ulcers, wheelchair users are recommended to reposition or perform pressure relieving exercises every 15-20 minutes (Stockton & Parker, 2002), which is often a difficult schedule to maintain, resulting in low compliance. Pressure ulcers impact a wide variety of wheelchair users, from everyday users of manual and power chairs to shorter term wheelchair users after injury or surgery in nursing home or home care settings. To address this issue, our project will use human-centered design strategies to explore technologies necessary to build an innovative soft robotic solution for addressing pressure ulcer prevention. An active, soft robotics cushion that includes (1) custom pneumatic bladders, designed to be patient-specific in their geometries, sizes, and configurations, and (2) light-weight electronics for sensing and control available to power and manual wheelchair users alike is foundational to a disruptive approach to pressure ulcer treatment. In 2023, we produced a conceptual design and first prototype (Robinson et al., 2023). This project aims to build a testable prototype to allow users to autonomously alleviate pressure, eliminating the need to readjust position while reducing pressure ulcer occurrence, leading to reduced pain and less time spent treating ulcers. This project brings together an interdisciplinary team of clinicians, researchers, and students from University of Illinois' Colleges of Engineering and Applied Health Sciences at Urbana-Champaign and OSF HealthCare's Home Care Services and Illinois Neurological Institute.

P427 From Angiograms to Simulated Flow in Cerebral Vasculature

It is estimated that 1-2% of the general population may have an intracerebral aneurysm. An intracerebral aneurysm is a result of the dilatation of a blood vessel in the brain that is at risk of rupture due to the increasing wall stress as the radius of the vessel increases. Although interventions exist for avoiding rupture, such as clipping, coiling, or stenting, many aneurysms rupture prior to detection or treatment. Nearly 50% of aneurysms that rupture result in mortality with the rest resulting in significant long-term morbidity. In a study of very small aneurysms, mean disability scores at 6 months after hemorrhage indicated moderate disability even for aneurysms less than 5 mm [1]. Size or change in morphology have been a primary determinants for intervention, but even small aneurysms, below the intervention size, may rupture. Further follow up imaging must be targeted at the problematic vasculature to ensure that critical information about the aneurysm, its size changes, and physiological changes are monitored to predict progression and avoid a catastrophic rupture. The long-term goal of this new collaboration is to develop fully automated methods to detect aneurysms, characterize the physiological impacts on flow, and assess rupture risk from standard clinical imaging protocols.

Current guidelines for determining aneurysm intervention are largely based on size, but size measures on a single imaging scan may be challenging in small aneurysms and the size, by itself, does not consider the rupture risk of small aneurysms. The International Study of Unruptured Intracranial Aneurysms (ISUIA) calculated cumulative 5-year rupture risk for aneurysms less than 12 mm in diameter is 2.6% [2]. However, Malhotra et al found that there is insufficient evidence to suggest small unruptured aneurysms have little to no risk of rupture, in particular because of heterogeneous definitions of growth and surveillance [3]. Many aneurysms rupture at a relatively small size with debate about treatment [4]. Despite advances in imaging technology, quantitative analytics including machine learning and artificial intelligence, aneurysms under surveillance may rupture before meeting guidelines for intervention. In a case control series of 127 patients, 33% of the ruptured aneurysms at time of presentation were classified as small, measuring less than 5 mm, while 67% had a diameter larger than 5 mm (mean 11 mm) [1].There is a clear need for assessing the stresses and pressures on the vessel wall to provide a more specific risk of rupture based on the mechanics leading to aneurysm. However, detailed flow maps are not available throughout the cerebral vasculature due to lack of suitable methods for providing this detailed information.

In this proposal, we will develop 3D vascular models from common angiographic neuroimaging procedures, such as MR angiography (MRA) and CT angiography (CTA)). We will then use the 3D vasculature models to simulate flow using a computational fluid dynamics (CFD) approach. Our immediate goals include providing additional biomechanical information about the state of the aneurysm and to create improved mental representations of patient specific pathology which will improve surgical planning through 3D (VR based) representations of anatomy. Our long-term goal is that by simulating flow, we hope to delineate changes to the physiology in the small aneurysm that may indicate that it is at increased risk of rupture and even to detect regions where aneurysms are likely to exist based on the flow. This initial project will develop automated algorithms to extract cerebral vasculature from healthy controls and aneurysm patients to form 3D connected vascular models. We will then use these models to simulate flow in the vasculature, to compare the simulated flow around aneurysms to other healthy portions of the vessels in the brain.

