1. Open Research Fund application

Reference number	214544/Z/18/Z
Applicant name	Dr Tarek Loubani
Title of application	Development of a high-quality, low-cost, open-source hemodialysis machine. Phase I: Device design & prototype development
Total amount requested	£50,000.00

2. Application summary

Application title
Development of a high-quality, low-cost, open-source hemodialysis machine. Phase I: Device design & prototype development

Proposed duration of funding (months, this should be no longer than 1 year)
12

Proposed start date	01/01/2019

Is your application being submitted through a university?	No

Name of administering organisation
Glia Inc

Lead applicant's address at administering organisation	
Department/Division	Open Medical Device Development Division
Organisation	Glia Inc
Street	54 Craig Street
City/Town	London, Ontario
Postcode/Zipcode	N6C1E8
Country	Canada

Research funding area Please select from the drop-down list the funding area that you consider your research falls under
Population and Public Health

3. Lead applicant

Lead applicant details	
Full Name	Dr Tarek Loubani
Department	Department of Medicine
Division	Division of Emergency Medicine
Organisation	University of Western Ontario
Address Line 1	800 Commissioners Road East
City/Town	London, Ontario
Postcode	N6A 5W9
Country	Canada
Telephone No.	519-488-6475
Email Address	tarek@tarek.org

ORCID iD	
ORCID iD	0000-0001-8315-9954

Career history (current/most recent first)			
From	**To**	**Position**	**Organisation**
07/2017	08/2050	Associate Professor	University of Western Ontario
03/2016	07/2021	Medical Director	University of Western Ontario
07/2011	07/2021	Technology Director	University of Western Ontario
07/2010	06/2017	Assistant Professor	University of Western Ontario
07/2010	07/2050	Consultant physician	University of Western Ontario

Education/training				
From	**To**	**Qualification**	**Subject**	**Organisation**
07/2009	06/2010	Specialization in Emergency Medicine	Emergency Medicine	Queens University, Canada
07/2007	06/2009	College of Family Physicians certificiation	Family Medicine	McGill University
08/2003	05/2007	Doctor of Medicine (MD)	General medical degree	University of Western Ontario
08/1998	05/2002	Bachelor of Science (BSc)	Honours Psychology, Minor Chemistry	Dalhousie University

Source(s) of personal salary support
University of Western Ontario, Shuttleworth Foundation, Ministry of Health and Long-term Care (Ontario), Division of Emergency Medicine, London Health Science Centre

Clinical status Do you have a medical/veterinary degree?	Yes

Please specify
Medical graduate

What is your specialty?
Emergency Medicine

Are you clinically active?	Yes

Career breaks Have you had any career breaks or periods of part-time work, for example parental or long-term sick leave?	No

Do you wish to undertake this award part time?	No

Career contributions
What are your most important research-related contributions to date? This may include contributions to health policy or practice, or to technology or product discovery and development.

My most important research-related contribution has been the creation of an open source medical devices research laboratory with branches in the developed and developing worlds. This lab's main contribution is proving that open source medical devices are feasible and can be as high quality as much more expensive premium brands.

In 2015, our research team created a stethoscope that performs on par with the a premium $250 USD stethoscope at a cost of $2.83 USD. To reduce cost, 3D printers and commonly found parts are used. This device was validated in a study we published in PLOS ONE.

Since 2017, our team designed, developed and deployed a 3D printed tourniquet to prevent deaths by limb exsanguination. I have been able to run multiple field tests in real-time war-torn environments in the Gaza Strip, resulting in feedback that has improved the device design and use. Our team has created over 1000 tourniquets for use in recent conflicts, of which over 500 have been deployed, saving many lives.

Since 2016, our team has been working on an open source pulse oximeter - a vital tool to rapidly and non-invasively assess oxygen saturation in patients. Our device costs approximately $25 USD as compared to $1000 USD for commercial units, and is currently in clinical trials.

Since 2016, our team has been developing an electrocardiogram machine for detecting heart problems such as arrhythmias, ischemia and hypertrophy with high sensitivity. Although vital in hospitals, in many low- and middle-income countries ECGs are also unattainable due to high costs and the complex nature of ECG interpretation. We have just entered the prototype stage of this device.

These devices have the ability to reach many different communities with few resources and has the potential to exert downward pressure on prices for high-quality premium brands, closing the socio-economic gap between those with access to quality health care and those without.

