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Infection control in a developing world

The global HIV and tuberculosis (TB) epidemics have placed enormous burdens upon already overstretched healthcare workers and poorly resourced healthcare facilities in sub-Saharan Africa. The rapid emergence of multi-drug resistant TB, and its association with hospital-based outbreaks, have highlighted the role that healthcare facilities inadvertently may play in maintaining TB transmission, and the vital importance of attaining good TB infection control. James Elston, a specialist physician in infectious diseases and general internal medicine, who recently returned from a second stint in Swaziland, says many of the region's healthcare facilities are outdated, poorly ventilated, and were not designed for their current purpose. Here he describes how UK-based architects and healthcare engineers responded to an urgent call for assistance and, via close collaboration, and using novel design software, empowered healthcare workers to dramatically and rapidly improve their TB inpatient facilities, and protect the health of patients and staff.

Tuberculosis (TB) is caused by a bacterium (*Mycobacterium tuberculosis*) and most commonly affects the lungs. TB is transmitted from person to person via inhalation of droplets containing bacteria that are produced by an infected person, for example during coughing or sneezing. The disease is second only to HIV as the greatest killer worldwide due to a single infective agent, with 8.7 million people having developed TB disease, and 1.4 million deaths having been caused by TB, in 2011.[1] HIV increases the likelihood of developing TB disease, and tuberculosis is the leading cause of death for people living with HIV; thus the worldwide HIV epidemic has led to a resurgence in TB in many countries worldwide, particularly in sub-Saharan Africa. Furthermore, drug-resistant TB is increasingly prevalent, and multidrug-resistant TB (MDR-TB, resistant to two of the first line anti-TB drugs) is associated with markedly worse outcomes.

The new TB ward, showing the new exterior near the front entrance, with the nursing station front left, and encompassing the whole veranda to the right, with the 'whirly bird turbines' just visible along the whole length.

TB and infection control in healthcare facilities

Political commitment, and efforts to combat the HIV/TB epidemic, have increased significantly, particularly in the past decade, and funding, mainly provided by donor governments and private donors, has increased over 50-fold since the mid-1990s, peaking at US $15.6 million in 2008, (although it has plateaued since then following the global financial crisis).[2]

Much of this funding has been focused on community-based HIV and TB control programmes, and in most cases has successfully delivered improved population access to HIV diagnosis and treatment.

However, infection control in healthcare facilities has been largely neglected in the policy and practice of TB control. Following several outbreaks of MDR-TB associated with high mortality, it is now well recognised that poorly ventilated, inadequately designed, healthcare facilities may play a major role in maintaining TB transmission in the developing world.[3] Nevertheless, there has been relatively little investment in developing healthcare infrastructure.

Why, in the face of the evidence for the role of healthcare facilities in TB transmission, and the consequent morbidity and mortality, should this be the case?

This article was written by James Elston, with input from co-authors Ian Hinitt, Steve Batson, Cath Noakes, John Wright, John Walley (professor in International Health, Nuffield Centre for International Health, University of Leeds), and Clare Humphreys (speciality registrar in Public Health, Yorkshire).

Addressing infrastructure in the developing world

Many internationally funded community-based HIV/TB control programmes have been donor-led. Commonly donors drive the agenda, and then design and maintain overall control of the programme and its funding duration. The situation with infrastructure is more complicated, and there is less control afforded to the donor, and more perceived risk. For example, in order to address infrastructure, both the funder and the recipient healthcare facility need to agree the agenda, and have the same vision for the facility and its use. When the owner may be government, an NGO, a religious organisation, or parastatal, and when the subject is as sensitive as TB care (which often is associated with fear and stigma), this is not as simple as it sounds.

