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The NED foundation experience: A model of global neurosurgery

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ABSTRACT

Introduction: The Neurosurgery Education and Development (NED) Foundation (NEDF) started the development of local neurosurgical practice in Zanzibar (Tanzania) in 2008. More than a decade later, multiple actions with humanitarian purposes have significantly improved neurosurgical practice and education for physicians and nurses.

Research question: To what extent could comprehensive interventions (beyond treating patients) be effective in developing global neurosurgery from the outset in low and middle-income countries?

Material and method: A retrospective review of a 14- year period (2008-2022) of NEDF activities highlighting landmarks, projects, and evolving collaborations in Zanzibar was carried out. We propose a particular model, the NEDF model, with interventions in the field of health cooperation that have simultaneously aimed to equip, treat, and educate in a stepwise manner.

Results: 138 neurosurgical missions with 248 NED volunteers have been reported. In the NED Institute, between Nov 2014-Nov 2022, 29635 patients were seen in the outpatient clinics and 1985 surgical procedures were performed. During the course of NEDF's projects, we have identified three different levels of complexity (1, 2 and 3) that include the areas of equipment ("equip"), healthcare ("treat") and training ("educate"), facilitating an increase of autonomy throughout the process.

Discussion and Conclusion: In the NEDF's model, the interventions required in each action area (ETE) are coherent for each level of development (1, 2 and 3). When applied simultaneously, they have a greater impact. We believe the model can be equally useful for the development of other medical and/or surgical specialties in other low-resource healthcare settings.

1. Introduction

For a long time, it has been difficult to find a place for surgery in global health policies more focused on addressing specific diseases. In 2015, coinciding with the end of the United Nations' Millennium Development Goals, an international commission of experts (The Lancet Commission on Global Surgery) published the first report on the state of surgery worldwide (Meara et al., 2015) showing more than 90% of the population in most African countries cannot receive reliable surgical and anesthesia care, causing globally almost three times as many deaths as HIV/AIDS, tuberculosis, and malaria (Meara et al., 2015; Park et al., 2016).

Surgical care is essential for the treatment of many conditions, from infectious diseases to cancer; therefore, investing in the development of global surgery should be a priority for the international community. Building hospital capacity and training specialists in low- and middle-income countries (LMICs) is a huge challenge, particularly in neurosurgery. Each year, more than 22 million people suffer neurological disorders or injuries that warrant the assistance of a neurosurgeon, and over half of them need surgery.[3,] But healthcare systems are not truly prepared to address these needs (Piquer and García-Rubio, 2022). In the neurosurgical individual scenario, more than 20,000 additional neurosurgeons worldwide would be needed to meet the estimated volume of cases

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Abbreviations list

CAANS	continental association of African neurosurgical societies
COSECSA	College of Surgeons of East-Central-Southern Africa
CT	computed tomography
ETE	equip, treat and educate
FIENS	Foundation for International Education in Neurological Surgery
LMICs	low- and middle-income countries
MMH	Mnazi Mmoja Hospital
NED	Neurosurgery Education and Development
MRI	magnetic resonance imaging
NEDF	Neurosurgery Education and Development Foundation
NEDI	Neurosurgery Education And Development Institute
TBI	traumatic brain injury
WFNS	World Federation of Neurosurgical Societies

(Dewan et al., 2019). The greatest shortage of personnel is in Africa, where despite accounting for 15% of the global volume of neurosurgical disease, there is the only access to less than 1% of the practicing neurosurgeons worldwide (Beer-Furlan et al., 2019). On the African continent, regional inequalities are also enormous. Of the estimated 1974 neurosurgeons working in Africa in 2020, a majority of them – 73% – practiced in North and South Africa while the rest cover the neurosurgical needs of 48 countries (Kelechi, 2021) (in East Africa, for example, the ratio of neurosurgeons per capita is 1 per 10 million people).

It is known today the development of essential surgical services is among the most cost-effective interventions with economic and social significance. In fact, many surgical procedures are equally or more cost-effective than common public health measures such as vitamin supplementation or anti-retroviral therapy for HIV/AIDS (Schecter et al., 2015). It's similar when it comes to specific procedures in neurosurgery; treating hydrocephalus in LMICs countries is now more cost-effective than anti-retroviral therapy or cesarean delivery (Meara et al., 2015). Furthermore, in resource-limited health systems, innovation is providing creative solutions and helping to reduce costs, and faced with an obvious need, it seems reasonable to try to change the situation. Seen from this prism, offering the possibility of treatment to a child with congenital hydrocephalus becomes (almost) a moral duty anywhere in the world. Today we have the knowledge, resources, and willingness to promote social change through effective health interventions. Failure to do so may be unfair.

In this regard, the Neurosurgery Education and Development (NED) Foundation (NEDF) provides neurosurgical care and improves neurosurgical education for physicians and nurses, focusing its activities on the East African region, particularly in Tanzania/Zanzibar. In this report, we present the experience of the NEDF in the development of neurosurgery in a scarce and poor health system such as the one in Zanzibar (Tanzania), highlighting the results obtained after more than a decade of active service, between 2008 and 2022. Our ultimate objective is to describe the model of international health cooperation that has guided the different interventions throughout time. We believe that this model can also be useful for other organizations interested in promoting social change through health interventions.

