Role of Technology Helping Epilepsy Diagnosis in the Developing World Through TeleEEG

Stephen Coates and Charlotte Stow

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[++]Waste not, Want not. Folk Song, 1870.

*Our entirely charitable collaborations with world-class partner organizations that share our values and goals, notably include ROW Foundation, Rotary International (Durham Elvet and Darlington), Persyst, GOHE, and Lifelines iEEG through which we are able to deliver cost-effective solutions reaching the global health technical equivalent of the rural last mile.

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Abstract

UK Charity TeleEEG has proven a scalable and lean deployment model, enabling consultant physicians specializing in epilepsy diagnosis by EEG to volunteer as a virtual global team donating basic EEG equipment and skills. It was established in 2011, for the benefit of patients based in low- and middle-income countries (LMICs) who are suffering the long-term effects of an average 75% epilepsy treatment gap affecting neonates to octogenarians totaling 50,000,000 people worldwide. TeleEEG is delivering innovations in working practice, devices, consumables, and processes, underpinned by technology and adapting advances in machine learning.

Introduction

The Scale of the Problem

Epilepsy is one of the world's oldest recognized conditions, with written records dating back to 4000 BC.

Approximately 80% of the 50–70 million people affected by epilepsy live in lower resource regions where access to appropriate care is lacking, stigma continues to be a huge problem, and people with epilepsy face limited health and education options. More than 5 million new cases are diagnosed every year, and the number of people with epilepsy is expected to increase further (World Health Organization 2009).

Epilepsy accounts for over 13 million disability-adjusted life years and is responsible for more than 0.5% of the global burden of disease. Around 7.6 per 1000 persons have epilepsy during their lifetime. It has a bimodal distribution according to age with peaks in the youngest individuals and in those over 60 years of age (WHO 2006). Epilepsy has a variety of causes, ranging from genetic, metabolic, infectious, structural, immune, and unknown. There is a higher incidence of epilepsy in low- and middle-income countries (LMICs). This may in part be due to birth trauma and parasite infection (WHO).

Epilepsy carries a significantly increased risk of premature mortality. These include Sudden Unexpected Death in Epilepsy (SUDEP). SUDEP is responsible for around 1 in a 1000 deaths in epilepsy (Lhatoo et al. 2015). Status epilepticus is a condition characterized by seizure duration of over 30 min or seizures occurring close together without recovery in between. Status epilepticus, if left untreated, can lead to significant brain damage and death. Further, suicide is more prevalent in people with epilepsy than in the general population.

There is an excess mortality in LMICs, due to epilepsy. This is likely to be associated with lack of access to health facilities and causes such as drowning, head injuries, and burns.

A survey conducted by the International League Against Epilepsy (ILAE), the International Bureau for Epilepsy (IBE), and the World Health Organization (WHO) showed that people with epilepsy had access to specialist care in 89% of high-income countries, compared with only

56% of low-income countries(WHO). Individuals with the skills to diagnose and treat epilepsy are in short supply. It is not uncommon for under-resourced countries to have zero to two neurologists in the entire country. Further, there is a lack of medical equipment to help diagnose epilepsy. Electroencephalography (EEG) machines are not widely available, particularly outside of hospitals in urban areas. Further, skilled EEG technicians to record EEGs are also severely lacking. In addition, nearly two-thirds of people in resource-poor countries reside in rural areas, while nearly all the neurologists in these countries practice in or close to large cities and towns. Consequently, most people with epilepsy in resource-poor countries are diagnosed, treated, and followed by primary and secondary care physicians who lack specific training or expertise in epilepsy management.

The costs of healthcare, including travel, can be prohibitive for some. People arriving at an epilepsy clinic may have taken time off tending to their land and travelled many miles. Clinics have sometimes only "one shot" at making the correct diagnosis and carrying out the proper treatment. If they get it wrong the person can return to their village reporting poor performance of western medicine making referrals to the clinic less likely from their community.

The WHO program "Fight Against Epilepsy" ran pilot projects in Ghana, Mozambique, Myanmar, and Vietnam from 2012 to 2017 (WHO 2017). These projects aimed to educate the populations on epilepsy as well as empower health workers in primary care to diagnose and manage epilepsy. However, although there is some access to EEG in resource-poor countries, clinics are often private facilities. Moreover, minimum standards for EEG laboratories in resource-poor countries do not exist, and there are no governmental or professional authorities to ensure quality control. Most EEG laboratories in resource-poor countries are managed by laboratory technologists and nurses with no formal training in performing EEG recordings. Even in the best medical schools in these countries, postgraduate students undergoing training in neurology often receive inadequate exposure to EEG and epileptology. Consequently, EEG results are frequently misinterpreted, leading to overdiagnosis of epilepsy and unnecessarily prolonged anti-epileptic drug (AED) therapy. Given that the quality of the recording and its interpretation could not be ensured, the WHO issued a statement recommending that EEG should not be routinely used for the diagnosis of epilepsy in nonspecialized healthcare in LMICs. If there were clinical evidence for the diagnosis of convulsive epilepsy, treatment should be started without EEG. EEG should be done in specialized facilities under optimum technical conditions and with adequate expertise for interpretation of the data and results.