'Ownership' key

'Ownership' is often the key issue, and many international funders (including the Department of International Development, UK) make it clear they will not fund new infrastructure which is viewed as assets for the recipient, and through concern about recurrent costs. Without a proactive potential recipient, and a flexible donor, partnership is not practical. Even when these conditions are met, there may be a barrier at the design stage, which often is severely limited by lack of local expertise in producing the design. The local design may not meet requirements for international funders – for example in health and safety – and the donor may be unable, or unwilling, to produce and impose an alternative design. Furthermore, concerns regarding financial accountability, and reliance on local labourers and materials, may make the proposition even less appealing to fund. Local private sector involvement is historically patchy, and direct government funding is often challenging to secure in resource-poor settings.

How then can poorly resourced healthcare facilities be assisted to tackle the twin epidemics of HIV and TB?

Here we describe an example of how healthcare workers (HCWs) at a hospital were empowered to dramatically improve their TB inpatient facilities, and protect the health of patients and staff, with the assistance of UK-based architects and healthcare engineers.

Case situation: Swaziland and HIV/TB

The Kingdom of Swaziland in southern Africa (population ~1 million) has the world's highest HIV prevalence and highest TB incidence. Approximately a quarter of all adults aged 15-49 (and half of all women aged 30-34) are living with HIV, and 80 per cent of TB cases are HIV positive.[4] TB was declared a national emergency by the Prime Minister of the Kingdom in 2011. High-level political commitment, combined with international funding and partnership, have led to significant progress in developing HIV and TB community-level programmes, and improving access to HIV and TB diagnosis and treatment in recent years. However, significant challenges remain, not least in TB infection control.

Above: The main hospital thoroughfare corridor, with the TB 'isolation' wards to the left. Top right: A view from the main hospital thoroughfare corridor to the TB ward, showing the connecting air bricks. Right: Doors and windows dividing the TB wards from the veranda (view from the veranda).

The Good Shepherd Hospital

The Good Shepherd Hospital (GSH) in Swaziland is a 225-bed regional hospital for Lubombo with a catchment population of ~220,000, serving the most rural and economically deprived population in the country. GSH is considered one of the leading healthcare facilities in the country, and, in partnership with international bodies, has been pivotal to delivering improvements in HIV and TB care services in the community, and improving access to care for people in the region. However, like many healthcare facilities in the region, GSH has been hampered by its infrastructure. GSH was founded in 1949, and much of the current building is around 50 years' old. The medical landscape has changed dramatically over the past 20 years following the explosion in the HIV, and later TB, epidemics. The vast majority of inpatients are HIV positive, and active tuberculosis is commonly encountered, in stark contrast to the case mix when the hospital was originally constructed. Quite simply, GSH was not designed for its current purpose. GSH is owned by the Catholic Church but is a parastatal, with running costs mainly funded by the Government.

GSH TB inpatient facility

The basic layout of the TB inpatient facility at GSH consisted of two separate ward areas for male and female patients. Each TB ward opened onto the main hospital thoroughfare corridor by a single sliding door. Each ward consisted of separate rooms (without windows) linking to a veranda, which had windows. The rooms were separated from the veranda by a wall with door and small window. The nursing station was located along the corridor from the TB ward, allowing no direct vision to the ward. There was no dedicated TB nursing team, and TB inpatients were cared for by HCWs looking after all male and female medical patients respectively.

'Ideal conditions' for transmission

The layout of the TB wards did not allow for adequate natural ventilation, and there was no sunlight (UV exposure) directed into the rooms (aside from veranda areas), meaning that the environment was favourable to maintaining suspended airborne droplets containing viable TB baciili for long periods. Air bricks between the veranda and wards and corridor enabled some ventilation, but also allowed cross-transfer of airborne microorganisms between TB and non-TB spaces. In addition, separation (cohorting) of patients with TB was not achieved, as patients

moved relatively unrestricted in and out of doors connected to the main corridor (the female TB ward bathroom was located across the main hospital thoroughfare corridor), and TB patients often mixed with non-TB patients (the majority of whom are HIV positive).