2. Material and methods

In this 14- year period (2008–2022), we retrospectively review the evolutionary course of NEDF activities in global neurosurgery in Zanzibar highlighting landmarks, projects, and evolving collaborations.

2.1. Study site characteristics and background

In 2008 a team of volunteers from the NEDF traveled to Zanzibar (Tanzania) to give neurosurgical service at the Mnazi Mmoja Hospital (MMH), the only tertiary care referral hospital in the Zanzibar archipelago (consisting of two main islands, Unguja and Pemba, and numerous other minor scarcely populated islets), which has 1.8 million inhabitants. Although active since 1955, this hospital had never offered neurosurgical care to patients on the island, as no neurosurgeon had previously practiced in Zanzibar. During the first trip, the NEDF team treated as many patients as possible, taught local health workers how to perform some simple procedures, and donated the equipment they had managed to transport to the island. Local health authorities asked the foundation to go further. They needed to develop neurosurgery in the long term. The challenge was enormous, but so were the needs. Assisting the Zanzibar Ministry of Health in this task required creating the necessary infrastructure, partnership, and training of health professionals.

Initially, the most viable option was the organization of short-term surgical missions carried out by volunteers, providing basic medical and surgical materials. At times, the volunteers transported a portable neuroendoscope that allowed local patients to be treated (Piquer et al., 2010). At the same time, they could begin training local professionals in such a high-impact surgical technique (a good example of innovation and adaptation to the local context).

Later, the NEDF scaled its interventions. and in 2014 it financed the construction of the first neurosurgical monographic Institute, known as the NED Institute (NEDI) (Fig. 1), built within the MMH grounds but with sufficient autonomy to hire its own staff and operate as a specialty center. Currently, this institute acts as the single humanitarian neurosurgical care provider in Zanzibar. It has three hospitalization rooms with a total of 24 inpatient beds, two dedicated neurosurgical theaters, a sterilization center, a post-operative recovery area with six beds, two outpatient clinic consultation rooms, a minor surgery room, a conference room, and an office. It is equipped with anesthesiology ventilators, cardiac monitors, a surgical microscope, and C-Arm X-ray machine. The NEDI's surgical storage holds over 30 boxes of surgical material, including all the basic materials to perform neurosurgical procedures.

2.2. NEDF main activities

Clinical data was collected since the beginning of NEDF's activity in 2008, which reflects the number of medical missions with the corresponding volunteers involved, the different medical and nursing specialties that have participated, and the number of patients treated and

Fig. 1. The NEDI within the grounds of Mnazi Mmoja Hospital.

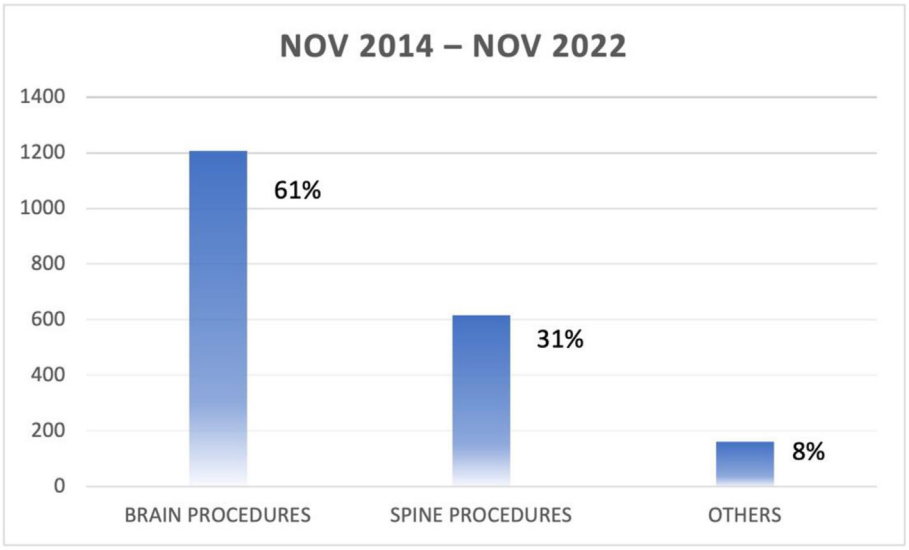

Fig. 2. Proportion of brain and spinal procedures (surgeries), and a third small group referred to as "others" for unclassified patients.

visited in outpatient clinics.

We present gross clinical data regarding neurosurgical patients operated on at the NEDI from November 15th, 2014, after the opening of the institute, to November 30th, 2022. An electronic database using an Excel spreadsheet was used for data registration, continuously filled in by the local staff and volunteers. During the document review, an important drawback has been the wide range of nomenclature adopted to describe surgical notes. Therefore, and for practical purposes, we have divided the results into two large groups: brain and spinal procedures, and a third small group referred to as "others" for unclassified patients due to lack of accurate information. Brain pathology included: hydrocephalus, traumatic brain injury (TBI), tumor, and congenital malformations among others; while spine pathology was mostly related to degenerative conditions, neural tube defects, and spinal cord injury (Fig. 2).