TeleEEG as a Potential Solution

The EEG is a means of measuring the electrical field produced by the brain. This is mediated by applying electrodes to the scalp, and amplifying and recording the results. This can be analyzed off-line.

The first EEG recording in a human was made in 1924 by Hans Berger. In 1935, Gibbs, Davis, and Lennox described interictal spike and waves and the three cycles pattern of clinical absence seizures, which began the field of clinical electroencephalography. Subsequently, in 1936, Gibbs and Jasper reported the interictal spike as the focal signature of epilepsy.

A routine EEG is carried out by applying around 21 electrodes to a patient's scalp. A recording of the electrical activity of the brain is then made. This usually takes around 30 min for an adult and an hour for an infant. During the recording, activating procedures are carried out. These procedures can help in revealing any epileptic activity on the EEG. These include hyperventilation and photic stimulation. Hyperventilation involves deep and rapid breathing for a period of around 30 min. Photic stimulation uses a flashing light at rates of between 1 and 30 times per second to help reveal any epileptic activity which is sensitive to changing light conditions. The routine EEG can show abnormalities in up to 50% of patients with epilepsy. The yield is increased to around 80% on further EEG investigations.

The first EEG machines were large and recorded on reels of paper. However, as technology progressed, these machines became smaller and recorded onto electronic files. The brain waves recorded on the EEG could then be displayed on monitors. Equipment became cheaper and more portable. Further, internet accessibility has grown exponentially making the potential for transferring EEG files for remote interpretation practical. Thus grew the concept of TeleEEG.

Proof of concept of remote EEG interpretation or "TeleEEG" as a practical clinical utility was provided in a novel service for remote EEG reporting for a hospital in Truro, Cornwall, UK, in 2011 (WHO). This involved the production of EEG files from individual patients which were then uploaded to a server. The interpreting clinician would then download the files and read them. A report of the EEG would then be e-mailed back to the referring hospital.

The first charitable TeleEEG service was set up in Dhulikhel hospital outside Kathmandu in Nepal in 2012. Until then no EEG service was available for this hospital. A donated XLTEX EEG machine produced EEG files of around 20 Mbytes on a daily basis. These were then uploaded onto a server for off-line remote interpretation. The format of the EEGs meant that dedicated reading software was necessary; however, this was readily available.

Since then, TeleEEG services have grown exponentially. To date, TeleEEG services have been set up in 40 clinics in 17 countries. This has been facilitated by the recruitment of 45 volunteer doctors with skills in EEG interpretation. Over 13,000 EEG cases have been reported to date. Neonates and elderly patients have had their EEGs interpreted with a median population age of 13 years. Routine EEGs were given 5 days for a report to be issued, and urgent EEGs are carried out in under 24 h. The average response time was found to be 3.8 days.

Zinhle from Swaziland. Zinhle was 4 years old when she was first diagnosed with epilepsy. She was having daily seizures despite drug treatment. She could not attend her local school and was getting injured from falls during her seizures. On one occasion, she narrowly missed being severely burned after she fell onto the fire in her home. However, after an EEG was carried out through TeleEEG, the type of epilepsy was established, and the appropriate medication given making her now seizure free. She now loves attending her local school and is playing in the girls' soccer team.

Swaziland Epilepsy Organisation Mbabane Hospital:

> The Swaziland Epilepsy Organisation has been able, through its patron HRH Prince Manzini, to facilitate a donation of one of the TeleEEG machines reporting over the internet, from a consultant clinic Neurophysiologist from the United Kingdom whose name is Dr Steve Coates. The donation came with training of personnel on how to operate the EEG machines. Until then we did not have an EEG machine.
>
> The EEG machine was received by the Deputy Prime Minister, Paul Dlamini, together with the Minister of Health, Sibongile Ndlela-Simelane, on the 4th of July 2016. The donated machine was set-up at the Mbabane Government Hospital Psychiatric Department.
>
> Before this donation, there was no EEG machine in Swaziland, which means no EEGs were done on Epileptic patients. This also means that we were never sure of the type or class of seizures patients had during that time.
>
> This programme we work as a team because we send EEGs to Dr Steven Coates, he then sends them to the Drs who interpret, and they bring their results to us. We are very grateful that a lot of clients have benefited from it.

Swaziland Epilepsy Organisation Mbabane Hospital, 4 July 2016

Patient Testimonial, Swaziland:

How long have you been living with epilepsy?

I started having seizures when I was 6 years old. I am now 24 years, which means that I have been living with epilepsy for 18 years.

How do you feel about living with epilepsy for such a long time?

It makes me feel uncomfortable. Sometimes I feel like I am losing my mind.

How are they treating you at home?

I am well taken care of at home because they support me when I get sick. They also make sure I am kept away from open fire and that I am not exposed to too much heat from the sun as this may trigger the seizures.

