Mechanical ventilators for low and middle-income countries: informing a context-specific and sustainable design

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Editor - The COVID-19 pandemic transiently raised the need for greater intensive care mechanical ventilation capacity around the world. Whilst intensive care units (ICU) were under immense pressure globally, several high-income countries (HICs) did not ultimately require novel prototype ventilators, as standard ventilators' supply was sufficient to meet demand. In contrast, mechanical ventilation capacity was, and largely remains insufficient in the vast majority of low and middle income countries (LMICs), limiting access to critical care and surgery.[1]

Standard ventilators used in HIC hospitals are unaffordable and unsustainable for hospitals with limited resources in LMICs. In response to the COVID-19 pandemic, some non-governmental organisations specifically began work on designing ventilators for LMICs. However, to our knowledge, no one has systematically surveyed a variety of LMIC sites to understand the contexts and challenges that need to be addressed in ventilator design.

Here we identify the key technical requirements for the design of a context-specific and sustainable mechanical ventilator for use across LMICs.

We performed a cross-sectional survey aimed at providing an overview of mechanical ventilation capacity and infrastructure in LMICs. The information was requested with reference to typical working patterns, not specifically to any surge in service demand like that associated with the COVID-19 pandemic waves. Results from this survey and those available in the literature were critically considered to identify key technical parameters to support the design of a context-specific and sustainable mechanical ventilator. Ethical approval was not required for this survey because it did not require patient data. The study followed EQUATOR Network guidelines and standards for reporting qualitative research.

The survey (Supplementary Appendix) consisted of 63 questions, used to define respondents' profiles, their hospitals' characteristics, current mechanical ventilation infrastructure and environment, and the estimated need for mechanical ventilation, associated maintenance and monitoring equipment. The survey was shared via email to 16 anaesthesia and critical care national and international societies and healthcare institutions, and via social media, directly reaching out to a convenience sample of 81 LMICs as defined by the World Bank.

Fifty respondents, mostly anaesthetists (45%) and intensivists (44%), with >6 year experience (72%), from different, large teaching and public hospitals (76%) contributed from 23 LMICs in Africa, Asia, Central and South America. Characteristics of respondents and their institutions are presented in Supplementary Table 1, country-by-country details are listed in Supplementary Table 2, and the geographical distribution of responses is illustrated in Supplementary Figure 1.

Supplementary Table 3 summarizes the power and gases availability. Loss of electricity was found to occur daily 19% (9/48), weekly 25% (12/48), less frequently 48% (23/48), or did not occur 8% (4/48). The majority of these outages [72% (31/44)] were reported to last <2 hours, with back-up power from external fossil fuel generators and batteries reported to be supplied within 1 hour in 91% (40/44).

This electricity availability is similar to that reported in a survey of 10 hospitals in Tanzania.[2] As access to electricity varies within most LMICs, where larger hospitals typically have more reliable supply,[3] the design of a context-specific mechanical ventilator needs to include an emergency battery to supply electricity, but our results suggest that the battery power may only be needed for a few hours (Table 1), limiting the cost for this relatively expensive component.

Compressed air was always available in 35% of hospitals, either piped 68% (19/28) or supplied via cylinders 29% (8/28) (Supplementary Figure 2). Oxygen was reported as always available in 74% of hospitals, at high pressure either piped 44% (20/46), or supplied via cylinders 46% (21/46), or at low pressure via concentrators 11% (5/46).

This oxygen availability was lower than observed in 99 Sri Lankan ICUs where piped oxygen was available,[4] and lower than in 10 hospitals in Tanzania.[2] Our result on oxygen availability matches a survey of 97 clinicians from public district and provincial hospitals in urban and rural areas in 19 countries throughout Africa, Asia and South America, where 75% reported that oxygen was available most or all of the time,[5] and is similar to that reported from 97 Ugandan anaesthetists, where 63% had always access to oxygen.[6] Overall, our results were more conservative than or comparable with those obtained from a total of 293 respondents plus 10 hospitals across 22 LMICs, supporting the representativeness of our findings.

Considered together with evidence from the literature,[2 4 6] our results on compressed air and oxygen availability suggest that the design of a mechanical ventilator for hospitals with limited resources may need to include an air compressor, and either a gas cylinder or an oxygen concentrator (Table 1), where modular designs would allow integration of features as necessary.

Most institutions 96% (48/50) reported having emergency departments, operating theatres and ICUs, and 4% (2/50) reported having only two of these three. Supplementary Figure 3 displays the number of ventilators that were functioning, non-functioning, and perceived to be required for each of these 3 departments. Over half of respondents (25/48) reported that ventilators were used 7 days a week, and 15 of these reported they were in use 24 hours per day. ICUs had the greatest estimated requirement for ventilators with 28% (13/47) requiring over 15, 40% (19/47) requiring 6-15, and 32% (15/47) requiring 0-5 ventilators per Unit. Emergency departments and operating theatres required a relatively smaller number of ventilators, with 76% (35/46) and 50% (23/46) requiring between 0-5 per Unit, and only 9% (4/46) emergency departments and 22% (10/46) operating theatres requiring >10 ventilators. A lack of funds and technical maintenance support combined was the most frequent reason for non-functioning or not used ventilators, where a lack of funding was cited in 74% (34/46) of responses (Supplementary Figure 4).