2.3. NEDF model

In the second part, we present a model that has guided the work of the NEDF for more than a decade of experience in promoting global neurosurgery. A serious effort has been devoted to supporting the sustainability of this singular low-resource healthcare setting by intervening in three areas: infrastructure, medical care, and training, which constitute major gaps in the local health system (Anne, 2014).

Consequently, interventions in the field of health cooperation have aimed to simultaneously Equip, Treat, and Educate (ETE) in a stepwise manner, composing the three pillars of this model. We have differentiated two essential parameters: the degree of difficulty of the required interventions (complexity), as well as the capacity for the local professionals to carry them out (autonomy). The model applies the principle of increasing levels of complexity beyond the scope of healthcare (treat) and training (educate) and extends it to the domains of equipment (equip).

We set out to classify interventions with increasing complexity at each level of progress. In parallel, every level is associated with greater autonomy as local healthcare providers. Thus, interventions are grouped from lower to higher complexity as the local team gains greater autonomy and capacity at each stage. We note that external support has been necessary throughout the process, but not in equal proportions during the different phases, and always keeping the endpoint of a gradual reduction of it along the course. This is a distinctive model of international health cooperation that we make available for discussion and validation.

Table 1
Summary of main surgical procedures performed at the NEDI from November 2014 to November 2022.

BRAIN PROCEDURES	n = 1206	
HYDROCEPHALUS	577	29,1%
BRAIN TRAUMA	287	14,5%
BRAIN TUMOR	192	9,7%
TUBE DEFECT (HEAD)	21	1,1%
OTHERS (BRAIN)	129	6,5%
SPINE PROCEDURES	n = 616	
DEGENERATIVE SPINE	362	18,2%
TUBE DEFECT SPINE	115	5,8%
TRAUMA SPINE	82	4,1%
TUMOR SPINE	57	2,9%
OTHERS (non-specified)[a]	n = 163	8,2%

[a] Refers to those procedures that could not be properly classified because the information collected in the NEDI's electronic database was incomplete (particularly during the first few years of surgical missions).

3. Results

3.1. Clinical results

138 NEDF neurosurgical missions have been reported since 2008, including 248 volunteers. These international surgical camps were always arranged by the NEDF and even though the gross of the volunteers was coming from Spain, it is worth mentioning that others were sent from other countries such as the United Kingdom, Kenia, Germany, Portugal, Chile, Czech Republic, Ital, United Arab Emirates, Norway, France, etc. The surgical teams were composed mainly of 4–10 of the following healthcare professionals: neurosurgeons (including the main coordinator), anesthesiologists, scrub nurses, and sometimes intensivists, and/or physiotherapists. Missions lasted for around 1 week and were composed of one clinical day and five surgical days, with both theatres simultaneously active, at times.

In the NEDI, during the study time frame (Nov 2014–Nov 2022), 29635 patients were seen in the outpatient clinics and 1985 surgical procedures were performed at no cost for the patients (Table 1). The proportion of brain surgical interventions was about twice as high as that of the spine. The most frequent surgeries were those related to the treatment of hydrocephalus (n = 577), comprising 47.8% of brain surgeries and 29.1% of the whole series. The second most frequent brain

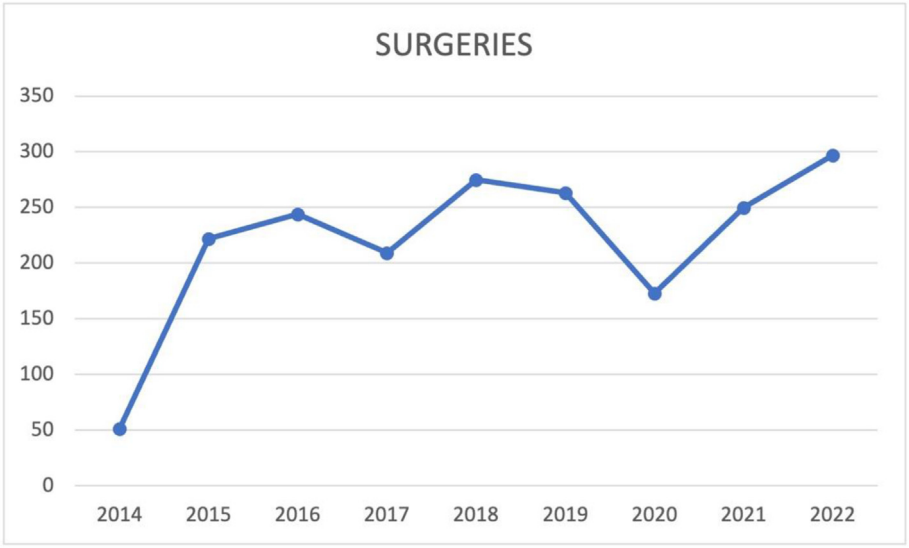

Fig. 3. The course of the number of surgeries performed at NEDI.