And how are they treating you at school?

I am well taken care of at school as well. They look after me when I have seizures and take me to the hospital as and when necessary.

How long have you been on antiepileptic drugs?

I started treatment in 2011. I was on Tegretol which did not give me the desired results. This medication made my condition worse. I have also consulted traditional healers and prophets who prayed for me and gave me concoctions to drink before going to sleep. Still there was no improvement.

When did you have your TeleEEG appointment?

16 November 2016.

Was the process involved in the TeleEEG test explained to you, and why was it important that you do the test?

Yes, they performed the EEG test to determine which type of epilepsy I have. Accordingly, my medication was switched from Tegretol to Epilim. I am happy to say that I am responding well to the Epilim. I sometimes go for a whole month without experiencing "fits" or seizures.

Would you encourage other people living with epilepsy in Swaziland to visit the nearest health facility for treatment?

Yes, I would like to encourage people with epilepsy to seek medical attention. I am proof that with the correct diagnosis and treatment, it is possible to live a seizure free life.

Full video of this testimonial reference can be viewed on the TeleEEG website and at https://youtu.be/CNYiLo7lZZw

TeleEEG has proven to be a practical solution to the lack of specialist EEG interpreters in low- and middle-income countries.

Challenges to TeleEEG Services

Before a TeleEEG service could be considered for a clinic, it was first necessary to ensure that there was good infrastructure on the ground to diagnose and manage patients with epilepsy. At least one staff member needed some skills in diagnosing epilepsy and how to use the results of any TeleEEG report. Further, they needed skills in managing epilepsy with appropriate therapies. Clinicians also need to know what an appropriate and inappropriate referral was for EEG.

The lack of trained staff to carry out routine EEG recordings presented challenges to setting up a TeleEEG service. The most effective method of training is face to face. However, this imposes its own problems, especially if the clinic is remote. TeleEEG trainers would sometimes require up to 1 week to allow for travelling and training. Training would typically take 2 days with a minimum of 2 local staff recording EEGs in as many patients and volunteers as possible. Language barriers could be overcome by utilizing local medical staff with interpretation skills. Most TeleEEG clinics were set up using local on-site training.

Remote training was possible and has been deployed in clinics in Guyana, Mali, Pakistan, and Haiti. This of course depends on the local staff being able to go through the training materials and understand them. Video conferencing using such platforms as Skype was also used to fine-tune the training.

Providing EEG equipment was necessary to potential clinics. In economically wealthy countries, EEG equipment is typically renewed every 5 years. The old equipment is either scrapped or sent for auction. Hard drives are typically destroyed for reasons of patient confidentiality. By contacting hospitals in the UK directly, TeleEEG has been able to get some donations of equipment. These were usually heavy PC stack type EEG machines with significant shipping costs. Further, the clinic receiving the equipment would usually have to pay their country's import duty, even though these were charitable donations. This imposed a cost on the clinics which were already poor. Although these machines were of good quality, the EEG files produced could sometimes be large. This would impose a limit on their upload if the Internet service in the particular country was poor. Therefore, the deployment of these machines was limited to countries with reasonable Internet dependence.

Laptop EEG machines are available. These can be transported easily by hand, or if sent by courier, would impose a minimum import duty. Laptop EEG equipment can also be battery operated to allow for any loss of mains electricity which can be a common occurrence in some of the poorer countries.

Cheap versions of laptop EEG machines are available. These have several advantages. They can produce EEG files of only 6 Mbytes – ideally suited for low bandwidth Internet connections. The machine runs off a laptop which can continue running the EEG test on a patient even if the mains electric power fails. Consequently, many Tele-EEG clinics had these machines deployed.

EEG tests require peripheral items, such as electrode pastes and gels. These are used to scour the scalp and to provide a good contact between the scalp and the electrode. Although local sourcing of these items is encouraged, sometimes these are not readily available for clinics.

Finally, a ready supply of specialist EEG interpreters is required to read the uploaded EEGs. The EEGs might not be of the best quality, so interpreters need to be well experienced to handle this. A challenge is to recruit a sufficient number of experienced interpreters to meet the demand of uploaded EEGs.

Mind the Gap

TeleEEG is delivering the following 2-year plan and 10-year vision to help global healthcare providers address and reduce the epilepsy treatment gap with TeleEEG.

This 2-year plan is establishing partners and funders to enable the charity to achieve the goal of 40 TeleEEG clinics by 2021 in 20 under-resourced countries (Fig. 1).

10-year vision to achieve diagnostic coverage capability throughout the developing world in 139 countries with 2,400 TeleEEG clinics by 2031 (Fig. 2).

