World J Surg (2015) 39:363–372
DOI 10.1007/s00268-014-2805-7

ORIGINAL SCIENTIFIC REPORT

Assessment of the Availability of Technology for Trauma Care in India

Mihir Tejanshu Shah · Manjul Joshipura · Jered Singleton · Paul LaBarre · Hem Desai · Eliza Sharma · Charles Mock

Published online: 3 October 2014

Abstract

Background We sought to assess the status of availability of technology for trauma care in a state in India and to identify factors contributing to both adequate levels of availability and to deficiencies. We also sought to identify potential solutions to deficiencies in terms of health system management and product development.

Methods Thirty-two technology-related items were selected from the World Health Organization's *Guidelines for Essential Trauma Care*. The status of these items was assessed at 43 small and large hospitals in Gujarat State. Site visits utilized direct inspection and interviews with administrative, clinical, and bioengineering staff.

Results Many specific individual items could be better supplied, including many that were very low cost (e.g., chest tubes). Many deficiencies arose because of mismatch of resources, such as availability of equipment in the absence of personnel trained to use it. Several locally manufactured items were fairly well supplied: pulse oximetry, image intensification, and X-ray machines. Ventilators were often deficient because of inadequate numbers of units and frequent breakdowns.

Conclusions Availability of a range of lower-cost items could be improved by better organization and planning, such as: better procurement and stock management; eliminating mismatch of resources, including optimizing training for use of existing resources; and by strengthening service contracts and in-house repair capabilities. From a product development viewpoint, there is a need for lower cost, more durable, and easier to repair ventilators. Promoting increased capacity for local manufacturing should also be considered as a potential method to decrease cost and increase availability of a range of equipment.

Introduction

Trauma causes over 5 million deaths per year, 90 % of which are in low- and middle-income countries (LMICs) [1]. In high-income countries, improvements in planning and organization for trauma care have been shown to decrease overall mortality by 15–20 % and preventable deaths by 50 %. A component of this improved organization has involved assuring timely availability of physical resources, including equipment and supplies [2–4]. With an intent to set globally applicable minimum standards for

Electronic supplementary material The online version of this article (doi:10.1007/s00268-014-2805-7) contains supplementary material, which is available to authorized users.

M. T. Shah (✉) · H. Desai
Smt. NHL Municipal Medical College,
Ahmedabad, India
e-mail: mihir.28290@gmail.com

M. T. Shah · M. Joshipura
Academy of Traumatology (India),
Ahmedabad, India

J. Singleton · P. LaBarre
PATH, Seattle, WA, USA

E. Sharma
Rangpur Medical College, Rangpur, Bangladesh

C. Mock
Department of Surgery, University of Washington, Seattle, USA

trauma care, the World Health Organization (WHO) published the *Guidelines for Essential Trauma Care* (EsTC). These guidelines define standards for the human and physical resources required to maintain a minimum, acceptable level of trauma care. A component of the physical resources defined by this publication is technology-related [5].

Evaluations in India and elsewhere have used the *Guidelines for EsTC* to address technology-related resources [6–11]. However, those prior evaluations did not delve into factors contributing to low availability of some technology-related resources and adequate availability of others. Hence, in the current study, we sought to evaluate the factors that influence the availability of technology-related items for trauma care in an Indian state. By so doing, we hoped to identify potential solutions to deficiencies in two broad categories: health system management (e.g., procurement, stock management, financing) and product development (e.g., development of medical devices that are more durable and require less maintenance) [12].

Methods

Site selection

India is a lower-middle country with a population of 1.24 billion people and an annual per capita income of US$1199 per capita. Indian states range in per capita income from $465 (Bihar) to $3788 (Goa). Gujarat has a population of 60 million people and a per capita income of $1688, slightly above average for India [13–15]. Sixteen out of 33 districts of the state were purposively selected to represent the spectrum of geography, economics, and level of development of trauma care. These included three districts classified as "backward/low-income (in dire need of assistance)" by the state government. The other 13 districts were classified into either medium or high-income using a method developed by the National Institute of Rural Development, which uses a composite of 57 indicators of economic development [16, 17].

The government health care system is divided into three levels. Primary health centers (PHC) majorly provide only outpatient services and were not included in the study. Community health centers (CHC) forming the secondary level are 30 bed hospitals, which typically have 2–3 doctors, 2–3 nurses, and around 20 other staff members. CHCs throughout the country are uniformly regulated by the Ministry of Health. Differences in medical care offered by these CHCs exist based only upon the income level of the district in which they are situated [18, 19].