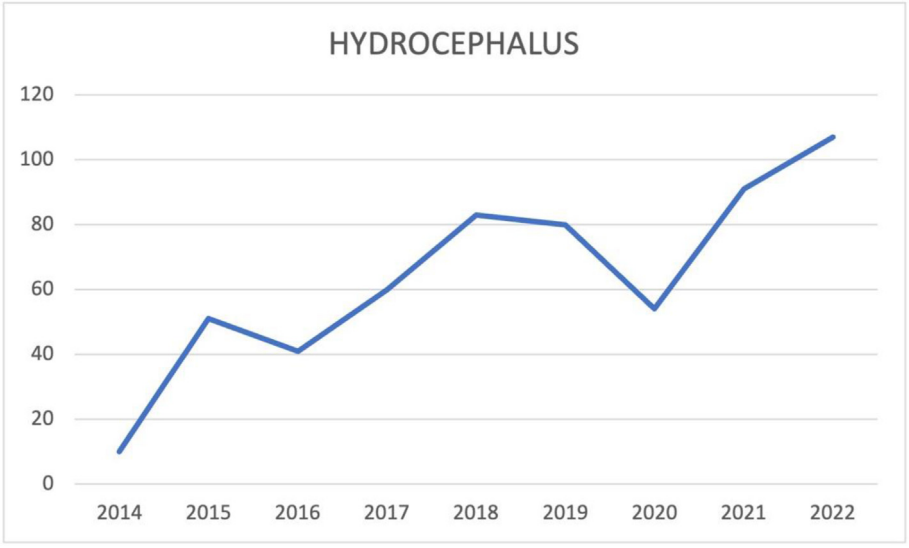

Fig. 4. The most frequent surgeries at NEDI were related to the treatment of hydrocephalus.

surgery was related to TBI, followed by the management of brain tumors. On the other hand, the most frequent spinal interventions were on degenerative spine (58.8%), representing 18.2% in total, followed by neural tube defect repairs, spinal cord injury and spinal tumor surgery. It is noticeable that the number of surgeries has increased over the years except for a significant decrease in 2020 coincident with the Covid-19 pandemic. (Figs. 3–5).

After the first few years, it has been possible to organize and carry out daily academic activities including clinical case presentations and discussions as well as one ongoing weekly online session in which relevant clinical and academic topics are reviewed and discussed with local doctors and nurses, which have been exceedingly useful for periods between missions, avoiding lack of contact that can undermine the progress of the project.

In addition, the NEDF's commitment to teaching and education has been decisive, with the organization of 29 training courses so far both in Zanzibar and in different East African countries, especially after the creation of the NEDI itself. A variety of courses for both nursing and medical staff included suturing techniques, neurocritical care, neuroendoscopy techniques, spine, and brain anatomy and surgery. Partnerships with multiple associations like the College of Surgeons of East-Central-Southern Africa (COSECSA), the Continental Association of African Neurosurgical Societies (CAANS), and the World Federation of Neurosurgical Societies (WFNS) together with the presence of some of most elite international faculty, higher academic levels have been achieved. Recent remarkable examples include the "Hands-on African Spinal Microsurgery program: a lumbar spine course" in October 2021 and Neuro-oncology Brain hemisphere Anatomy through clinical cases in March 2022, with the participation of Paul H. Young and Prof. U. Türe. Likewise, in 2018 the NEDF began the sponsorship of international short-term fellowship programs (3–4 months) with the support of COSECSA and the Valencia International University, in which every year, a visiting neurosurgical resident from Africa joins the neurosurgical department at Hospital Universitario de la Ribera in Valencia and Hospital General Universitario de Alicante in favor to improve both their clinical and anatomy laboratory training.

3.2. *NEDF model*

During the expansion and progress of NED's project, we have been

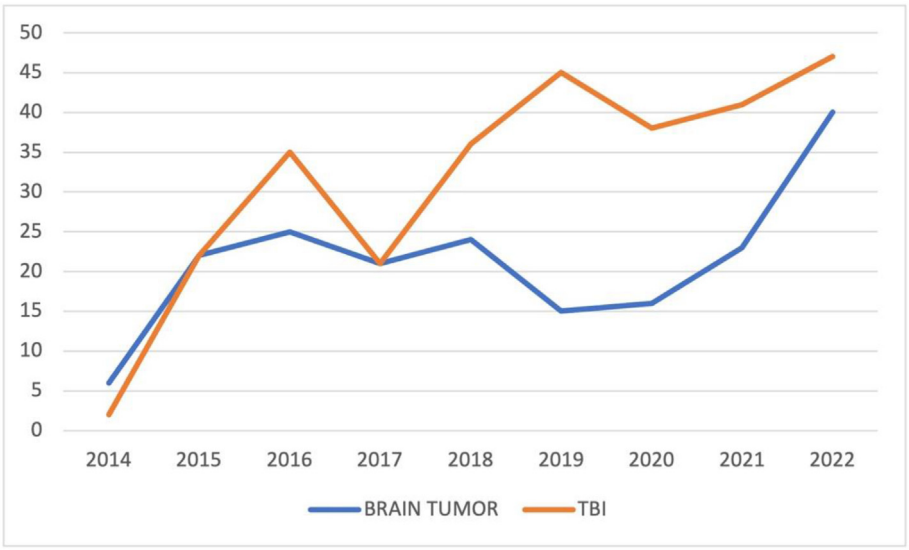

Fig. 5. Although not constant, a noticeable increase in surgical interventions for traumatic brain injury (TBI) and management of brain tumors has become evident at NEDI, as part of local trainees' autonomy and continuous external support.