This will be accomplished through two aims, briefly described here:

Aim 1: Develop an automated algorithm to generate a fully connected, 3D vascular model from MRA and CTA scans.

Aim 2: Use the 3D vascular model to perform flow simulation to identify physiological disruption to smooth flow indifferent regions of the vasculature to identify regions that need to be further examined and followed longitudinally.

This project brings together experts across clinical neuroscience (Sourabh Lahoti (OSF) and Suguna Pappu(Carle)), neuroimaging with MRI (Brad Sutton), computational fluid mechanics (Surya Pratap Vanka) and 3Dmodeling with medical imaging data (Matthew Bramlet). The project will provide significant benefits to patients with suspected aneurysms in the OSF patient workflow by the end of this one year project. These models can be useful in planning surgical intervention to place a stent, for example, through a virtual reality presurgical planning platform. Further, the project will generate a large amount of 3D vascular maps for both healthy and pathological patients that we can use for future AI-based projects to determine changes in vascular structure indicative of aneurysm. We will design the outputs of this aim to produce results that are clinically auditable and provide views to ensure that the clinical needs are met through the level of vasculature that will be modeled.

P428 Low-cost haptic enhancement for surgery via stochastic resonance

The aim of this project is to develop a wearable device that can enhance surgeons' haptic sensitivity during remote surgery. In the past three decades, minimally invasive surgery (MIS) has been the gold standard for many surgical procedures, especially in general surgery. Advantages of MIS include faster recovery time and less pain and suffering for the patient post-op. However, for the surgeon, it requires a great deal more hand-eye coordination skills, adapting to increased motor and safety constraints given the reduced sensory information such as lack of depth cues and altered haptic feedback, resulting in higher physical and cognitive workload for the surgeon.

A great deal of research has been done to address the problem of haptics in MIS. Some have investigated the effect of vibrotactile feedback on haptic perception in simulated MIS. Vibrotactile feedback provided through wearable vibrator has been shown to be an effective sensory substitution for force feedback in tissue manipulation. When introduced at a subthreshold level to the surgeon's arm, vibrotactile stimulation enhances haptic sensitivity as evidenced by improved performance in a palpation task. In particular, the surgeon's tumor detection accuracy in laparoscopic surgery, where haptic feedback is generally lacking, is better. This phenomenon is known as stochastic resonance (SR), and is characterized by an enhanced signal-to-noise ratio of weak signals in a non-linear system when random white noise is added. Furthermore, results suggest that heightened sensitivity persists even after termination of the subthreshold vibrotactile stimulation. However, it is not known how long this SR after-effect continues, nor how the heightened sensitivity is achieved in the haptic sensory system.

It is envisioned that, using a wearable vibration device, a surgeon's haptic system can be activated and sensitized using SR to enable hyper-sensitive haptic perception. Furthermore, it is possible to remove the device from the surgeon prior to entering the operating room, if the after-effect of SR can persist for the duration of the surgery, thus freeing the surgeon from wearing an external device during surgery.

In this proposed project, the aim is to develop a cost-effective, compact device designed to render subthreshold vibration signals to the skin. This device, fashioned as an armband, will incorporate modified, low-profile electromagnetic actuators. Its primary function will be to assess the duration of the SR after-effect during a simulated palpation task. Insight into the mechanism of SR effect will be used to inform the design of the wearable device for surgical applications. If successful, this technology has the potential to be scaled up and widely distributed through consumer-style wearables, as well as enabling better sensitivity for telemedicine applications and eventually telesurgery. This has important future benefits for treating remote patients located in rural areas with limited access to specialized surgeons. An invention disclosure for the device will be submitted if the results show promise.