Research outputs
List up to 5 of your most significant research outputs, ensuring that at least two of these are from

the last five years. Provide a statement describing their significance and your contribution (up to 50 words per output).

Research outputs may include (but are not limited to):

- Peer-reviewed publications and preprints
- Datasets, software and research materials
- Inventions, patents and commercial activity

For original research publications please indicate those arising from Wellcome-funded grants in **bold**, and provide the PubMed Central ID (PMCID) reference for each of these. Please refer to guidance notes.

Publications should be in chronological order with the most recent first. Please give citation in full, including title of paper and all authors. Citations to preprints should state "Preprint", the repository name and the articles persistent identifier (e.g DOI).*

*(*All authors, unless more than 10, in which case please use 'et al', ensuring that your position as author remains clear.)*

1. Publication: Validation of an effective, low cost, Free/open access 3D-printed stethoscope, PLoS One. 2018. Authors: Alexander Pavlosky, Jennifer Glauche, Spencer Chambers, Mahmoud Al-Alawi, Kliment Yanev, Tarek Loubani PMCID: 29538426.
   This article demonstrates that an open source, low cost device performs as well as a premium brand stethoscope. Tarek's roles include: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing
2. Invention: 3D printed Tourniquet. Preliminary research findings: 3D printed open source tourniquet: Rationale, failure analysis and proposed next steps of the Glia tourniquets during the Gaza protests (May 11). Author: Tarek Loubani. Link: https://medium.com/@trklou/3d-printed-open-source-tourniquet-rationale-failure-analysis-and-proposed-next-steps-of-the-glia-97e8441b4c5a
   This device was developed to stop death by bleeding from injured limbs. Tarek's roles include: Feasibility study, collaboration in device development, collaboration in field testing.
3. Invention: Open Source electrocardiogram (Prototype stage): https://github.com/GliaX/ecg/
   This device is now in the late prototype stage. Tarek's role includes feasibility study, clinical design and research guidance.
4. Invention: Open Source pulse oximeter (clinical trial stage): https://github.com/GliaX/pulseox/
   This device is now in the clinical trial stage. Tarek's role includes feasibility study, clinical design, research guidance and clinical trial monitoring.
5. Invention: Open Source otoscope (released): https://github.com/GliaX/otoscope
   This device has been released and is being produced. Tarek's role includes clinical assessment and device dissemination.

Principles of open research

Briefly outline how you have embraced and adopted the principles of open research during your career to date

Free and open access are the foundation of my life's work - it's in the DNA of every project I'm involved with. Without the concept, our research team would create medical devices that ossify and decay the moment they are released. By releasing our data as open access and our devices as open source, our devices become everybody's devices, open to being modified and extended by others in ways that we do not - and cannot - predict.

To date, our team has created and released an open source stethoscope, tourniquet and otoscope. Our pulse oximeter and electrocardiogram are undergoing testing and the hemodialysis machine is planned to commence in fall of 2018. All of the work on these devices is available in our public

repository for use by other researchers, creators and curious contributors.

I advocate openness by embedding it in the work that I do. Free and open source principles touch all the projects I work on, and I intentionally build teams around me that share the same philosophy.

I worked with an open access medical journal, and only published in open-access journals, even when I had more prestigious options and it was detrimental to my career advancement.

4. Team members and collaborators

Will you require any team members or key collaborators for this proposal?	Yes

Please list your team members or key collaborators (name and organisation) and provide a very brief outline of their role in the proposed research.
Dr. Beverley Gibbs, Director of Learning & Teaching, Department of Mechanical Engineering, The University of Sheffield Dr. Gibbs is a director of the Department of Mechanical Engineering at Sheffield University in the United Kingdom. In September 2018, Dr. Gibbs will supervise and mentor masters-level students at Sheffield University who will tackle engineering and study of critical segments of the dialysis machine project. Melanie Columbus, PhD. Research Coordinator Dr. Columbus is a research coordinator with the Division of Emergency Medicine at Western University. Dr. Columbus will design the clinical trial and ensure adherence to rigorous quality standards for the calibration, validation and clinical trials for the hemodialysis machine. Luka Mustafa, PhD Candidate (University College London), Engineer (IRNAS) Mr. Mustafa is the Chief Operating Officer of IRNAS, based in Slovenia and PhD candidate in engineering at University College London. Mr. Mustafa will lead the IRNAS engineering team in developing and coordinating a prototype for a high-quality, low-cost hemodialysis machine. The team will develop firmware, additional software development, hardware design, testing and calibration and compliance with all regulatory bodies. Carrie Wakem, Project Manager Ms. Wakem is project manager of the research team. Her responsibilities will include managing the team's financial and evaluation reports, maintaining a publicly accessible log of the progress of the project, organizing weekly team meetings, project taskboard, calendar, quarterly reports, and legal and financial paperwork. Alex Pavlosky, Research Assistant Mr. Pavlosky is a fourth year medical student. He assisted with publication of the stethoscope research. He will be assisting with the development and design of the hemodialysis project. Emily Stephenson, Research Assistant Ms. Stephenson is a third year medical student. She assisted in the design of the electrocardiogram, prepared ethics approval for the upcoming electrocardiogram study, and has ensured that the electrocardiogram meets regulatory requirements.