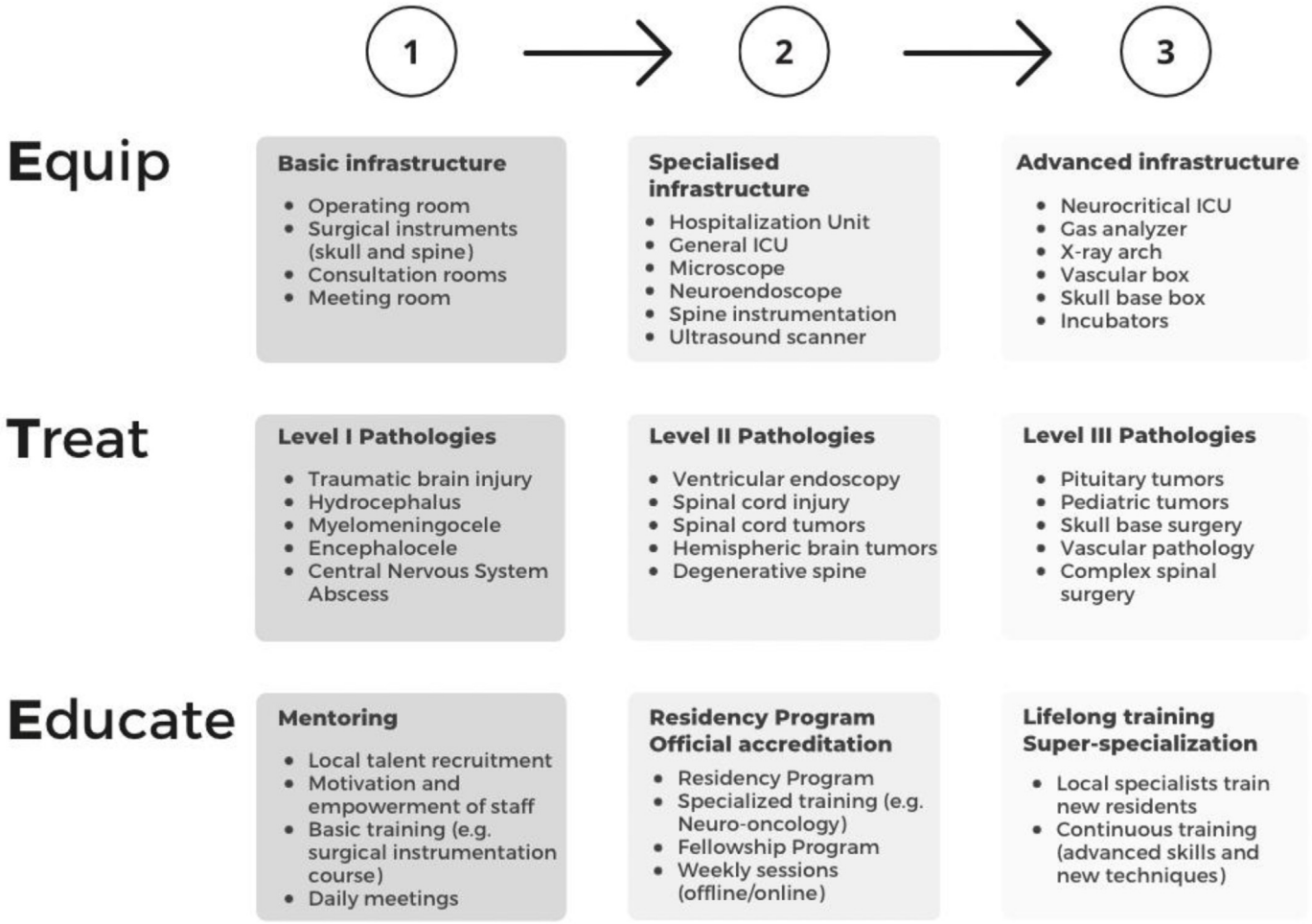

Fig. 6. The NEDF health cooperation model: Equip, Treat and Educate (ETE) areas(domains) with three different levels (1,2 and 3).

able to identify three different levels of complexity (1, 2 and 3). Fig. 6 summarizes the main schematic results obtained after the application of the health cooperation model developed by the NEDF.

During the first level (2008–2013), external support was essential to carry out the most basic actions in ETE areas, from upgrading the basic infrastructure inside MMH (principally the operating theatres, wards and outpatient clinics) to elementary training in order to carry out some of the simplest tasks, for example, neuroimaging interpretation (when

available), positioning of the patient and draping, incision and surgical planning in every case. In line with this logic, primarily, physicians carried out only the less complex pathologies (e.g. TBI and brain and spinal infections); for example, emergency surgical indication for a patient with acute traumatic brain injury was based most of the time on clinical judgment (low Glasgow coma scale, pupillary changes and response, large scalp wounds with an evidently depressed skull fracture, etc), with the resulting exploratory burr hole and/or craniotomy/craniectomy. Only in a scarce number of elected surgeries did patients have access to afford a CT scan test in a nearby private institution, and the vast majority of them were operated on during volunteer missions (e.g., brain abscess or epidural abscess). Education interventions prioritized the search for motivation and empowerment of local talent, and training of local health workers focused on the acquisition of basic skills through the organization of introduction courses (e.g. teaching surgical instrumentation techniques for nurses). At this level, mentoring - or external tutoring - was a mandatory educational tool.

