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Upper-limb prostheses for low- and middle-income countries

The loss or absence of an upper limb can have devastating results. Without an appropriate prosthesis and training, the ability to perform activities of daily living with the residual limb is greatly reduced. Indeed, certain activities, such as riding a motorbike, carrying out particular household chores or farming activities, may prove impossible. In people with unilateral limb absence, overuse injuries to the other limb are common.[1] Limb absence can also have major psychological impacts, which may be more severe than in lower-limb amputees.[2] These problems may limit an individual's ability to form relationships, attend school or work and are exacerbated when people are surviving at a subsistence level.

This article reports on preliminary work on a project which aims to address these problems by creating practical upper-limb prostheses suitable for use in low- and middle-income (LMIC) countries. Funded through the Engineering and Physical Sciences Research Council (EPSRC) and National Institute for Health Research (NIHR) Global Challenges Research Fund, teams from the University of Salford, University College London, University of Southampton and University of Portsmouth are partnering with Makerere University (Uganda) and the University of Jordan to develop a body-powered upper-limb prosthesis that is fit for its purpose and its circumstance.[3] The team is being supported by an advisory group, with members from academia, industry and two non-governmental organisations, the International Committee of the Red Cross (ICRC) and Médecins Sans Frontières.

In this article, we first explain the problems faced by current upper-limb prosthesis users and then highlight findings from the first research visit to Uganda, which formed part of the scoping work to inform the design requirements for a new body-powered prosthesis.

Body-powered (BP) prostheses

In higher income countries, well-fitted, high-quality but often expensive electrically powered (myoelectric) upper-limb prostheses are widely available to restore acceptable appearance (cosmesis) and a degree of function. These prostheses use electrical signals from the skin to control the power given to a motorised hand. However, self-reported non-use and rejection rates remain high[4] and a recent study by three of the authors (AC, LK and JH) using activity monitors showed that unilateral users of myoelectric prostheses still rely heavily on their intact upper limb.[5] To address this, much of the focus of researchers to date, with a small number of notable exceptions,[6–9] has been on developing more sophisticated powered prostheses. The focus on western markets means the well-known devices are very costly, but there remains a significant question mark over whether the cost is matched by a correspondingly high level of performance; for example, the recent Cybathlon upper limb prosthesis competition was won by a person using a body-powered (BP) device.[10] A third category of prosthetic device is the passive limb. These generally have better appearance, being more anthropomorphic, and are often lighter. Whilst they are not actuated, people can still use them in effective passive ways. This trade-off between the appearance and the function is one of the central questions to the designer and user of a prosthesis.

A reliance on overseas donations of materials and components was a notable feature across several sites

The most common design of BP upper-limb prostheses being used by people today was introduced in the first half of the twentieth century,[11] with only relatively minor changes evident in the subsequent decades. A typical BP prosthesis uses the relative motion of another part of the body, usually the shoulder on the opposite side of the body, to pull on a cable and actuate the prosthesis via a harness and Bowden cable arrangement for opening or closing a hand. A semi-rigid socket covers the residual limb and holds the prosthesis in place. BP prostheses offer a degree of function; because the user can feel the position of the cable through their own movements it provides a feeling of how much the hand is open, and yet they do not rely on batteries, sensors, signal processing or electric motors, which makes them well suited to LMICs. Additional advantages for use in LMIC settings are that componentry could be assembled

FIGURE 1. Mural at CoRSU

locally, maintenance could be local and so the cost could be relatively low. However, there has been relatively little innovation in the design of BP prostheses, likely due to research being focused on high-tech and complex (multi-degree of freedom) hands and myoelectric control, and the low margins available to manufacturers. In contrast, our project is focusing on the development of affordable and high-quality body-powered prostheses.

Perhaps unsurprisingly, a number of studies[6,12] report user dissatisfaction with current designs of body-powered prostheses and self-reported rejection rates remain high. There are many design features which may contribute to user dissatisfaction. For example, the prosthesis can require a significant physical effort to complete a simple and frequent task such as picking up a glass, due to high friction forces within the system.[9] Arguably the most functional of end-effectors, the 'split hook', is perceived to be unattractive or, in some countries, completely unacceptable. A recent project[13] found that the materials used are generally not well liked. Finally, heat-related discomfort can be a problem for amputees, and socket materials with poor heat conduction properties often exacerbate the problem.[14] Of particular relevance to LMIC contexts, the cost of Western-made devices is relatively high, and the process of making a well-fitting prosthetic socket is time consuming, requires skilled personnel and access to specialist materials and facilities.

Uganda visit

The project started in February 2018 and one of the first activities was to carry out a scoping study in Uganda. To give a context for this, Uganda's population is around two-thirds the size of the UK's, but their GDP is less than 1 per cent of the UK's figure. Nevertheless, overall life expectancy has increased significantly over the last 20 years or so and the economy continues to grow at around 5 per cent per year.

The study was carried out to inform design requirements, which would be influenced by the level of manufacturing capability available to clinicians as well as the process and policies in place, and of course by the needs and desires of the users themselves. The visit was hosted by Makerere University in Kampala, who organised a series of visits to clinics and hospitals as well as informal discussions with prosthesis users.