People

Pilot #1

> Steve Coates, one of our UK consultants, set up a charity called TeleEEG to provide EEG services in third world hospitals. I am very impressed with what he has done. As BSCN President I support TeleEEG, as well as do a little of the reporting.[+]

It takes a certain type of person to trailblaze. Innovation is demanding and rewarding in equal measure. In the triumvirate of people, process, and technology, here, it is people first. For every Tele-EEG clinic that is enabled, we require at least one such individual to understand, drive, optimize, and "own it." Without this key stimulus, with all the innovation and technology in the world, it will not work. Within the confines of their day-to-day professional and personal lives, they must follow through on commitments come what may. The greater their endurance and long-sightedness, the further we go. Such is the nature of exploration.

TeleEEG Chief Executive Officer, and benevolent founder Dr Stephen Coates, has a first degree in engineering and majored in communications systems, specializing in satellite communication. In the British Royal Air Force, as Flight Lieutenant Engineering Officer, Communications Electronics, he commanded the UK contingent of the Mission Control Team for launch and orbital guidance of the SKYNET 4 system of communication satellite. The Chartered Engineer went on to become consultant physician specializing in clinical neurophysiology and a Fellow of the Royal College of Physicians (Edinburgh).

Tech Spec

To make TeleEEG work in the field, one also needs a capable, proactive person carrying out the EEG recordings, a technical specialist. Tele-EEG Trustee Anne Clarke is just such a person.

A good technician needs not only to be able to carry out the technical requirements of an EEG, which include well applied electrodes, full recording, hyperventilation, photic stimulation, preparation of the EEG, and upload, but also to recognize that at the end of the EEG leads, you have a person. Anne puts the person at ease and can give a good history about the patient and why they were having an EEG by teasing out the information. During the recording, she will comment on how well the patient cooperated and any anomalies that occurred during the recording. This helps significantly in the interpretation and provides a great model to emulate and replicate.

Funding Required	£59,208
2 Year Period	2019 - 2021
TeleEEG Clinics in Developing World (30 supported, 10 added)	40
Population Served by 40 TeleEEG Clinics	20,000,000
People with Epilepsy in Service Coverage: Undiagnosed	500,000
Treatable Epilepsy Cases 70%	350,000
Total Epilepsy Cases Diagnosed by TeleEEG	5,000
Volunteer Consultant Physicians	60
Total Delivery Value	£918,456
Set-up & Enablement Cost Per Clinic	£5,921
TeleEEG cost per diagnosed patient	£11.84

TARGET: Reduce Epilepsy Treatment Gap by estimated 1%

Fig. 1 TeleEEG 2 year vision

This approach is imparted to nascent and aspiring technicians around the world by TeleEEG. When visiting TeleEEG clinics, for enablement and training, she will help fine-tune them as to carrying out neonatal EEGs as well as the idiosyncrasies of adult EEGs.

A specialist clinical physiologist within neurophysiology working in Truro NHS Hospital, for the Royal Cornwall Hospital Trust, Anne jointly authored the paper: TeleEEG in the UK (2012).

Team TeleEEG

TeleEEG has an extended supporting cast, too many to cite and all with the requisite capabilities, as defined above. They engage TeleEEG operationally every day and on a voluntary basis for the beneficiaries of the charity. Currently, including teams in territories, over 200 individuals are collaborating voluntarily in a virtual team and to the same end, learning which way to turn to facilitate

Fig. 2 TeleEEG 10 year vision

Funding Required	£10,800,000
10 Year Period	2021 - 2031
TeleEEG Clinics Established in Developing World	2,400
Population Served by 2,400 TeleEEG Clinics	1,200,000,000
People with Epilepsy in Service Coverage: Undiagnosed	40,000,000
Treatable Epilepsy Cases 70%	28,000,000
Total Epilepsy Cases Diagnosed by TeleEEG	6,000,000
Volunteer Consultant Physicians	3,600
Total Delivery Value	£55,107,360

Set-up & Enablement Cost Per Clinic	£6,000
TeleEEG cost per diagnosed patient	£1.80

TARGET: Reduce Epilepsy Treatment Gap by estimated 21%

the next piece of data, bringing new technologies, and working methods to diagnose and treat epilepsy in deeply challenged situations.

> I find some of these records challenging to report. One day after work when I was feeling particularly grumpy about the quality of a record I looked up the hospital it came from on the internet - it had to close for a period last year because they had no food for patients and staff. That was a rather humbling experience[+]

Mater Necessity

It is evident in TeleEEG's innovative approach that a technical, problem-solving mindset is required by all involved – necessity is the mother of invention. Rarely are two installations the same. Technical deployment alone is challenging, but when combined with hampering influences, be it political unrest, environmental issues, perceived legal constraints, or technological barriers, the design of the system for TeleEEG is thorough necessity, one that requires the least amount of in-person presence, while delivering exactly the same model as illustrated in 2011.

Here Is an Idea

Since the proof of concept in Truro Cornwall Hospital, UK and the Epilepsy clinic at Dhulikhel Teaching Hospital in Nepal was set-up and connected, a further 36 such Epilepsy clinics have been enabled in 17 countries and continue to be remotely advised by TeleEEG.