P430 Optimizing the Utilization of Rural Health Clinics

Rural clinics, such as mobile clinics and stationary microsites, serve as crucial assets in providing healthcare services, especially in remote crisis-stricken areas. However, their acceptance and utilization often depend on the challenges associated with transportation logistics, knowledge about the rural clinic and offered services, trust in the care delivered, accessibility and convenience, and availability. All these factors must be optimized to enable a high utilization rate of the rural clinic. This proposal suggests a transportation service concept tailored to maximize the utilization rate of rural clinics based on a predefined set of clinical services, any availability of resources(healthcare provider and equipment), any given distribution of clinical service needs of the population, any geo-spatial distribution of the population within a county, and budget limitations. We classify the served population into three categories: (A) Healthy population with a need for yearly checkups and vaccinations, (B) Population presenting symptoms and needing a diagnosis and potentially immediate treatment, and (C) Population in treatment. Each category of population may exhibit a different clinic visit behavior. Category A clinic visits can be more flexible in time and possibly be combined with errands into a “trip chain;” Category B may need to see a specialist immediately in an urban hospital, and Category C clinic visits can be combined with pharmacy visits and grocery shopping. These behaviors will be directly incorporated into the estimation of healthcare demand. The output of this project includes: (1) Deployment and operational plan, including microsite location and mobile clinic route, and operation hours of the rural clinics, (2) Mobility services for patients’ last-mile access (e.g., transportation to and from rural clinics, medicine delivery), (3) Service quality estimations (e.g., expected patient waiting and travel times), and costs to operate the transportation system, and (4) Implementation guideline, including the data points required from the community. The acquisition and update of the data for the model and software are tasks that the community must fulfill. As a demonstration, we will apply the developed methods to Cuba, IL, and assess effectiveness and economic validity of the proposed transportation concept for the planned rural clinics. We strongly emphasize the generalizability of the concept to other application contexts, and we will incorporate input from different communities as well as policymakers from Chicago and Springfield. Our long-term goal is to develop this concept into a product based on which the state can generate implementation grants for public health districts or other health care organizations. All our proposed models and algorithms will be developed in alignment with this long-term goal. The execution of the project is planned as follows: Identifying the data points that determine transportation needs. We will start by selecting a subset of clinical services and their clinical assessments and interventions (CAI) requiring a rural clinic visit. Examples include physical therapy sessions, neurological assessment, spinal consultations, brain imaging appointments, cardiac assessments, vascular procedure follow-ups, heart health checks, diabetes management visits, blood sugar check-ups, insulin adjustment appointments, and vaccinations, among others. Each CAI will be characterized by parameters such as specific provider specialization, required equipment, visit duration, and more. The project will take the following steps. Determining the geo-spatial distribution of health care demand, by mapping out the geo-spatial distribution of the population within the county, identifying clusters of communities and their corresponding healthcare needs (by type and frequency). This step will involve analyzing demographic data, healthcare utilization patterns, and geographical factors to understand where the demand for rural clinic services is highest, and how it varies across different areas. Optimizing rural clinic deployment and patient mobility services, by

using the identified CAI and population distribution data, we will develop integrated optimization models and solution algorithms to optimize deployment plan and patient service schedules. This optimization process will take into account factors such as the types and frequencies of CAI, patient demographics, travel distances, and available resources (vehicles, drivers, etc.). The goal is to minimize travel times, maximize resource utilization, and ensure timely access to healthcare services for all communities. Pilot implementation in Cuba, IL, by working closely with local healthcare organizations and community leaders. This pilot phase will involve testing the transportation routes and schedules in real-world conditions, evaluating the effectiveness and feasibility of the concept, and making any necessary adjustments based on observed outcomes and feedback. By applying the developed methods in a practical setting, we aim to validate the effectiveness of our approach and lay the groundwork for future scalability and expansion to other regions. The deliverables of the project include (a) A list of data points required to optimize rural clinic utilization, (b)Models and algorithms to optimize the rural clinics' operational plan and last-mile mobility services, based on population, CAI distribution, budget, and fixed or flexible visiting hours, and (c) Findings and recommendations for the OSF Living Laboratory in Cuba, IL.

P435 Sudden Cardiac Arrest AI ECG Recognition

Sudden cardiac arrest (SCA) in young individuals, while rare, stands as a significant cause of mortality among seemingly healthy individuals. Existing risk stratification tools often fail to identify high-risk individuals, underscoring the need for more accurate screening tools. Electrocardiograms (ECGs) serve as a primary source for cardiac screening, but the need to have reads performed by highly-trained experts is a barrier to the scalable deployment of the nation-wide screening approaches that would be needed to eliminate the risk of SCA in the young. While automated software for ECG analysis has been developed, it lacks the necessary sensitivity and specificity, leading to either unnecessary testing or critical reads being missed. Currently, there are no ongoing studies globally that employ deep learning algorithms for the comprehensive diagnosis of ECG abnormalities linked to SCA in young patients. Data have shown that even for an experienced cardiologist accurately interpreting an ECG and identifying patients at risk for a cardiac arrest is challenging. The goal of this project is to develop a viable approach for leveraging artificial intelligence (AI) to improve risk stratification using surface ECGs. To this end, we will address two fundamental challenges: 1) the lack of appropriate datasets from young persons (12-25 years) to drive model development; 2) the difficulty of targeting deep learning methods at rare conditions for which large-scale clinically-labeled datasets are difficult to obtain. We will address the first challenge by leveraging multiple diverse datasets. In particular, the Children's Hospital of Illinois (OSF) and other OSF Hospital Networks, which serve as a major referral center for pediatric and young adult SCA cases can offer an ideal setting to develop and validate AI models. These cases will be augmented as-needed through partnerships with other organizations that are currently under development. The second challenge will be addressed by leveraging recent advances in self-supervised representation learning, which make it possible to leverage large-scale ECG data as a means to learn useful representations of electrophysiological features, even when the datasets are not enriched for rare conditions of interest. Subsequent finetuning of these representations using more modest datasets containing cases of interest has been shown to yield effective classification performance. This project would provide the first exploration of this approach in the context of pediatric ECG analysis. Moreover, this effort could illuminate the subtle features of ECG traces and lead to an improved understanding of the key patterns involved in SCA risk in young persons. The outcomes of this study will not only benefit children in Illinois but also have global implications, particularly in low- and middle-income countries where access to expert cardiologists is limited. With over 300 million annual screening ECGs conducted worldwide, accurate ECG diagnosis through AI models could potentially save lives, especially where specialist opinions are scarce. The HealthCare Children's Hospital of Illinois has been ranked as a leader among children's hospitals in the state of Illinois. This project aims to further showcase the forward-thinking approach and state-of-the-art diagnostic methods developed and implemented at OSF HealthCare.