FIGURE 2. Example of an upper-limb prosthesis. The colour of the hand highlights some of the compromises that are made when working in resource-limited settings, where reliance on donations is common

To help better understand the prosthetics resources and provision in the Ugandan context, the team visited a number of clinical sites in Uganda. The first visit was to the Orthopaedics Department at Mulago National Referral Hospital, the largest public hospital in Uganda. The Mulago Hospital complex has an orthopaedic workshop and is home to the School of Orthopaedic Technologists, which trains around 40 technicians per year, some of whom operate the nine regional orthopaedic workshops in Uganda that fabricate and maintain prosthetics and orthotics. The Mulago Hospital Orthopaedic Workshop (MHOW) was founded in the 1990s with help from the ICRC, although it is no longer funded through this source. The workshop has a reasonable range of machines for the manufacture of prosthetics/orthotics and other aids, but many are not usable due to problems sourcing spare parts. Indeed, a reliance on overseas donations of materials and components was a notable feature across several of the sites, which makes planning and maintenance of equipment extremely challenging. Funding for public healthcare is very limited and cost sharing between the state and the patient is often needed to pay for materials. Perhaps unsurprisingly, those who can afford private healthcare often opt for it.

About 30 lower-limb and 10 upper-limb amputees attend at the MHOW every month. By contrast to the UK, the main reason for limb amputation is trauma (mainly resulting from road traffic accidents), followed by tumours. Although national statistics on limb loss are not available, the number of amputees seen at Mulago is thought to be a small proportion of the total in Uganda; for example, a German charity is reported to see around 400 people with limb absence per week.

The majority of upper limb prostheses fabricated at MHOW are cosmetic and currently cost between 1.5 and 3.5 million Ugandan shillings (~£285–665), which is beyond the reach of many. Those who receive body-powered prostheses often report problems with maintenance and hence in the longer term typically resort to using them as solely cosmetic devices.

On day 2, the team visited Comprehensive Rehabilitation Services in Uganda (CoRSU) Hospital (figure 1). CoRSU is an organisation established in 2006 and is 50 per cent supported by donations. The patients are primarily children with disabilities; however, some adults are seen on a private basis. CoRSU generally do not prescribe upper-limb prostheses to children under the age of 8 years old and will often encourage children to learn to manage without a prosthesis due to the various challenges associated with their current provision. To address some of these challenges, the CoRSU team is starting to investigate the use of 3D printing.

Rehabilitation for children

Day 4 saw the team visit Katalemwa Cheshire Home for Rehabilitation Services (KCH). KCH is an NGO that specialises in rehabilitation for children with disabilities and their families. Children are admitted for a maximum of 3 months, for pre- and post-surgical care. The KCH workshop consists of metal, wood, leather and plastic sections. The metal-working section was particularly impressive, with facilities which include arc welding stations, used to produce high-quality wheelchairs, tricycles and standing frames. They also provide upper-limb prostheses, but are limited in the training they can provide to amputees and materials/components that they can access. When KCH receive donations of myoelectric prostheses, these are generally dismantled to repurpose some of the components, as the donations rarely match the specific needs. Further, there are often long periods of time without donations. The team also visited the Uganda Industrial Research Institute (UIRI) and the Uganda Manufacturing Association, who are interested in supporting the setting up of spin-off companies.

Issues to be addressed

The team identified a number of issues from the scoping visit. There are no statistics available regarding adults in need of upper-limb prostheses, but without doubt the demand for high-quality prosthetic services far exceeds supply. The main reasons for adults living with upper limb loss appears to be transport accidents and violence. In general, upper-limb prostheses are difficult to obtain, for many they are not affordable and often they are not appropriate (figure 2). Existing orthopaedic workshops are somewhat dependent on cash contributions by patients and on prostheses parts donations (including government-funded workshops). Part of the reason for this may be the relatively high cost of prosthetic components, which are imported mainly from suppliers of European prosthetics companies, and other brands from India, and are subject to tax. Finally, the limited number of well-resourced clinical centres, coupled with the difficulties faced by many in travelling to these centres, means that the traditional approaches to socket design, manufacture and fitting may be another limiting factor in the provision of high-quality prostheses to those who need them.

Nevertheless, it is clear that Uganda has the space, skills and motivation to establish the manufacturing of prostheses parts that are currently imported at a high cost. As an example, a number of universities are now offering biomedical engineering courses, producing a workforce that is well placed to take on challenges such as those outlined above. Workshops which are highly dependent on donations require support to find ways of creating additional sources of income in order to shift into a sustainable model of operation. Prostheses users are very likely to be interested in being part of a network to support and inform each other. The establishment of a network of prostheses users would also enable the creation of a national register of prostheses users, which could be used for the collection of demographics and to measure the impact of actions taken to improve the provision of prostheses.

The team have recently carried out a similar scoping study in Jordan and is carrying out an in-depth user-centred study in both Uganda and Jordan over the coming months. We will report on this and our novel prosthesis designs in due course.

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Laurence has an interest in the design of assistive technologies and monitoring of their use

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