In contrast, tertiary centers vary vastly, depending upon norms imposed by national regulatory bodies for training program approval, policies formulated by state and local government, and income level of the area. Tertiary centers with a medical school are at higher standard than those without one; and tertiary centers with both medical schools and residency programs provide the highest level of healthcare [20, 21].

For this study, a total of 21 CHCs and 22 tertiary centers (Table 1) were evaluated out of a total of 273 CHCs and 74 tertiary centers statewide. All facilities evaluated were government-operated or government-affiliated because they provide the vast majority of trauma care in the state.

Criteria for evaluation

Guidelines for EsTC list 260 items of human (training, staffing) and physical (equipment, supplies) resources that are considered as either "essential" or "desirable" at different levels of the health care system. Essential items are those that are considered the most cost-effective and are universally applicable in countries at all economic levels; for example, basic airway equipment and chest tubes. Desirable items are those that add value but are not as cost-effective and are more applicable to middle-income environments or large urban centers; for example CT scans [5]. For this study, essential and desirable items were considered together.

Technology-related items were selected from the list of resources recommended by the *Guidelines for EsTC*. These included medical devices (machinery and equipment) used for both diagnosis and treatment. Two data collection forms were created: the tertiary center form had 32 items and the CHC form had 16 items.

Site visit process

The forms were used to interview key staff at each facility. These included hospital directors; heads of departments of surgery, orthopedics, and other relevant specialties; emergency department (ED) head; nursing matron/head; and clinicians (doctors and nurses) on duty in the ED, intensive

Table 1 Number of facilities evaluated based on income status of district and on training programs

	Low-income districts	Medium-income districts	High-income districts
Community health centers	3	9	9
Tertiary centers			
No medical school or residency program	3	4	2
Medical school only	–	1	4
Both medical school and residency	–	3	5

care unit (ICU), operating rooms (OR) and wards; and biomedical engineers and maintenance staff. Direct inspection of facilities and equipment in ORs, EDs, ICUs, and wards was carried out. Visits lasted between 4 h (CHCs) and 10 h (tertiary). Each of the items was assessed as:

- Absent: 0
- Inadequate: 1
  Less than half of those who need this service receive it when needed
- Partly adequate: 2
  Most, but not all, of those who need this service receive it when needed
- Adequate: 3
  Virtually all of those who need this service receive it when needed

Items were assessed based on their timely availability for all who need them, not their mere physical presence. For each item recorded as 0–2, reasons for lack of full-time availability were given, including one or more of: not present, lack of reagents, awaiting repairs, need for pre-payment, lack of trained staff, and others. When differing scores were given by different respondents, an average/consensus value was recorded. One score for each institution for each category was thus derived.

Names of respondents were not recorded. This study was approved by the health departments of the involved districts and/or senior management of the specific facilities surveyed, as appropriate.

Table 2 Ratings of availability of trauma care technology at community health centers

	Low-income districts	Medium-income districts	High-income districts
Number of facilities assessed	3	9	9
Airway			
Basic airway equipment[a]	2 (2–3)	2 (0–3)	2 (0–3)
Advanced airway equipment[b]	0	0 (0–3)	0 (0–2)
Breathing			
Oxygen supply	3	3 (2–3)	3 (2–3)
Chest tubes and underwater seal bottle	0	0 (0–2)	0
Pulse oximetry	0 (0–2)	1 (0–3)	1 (0–3)
Bag-valve-mask	3	3 (1–3)	3
Circulation			
Blood transfusion capabilities	0	0 (0–1)	0 (0–3)
Urinary catheter	3 (0–3)	3	3 (0–3)
Laboratory facilities for hemoglobin	2 (0–2)	2 (0–3)	1 (1–3)
Imaging			
X-rays	0.5 (0–2)	1 (1–3)	1 (0–2)
Ultrasonography[c]	0	0 (0–1)	0
Operative equipment			
General surgical procedures[d]	0	0	0 (0–3)
Skin grafting	0	0 (0–1)	0
Extremity injury			
Closed reduction	0	0 (0–3)	0
External fixation	0	0 (0–2)	0
Spinal injury			
Materials for spinal immobilization[e]	0	0 (0–3)	0

The ratings of availability of items in the table are: 0 (absent), 1 (inadequate), 2 (partly adequate), 3 (adequate). Values in the cells indicate the median value and range, if applicable. If all facilities in a category had the same rating, no range is given