P438 Detection of E. coli bypassing blood culture

The detection of genetic information from crude biological matrices such as solid tissue or liquid tissue (e.g., blood)has many applications. Rapid detection of pathogenic DNA is critically important for bacteremia, sepsis and stewardship of antibiotic resistance, where the rate limiting step for detection of small number of pathogenic nucleic acid molecules is the blood culture. If an infection is suspected, broad-spectrum antibiotics are typically immediately prescribed, and as the number of pathogens could be too low to be detected by PCR based tests from 5 mL of whole blood (many septic patient samples can have very low pathogen counts (1-3 CFU/mL) (1)). Hence a blood culture is performed to exponentially grow the initial few pathogens. As per FDA requirements, the blood culture is run up to 5 days for confirmed negative but is stopped as soon as positive results are obtained. A small volume from that culture bottle is taken then to run PCR based identification tests, for example using BioFireTM system for detection of up to 19 pathogens (2-4).

An important practical challenge to understand is that if a culture step is to be eliminated, then we must detect the few pathogens that might be in the sample. In this case, antibiotic treatment could be initiated. Although a few non-culture technology platforms for bacteria detection are available (e.g., T2Bacteria Panel, Qvella), these approaches can detect one target/sample in 4-6 hours, with the use of expensive instruments, rendering these tests not cost-effective or not suitable for resource limited settings.

In this proposal, we will demonstrate the feasibility of a new nucleic acid amplification-free assay to achieve the detection of low E. coli counts in <2 h., analyzing large volumes of whole blood (>1 mL) from clinical samples. This project will provide a new diagnostic tool that will help eliminate the blood culture barrier. Rapid detection of low concentrations of bacteria, in combination with other information already available (e.g., patient history, physical examination, and routine investigations) could significantly accelerate clinical decisions for the early detection of bacteremia and sepsis, not only in centralized laboratories, but especially in remote or under-resourced regions where access to bulky and expensive instrumentation can be extremely limited. We believe our technology meets the goals of the Innovation Track Program. Our specific aims are below.

Aim 1: CRISPR cascade-based biphasic reaction: We will combine for the first time the CRISPR-cascade signal amplification method with our biphasic reaction in whole blood. Likewise, we will achieve detection of low E. coli counts in <2 h from whole blood. We will study multiple variables of the assay, such as temperature, RNP T1 and RNP T2 ratio, BNA concentration, etc., to improve the signal-to-noise ratio and reduce the background noise (our target on/off ratio is 1.2 for a 5-min. reaction). This will be the first demonstration of a CRISPR assay from blood.

Aim 2: Detection of E. coli from clinical samples at UIUC: We will analyze 30 de-identified clinical whole blood samples from patients positive for E. coli at UIUC, using the developed CRISPR cascade-based biphasic assay via approved IRB protocols in collaboration with OSF HealthCare (Peoria, IL). Clinical samples will be obtained through OSF HealthCare using an existing protocol (IRB-838860) and others we will prepare.

Aim 3: Pilot clinical study: We will also transfer our CRISPR cascade-based biphasic reaction to OSF HealthCare. We will design a small clinical study (~20 E. coli positives samples) to assess the viability of our approach in the clinic.