Unable to maintain isolation

Healthcare workers (HCWs) were unable to effectively maintain isolation, in part due to the location of their duty nursing station, and in view of competing duties. Those such workers looking after TB patients were provided with one N95 particulate respirator mask per month (these masks are protective against TB exposure, although this is time and care-dependent; it is recommended that they are changed at least weekly by most experts. In the UK, HCWs caring for TB patients generally use a new mask for every working shift).

Given the very high prevalence of HIV in the country, it is known that many of the HCWs are themselves living with HIV, and are thus at elevated risk of TB. That the medical, nursing, and auxiliary staff continued to provide care for TB patients in these circumstances reflects their courage and dedication to duty. Nevertheless, it would have been understandable if, when tasked with caring for TB and non-TB patients during the same shift, such staff may have minimised the time spent in the TB wards, meaning that TB patients may have received less direct care than others, and may consequently have had longer than necessary lengths of stay, further exacerbating the situation.

'Emergency situation'

By mid-2012 it was very clear that hospital-based TB transmission was occurring. Several staff members had developed active TB, including cases of MDR-TB, and new cases were continuing to be diagnosed regularly. It was not possible to track patient infections, though this could be assumed. Clinicians, nursing staff, and hospital management, were very concerned, and eager to find a solution. Previous visiting public health practitioners had made basic plans for ward refurbishments in previous years, but requests for funding had gone unanswered. There was empathy in all quarters, and the National TB Programme considered this to be an emergency situation; nevertheless there was no way forward in sight.

Finding a solution: first steps

In late September 2012 the situation was re-evaluated. A new basic design for refurbishment of the TB inpatient facility was created by myself, as an infectious disease/public health practitioner who had arrived from the UK. The design was adapted from drawings created by previous visiting public health practitioners, and was created in consultation with Good Shepherd Hospital clinicians and nursing staff, and the hospital management team. The main aim of the project was to better protect healthcare workers and patients against TB exposure by maximising natural ventilation, and ensuring separation (cohorting) of TB inpatients away from others.

Swift completion at minimal cost

From the outset it was understood that this was an emergency measure that needed to be relatively straightforward, to enable completion within a short period of time, and at minimal cost, using local contractors and the 'in-house' maintenance team, with locally sourced materials. Under these circumstances it would not be possible to create a 'perfect design', and the project would be one of retrofit, rather than creating a new purpose-built structure. A prominent feature of the new design was to make full use of the advantages that GSH already possessed, and in particular a long veranda, which was elevated from the ground for much of its length, exposed to

Courtesy of Bowman Riley Healthcare Architects

Computer-generated images of the proposed TB ward retrofit using Building Information Model (Revit) software.

sunlight for much of the afternoon, and in a good position for capturing the prevailing wind (generally east to west). The preliminary design was approved by the Swaziland National Quality Assurance and infection control teams, and was greeted enthusiastically by the GSH management, who pledged funding.

Private sector input

The National TB Programme also pledged to divert some private sector funding. However, further funds were required, and there was a realisation that, in order to achieve a quality end-product, it was highly desirable to seek expert assistance in order to optimise and produce a professional plan. I was put in touch with Ian Hinitt, founder and managing director of Apex 4D – innovators in healthcare built environment (*HEJ* – October 2013), who was formerly deputy director of Estates at the Bradford Teaching Hospitals NHS Foundation Trust, via Professor John Wright, consultant in Clinical Epidemiology and Public Health at the Bradford Institute for Health Research.

Collaborative working

Ian Hinitt responded enthusiastically to the request, and offered technical support on a pro-bono basis. He recruited Steve Batson, director at Bowman Riley Healthcare Architects, via the two companies' collaborative international joint venture, 3DiFM, and Dr Cath Noakes, a Reader in Infection Control Engineering at the University of Leeds, to contribute their expertise in healthcare design and ventilation. Within a few days Ian Hinitt, Steve Batson, Cath Noakes, and I, had formed a working group via 'Skype', and collaborative working was initiated.