[a] Oral or nasal airway; suction

[b] Laryngoscope, endotracheal tubes

[c] Ultrasonography, especially for diagnosis of hemoperitoneum

[d] General surgical procedures, including laparotomy, neck exploration

[e] For spinal immobilization: C collar, back board

Results

Community health centers

Twenty-one CHCs were assessed. In general, items needed for both resuscitation and definitive care were better supplied in areas with better economic status (Table 2). However, most CHCs had notable deficiencies in airway equipment, pulse oximetry, and even basic laboratory measurements. Blood transfusions were available at only a few CHCs (only 2 centers having any blood transfusion capabilities at all). Interestingly, oxygen was usually well supplied, with a median rating of 3 (adequate) at CHCs in all categories of districts. Capabilities for definitive care were even more deficient, with median ratings of 0 for operative equipment, extremity injury, and spinal injury for all categories of districts. X-ray availability ranged from absent to partially available, but rarely fully adequate. A few CHCs in high-income areas had capabilities for general surgical procedures, but only 3 had any capabilities for care of fractures. Even low-cost materials for spinal immobilization (C-collars, backboards) were nearly uniformly absent, with only 2 CHCs having any level of availability.

Tertiary centers

Twenty-two tertiary centers were assessed. Paralleling the general medical capabilities, technology for trauma care

Table 3 Ratings of availability of technology for acute resuscitation at tertiary centers

	No medical school or residency program			Medical school only	Medical school and residency program
	Low-income districts	Medium-income districts	High-income districts		
Number of facilities assessed	3	4	2	5	8
Airway					
Basic airway equipment[a]	3	3 (2–3)	3	3	3
Advanced airway equipment[b]	2	2	3	3 (2–3)	3
Breathing					
Oxygen supply	1 (1–2)	2.5 (2–3)	3	3	3 (2–3)
Chest tubes & underwater seal	1 (0–2)	1.5 (1–2)	1.5 (1–2)	2 (1–3)	3
Pulse oximetry	2 (0–3)	2 (0–3)	3	3	3 (2–3)
Arterial blood gas	0	0 (0–2)	2.5 (2–3)	3 (0–3)	3 (2–3)
Bag–valve–mask	3	3 (0–3)	3	3	3
Mechanical ventilator	1 (0–1)	0.5 (0–3)	2 (1–3)	2 (2–3)	2 (1–3)
Circulation					
Blood transfusion capabilities	2 (0–2)	0.5 (0–3)	1.5 (0–3)	2 (2–3)	2 (1–3)
Urinary catheter	3	3 (1–3)	3	3	3
Lab facilities for hemoglobin	3 (2–3)	2.5 (1–3)	2.5 (2–3)	3 (2–3)	3
Electronic cardiac monitoring	2 (0–3)	3 (1–3)	3	3 (2–3)	3 (2–3)
Lab facilities for electrolytes	1 (0–2)	0 (0–3)	2.5 (2–3)	2 (0–3)	3 (2–3)
Lab facilities for lactate	0	1.5 (0–3)	0	0	0 (0–3)

The ratings of availability of items in the table are: 0 (absent), 1 (inadequate), 2 (partly adequate), 3 (adequate). Values in the cells indicate the median value and range, if applicable. If all facilities in a category had the same rating, no range is given

[a] Oral or nasal airway; suction

[b] Laryngoscope, endotracheal tubes

was better supplied at institutions with residencies and/or medical schools (Tables 3, 4, 5). They were better supplied in high versus medium versus low-income areas. Some specific items of note include:

- Airway equipment was fairly well supplied in most locations.
- Despite their low cost, chest tubes were deficient at many institutions, with median rates of below 3 for all categories of institutions except the highest level (those with medical school and residency programs).
- Pulse oximetry was well supplied, except for institutions without medical schools in low- and medium-income districts, where median ratings were 2.
- Ventilators had less than optimal availability nearly everywhere (all categories of institutions having median ratings of availability less than 3).
- Several capabilities were primarily available only at the upper end of the spectrum: angiography, neurosurgical capabilities, vascular grafts, prosthesis for amputees.
- Operative equipment for orthopedics and general surgery were well supplied at most facilities except for the lower end of the spectrum (Table 5). For example, capabilities for closed reduction, skeletal traction, external fixation, and internal fixation had a median rating of 3 for institutions with medical schools, but less than 3 for institutions without medical schools.
- Several capabilities had median ratings of zero for all categories: therapeutic angiography, intra-cranial pressure monitoring, compartment pressure measurement, and availability of prosthetics for amputees.