P441 Multi-Modality Super-Resolution Brain Imaging for Neonates

This proposal responds to the special focus area of addressing “maternal and child health.” Engineers from UIUCECE, in collaboration with doctors from OSF neonatology, will collaboratively develop an innovative transcranial super-resolution Doppler imaging for neonatal encephalopathy.

Brain imaging techniques are crucial for the diagnosis and management of hypoxic-ischemic neonatal encephalopathy (HIE). HIE is a severe condition that occurs when a baby’s brain is deprived of oxygen and blood flow during or immediately after birth. Imaging techniques such as magnetic resonance imaging (MRI) and computed tomography (CT) are essential tools for diagnosing HIE and assessing the extent of brain injury. MRI is the gold standard for assessing brain injury in neonates because it provides high-resolution images of the brain and soft tissues without ionizing radiation. CT is not commonly used due to concerns about radiation exposure but can be helpful in emergencies when a rapid diagnosis is required. Early and accurate diagnosis of HIE is critical for effective treatment and improving outcomes for affected infants. Imaging techniques provide valuable information to healthcare providers and can aid in developing individualized treatment plans. Therefore, the need for imaging techniques for HIE diagnosis is clear and remains a critical component of managing HIE.

Although ultrasound imaging is a valuable tool for the diagnosis and management of HIE, it has several limitations. One significant disadvantage of ultrasound is its limited ability to detect subtle brain injuries compared to MR. Traditional ultrasound cannot provide detailed information about brain structure and function or assess white matter injury accurately. Therefore, it may miss or underestimate the extent of brain injury in some cases, potentially leading to delayed or inappropriate management decisions. Additionally, ultrasound is highly operator-dependent, meaning that the quality and interpretation of the images can vary based on the operator’s skill and experience. The accuracy and sensitivity of ultrasound imaging also decrease as the infant’s skull thickens, making it less effective in older infants. Finally, ultrasound cannot provide information on the functional status of the brain, which is critical in determining long-term outcomes for affected infants. Despite these limitations, ultrasound remains a valuable tool for the initial assessment and monitoring of HIE, particularly in resource-limited settings where MRI may not be readily accessible.

The long-term goal of this research is to develop a reliable, safe, accessible, economical, and easy-to-operate diagnostic imaging technique for early HIE diagnosis in the neonatal brain. We believe such imaging techniques could be a game-changing diagnostic tool for existing HIE diagnostic paradigms, enabling early intervention and better post-HIE management. The objective of this proposal is to develop a non-ionizing, portable, functional multi-modality photoacoustic (PA)/super-resolution ultrasound-localization (UL)/ultrasound brain imaging technique with enhanced resolution of cerebral blood flow capable of revealing the early signs of brain abnormality caused by HIE. To attain this objective, the investigative team aims to: 1) develop a deep-learning workflow for transcranial super-resolution cerebral flow imaging; 2) investigate the feasibility of early HIE diagnosis in a rat model of hypoxic-ischemic brain injury with multi-modality PA/UL/ultrasound imaging. The multi-modal imaging technology can be seamlessly integrated and used with an electroencephalogram (EEG) as real-time physiological feedback for demonstrating the early diagnosis of HIE.

P448 Development of Virtual Nasendoscopy from 3D Dynamic MRI

Situation:

The act of swallowing is a complex process involving many muscles working in concert to send fluids and solids down the esophagus while protecting the airway from aspiration. A significant number of pediatric diagnoses disrupt this process and result in a variety of pathologic swallowing conditions. Despite the complex nature of this pathology, the diagnostic tools available to the practitioner are poor surrogates of the actual pathology and can come at great risk (radiation exposure, aspiration, need for sedation…) to the patient. Even relatively safe and common procedures, such as nasoendoscopy, are uncomfortable, especially for children, and are very limited in what they can visualize about the dynamics of swallowing anatomy as they only see the movement of surfaces of the structures and the procedure itself disrupts normal conditions for swallowing.

This project hypothesizes that recent advances in dynamic magnetic resonance imaging (MRI) can be used to generate a virtual nasoendoscope that will provide the benefits and expected view provided by nasoendoscopy while also allowing for true 3D visualization to enhance information available about a patient's specific swallowing pattern. MRI will provide full visualization of soft-tissue structures of the oropharynx without the need for sedation, inserted scopes, or radiation, all completely safe and suitable for patients from young children to adults. This project aims to acquire 4D MRI imaging data, automate segmentation of the key anatomic structures, and create a novel 4D digital media output format to allow the practitioner to review this 4D animated data in virtual reality (VR)as an adjustable virtual nasoendoscope.