Advances in promoting neurosurgery were made as milestones defined for each level of development were met. In this sense, the second level started in 2014 and involved what we have called a 'specialized' infrastructure (the NEDI), harboring more specific and expensive types of technology and instruments in the operative theater, like a C-arm X-ray machine or a neuro-endoscope for ventricular endoscopy. The incorporation of computed tomography (CT) scan machine in MMH available for all patients at 24 h a day was a significant advance. But, definitely, it was the acquisition of a surgical microscope that was paramount in making a turning point in the history of the NEDI, opening new opportunities to treat more complex pathologies (e.g. degenerative spinal conditions or hemispheric brain tumors). This, in turn, demanded a consequent increase in neurosurgical training, allowing them to acquire new skills.

Educational interventions at this stage are being accredited locally by competent organizations. In this manner, in 2018, the NEDI was accredited by the COSECSA for the training of specialist residents in neurosurgery. Accordingly, the first female neurosurgery resident in Zanzibar's history has been admitted for training at NEDI (Fig. 7), becoming the main milestone during the second level of education.

Finally, since 2019 the NEDF has entered the third level of development, a milestone in itself, albeit with a slowed growth by the COVID-19 pandemic situation. It is the culmination of a set of previous interventions in all three areas. The acquisition of a magnetic resonance imaging (MRI) machine opened new possibilities for more accurate diagnosis and surgical planning and shifted the clinical practice ever since. Full financial coverage was provided to grant access to every patient who needed either a CT scan or an MRI. A significant increase in microneurosurgical procedures has been noteworthy since 2020 with the growth in brain tumor interventions and degenerative spine coinciding with Dr. Piquer's year-long continuous mission. Gaining autonomy has granted an increment in the number of surgeries related to TBI and hydrocephalus from local trainees (Figs. 4 and 5).

Fig. 7. Mulhati Abdall, the first female neurosurgery resident in Zanzibar's history is currently being trained at NEDI.

As the third stage progresses, local specialists will hopefully be able to deal with most of the complex neurosurgical conditions (e.g. neurovascular and skull base surgeries). To this end, we are putting in place a more advanced infrastructure, such as an intensive care unit (ICU) for neurocritical patients. In the future, it is expected that the department's experienced local specialists will also have to fulfill the capacity to train new residents.

From the first to the third level or stages of development, autonomy -the ability of local professionals to perform their practice with independence-increases sequentially in all areas. Once we consolidate the third level, it is expected that the local team will be completely autonomous and external support should be limited to that required on an ad hoc basis.

4. Discussion

Worldwide disparities in neurosurgical access have urged the development and growth of global neurosurgery, but neurosurgery training in Africa has begun later than in other continents and has been highly regionalized (Ukachukwu et al., 2022). South Africa and some North African countries established training paradigms before other African subregions, accounting for their overwhelming strength and advancement, as well as significant workforce growth and projection over time (Gasco et al., 2011). The COSECSA and the West African College of Surgeons (WACS) constitute the principal training programs in sub-Saharan Africa, but there are several independent national training programs from various universities and hospitals, with an inherent lack of uniformity in their curriculum, duration, expected competencies, and certification processes, and their qualifying credentials are not weighted equivalently by the various governments (Khamlichi, 1998, 2001; Rallo et al., 2020). Altogether, there are 106 neurosurgery training sites in 26 African countries, of which 15 are being developed in 7 East African countries, and only 2 in 1 Central African country (Ukachukwu et al., 2022). In an intent to scale up the training capacities to meet the medium and long-term needs, several international collaboration programs have been developed between HIC and LMIC institutions in the last two decades based on multiples models, comprising some of the following options: neurosurgical missions and surgical camps, short and long-term fellowship programs where visiting neurosurgeons from a LMIC temporarily join an academic training program in a HIC, long-term long--distance mentorship and finally, with the advent of technological resources, distance electronic learning (eLearning), which has become an attractive supplementing tool for training of physicians from LMICs (Dewan et al., 2019; Blankstein et al., 2011; Cadotte et al., 2014; Ibrahim and Bernstein, 2015; Almeida et al., 2018; LIANG et al., 2016; Piquer et al., 2015; Punchak et al., 2018; Romach and Rutka, 2018; Sedney et al., 2014; Leidinger et al., 2018; Fuller et al., 2016; Shah et al., 2018; Warf, 2013; Karekezi and Khamlichi, 2019; Karekezi et al., 2020). Various specific examples directed towards neurosurgical training in LMIC encompass collaboration between Duke University Department of Neurosurgery in the United States, spearheaded by Dr. Michael Haglund, and Mulago Hospital Department of Neurosurgery in Uganda to increase neurosurgical workforce and capacity (Fuller et al., 2016), or the establishment of the first neurosurgical residency program in Haiti, created through collaboration between the University of Miami and the Haitian