Factors contributing to deficiencies: community health centers

Factors contributing to deficiencies in availability of technology are indicated in Table 6. The absence of equipment implied that it was never available (and in most cases not planned to be stocked). Shortage of equipment implies that items were stocked and planned for but that there were not enough units available to meet needs. For CHCs, this applied to pulse oximetry. More frequent problems, however, were training and staffing. Despite the low cost and physical availability of suction machines, they were often not used because of lack of training of staff. Lab tests and X-rays were sub-optimally available because of problems with staffing. In line with government policy,

Table 4 Ratings of availability of technology for imaging at tertiary centers

	No medical school or residency program			Medical school only	Medical school and residency program
	Low-income districts	Medium-income districts	High-income districts		
Number of facilities assessed	3	4	2	5	8
X-rays	2 (1–3)	2 (0–3)	2.5 (2–3)	3	3
Portable X-ray	1 (0–3)	0 (0–2)	2.5 (2–3)	0 (0–3)	3 (0–3)
Ultrasonography[a]	0	0 (0–3)	1 (0–2)	1 (1–2)	3 (2–3)
CT scan	0	0 (0–1)	0.5 (0–1)	0 (0–2)	2 (1–2)
Angiography diagnostic	0	0	0	0 (0–1)	1 (0–3)
Angiography therapeutic[b]	0	0	0	0	0

The ratings of availability of items in the table are: 0 (absent), 1 (inadequate), 2 (partly adequate), 3 (adequate). Values in the cells indicate the median value and range, if applicable. If all facilities in a category had the same rating, no range is given

[a] Ultrasonography, especially for diagnosis of hemoperitoneum

[b] Therapeutic angiography, especially for embolization of bleeding

Table 5 Ratings of availability of operative equipment at tertiary centers

	No medical school or residency program			Medical school only	Medical school and residency program
	Low-income districts	Medium-income districts	High-income districts		
Number of Facilities assessed	3	4	2	5	8
Basic neurosurgical procedures[a]	0	0	0	0	1 (0–3)
Advanced neurosurgical procedures	0	0	0	0	0.5 (0–2)
Spinal injury	0	0 (0–2)	1 (0–2)	0 (0–1)	3 (1–3)
General surgical procedures[b]	0 (0–3)	3 (2–3)	3	3 (1–3)	3
Vascular grafts	0	0	0	0	1 (0–3)
Skin grafting	0	2 (0–3)	2 (1–3)	3 (1–3)	3
Head injury					
Monitoring ICP	0	0	0	0	0
Extremity injury					
Closed reduction	0	2 (0–3)	2.5 (2–3)	3	3
Skeletal traction	0	2 (0–3)	2.5 (2–3)	3	3 (0–3)
External fixation	0	2 (0–3)	2.5 (2–3)	3	3
Internal fixation	0	2 (0–3)	2.5 (2–3)	3	3
Compartment pressure measurement	0	0	0	0	0 (0–3)
Image intensification	0	0 (0–3)	2	3 (1–3)	3 (2–3)
Prosthetics for amputees	0	0	0	0	0 (0–2)

The ratings of availability of items in the table are: 0 (absent), 1 (inadequate), 2 (partly adequate), 3 (adequate). Values in the cells indicate the median value and range, if applicable. If all facilities in a category had the same rating, no range is given

ICP Intracranial pressure

[a] Basic neurosurgical procedures include Burr holes (drill or other suitable equipment) and Treatment of open depressed skull fractures

[b] General surgical procedures, including laparotomy, neck exploration

most CHCs provide X-ray and hemoglobin estimation only during weekday, daytime hours. Hence, patients who present outside of these hours are unable to get basic diagnostic services.

Mismatches of resources were widespread. For example, functional X-ray machines often lay idle because of insufficient supply of plates or because trained staffs were not on duty. Because of a sub-urban/rural location of CHCs, very few have surgeons. In some CHCs in low- and medium-income districts, there was misallocation of funds to fully functional OR where no operation had ever been performed because of lack of surgeons.

Table 6 Factors contributing to deficiencies in technology for trauma care at community health centers and tertiary centers

Equipment type	Training	Staffing	Breakdowns/ maintenance	User fees	Infrastructure and logistics	Shortage of materials	Shortage of equipment	Absence of equipment
Community health centers								
Suction	57 %							
Pulse oximetry	47 %		31 %				18 %	24 %
Hemoglobin		87 %						5 %
X-ray		95 %	38 %			52 %		
Ultrasonography	19 %							81 %
Tertiary centers								
Suction			17 %					
Pulse oximetry			43 %				13 %	
Hemoglobin			9 %	4 %	4 %	9 %		
Electrolytes		5 %	14 %	5 %			15 %	9 %
Arterial blood gas			3 %	7 %			18 %	41 %
Ventilator		22 %	30 %	13 %	36 %		43 %	
X-ray		14 %	23 %	9 %	4 %	23 %	13 %	
Ultrasonography	47 %	47 %		20 %	4 %		26 %	14 %
CT Scan	27 %	11 %		43 %			21 %	45 %
ICP measurement								100 %
Prosthetics					100 %			95 %
Image intensifiers		16 %	16 %				17 %	27 %