If successful, this visualization methodology may obviate the need for fluoroscopic studies which carry a high radiation burden, and even replace endoscopic methods with a 4D virtual endoscopy format.

Background:

Oropharyngeal dysphagia is a symptom which arises from difficulty transferring food from the mouth into the pharynx and esophagus to initiate the involuntary swallowing process. Dysphagia can result from a variety of disturbances, from neonatal patients to elderly patients with stroke and Parkinson's Disease. Oropharyngeal dysphagia in pediatric age group can result from congenital and acquired brain injuries, structural anomalies of oropharynx and upper airway, neurodegenerative diseases and in sick newborns because of delay in starting oral feeds. Depending on severity, this condition results in significant decreases in quality of life, the requirement of a feeding tube, and can result in death. It has been reported that nursing home patients with oropharyngeal dysphagia have a 45% 12-month mortality from aspiration-induced pneumonia. In children, dysphagia is associated with low birth weight, preterm birth, and other economic and racial health disparities, leading to a lifetime of developmental and quality of life impacts. The North American Growth in Cerebral Palsy Project and Oxford feeding study have reported that 58% to 89% of children with cerebral palsy have feeding problems. Feeding difficulties at 4 weeks of age were associated with significant functional impairment at age 4 years and 8years of age. Early and persistent feeding difficulties are a marker for subsequent poor growth

and poor neurodevelopmental outcomes in children with cerebral palsy [1-3]. Quality of life is significantly impaired both for children with feeding disorders and their caregivers [4, 5].

For managing dysphagia, imaging plays a significant role in the diagnosis, monitoring, and guidance of treatment. This includes video fluoroscopy, nasoendoscopy, impedance manometry and, relatively infrequently, MRI. Video fluoroscopy (VFSS) involves ionizing radiation and results in a projection through the entire anatomy during the swallowing of a radio dense contrast material. Especially in children, radiation exposure is also a concern withs, so a non-ionizing radiation nasoendoscopy procedure is often used to examine swallows. A newer modality called impedance manometry has been used to evaluate pharyngeal swallow in adults and children These procedure uses a scope or a manometry catheter placed through the nose to evaluate oropharyngeal swallow [6,7]. These are invasive and uncomfortable approaches and despite topical anesthetic and children cry and are uncooperative which limits the use of these test in pediatric population, especially toddlers age group. Further, it can only see surface movements and cannot visualize underlying dynamic anatomy. Also, it can suffer from distorted depth cues, making quantitative and longitudinal measurements challenging. However, the clinical care team in ENT, SLP, and GI are able to read the nasoendoscopy and interpret the dynamic information to provide insights into the clinical case.

MRI can provide high quality, isotropic visualization of the soft tissue structures (muscles, fatty and connective tissues) with no ionizing radiation in a completely non-invasive imaging procedure. However, MRI has traditionally been a slow imaging method, restricting its use in fast swallowing dynamics and limiting it to static anatomy scans. Even today, existing clinical MRI protocols are not able to achieve fast enough temporal resolution to provide artifact free images of swallowing. Because of this, there are very few radiologists trained to read dynamic MRI's to extract meaningful characteristics of the functional anatomy of swallowing. In this proposal, we will provide an innovative approach to enabling MRI to seamlessly be integrated into the clinical care pipeline, by creating a virtual nasoendoscope from an advanced fast dynamic MRI acquisition. This will enable the clinical care team to incorporate this imaging data similarly to nasoendoscopy, while also enabling them to change transparency and visualize underlying structures.

Assessment:

Success of this project looks like the following:

A pediatric patient with dysphagia is scanned in MRI generating a highly complex 4D imaging dataset. This time-sequential 3D dataset is then input into this project's proposed tool and separated into time segments. Each segment is then segmented into clinically relevant elements. The segmentation process therefore creates a stack of sequential 3D models awaiting translation into a viable MR 4D digital format. This 4D digital format is then played in VR for the clinician to analyze within the framework of the technology to attain improved mental representations of the pathology in the stead of traditional imaging techniques. Ultimately, success is achieved if the practitioner achieves diagnostic confidence utilizing this MRI and 4D VR visualization technique.

REFERENCES CITED

1. Motion S, Northstone K, Emond A, Stucke S, Golding J. Early feeding problems in children

with cerebral palsy: weight and neurodevelopmental outcomes. Developmental medicine and child

neurology. 2002;44(1):40-3.

2. Sullivan PB, Juszczak E, Lambert BR, Rose M, Ford-Adams ME, Johnson A. Impact of feeding problems on nutritional intake and growth: Oxford Feeding Study II. Developmental medicine and child neurology. 2002;44(7):461-7.