There is now an awaiting service list including over 20 university hospitals in LMICs where conditions are sometimes so dire that requests come with calls for help with non-EEG related items including, "theatre bed, neonatal resuscitaire, nebulizing machines, suctioning machines, laundry machines, anesthetic drugs, antihypertensives and inhalers."

With new TeleEEG clinics coming online every month, effort is channeled on a daily basis by tenacious individuals throughout Central and South America, Africa, and Asia. The model that a decade ago was an idea has proven to be a highly effective strategy and efficient intervention. It maximizes the use of resources and provides peer-to-peer learning and advice. It is lean and scalable by design, one clinic at a time, which once set up becomes self-sufficient units connecting digitally in a hub and spoke model through cloud infrastructure.

Sustainability and self-sufficiency are a must. In the absence of commercially produced and supplied consumables we rely on locally available materials and good old-fashioned ingenuity. This and innovations around devices help to make the most of the donated EEG machine and supporting systems.

The key remains PEOPLE, and with the right people in a place, this supercool concept is rapidly deployed and equally quickly becomes highly organized and effective.

Process

The Virtual Organization

Given the proven mechanisms of this virtual organization and the caliber of strategic partners, volunteers and University Hospitals involved, we have few but key variables that can drive this growth, namely physicians, equipment, and minimal funding.

The organization runs entirely in the cloud so as to minimize overhead costs and to enable contributing individuals to connect and participate efficiently. We lean on technology to help ensure all that we do is properly governed, reported, protected, and stored so as to protect and enable us all while we carry out the worthwhile contribution of epilepsy awareness raising and treatment.

Good for the Soul

> No one should take this on thinking that it will be easy to run through a few quick cases. There are technical challenges of all sorts, hardware, software, electrodes, people. So far, the illnesses have been familiar - common epilepsy syndromes and functional illness. The language is English. Often imperfect but always good enough. I have enjoyed it and think it worthwhile.[+]

Nothing worthwhile is easy, and while it is simple for a qualified professional to join the team of TeleEEG volunteers, once they decide to give an hour or two a week of personal time to contribute as part of our global virtual team, there are real challenges in what we do from a technical perspective. The most common concern that people raise is unsurprisingly that of the risk for potential litigation, both from those who are donating equipment and also on the part of volunteer interpreters. TeleEEG volunteer interpreters have their own professional liability insurance. Letters of authority are sought from the organizations employing physicians as required, i.e., local institutional approval. Equipment provided as new or reconditioned by manufacturers is gifted by way of charitable donation to the beneficiary hospital. TeleEEG raises fund through its global partner organizations and by personal donations made by consultants and associates, and this fundraising pays for the cost of setting up TeleEEG. We work predominantly with University Hospitals, and TeleEEG is an advisory service only. This is as stated on our website and through our communications with new clinics and their staff. The referring clinician is and remains responsible for their patient and may choose to act on our EEG interpretation or not.

Our global team regularly reinforces that the reward for their efforts is repaid many times over by the knowledge that they are able to make a difference in this way.

Technology

One Person's Trash

The hunt for efficiency is a sport and an art and where possible we deploy recycled EEG equipment. As large healthcare providers relatively regularly decommission equipment that can be refurbished, we remain on the hunt for donations of EEG equipment. Hardware is selected for portability, durability, and simplicity for ease of use. It must also be long-lasting and not overly complex. As such, we are happy to recycle and upcycle. This makes good economic sense, naturally, as well as being environmentally sound policy, and by maximizing use of resources, we can enable more clinics.

We are technologically agnostic as regards manufacturers of medical devices, and the overriding requirement is that equipment meets our criteria. This can be momentarily challenging for new interpreters, consultant physicians, who can currently face a plethora of software to read different EEGs depending on which countries they are volunteering to advise remotely, by choice, language or allocation. But they are ordinarily highly proficient software users and competent with technology, surrounded by IT administration support be that in faculty, business, or practice. As systems increasingly converge online, one interface to read and report across all systems is an ever-closer reality. Many of our software programs already deliver interoperability with online and mobile solutions, and for those with local installations, migration is inevitably already underway.

Dispatch

> Waste not, want not, is a maxim I would teach,
> Make your watchword 'despatch' and practice what you preach,
> Never let your chances, like sunbeams pass you by,
> As you never miss the water 'til the well runs dry[++]

It is less of a challenge to find economical, secondhand machines or fund low-cost EEG machines than it is to get them to their desired location. Delivery of technical equipment to troubled territories can be fraught with difficulties. From parcels going missing in transit, to excessively heavy import duties official or otherwise being levied as kit passes through ports and states. More often than not, the burden on the recipient is too much and can outweigh the cost of the kit.

Virtual Training

In the early days of deployment, the team would always take the equipment TeleEEG was donating in person to deliver and install along with the training sessions for the recipient healthcare workers and physicians. We delivered this way for the first few years of deployment. Over time, we have enabled group sessions where, for example, in Nigeria, we were able to train a group of 20 individuals in 1 visiting session, by taking 7 EEG machines out on one trip. By the time of our return to the UK, we had seven clinics up and running.