Ministry of Health and National Medical School (Shah et al., 2018). Furthermore, collaborative partnerships with the Foundation for International Education in Neurological Surgery (FIENS) are examples of education-focused initiatives to help develop neurosurgical capacity/-workforce abroad. Also, WFNS centers have contributed to neurosurgical training in places such as Rabat, Nairobi, Alger, and Dakar (Veerappan et al., 2022). The WFNS Rabat Training Center has trained 69 neurosurgeons from 17 sub-Saharan countries (Karekezi and Khamlichi, 2019; Karekezi et al., 2020), proving to be cost-effective and sustainable in sub-Saharan African countries. Likewise, several international programs have started to collaborate in developing neurosurgery in Tanzania, with remarkable results. For example, Madaktari Africa started training neurosurgeons in rural Tanzania in 2006 (Ellegala et al., 2014). In Dar es Salaam, the Tanzania Neurosurgery Project from Weill-Cornell Medical College has organized visits by neurosurgical fellows from overseas, weekly telecast conferences with local surgeons, and a yearly Neurotrauma Meeting, as one of the most important scientific forums for neurosurgery in East Africa (Kahamba et al., 2013; Wait and Härtl, 2010).

But until NEDF's arrival, no neurosurgeon had ever practiced in Zanzibar. Patients with these pathologies were not treated since neither basic facilities/services nor trained personnel existed, a transcendental limitation at that moment, with a unique, risky initial scenario in global neurosurgery; but at the same time, setting the ground, and becoming a central incentive, for the NEDF to focus its activities and projects in the area: an isolated land, the Zanzibar Archipelago, embedded in extreme poverty, high incidence of neural tube defects (inadequate prenatal care health programs and malnutrition were predominant), and long-distance and limited means of transportation to reach a specialized referral center at the peninsula. All these factors lead, in 2014, to the establishment of the NEDI at the MMH in Zanzibar, as the first humanitarian neurosurgery institute in the region.

In relation to local medics and particularly during the first few years, some limitations are worth mentioning: low self-confidence, motivation and commitment to academic activities, intense workload with lack of resources at the NEDI, difficulties in the clinical and surgical decision-making process, and in the act of prioritizing according to the patient condition, with the resulting need for frequent external supervision and support, mainly during surgical missions. In a like manner, it became evident that local practitioners had a different understanding of the value of time, with torpid management of emergencies, and delays in patients' initial assessment in the emergency department at the MMH, having scant communication between medical teams in relation to the management of patients requiring more than one specialist, notably when intensive care doctor evaluation was demanded. Lastly, technical service and equipment maintenance and repair (e.g., neuroendoscope, C-Arm X-ray machine and surgical microscope) have been an additional challenge since it requires the intervention of outsourced official providers that mostly fly in from Kenya and South Africa.

All things considered, the evolution of NEDF projects have been based on the following core principles: empowerment, sustainability, and a top-down approach (Haglund et al., 2017). Adaptation to local conditions and dependency avoidance have been crucial. Physicians, including volunteers, must engage with local sociocultural challenges (Leidinger et al., 2018) in order to build an appropriate doctor-patient relationship and cultivate essential cooperation between colleagues for the project to expand. Donations, financial and strategic support from the NEDF and the Revolutionary Government of Zanzibar, with hundreds of volunteers, and continued missions have allowed common projects to be sustained throughout time (Fig. 8). The NEDF efforts will continue in pursuance of the future viability of the project through the authorities alone, but due to local political and economic factors, the foundation's long-term plan remains loyal to the future sustainability of Zanzibar's NEDI and neurosurgical development.

As previously published by our group (Leidinger et al., 2018), the involvement of the NEDF in neurosurgical education remains multilayered: 1) At the local level, the NEDF is accredited by COSECSA to formally train local neurosurgeons and nurses through surgical-camps volunteers (2 x month) and long-term volunteers who develop daily academic activities and surgeries. 2) At the continental level, this endorsement facilitates the organization of international courses and meetings for trainees from East Africa, allowing the connection with a global network of neurosurgical institutions, and providing opportunities for trainees to benefit from participation in international meetings and enhance their clinical research skills. 3) At the international level, NEDF has relation with FIENS, WFNS, and other medical associations and promote agreements between the Revolutionary Government of Zanzibar and foreign training centers. Recently, two Zanzibari neurosurgeons are formally finishing training in Egypt and in Cuba.

Finally, the NEDF's top-down approach, inspired by the Duke Division of Global Neurosurgery and Neuroscience, led by Dr. Haglund (Haglund et al., 2017), was centered on the core principle of the umbrella effect that neurosurgical upgrowth could bring along in order for other specialties to benefit from, assuring not only the benefit of neurosurgical care itself but also an effort for expansion of neurosurgery-related disciplines, especially nursing, anesthesia, intensive care and neuro-radiology. In that respect, and among other initiatives, they have developed a well-equipped ICU in MMH, with assistance from intensive care doctors. Moreover, the local government has promoted and supported the acquisition of CT scans and MRI machines at MMH, at no medical costs for all patients. This, together with the reinforcement of a properly trained anesthetist team and the availability of a variety of laboratory and radiological tests, has allowed the local hospital to increase the management of more complex neurosurgical cases.