I provided the basic design plans, together with dimensions, photographs of the site, and information on local climatic conditions, as well as a briefing on the particular challenges relating to the local working environment, resource limitations, and the potential funding avenues. The UK-based team then carried out an initial assessment of the plans to determine suitable ventilation methods and flow paths, and refine the ward and nursing station layout. Once this design had been agreed as feasible, the group worked together to detail the plans. Iain Hinitt, Steve Batson, and colleagues at Bowman Riley, took the lead on drawing up the plans using the internationally renowned Health Facilities Briefing System (HFBS), and Building Information Modelling (BIM) design software, while Cath Noakes tackled sizing the ventilation systems. The whole process was an iterative collaborative effort, drawing on the engineering and clinical knowledge of the team to develop a workable approach.

'Low-cost, low-tech, and resilient'

Challenges of undertaking this work were many and varied, as described by Ian Hinitt, who said: "Our site survey had to be done remotely by photographs, videos, and Skype, working closely with James Elston to interpret the physical aspects of the hospital building and layout. The budget was unknown, but restrictions were assumed to be very tight. Therefore the design had to be low-cost, low-tech, and resilient to harsh operating conditions. Space utilisation and functionality were a compromise, as the hospital infrastructure and existing layout itself did not allow much room and scope for the planned refurbishment and redevelopment. We needed to maintain hospital function (e.g. maintain bed numbers as much as possible long-term), and minimise the impact and disruption to normal day-to-day activity.

Local contractors and materials

"The redevelopment would have to be reliant on local contractors and local materials, and simplicity of design was important, as resources for future maintainability and operability were likely to be scarce. The simplicity of design would also ensure timely construction – to minimise disruption to patients, and maintain hospital functions, as much as possible. Speed of delivery was crucial, as the emphasis from the outset was that this was an emergency, so we had to respond fast (to protect people, and also to avert a potential strike by staff!).

"We had to accept that there would be both compromises to current design philosophies, and limitations as to what we could achieve in this scenario; the design could not be perfect, but we were confident that whatever we could help produce would be a significant improvement in protecting the health and wellbeing of both patients and staff."

Knowledge limitations uncovered

"Tackling this project also highlighted limitations in current research knowledge," Cath Noakes added. "Most knowledge on healthcare ventilation design for infection control is from the developed world, where it is assumed that any high risk environment will be mechanically ventilated, and maintained under negative pressure. However, in this situation, lack of power reliability meant that this was not an option, and could even add to the risks in the event of power failure. There is currently only a small body of work on natural ventilation systems for infection control, and even though the WHO produces some good guidance,[3,5] it is predominantly focused on new-build, rather than on tackling a difficult retrofit on a low budget. For example, although 'whirly-bird' turbine ventilators are commonly used in developing countries to aid natural ventilation flows, we found that there is a lack of reliable data available to size such systems."

Innovative approaches

Developing the design for this ward required thinking through the fundamental issues to develop practical and affordable solutions as a team, as this was a situation where simply applying design guidance was not possible. The constraints of the current ward, and the budget limitations, meant that many 'ideal' solutions would not work. However, by applying basic principles of stack and wind-driven ventilation design with the understanding of how TB is transmitted, the team was able to develop a low-tech solution that enabled safe cohorting of patients, minimised air transfer paths between patient groups, and maximised ventilation to all groups.

The design work led by Bowman Riley was undertaken using BIM software and Revit Architecture to provide a 3D model and simulate the site. The use of these software systems in developing this design was of particular benefit, enabling the team to model the refurbishment from the UK without the need to survey the hospital in person, and to easily change design features, perform sizing calculations, and finally to present a professional design for consideration by the funders.

Progress

Through several stages a final design was produced by April 2013.

Cohorting of TB patients separate from other inpatients would be achieved by creating a separate new entrance into the front of the veranda ward, and sealing off the doors and windows connecting this space to the main hospital corridor, preventing both occupant movement, and air ingress. Furthermore, a new nurses' station would be constructed adjacent to, but physically separated from, the new ward area, which would protect staff from TB exposure, but also allow more close supervision and care of TB patients. The GSH management committed to providing staff to form a dedicated TB nursing team for each shift, and to providing N95 masks at more regular intervals.