Each row shows percent of that type of health facility that reported that type of contributing factor. More than one factor may be present; hence row totals may be more than 100 %

ICP Intracranial pressure

Owing to the remote location of many CHCs, there was difficulty accessing trained biomedical engineers technicians and thus breakdowns were prolonged. The most frequently cited equipment for which breakdowns contributed to deficiencies were pulse oximeters (31 % of CHCs reporting that breakdowns contributed to lack of availability) and X-ray machines (38 %).

Factors contributing to deficiencies: tertiary centers

Lack of training of staff and/or lack of adequate numbers of trained staff were especially problematic for ultrasonography and computerized tomography (CT). Very often, these pieces of equipment were not available, especially on weekends and nights, due to absence of staff to run them. At low-income centers, lack of X-ray plates and reagents for blood tests were common. Breakdowns especially contributed to deficiencies in pulse oximetry, ventilators, and X-rays. Downtime for this equipment was much less in high-income areas owing to proper maintenance contracts and in-house biomedical engineer teams. However, in low-income areas, downtimes were long and maintenance staff was scarce. Most equipment was imported and while parts sourcing for repairs were not an issue in high-income area, it posed a significant challenge for peripheral centers and low-income areas.

Shortage of sufficient numbers of units contributed to decreased availability of arterial blood gasses, CT scans, and especially to ventilators. User fees limited timely availability of many types of services; that is, services that could not be provided until they were paid for in advance. This was especially a problem for CT scans.

There were many mismatches of resources. On the one hand, most centers in higher-income areas had ventilators in short supply. On the other hand, there were many centers in lower-income areas having ventilators in adequate supply but which were unused because of lack of proper oxygen supply, inadequate electricity, or lack of trained staff. Likewise, in low-income areas, funds were used for expensive equipment like CT scanners and image intensifiers which lay unused for long periods of times because of lack of staff.

Logistical issues applied to only larger tertiary centers which had abundance of equipment. For example, equipment like portable sonography units lay unused and even unopened in the radiology department but was in shortfall in the ED. Such issues stem from the fact that equipment is bought by each department individually and there is no mechanism to transfer equipment from one department to another.

Origin of manufacture

Most of the equipment in CHCs was imported, other than hemoglobinometers, suction, and pulse oximetry (Table 7). At tertiary centers, equipment that was notable in being locally manufactured (i.e., manufactured within the country) included: cardiac monitors, pulse oximetry (especially stationary units), image intensifiers, and X-ray machines.

Pediatric considerations

Pediatric sizes of equipment were available at only a few CHCs (Supplemental electronic Tables 1 and 2). Pediatric airway equipment, chest tubes, nasogastric tubes, and urinary catheters were absent at most places. The only exception was IV cannulas, which were in fairly good supply in pediatric sizes. At most locations, lab tests could only be done with adult size volumes. At tertiary centers, most equipment was available in pediatric sizes except in low-income areas. Chest tubes and cervical collars were problematic at most centers, however.

Table 7 Percentage of equipment locally sourced versus imported

	Local	Imported
Community health centers		
Hemoglobin	68 %	32 %
Ultrasound—stationary	0 %	100 %
X-ray—stationary	35 %	65 %
Pulse oximetry	57 %	43 %
Suction equipment	100 %	0 %
Tertiary centers		
Laboratory		
Hemoglobin	0 %	100 %
Arterial blood gases	0 %	100 %
Electrolytes	5 %	95 %
Radiology		
Ultrasound—portable	10 %	90 %
Ultrasound—stationary	7 %	93 %
X-ray—portable	42 %	58 %
X-ray—stationary	40 %	60 %
CT-scan machine	17 %	83 %
Image intensifiers	68 %	32 %
Ventilators	7 %	93 %
Pulse oximetry—portable	44 %	56 %
Pulse oximetry—stationary	79 %	21 %
Cardiac monitor	52 %	48 %
Suction equipment	100 %	0 %

Percentages based on total number of pieces of equipment evaluated

Mechanical problems

Supplemental electronic Table e-3 lists specific mechanical problems frequently cited for given medical devices. For example, detachment of probe and wire was the most commonly cited problem for pulse oximeters. Overall, software issues accounted for the largest single cause of problems for all equipment considered together.