The next evolution was to remotely enable a clinic; this first took place at the end of 2019, where through video and e-mail, despite various usual technical complications, the hospital team were able to successfully upload their first quality EEG.

In addition to basic EEG training, we collaborate with online training provider GOHE that charitably provides further education by way of EEG technician training that can lead to certification with the leading US accreditation body. The aim is to enable self-sufficiency and in-country professionals by training-the-trainer, providing career and wage advancement opportunities along with a great network of supportive and like-minded technical specialists around the world.

This virtuous circle also extends to patients who can find themselves seizure-free for the first time in their lives and are able to engage in education, sport, community, relationships, and employment as never before.

Data, Data Everywhere

One of the main challenges for most organizations is the appropriate and efficient handling of data. It is not uncommon for organizations to be managed and run from multiple disparate spreadsheets. This inefficient practice, leaking data and creating silos, is error prone and is to be avoided where possible.

From regulatory considerations in doing the right thing to practical considerations of accuracy, TeleEEG has aligned with best-of-breed technological partners and donated enterprise-level software tools enabling it to embed regulatory best practice. Data has a value, be that knowledge-based or fiscal. It is our duty to protect and nurture this in the right way, while also aligning this with the values of the organization for the benefit of patients.

Resourcing Criteria

We provide under-resourced countries with EEG equipment and train local staff on performing EEG tests and report EEGs remotely as an advisory service. This is entirely free and provided on a charitable basis. As such, we need to know that this service will be used effectively and ask applicants to determine need as below:

1. Approximately how many potential patients with epilepsy do you see in your clinic per month?
2. How far is your nearest EEG Clinic?
3. Do you have a room in your clinic where an EEG machine can be installed and left set up?
4. Do you have a minimum of 2 staff available for 2 days of training?
5. Do you have Internet access within your clinic?

Providing an online form for completion: Clinic Criteria for TeleEEG – Click to Submit

Skateboard to Supercar

TeleEEG has a good management system whereby clinics upload zipped EEG files, and these are allocated to interpreters who receive an e-mail alert, log in, read, and report. In system-design terms, this is fondly referred to as a skateboard. It is a minimally viable solution to get from A to B. It is secure, usable, and functional. In many instances, it is enough, and perceived wants tend not to translate to the reality of the needs of users.

However, the existing system does have limitations as regard to data input; varying types of text field content, for example, lead to a manual process requirement for data analysis. It is at the basic end of the scale as regarding patient case management. This suits new clinics which are on the steepest of learning curves. It is fit for purpose, but limited for advancement of knowledge, people, and practice. Most consulting physicians are fluent with sophisticated systems for patient and case management, so there is currently compromise and understanding on their part. Fortunately, again through strategic partners, we have been able to secure access to and are in the process of configuring and deploying a system ordinarily used by pharmaceuticals in clinical field trials. Such a system has the advantage of being constantly developed through the imperative of cutting-edge commercial investment, thereby preventing the situation where we end up in a technology cul-de-sac with proprietary software that is no longer maintained. It also enables us to adopt industry best practice and standards.

The reality is that fully transitioning to this today would be like moving from using a skateboard to a supercar. Of course, many people dream of supercars, but most could not drive one safely or comfortably. Fortunately, we can comfortably use a fraction of this facility in the confidence that the capacity is there for scale and volume. The system, for example, could allow for continuous monitoring, streaming video that is simultaneously uploaded via superfast broadband to a military grade cloud provision and simultaneously available for viewing and monitoring at any connected location around the world. In fact, our use of it will be slight by comparison while we are governed by the usually slow broadband connections in the field, and clinics upload zipped one-hour EEGs that are small by comparison to this illustration.

There is always a temptation to want to "tweak" such a platform to tailor it to today's situation, but experience tells us that when the mature market has designed and paid for a software solution, then the best advice is to leave it "vanilla," i.e., to resist the temptation to change for the sake of buy-in or ownership, to trust that there is experiential rationale behind its form and function.

There are new opportunities, with which we are engaged, for new low earth orbit satellite systems that will bring low or no cost internet to remote areas of the world. These would greatly enhance our clinic communications and allow for greater bandwidths and faster uploads. It could even lead to possibilities of continuous EEG monitoring from ICUs.

Wearable Sensory Technologies

Electroencephalography (EEG) is a method of recording the brainwaves of people with potential diseases such as epilepsy. To do this, small electrodes are usually pasted to the scalp using adhesive conductive paste after first scouring the scalp with scouring paste to ensure good connectedness for optimum conductivity.

This is a time-consuming process and for a first-time trainee who is not necessarily a technician, more usually a nurse, in an under-resourced or challenging situation and with a patient who is also entirely new to the process, can find it rather daunting. There are also ongoing training and quality standards considerations which we address through process and support.

The electrodes have to be in particular positions on the scalp to give a reasonable electrical view of the brain. The usual method of placing these electrodes on the scalp uses a measuring technique called the 10–20 system. This places various electrodes at 10% or 20% distances along set lines along the scalp in a preconfigured manner so as to enable a quality EEG report.