3. Fung EB, Samson-Fang L, Stallings VA, Conaway M, Liptak G, Henderson RC, Worley G, O'Donnell M, Calvert R, Rosenbaum P, Chumlea W, Stevenson RD. Feeding dysfunction is associated with poor growth and health status in children with cerebral palsy. J Am Diet Assoc. 2002;102(3):361-73.

4. Simione M, Harshman S, Cooper-Vince CE, Daigle K, Sorbo J, Kuhlthau K, Fiechtner L. Examining Health Conditions, Impairments, and Quality of Life for Pediatric Feeding Disorders. Dysphagia. 2023;38(1):220-6. PMCID: PMC9616965.

5. Simione M, Dartley AN, Cooper-Vince C, Martin V, Hartnick C, Taveras EM, Fiechtner L. Family-centered Outcomes that Matter Most to Parents: A Pediatric Feeding Disorders Qualitative Study. J Pediatr Gastroenterol Nutr. 2020;71(2):270-5. PMCID: PMC8204401.

6. Kovacic K, Kern M, Pawela L, Shaker R, Sood MR. Characteristics of high-resolution esophageal manometry in children without dysphagia. Neurogastroenterol Motil. 2022;34(2):e14184. PMCID: PMC10128867.

7. Rommel N, Selleslagh M, Hoeman I, Smet MH, Davidson G, Tack J, Omari TI. Objective assessment of swallow function in children with suspected aspiration using pharyngeal automated impedance manometry. J Pediatr Gastroenterol Nutr. 2014;58(6):789-94.

P449 Real-time biomarker assessment platform for building trust in healthcare & research

This proposal outlines the development, validation, and implementation of a platform for novel point-of-care rapid biomarker testing: a palm-sized device that employs real-time, highly sensitive, single-step, enzyme-free assays to quantify salivary biomarkers and provide patient results in the same visit, minimizing hesitancy in study participation among community participants and clinical patients. The aims of the proposed project meet several Jump ARCHES goals. Aim 1 – develop and apply single-step, enzyme-free assays to quantify salivary biomarkers using a handheld palm-size device – will establish assay feasibility and effectiveness to exponentially increase point-of-care (POC) and in-the-field assessment of biomarkers in social, behavioral, and health research projects while maintaining high test sensitivity. Aim 2 – develop and validate a real-time (~20 minute) assay for oxytocin (among other biomarkers with immediate freezing requirements like C-reactive protein (CRP) and inflammatory cytokines) – has major implications for clinic and community-based interventions related to affiliative behaviors (e.g., mother-child attachment; romantic relationships; sexual risk-taking). Aim 3 – test acceptability and uptake of the new assay device and real-time results in community and point-of-care settings – will promote greater trust and curiosity in biosocial and health research and interventions among populations traditionally medically underserved or marginalized.

Ultimately, by allowing participants and patients to witness sample testing and eliminating the need for samples to be stored and shipped for outside tests, this project aims achieve the following short-term outcomes and long-term impacts:

• Reduce concern among participant and patient populations about how biological samples are handled and how they may be used in the future. This will translate into improved healthcare interaction and experiences, in turn increasing future healthcare engagement.

• Increase in participants' interest in and conversations with researchers and healthcare providers about how the device functions. This will spur greater interest and curiosity in science and engineering as well as their own health and healthcare experience.

• Improve intervention approaches through enhanced tailoring to meet the individualized needs of participants and/or clients. The immediate results this device will generate has applications for (a) baseline screening to identify intervention needs and levels (e.g., dosage) and (b) timely responsivity to intervention activities to promote Just-in-Time Adaptive Interventions (JITAI). JITAIs allow for interventions to be tailored in real time to expose participants to components that they respond well to and avoid those to which they do not. This technology has broad clinical and community applicability including family medicine, adolescent medicine, pediatric endocrinology, and obstetrics among others.

P450 Implementation of Health Access Points Within OSF's Rural Health Ecosystem

Clinical Motivations: Three of the key challenges faced by underserved rural communities in engaging with primary and preventative healthcare processes are the lack of access to basic health and social care infrastructure, awareness about preventative care, and decreased health literacy. Chronic disease prevalence and the occurrence of adverse events requiring emergency medical attention are disproportionately higher in subpopulations characterized by relatively lower economic conditions, and disadvantaged and underserved social and demographic factors, including rurality. (1, 2, 3).