Discussion

The purpose of this study was to identify priorities for strengthening availability of technology for trauma care in LMICs like India, in terms of both health system management (e.g., procurement, stock management, financing) and product development (e.g., development of medical devices that are more durable and require less maintenance). One major finding was the potential role of local manufacturing in decreasing cost and increasing availability of key items. Locally manufactured equipment such as pulse oximetry, X-ray equipment, and image intensifiers were more available than previously reported in other LMICs [6–10]. For example, in this study 77 % (17 out of 22) tertiary centers had an availability rating of 3 (adequate) for pulse oximetry, in comparison to prior reports of 43 % in Mexico and 0 % in Ghana [6, 7]. Similarly, in this study the median rating for availability of image intensification at tertiary centers was 3 in comparison to median ratings of 0 or 1 in Mexico, Vietnam, and Ghana [6, 7]. This suggests that a potential priority globally should be promotion of increased manufacturing capabilities for these and other key items that are often in short supply due to cost and availability.

Pulse oximetry has been identified as a major global priority needed to promote safe anesthesia and surgery [22–24]. Similarly, image intensification is an important tool in orthopedic surgery, to decrease operative time, decrease blood loss, and improve functional results [25, 26]. It is infrequently available in many LMICs. The current study suggests that local manufacture is a possible mechanism to increase availability of these important technologies.

A potential priority for expansion of local manufacturing identified in this study is that of ventilators. Major causes of preventable death from trauma are airway obstruction and respiratory failure. In the absence of ventilatory support, respiratory failure will be nearly universally fatal. About half of all tertiary centers in this study reported insufficient availability of ventilators.

Attention has been drawn globally to the possible role of increased local manufacturing, especially given the fact that only 13 % of manufacturers of medical devices are located in LMICs. However, before this can be widely promoted, a number of barriers must be addressed. These include, among others, lack of adequate levels or availability of: regulations and policies, quality assurance/quality control mechanisms, level of development of biomedical industry skills, supply chains of raw materials and components, and financing mechanisms. Although some of these may indeed be in place in a large middle-income country such as India, it is uncertain how these important components could be promoted in smaller and/or low-income countries [27, 28].

Another priority is development of equipment that is more durable and needs less servicing. Priorities for engineering changes to improve durability are pulse oximetry, ventilators, and X-ray machines (Table 6). Pulse oximetry units were most often broken due to detachment of probe and wire. Ventilators were out of service for a variety of reasons, primarily related to overuse and mishandling. The combined problem of lack of sufficient number of ventilators and frequent breakdowns indicates that a future priority is to design and manufacture low-cost, durable ventilators designed for LMICs realities. Ventilators designed for high-income countries have a variety of higher-cost features such as wave form displays and capabilities for proportional assist ventilation and oscillation, that might not be needed nearly as much in LMICs, where there is a high unmet need for more simple modes of ventilation.

This study also identified several health system issues that could be strengthened. There were many low-cost, but critical, pieces of equipment, such as chest tubes, that were often deficient. Their availability could be increased by improvements in procurement, stock management, and logistics. An excellent example of an item for which improvements in logistics is needed is that of prostheses. India has produced a well designed and affordable alternative to imported prostheses in the form of the Jaipur foot, manufactured by a local non-government organization (NGO). It enables amputees to walk in rural conditions, work in muddy fields, and to climb trees. It has been widely used in Asia and Africa [29]. This NGO provides all its assistance, including the prostheses, *free of charge*. The organization has its branch at one of the tertiary centers in the study. However, most of the doctors in hospitals in the area (including that hospital) were not aware that such an organization existed, which led to most amputees under-utilizing this facility.

There were notable examples of wasteful mismatch of resources, such as fully functional X-ray machines and trained technicians available, but X-rays not being available as film would run out. At a few centers, costly CT scanners machines had been bought since a few years but had never been used because of lack of trained technicians. Such mismatches could likewise be addressed by improved organization and planning.

Some pieces of equipment were under-utilized due to insufficient training or staffing. Functional suction machines at many CHCs were rarely used as staff had limited training in trauma resuscitation. Ultrasound machines in both CHCs and tertiary centers were often unused at nights and weekends due to technicians and radiologists not being on duty. Increased availability of trauma training courses, such as Advanced Trauma Life Support (ATLS) or National Trauma Management Course, would be a reasonable investment for any facility that receives significant numbers of trauma patients. An assessment of the knowledge of ATLS principles among ED medical officers in India found that only 2 % of junior and 9 % of senior medical officers were able to pass a trauma management quiz [30]. More targeted education, such as training in FAST, for clinicians in busier EDs, is also a priority.