Ms. Stephenson has also been involved with the preliminary planning and preparation of the hemodialysis project and will complete a feasibility and regulatory study on the device in preparation of deployment.

Mohammed Abu Matar, Engineer
Mr. Mohammed Abu Matar is an engineer based in the Gaza strip. He manages the research and production team there, producing and testing devices in collaboration with the Canadian team. The team has contributed to projects in local health centres and projects with the World Health Organization.

This team will contribute to the dialysis machine project on a consultant basis, as well as preparing a field-viability study.

I confirm that the team members or key collaborators named above have agreed to be involved, as described, in the proposed research and are willing for their details to be included as part of this application.
Confirmed

5. Transparent decision making

Are you happy for us to share these details of your application on the Wellcome website?	Yes

6. Proposal summary

Provide an outline of what your successfully completed Open Research Fund activity will look like and what you will have achieved.
With support from the Wellcome foundation, our team will engineer a high-quality, low-cost prototype of the hemodialysis device ready for validation and clinical trials. The device will be created using 3D printing and low-cost electronics based on open source designs. Hemodialysis is essential for ensuring that patients with end-stage kidney disease can survive. In low-resource settings, hemodialysis machines are used far beyond their usable life, providing lower-quality dialysis for patients, who suffer severe consequences over time. In addition to being very inexpensive (target price $500 USD as compared to $15,000 USD for premium brands), this device will have another very important feature: The ability to accept disposable circuits from any manufacturer. By being compatible with multiple brands of disposables, the device will be more affordable and accessible in low-resource settings. In low-resource locations where the supply of disposable circuits is unreliable, it will allow for a single machine to substitute for several. We will collaborate with engineers from the Department of Mechanical Engineering at the University of Sheffield and IRNAS to create this high quality, professional-grade hemodialysis device ready for testing. All design documents and source code will be accessible in an open-access repository.

7. Details of proposal

Provide details of your Open Research Fund proposal, including:
(i) the vision for your proposal, including aims, target audiences, activities;
(ii) how your proposal will influence open research practices in your field or more broadly;
(iii) how you will monitor and evaluate your proposal, including success indicators.

Vision

The goal of our medical research project is to develop, validate, certify and disseminate high-quality, low-cost, open-access medical equipment. The project relies on two pillars: the use of 3D printers and other rapid prototyping technology; and leveraging Open Access and Open Source principles and devices to decrease development costs and disseminate results to stakeholders. This model has been proved with two simple medical devices (the stethoscope and the tourniquet), with two more complex devices nearing completion (pulse oximeter and electrocardiogram). The main question of our research is: Can the successful model that developed, validated and deployed other low-cost devices also be used to develop much more complex devices such as a hemodialysis machine?

Over a 12 month period the Glia team and their collaborators will complete the first phase of our research, device design and prototype creation.

Our aims for this project are:

- Investigate what off-patent, open-source work has already been achieved that can be built upon
- Acquire access to appropriate ISO documentation and resource the international standards
- Consider the different types of end-users for the device and make a plan for their needs, such as those in low-resource and low-income communities
- Consider end-user experience in design, such as; using materials and building equipment that are easy to source in low resource settings and creating a device that resembles and operates as existing devices do today
- Consider the most appropriate device design for communities that have low-access to device disposables
- Construct a device that functions mechanically and electronically
- Ensure this device is low-cost, easy to use, and widely-accessible
- Meet regulatory requirements for Health Canada
- Engineer a usable prototype ready for clinical trials

Subsequent to the terms of this proposal, we will conduct validation and clinical trials to gain regulatory approval through Health Canada as a Class III or Class IV device. This will result in a final version of the device ready for distribution.