Natural ventilation

Improved natural ventilation would be achieved by removing three internal walls from the veranda, removing defunct separating walls, windows, and doors, separating the veranda from two of the rooms in the male TB ward, creating a new entrance into the veranda, and the insertion of floor-level vents and roof-level ventilation using wind driven 'whirly bird' turbines to promote throughflow. Improved ventilation was designed for both the TB inpatient area, and other wards, to ensure that all spaces would receive sufficient fresh air, and to minimise the chance of air transfer between TB and non-TB ward spaces.

Funding

I was able to take the design to potential local funders, and secured funding from four sources, including two private sector companies under the banner of corporate social responsibility – [the Motor Vehicle Association (MVA) of Swaziland, and Swaziland Electricity Company (SEC)]; one US-backed NGO, [University Research Council (URC)], and from GSH management itself – raising a total of 280,000 Swazi Emalangeni (~£18,800) for the refurbishment.

Working with Ian Hinitt, Steve Batson, and Cath Noakes, was incredible. Often when faced with overcoming such an urgent and important issue, one can feel overwhelmed, and doubts begin to set in.

Progress on the interior.

With these colleagues' help and advice we were able to make improvements in the proposed refurbishment plans, and the production of the professional design made a big difference. While we had already secured backing and some funds for the project, the design plans demonstrated a level of professionalism and projected confidence that the project would actually happen, and that the end product would be of good quality. We could also be much more confident of the budget required for the work. It was surprisingly straightforward from that moment on to secure the required funds. The respective organisations were receptive, and had been looking for a viable project to invest in, and, with their commitment and enthusiasm, the project gained real momentum – moving from possibility to reality.

Achieving change

The construction of the TB ward refurbishment began on 12 May 2013, and, at time of writing (the end of July) is nearing completion, slightly behind schedule, but on budget. It is, however, understood that while providing a healthcare environment with reduced anticipated burden of suspended TB bacilli is of clear benefit, it is not sufficient alone to achieve real change, and to fully minimise risk of TB exposure. Individual risk behaviour must be addressed; it is essential that healthcare workers and patients are educated on TB transmission, and use the facility appropriately. Therefore, two programmes for GSH staff were also run by myself and colleagues in late 2012 and early 2013 – firstly an HIV/TB education and health screening programme coupled with TB chemoprophylaxis and treatment, and later an infection control training programme (with particular focus on TB infection control). The former was supported by the Swaziland National Wellness team, and the latter attracted external funding and technical support from the University Research Council.

Full management backing

Both programmes received the full backing and proactive support of GSH management, and were an unqualified success, with high uptake of screening and TB chemoprophylaxis, and very good attendance. Further in-house education programmes are ongoing, and screening is set to be undertaken on a regular basis. Patient education is performed by nursing staff during daily duties, and protocols for the use of the TB inpatient facility are being finalised prior to opening.

It is hoped that this integrated, multi-pronged approach will lead to real change, and reduce the likelihood of TB exposure and transmission over the long term.

Reflections

According to Dr Petros Hailemarium, senior medical officer at the Good Shepherd Hospital, 'TB is one of the biggest killers in our region, and this project is a big step to reducing the spread of infection and saving lives. The whole project, and related work, have also demonstrated the value of international partnership in improving global health'.

The aim of the project – to better protect healthcare workers and patients from TB exposure by maximising natural ventilation and ensuring isolation (cohorting) of TB inpatients – has been achieved. Our approach necessitated good preparation, efficiency of working, clear communications, and good teamwork. Collaborative working via Skype and email was straightforward and time-efficient, despite the team being located across two continents.