Another health system problem that inhibited care was user fees, the need for out-of-pocket cash payments before services could be received. Some hospitals had innovative methods of overcoming these; for example, lists of philanthropic volunteers who offered to pay for parts of emergency care for low-income patients on an "as needed" basis. However, timely availability of high-cost items such as CT scans was still affected, with more than three fourths of tertiary centers reporting that the need for prepayment led to many patients not getting a timely scan. Similar problems have been noted in the provision of trauma and other emergency care in many LMICs [31]. Financing mechanisms are clearly an issue that trauma systems need to better address.

This study likewise highlighted the need for strengthening capabilities for repair and servicing, a component of trauma system development that has scarcely been touched. Hospitals in low-income districts suffered from long periods of inoperability of machines while awaiting spare parts (especially for imported equipment) or because service contracts were not as well developed as in higher-income areas. There have been a few global efforts to address this need, such as the NGO Medisend's efforts, but these are, thus far, very small in comparison to the need [32].

Before drawing conclusions from the data, the limitations of the study must be addressed. First, although physical inspection of equipment was objective, ratings (0–3) of availability of items was somewhat subjective. The authors attempted to overcome this potential problem by interviewing a range of persons at each facility. Second, the study only assessed government hospitals. In India, the private sector is fairly well developed and, in general, runs at a higher level than the government system. However, the government system takes care of most trauma patients, especially those who are lower-income. Despite these limitations, the study provides a more comprehensive assessment of trauma care technology than has previously been reported for any LMIC and allows us to draw some reasonable conclusions about ways to strengthen it.

Conclusions

This study has identified several successes and several problems with the availability of technology for trauma care in the study area. There were also a range of items that were deficient and whose availability could be improved affordably and sustainably by better organization and planning, such as by: better procurement and stock management for lower-cost items; eliminating mismatch of resources, including through optimizing training for use of existing resources; developing financing mechanisms that minimized delays caused by need for out-of-pocket prepayments; and by strengthening service contracts and in-house repair capabilities for critical items. From a product development viewpoint, a major finding of this study is the need for lower cost, more durable, and easier to repair versions of pulse oximeters and ventilators. Local manufacturing was highlighted as a potential method to decrease cost and increase availability of a range of equipment.

Acknowledgements This study was funded in part by grants from the University of Washington (UW) Royalty Research Fund and the UW Department of Surgery Research Reinvestment Fund. Support was also provided by private foundations and individual donors to PATH's Health Innovation Portfolio. The authors thank Professor Pankaj Patel and Dr. Haren Joshi for their assistance in arranging site visits.

Conflicts of interest No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References