We supply a 10–20 manual for further information, and there are a number of videos which serve as a reference point by way of repeatable demonstrations for trainees, including an introduction to the EEG, practicing the 10–20 system and how to apply EEG electrodes. Various approaches of headset or caps have been tried in an attempt to fix the distances and save time measuring; however, their cost, complexity and durability have been barriers to their adoption for use at clinics at hospitals in LMICs. Through an advanced digital technologies program in North East England, we are exploring alternative solutions and materials through precision additive coating technologies. Additive coating technologies can be used for everyday products as well as complex and specialist industrial parts by formulating raw materials to be suitable for 3D printing and other specialist printing and layering technologies.

We are fortunate to be able to access these product and process development assets and expertise at no cost to the organization in order to explore formulation preparation, precision deposition and characterization facilities for sensors, nano-enhanced inks, textiles, coatings, composites, resins, and polymers, as required subject to the design.

In the UK, Government-funded technology innovation centers exist which focus on high value manufacturing, created to support the UK process manufacturing industry. While we are operating a charitable venture in healthcare, the center's research and development team is keen to explore how industry can support the simplification of such a laborious technical role in the application of EEG.

We are designing a low-cost 3D printed gadget that we hope will help us to scale more efficiently and equip clinics with simple yet innovative tools for use during remote and virtual training. The aim is to significantly shorten training times, boost learner confidence, improve patient experience, and generate improved results. Time savings ultimately benefit the hospital, as well as the individuals involved.

We are often the first interaction with Western medicine and so aim for the experience as well as the result to be impactful in a positive way.

The proposition is for a headband method that is adjustable, incorporating hook and clip that electrodes can clip into and be supported by. Three-dimensional printing is able to produce good click-hinges, and with advanced materials, comes durability.

Practically, the electrodes need to sit firmly against the scalp, and it must allow for the technician to be able to part hair and prepare the scalp. Often, at new clinics, people learning to apply the electrodes easily become confused as to which electrodes they have applied, and so, a good visual representation will be invaluable, to initially simplify what they are doing. This will speed learning, confidence, and accuracy. A headband approach is favored, reinforcing our ethos and mantra of keeping things simple.

Stages of Separation

Another fascinating aspect of the rate of change, adoption, and growth with technological innovation is the rapid advancement in connectivity. Just 10 years ago, it was broadly accepted that we each knew everyone in the world through 6 stages of separation. You knew someone, who knew someone, et cetera, times six, and that last person knew, or had met, the famous actor. With the introduction of social media and platforms, this reduced to just three stages of separation as digital social circles expanded without physical or psychological barriers. So today, we find astonishingly that we are almost constantly directly in touch with whomever we wish at the press of a button through mobile devices.

In many LMICs, there is an increasing prevalence of mobile phone usage, so now, we are beginning to see potential service users or their family members who can find and connect with us directly 1:1 via social network platforms to help find solutions for patients who may have been experiencing epileptic seizures for 20 or even 40 years without proper diagnosis or treatment.

Technology is at once able to educate, connect, and signpost us in a matter of seconds. In a recent example, we were able to advise that while a new clinic had been due to go live that week, plans had been postponed due to coronavirus travel restrictions, hence, we were able to connect people and start discussions that would lead to proper treatment in due course before we had completed clinic setup. These are previously unimaginable levels of connectivity.

Good communication is at the heart of every successful relationship, venture, and solution. We are engaging tools that help harness and capture this from a customer relationship management (CRM) perspective and allow us to integrate all channels from web, social, search marketing, e-mail, and platform into one source.

Automation

The software that we use for communications and data can also be used to configure automated onboarding, so that for key workflows that are repeated, we can begin to standardize responses, and by channeling this way, begin to automate messaging, onboarding, evaluation, and processes that would otherwise be repetitive and increasingly resource heavy.

This also increasingly applies to tasks associated with promotional campaign management, where routine tasks and even more complex analysis of data using machine learning systems are able to provide us with time-saving solutions that turn a 1 h job into a 1 min job. Be under no illusion, these are not self-driving systems and require experienced oversight and informed decision-making in-the-moment. However, they are extremely beneficial and increasingly prevalent.

AI

This leads us to the most potentially impactful of all the advanced digital technologies on the not too distant horizon for LMIC TeleEEG, Artificial Intelligence (AI). Whatever one's perspective, in the active debate about human versus machine, the rapid deployment of such technologies for the healthcare sector is increasingly realistic.

Given the shortage of Consultant Neurophysiologists in LMICs worldwide, coupled with their number of cases, epilepsy treatment gaps, and level of maturity of service provision, we are actively embracing technical solutions, currently in development, which enable aggregation of data to support faster and better clinical decision-making. As with the aforementioned automation tools for communication, and as is increasingly seen and used to great effect in other walks of life, from paralegal to criminal case handling and processing, so too the first AI steps for EEG analysis and diagnostic support, created for use by consultant physicians, will ease the burden of workload and improve insights (Fig. 3).