'A right, not a privilege'

Ian Hinitt said: "3DiFM believes that access to health is a right, and not a privilege, equal to that of access to clean water. Working on this project has tested our ability to innovate at an international level, and we are delighted to have been invited to contribute to the development of GSH TB facilities, in support of our beliefs and values."

Steve Batson, meanwhile, stated: "We are pleased that our team was able to provide much-needed help to the Good Shepherd Hospital in Swaziland by providing our design and technical skills for free using BIM. The benefits of using

integrated BIM technologies for healthcare projects are significant in delivering improved health outcomes for the sector".

'Close to being overwhelmed'

Although this project is considered a success, there is an understanding that there is much work yet to be done. MDR-TB incidence is increasing rapidly in Southern Africa. MDR-TB care in the Kingdom of Swaziland is currently provided centrally by the National TB Hospital, which is close to being overwhelmed in coping with demand, both in terms of numbers, and the unique challenges involved in protracted MDR-TB treatment. The National TB Programme aims to decentralise care to the regions, and its staff have made explicit the need to provide a dedicated MDR-TB facility in Lubombo, which would ideally be situated at the GSH site. Our team is keen to explore ways that we might be able to contribute to assist this process. Furthermore, this work has inspired Ian Hinitt and his partners in 3DiFM to develop 'flat-pack' TB hospital facilities which are low-cost, functional, and resilient, and which support the WHO mission to combat the global TB epidemic.

Implications

Internet-based communications are now much improved in sub-Saharan Africa; Skype and email are almost universally accessible for large healthcare facilities in most countries. Our collaborative approach worked, and the use of BIM software was appropriate and successful. There is no shortage of need in the developing world in general with regard to improving TB infection control. We would advocate that this model of working is transferable to other similar settings.

Steve Batson suggests that there may be wider potential benefits in using design software in the future, when he says: "The health of the planet and health of humanity are intrinsically linked. There is considerable evidence for the association between climate change and the transmission of infectious diseases, and how the built environment directly impacts on health. Can we in future utilise BIM and the Health Facility Briefing System to create predictive simulated models that can help provide evidence in how climate variability and the built environment be improved to help mitigate infectious disease incidence?"

International partnerships

This case has demonstrated the value of international partnerships in global health. We would argue that such partnerships are beneficial to all parties, and for UK-based professionals indeed this type of work is a chance to step outside normal working patterns, push the boundaries, and use knowledge and skills for the benefit of those that arguably need them the most. This work also reflects well on the UK-based companies and organisations involved, and might be used in public relations. While this type of work would mostly be expected to be voluntary, there may also be potential commercial opportunities. Large international funders (such as the World Bank and Global Fund) have a renewed mandate that includes supporting infrastructure, and, while challenges remain (as detailed in this article previously), there may well be opportunities in the near future.

The GSH team (from left to right): Sister Mandisa Ndlovukazi, Dr Fred Busulwa, Staff nurse, Busani Mangoye, and Sister Vusani Ndzimanzi.

Opportunity to make a difference

We hope that this case will raise awareness of the global health threat that is TB, and how, through partnership, sharing expertise, and widening of our horizons, real change can be achieved, even in the most resource-poor countries. This case also highlights how quickly change can happen, and how relatively straightforward collaborative working can be. There has never been a better time to get involved in international health, and we would urge colleagues to be proactive, seek out an opportunity, and make a difference. ✚

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Dr James Elston

James Elston MBBS, MRCP (UK), DTM&H, CertMedEd, DLSHTM, MSc, is a specialist physician in infectious diseases and general internal medicine by background. He has a self-declared passion for global health, and a particular interest in infectious disease epidemiology and communicable disease control. He has experience of living and working in Africa, recently returning from a second stint in Swaziland, southern Africa. Having completed an MSc in Public Health (at the London School of Tropical Medicine), he is shortly to embark on further specialist training in public health based in the Yorkshire region. He is maintaining active links with Good Shepherd Hospital and Swaziland, and would welcome any queries or potential interest arising from this article via email to: drjameselston@gmail.com