1. World Health Organization (2012) Injuries and violence: the facts. World Health Organization, Geneva. http://www.who.int/violence_injury_prevention/key_facts/en/index.html. Accessed 20 Jan 2012
2. Mann NC, Mullins RJ, MacKenzie EJ, Jurkovich GJ, Mock CN (1999) A systematic review of published evidence regarding trauma system effectiveness. J Trauma 47:S25–S33
3. Nathens A, Jurkovich GJ, Cummings P, Rivara FP, Maier RV (2000) The effect of organized systems of trauma care on motor vehicle crash mortality. JAMA 283:1990–1994
4. Nathens AB, Jurkovich GJ, Rivara FP, Maier RV (2000) Effectiveness of state trauma systems in reducing injury-related mortality: a national evaluation. J Trauma 48:25–30
5. Mock C, Lormand JD, Goosen J, Joshipura M, Peden M (2004) Guidelines for essential trauma care. WHO, Geneva
6. Arreola-Risa C, Mock C, Vega Rivera F, Romero Hicks E, Guzman Solana F, Porras Ramirez G, Montiel Amoroso G, deBoer M (2006) Evaluating trauma care capabilities in Mexico with the World Health Organization's Guidelines for Essential Trauma Care. Pan Am J Public Health 19:94–103
7. Mock CM, Nguyen S, Quansah R, Arreola-Risa C, Viradia R, Joshipura M (2006) Evaluation of trauma care capabilities in four countries using the WHO-IATSIC Guidelines for Essential Trauma Care. World J Surg 30:946–956
8. Nakahara S, Saint S, Sann S, Phy R, Ichikawa M, Kimura A, Eng L, Yoshida K (2009) Evaluation of trauma care resources in health centers and referral hospitals in Cambodia. World J Surg 33:874–885
9. Nguyen TS, Nguyen HT, Nguyen THT, Mock C (2007) Assessment of the status of resources for essential trauma care in Hanoi and Khanh Hoa, Vietnam. Injury 38:1014–1022
10. Razzak JABS, Khan UR, Heller D, Bhatti J, Hyder AA (2013) Emergency and trauma care in Pakistan: a cross-sectional study of healthcare levels. Emerg Med J. doi:10.1136/emermed-2013-202590
11. Joshipura M (2008) Trauma care in India: current scenario. World J Surg 32:1613–1617
12. Free MJ, Green JA, Morrow M (1993) Health technologies for the developing world: promoting self-reliance through improving local procurement and manufacturing capabilities. Int J Technol Assess Health Care 9:380–396
13. Government of India (2011) Census of India, 2011. http://censusindia.gov.in/. Accessed 26 Nov 2013
14. World Bank (2013) World Bank: www.worldbank.org. Accessed 26 Nov 2013
15. Planning Commission (2013) Government of India. State-wise: population, GSDP, per capita income and growth rate. http://pbplanning.gov.in/pdf/Statewise%20GSDP%20PCI%20and%20G.R.pdf. Accessed 26 Nov 2013
16. National Institute of Rural Development (2013) Backward Regions Grant Fund Programme. http://www.nird.org.in/brgf/doc/brgf_BackgroundNote.pdf. Accessed 27 Oct 2013
17. Thaker H, Shiyani R (2009) Socio-economic development in Gujarat. Available from National Institute for Rural Development: http://www.nird.org.in/NIRD_Docs/OctLevel_208.pdf. Accessed 26 Nov 2013
18. Directorate General of Health Services (2011) Ministry of Health & Family Welfare. Indian Public Health Standards (IPHS). Guidelines for Community Health Centres. http://tripuranrhm.gov.in/Guidlines/IPHS_Guidelines_Health_Centres.pdf Accessed 27 Oct 2013
19. Planning Commission (2013) Government of India. Public Health Care System. http://planningcommission.nic.in/aboutus/committee/strgrp/stgp_fmlywel/sgfw_ch8.pdf. Accessed 27 Oct 2013
20. Medical Council of India (1999) Establishment of Medical College Regulations. http://www.mciindia.org/RulesandRegulations/EstablishmentofMedicalCollegeRegulations1999.aspx. Accessed 27 Oct 2013
21. Medical Council of India (2000) The Postgraduate Medical Education Regulations 2000. http://www.mciindia.org/RulesandRegulations/PGMedicalEducationRegulations2000.aspx. Accessed 27 Oct 2013
22. Funk LMWT, Berry WR, Lipsitz SR, Merry AF, Enright AC, Wilson IH, Dziekan G, Gawande AA (2010) Global operating theatre distribution and pulse oximetry supply: an estimation from reported data. Lancet 376:1055–1061
23. Lifebox (2013) Life box: saving lives through safer surgery. http://www.lifebox.org/. Accessed 27 Oct 2013

24. Walker IA, Newton M, Bosenberg AT (2011) Improving surgical safety globally: pulse oximetry and the WHO Guidelines for Safe Surgery. Paediatr Anaesth 21:825–828
25. Keenan W, Woodward A, Price D, Eckloff K, Richards J, Powell J, Shanahan S (1996) Manipulation under anesthetic of children's fractures: use of the image intensifier reduces radiation exposure to patients and theatre personnel. J Pediatr Orthop 16:183–186
26. Sri-Pathmanathan R (1990) The mobile X-ray image intensifier unit in maxillofacial surgery. Br J Oral Maxillofac Surg 28:203–206
27. World Health Organization (2012) Local production and technology transfer to increase access to medical devices. WHO, Geneva. www.who.int/medical_devices/1240EHT_final.pdf. Accessed 23 Mar 2014
28. World Health Organization (2014) Local production for access to medical products. http://www.who.int/phi/publications/local_production/en/. Accessed 23 Mar 2014
29. Arya AP, Klenerman L (2008) The Jaipur foot. J Bone Joint Surg Br 90:1414–1421
30. Douglas RJ, Vasanthi B, Giles AJ, Kumar GA (2010) Improving trauma care in India: a recommendation for the implementation of ATLS training for emergency department medical officers. Int J Emerg Med 3:27–32
31. Cannoodt L, Mock C, Bucagu M (2012) Identifying barriers to emergency care services. Int J Health Plan Manag 27(2):e104–e120. doi:10.1002/hpm.1098
32. Medisend (2014) http://www.medisend.org/. Accessed 23 Mar 2014