4.1. NEDF model

In a low-resource healthcare setting, the promotion of a medical or surgical specialty should adopt a tiered (stage or step) model. The present ETE model has conducted the effort of the NEDF in the rising of global neurosurgery over the years, but it can, as well, aid in the design of similar interventions in other contexts. This model identifies three levels of complexity (1, 2 and 3) corresponding to different stages of development of the three pillars: equip, treat and educate. At the start, physical space and equipment (infrastructure) would be scarce or non-existent, quality healthcare (assistance) for patients would be limited, and the education level of health professionals (training) would generally be insufficient. For these reasons, interventions in the field of international health cooperation must aim to equip, treat and educate at the same time (ETE model).

We believe a model for the integrated development of medical and surgical specialties must consider two fundamental parameters: complexity and autonomy. The model assumes that any (complex) process can be divided into different levels of difficulty, according to the requirements, resources or knowledge needed to perform certain tasks or reach certain milestones. These levels correspond to different stages of development. In terms of autonomy, it is about understanding the degree of external support that local teams would need during the whole process, in relation to infrastructure funding, healthcare, and education. Autonomy is a particularly relevant parameter to take into consideration when the objective is to develop a specialty ‘from scratch’ but with the coexisting intervention and collaboration from external organizations or groups. This support may be necessary on all accounts, but in different magnitudes as the team evolves and become fully autonomous. NEDF interventions largely intend to assemble sufficient capacity for the local team to provide neurosurgical services with full independence once level 3 has been reached in the future. Additionally, the beneficiaries should achieve full autonomy in the provision, management, and financing of surgical and medical assistance, thus upgrading the overall capacity of their health system.

The logic of the model is relatively simple. Interventions would become more complex at each level of development as the local team would acquire more capacities and autonomy to deliver healthcare. From

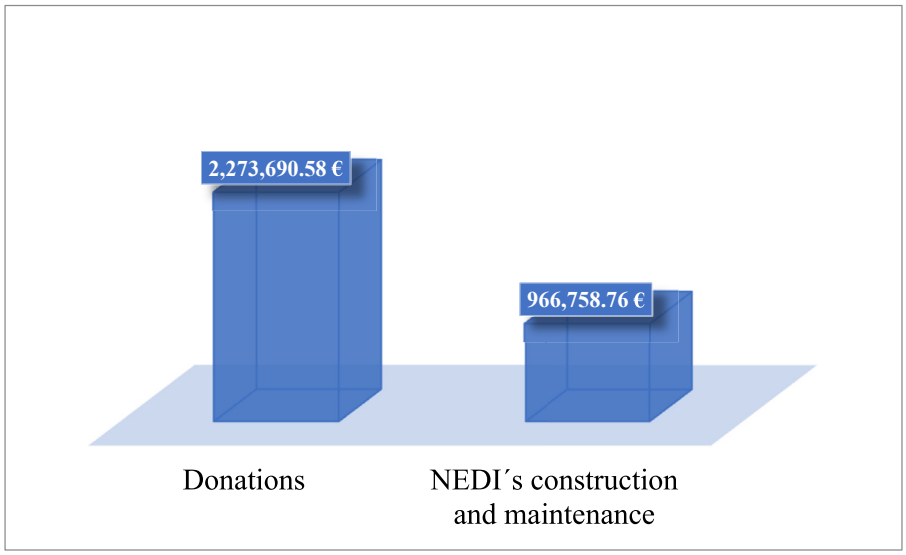

Fig. 8. General NEDF funding and costs from 2014 to 2022: Donations from more than 250 surgical missions and different private institutions have been crucial for the development and sustainability of NEDI, reaching over 2.2 million euros on medical and surgical equipment since its opening in 2014. NEDI's costs for construction and maintenance have been borne mostly by the NEDF, with financial help from the Minister of Health of the Revolutionary Government of Zanzibar.

the third level onwards, medical and surgical assistance should seek to resemble more advanced well-equipped health systems, with highly trained specialists who are able to handle a wide spectrum of complex pathologies.

The interventions required in each action area (ETE) are coherent for each level of development (1, 2 and 3). Altogether, these interventions have positive feedback with greater impact. Thus there is a coherence between the actions required at each level and domain, turning into an appropriate model of cooperation for under-resourced health systems, where this cooperation is often needed beyond the healthcare (assistance) setting in the long-term. Ultimately, we have presented the specific model that the NEDF has used for the development of neurosurgery in Zanzibar, and we believe it can be equally useful for the development of other medical and/or surgical specialties in other LMICs health systems.

5. Conclusions

The NEDF international collaboration model has set the ground for beginning and development of neurosurgical activities in Zanzibar since 2008. Complexity and autonomy have been considered as the main parameters to classify levels of interventions and progress in the areas of infrastructure (equip), healthcare (treat) and training (educate). External support has been necessary throughout the process, but not in equal proportions during the different phases, achieving a gradual reduction along the course. The authors believe this model can be equally useful for the development of other medical and/or surgical specialties in other LMICs healthcare systems.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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