Influence

Glia's stethoscope and tourniquet have already made a significant impact. Replicating this success with a low-cost hemodialysis machine will provide kidney patients around the world with access to one of the most essential medical devices. The availability of specifications for generic manufacturers to manufacture devices and the subsequent downward price pressure on premium brand manufacturers will increase the standard of care even in areas where our device is not directly available. It will also allow low-income communities to save costs while maintaining equivalent quality of care.

In the developing world, availability of a low-cost hemodialysis machine will allow ministries of

health and hospitals to forgo rationing of devices and provide them to hospitals and clinics, multiplying the availability dramatically. In addition, a hemodialysis machine that is universally compatible with branded disposables, meaning that low-resource communities can begin using the materials they have on hand, regardless of the brand of machine they currently have access to.

In broader terms, providing communities with open-access, low-cost medical device designs fosters a culture of self-reliance and sustainability. If low-resource communities can access the equipment they need via an open-access model, they feel more encouraged to troubleshoot problems, customize designs to meet their needs and share their findings with others. The ability to share successes in an open-access market allows medical and technical communities to work together, avoiding duplication of work and long feedback cycles.

Evaluation

In evaluating the success of the project, the team will review the following questions at the end of the 12 month period:

- Are the materials used easy to source?
- Is the machine equipped to accept the most common types of disposables?
- Does the device function as well as comparable premium brand devices on the market today?
- Is the device user-friendly?
- Is the device ready for clinical and validation trials?
- Can another person or group use our work to replicate their own. In other words: is our work open enough in a practical way?

Additional information
You may submit up to two A4 pages of additional information (such as graphs, figures, tables and essential unpublished data).

8. Outputs management and sharing

Will the proposed research generate outputs of data, software, materials or intellectual property that hold significant value as a resource for the wider research community?	Yes

Which approach do you intend to use to maximise the impact of your significant research outputs to improve health and benefit the wider research community?
Make research outputs available for access and re-use

Please provide an outputs management plan. Ensure this describes any significant data, software, materials or intellectual property outputs, their management, and resources required (refer to guidance).
At the end of 2019, our team will have engineered a prototype hemodialysis machine. The bill of materials, electronics design and source code will be accessible through our public repository. As work is completed, updates will be made to the repositories on an on-going basis. Our team already uses Github to store all project work publicly (see: https://github.com/gliax). The intellectual property that will be created as a result of this project is the source code for the hemodialysis machine and all its iterations. The intellectual property will not be patented, and all code and designs will be open sourced under the CERN Open Hardware License or GNU Public License version 3.

9. Costs requested

Currency requested Select the currency in which you wish to apply.
GBP - Pound Sterling

Salaries Are you requesting salaries?	No

Materials and consumables Are you requesting materials and consumables?	No

Equipment Are you requesting equipment?	No

Miscellaneous costs Are you requesting miscellaneous costs?	Yes

Miscellaneous costs

Description	Total (£)
Engineering costs for device development	50,000

Justification for costs requested Provide a high-level budget breakdown and justification for costs requested.
Engineering development of the device will cost approximately USD$230,000. Other sources of funding will include the Shuttleworth Foundation, University of Western Ontario, Ministry of Health (Ontario), World Health Organization and potentially others. We would like funds from the Open Research Fund to contribute to this engineering budget, which will be contracted from IRNAS and the University of Sheffield's Department of Mechanical Engineering. Other costs will include clinical trials, salaries and stipends. These funds will be acquired from other resources. At a high level, the engineering budget will be divided as follows: • ISO compliance preparation - $30,000 • Initial prototype design - $55,000 • Round 1 - prototype production - $15,000 • Round 1 - prototype testing (bench) - $5,000 • Round 1 - prototype testing (on location) - $10,000 • Round 2 - prototype revision and design - $15,000 • Round 2 - prototype testing (bench and on-location) - $10,000 • Final prototype preparation - $30,000 • Regulatory certification - $60,000

Summary of financial support requested	
	Total (£)

Salaries / Stipends	0
Materials and consumables	0
Equipment	0
Miscellaneous other	50,000
Total	**50,000**