Several technological initiatives such as remote monitoring using telemedicine, and policy-level interventions including the affordable care act and social funding of emergency care, have been instituted to improve healthcare access to rural and other underserved communities. Despite these interventions, the utilization of pre-primary and primary care has been relatively low (4,5). Low technology awareness and availability of connectivity often plague the adoption and usage of technological solutions in rural areas. This includes cell phone dead zones and slow speeds that can preclude use of cell phones for telehealth (6).

The use of community health workers (CHWs) has been shown to improve telehealth adoption, however, this approach is resource and cost intensive, especially for geographically dispersed rural communities (7). Community Health Workers are also a highly effective way to provide basic health screenings and health literacy education that can improve health disparities in underserved populations (8).

A solution providing basic, low-cost services is to position small-scale rural health access points, aka kiosks, staffed with CHWs in locations that are visited by rural communities such as churches, food pantries and branch libraries. The intent of this proposal is to incorporate the necessary digital connectivity and integration of existing OSF technology to support Community Health Workers and citizen/community scientists as they provide a small set of health and social care services and to conduct field trials of the same.

Anticipated services include Social Drivers of Health (SDoH) screening and navigation; first-line preventative health screening, health information and health literacy materials, assistance with appointment scheduling, and CHW-assisted telehealth visits. This proposal will provide a local front door to OSF services, bridge the gap in technology usage that is observed among underserved rural populations, and serve as referral bases for primary care clinics and microsites. A particular advantage of small-scale health access points, or kiosks, is that they provide a regular OSF presence in geographically dispersed rural areas. This is in comparison to mobile vans that only visit communities on an intermittent basis.

Technical Challenges: The primary technical challenge is in designing a kiosk, integrated with OCC, that is affordable for the organization and can help provide a circumscribed set of services and telehealth access to a diverse population. We will actively collaborate with OSF’s Community Care (OCC) technical team to integrate the kiosks with OCC in a manner that meets HIPPA and other compliance requirements.

This proposed work entails four overarching steps:
1. Develop, in collaboration with the OSF OCC technology team, a fully functional prototype that utilizes background integration with OCC and existing CHW workflows while expanding OCC capabilities as needed to support health access points
2. Develop detailed documentation for the kiosk, its functionalities, and its integration with OCC and existing OSF workflows and technologies
3. Develop a comprehensive playbook for implementation, including CHW training, community outreach and awareness building
4. Conduct field trials in two locations to demonstrate the functioning, efficacy and primary uses of the access points

Expected deliverables include the OCC-integrated prototype, detailed documentation for the kiosk, comprehensive playbook for implementation, and results from field trials conducted in two sites.

References
1. Head, A., Fleming, K., Kypridemos, C., Schofield, P., Pearson-Stuttard, J. and O'Flaherty, M., 2021. Inequalities in incident and prevalent multimorbidity in England, 2004–19: a population-based, descriptive study. The Lancet Healthy Longevity, 2(8), pp.e489- e497.
2. Niessen, L.W., Mohan, D., Akuoku, J.K., Mirelman, A.J., Ahmed, S., Koehlmoos, T.P., Trujillo, A., Khan, J. and Peters, D.H., 2018. Tackling socioeconomic inequalities and non-communicable diseases in low-income and middle-income countries under the Sustainable Development agenda. The Lancet, 391(10134), pp.2036-2046.
3. Zhang, Y., Khullar, D., Wang, F., Steel, P., Wu, Y., Orlander, D., Weiner, M. and Kaushal, R., 2021. Socioeconomic variation in characteristics, outcomes, and healthcare utilization of COVID-19 patients in New York City. PloS one, 16(7), p.e0255171.
4. Ma, A., Sanchez, A. and Ma, M., 2022. Racial disparities in health care utilization, the affordable care act and racial concordance preference. International Journal of Health Economics and Management, 22(1), pp.91-110.
5. Primm, K., Muraleetharan, D. and Gilreath, T., 2019. Use of emergency departments for preventative care among adults in the United States: estimates from the 2017 National Health Interview Survey. The Journal of Emergency Medicine, 57(4), pp.578-586.
6. Brodkin, J. Starling, Veriaon and T-Mobile made shaky claims on FCC coverage map..Starlink, Verizon, and T-Mobile made shaky claims on FCC coverage map | Ars Technica. Retrieved March 9, 2024
7. Telehealth.HHS.gov “Improving access to telehealth.” https://telehealth.hhs.gov/providers/health-equity-in-telehealth/improving-access-to-telehealth. Accessed March 11, 2024.
8. Rural Health Information Hub. “Screening and Health Educator Model.” https://www.ruralhealthinfo.org/toolkits/community-health-workers/2/educator Accessed March 13, 2024.