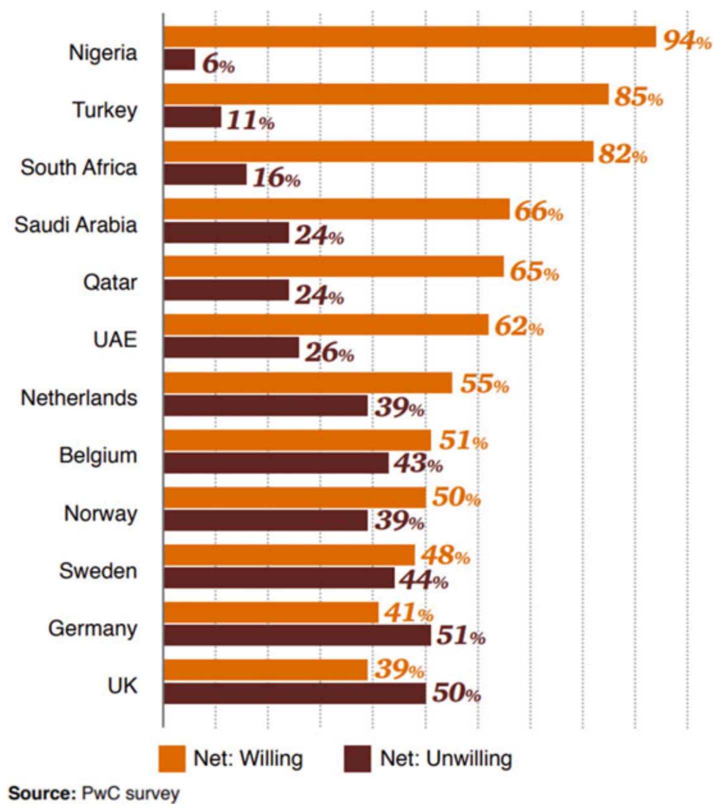
Anyone in remaining doubt about the likelihood of the predicted prevalence of AI in global health solutions need only understand patient inclination to engage with it, particularly in LMICs, where efficient solutions to longstanding problems are hungrily sought (PwC 2017).

A 2019 study comparing AI interpretation of EEGs with human interpretation of EEGs illustrated for the first time that an algorithm had been shown to exceed expert performance for IED detection and may thus be a valuable tool for expedited review of EEGs (2020).

Future Innovations

Higher broadband speed allows for the remote training of local staff. This also means quicker transfer times for EEG uploads and downloads. Further, the utility of continuous EEG monitoring

Fig. 3 Patient engagement with AI



in an ITU setting is being realized now in high-income countries. At present, this is beyond the reach of clinics in LMICs. However, accessible superfast broadband speeds make this a possibility in the future. TeleEEG has been in discussion with the SpaceX Starlink project. This project will allow high speed, cheap, or no cost internet access to the remotest parts of the planet. This would significantly impact the availability of the TeleEEG service throughout the world.

EEG equipment is gradually becoming more affordable. Further, the migration of EEG onto platforms such as tablets and smartphones is promising and would significantly reduce the price and availability of equipment.

The accurate and well attached placement of electrodes onto patients' scalps is time consuming and requires training. However, high impedance headsets are now available for clinical use. These allow for quick placement of the EEG electrodes onto the scalp without the use of abrasive pastes or contact gels. Moreover, as the electrodes are embedded into a headset, their placement onto the correct areas of the scalp is assured.

These headsets are currently very expensive. However, as the price lowers, they will become more available for clinics in LMICs.

Interpretation of the EEG remains a skill-demanding area. Interpreters usually go through years of training and exposure of various EEGs to become competent. The growth of AI promises to automate the process of interpretation of the EEG. At the moment, software for the automatic detection of epileptic discharges on the EEG is fraught with false positives. However, the future of this technology is encouraging.

Conclusion

The paradigm continues to shift. The hub and spoke model of deployment, as delivered by our virtual organization globally, is lean, scalable, and entirely digital.

The conclusions we draw from our experience over the last decade, helping epilepsy diagnosis in the developing world through TeleEEG, are that a team of professionals with SMART technical tools and collaborative mindset is the winning formula.

We share vision and resources, always starting small on a project-by-project basis, one step at a time, advancing quickly. The repeating model brings economies, and innovation extends to technological improvement.

By charitable collaboration with world-class partner organizations who share our values and goals, notably including ROW Foundation, Rotary International (Durham Elvet and Darlington), Persyst, GOHE, and Lifelines iEEG, we are able to deliver cost effective solutions reaching the global health technical equivalent of the rural last mile.

TeleEEG has proven its utility in the diagnosis of epilepsy in clinics in the developing world. To date, over 13,000 EEG interpretations have been carried out. Training of staff and supplying equipment have proven challenging but possible. Future improvements in online training, high impedance headsets, high speed internet access, and AI promise to enhance the TeleEEG service even further.

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