The median reported minimum and maximum operating temperatures were 20 and 30°C, and humidity was 30 and 60%. The design needs to consider the different environmental working conditions, where temperature and humidity reported here were typically higher in LMICs than in HICs. Testing must be performed in a relevant range of temperature, humidity and atmospheric pressure, depending on flow and pressure sensors employed (Table 1).

Detailed information on the frequency of anaesthesia mode is presented in Supplementary Figure 5, the perceived importance of monitoring techniques in Supplementary Figure 6, and proposed sustainable costs of consumables/patient/day in Supplementary Figure 7. Further results are presented and discussed in the Supplementary Appendix.

Overall, based on this survey's new and confirmatory findings, on evidence available from the literature,[1–9] on the authors' baseline experience of known needs, and collaborators' expert opinion, Table 1 summarises the key features to be considered when designing a mechanical ventilator to be useful and usable in LMICs. Inevitably, the requirements listed in this table will not be fully applicable to the very wide variety of all LMIC sites. However, there will be similarities in resource poor settings that are applicable to many sites. In this sense, the table considers the lower end of the resource spectrum, and provides the "lowest common denominator", which we think will capture some common issues of many sites. The trade-off between cost and sophistication is obvious, where in-country manufacture (or at least assembly) is needed for the design to be sustainable.

Authors' contributions

Preparation of the survey: DS, FF; Conceptualisation: MS, FF; Data analysis: JG, DS, FF; Interpretation: JG, DS, MH, EDR, MJS, MU, FF; Supervision: MH, MJS, MU, FF; Preparation of the manuscript: FF, JG; Critical revision and approval of the manuscript: JG, DS, MH, EDR, MJS, MU, FF.

Authors approved the final version of the manuscript and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All persons designated as authors qualify for authorship, and all those who qualify for authorship are listed.

All authors had final responsibility for the decision to submit for publication.

Data sharing

De-identified survey responses data will be made available upon request from the corresponding author.

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Table 1. Overview of key requirements for the design of a mechanical ventilator usable and sustainable in LMICs. Shades of blue: requirements identified by this survey; shades of green: requirements based on prior work,[10] expert opinion, and on the authors' baseline experience of known needs.

Parameter	Requirement
Electricity supply	AC: 100–240 V; 50/60 Hz; DC: 12–30 V; battery operation >2 hours * [+]
Compressed air	Air compressor *
Oxygen	Oxygen concentrator to deliver >10 L/min * or green labelled gas cylinder to support 2 hours of operation
Standards for electricity and gas supply	Match the national infrastructure (e. g. gas connectors, compatible gas pressures, electricity voltage and frequency, plugs and sockets *)
Operating temperature	15 – 35 °C
Operating humidity	20 – 70%
Patient monitoring [‡#]	Pulse oximetry, non-invasive blood pressure, electrocardiography, airway oxygen, pressure and flow, end-tidal carbon dioxide and suction.
Internet connectivity	Network access for remote device monitoring (location, usage, self-calibration[†] and self-testing reports), firmware updates
Consumables costs	<US$50 per patient per day
Support: technical and training	Local or in country as a priority; long-term contract for remote support; built-in self-calibration system; product life cycle
Manufacture, assembly and testing	In country as a priority, bench testing to meet regulatory standards; continuous operation over 14 days for critical care applications; built-in self-testing system [†]
Regulatory standards	CE marked or FDA approved (or similar)
Modes of ventilation	Pressure and/or volume control; spontaneous breathing support if ventilation is required for more than 1 day
Fraction of inspired oxygen	At least up to 80%
Respiratory rate	10 - 50 breaths per minute, increments of 1 or 2 [δ]
Positive End-Expiratory Pressure	5 to 20 cmH_2O, in 5 cmH_2O steps or less [δ]
Inspired-to-Expired ratio	1:1 to 1:3
Tidal volume	50[††] to 700 mL, in steps of 50 mL or less [δ]
Inspiratory pressure limits	15 to 40 cmH_2O, in 5 cmH_2O steps or less [δ]
Alarms	Gas or electricity supply failure, switched off, tidal volumes and pressures exceeded or not reached
Filtering and Humidification	Bacterial Viral Filter; Heat and Moisture Exchanger
Display and ventilation monitoring	Set and delivered inspiratory pressure, tidal volume, respiratory rate, PEEP, fraction of inspired oxygen, ventilation mode

* For electricity international standards see International Electrotechnical Commission guidelines: https://www.iec.ch/world-plugs; + 98% (135/137) LMICs have either 220 or 230 V, AC, and 84% (115/137) LMICs have frequency of 50 Hz; †† 30 mL for ventilation in neonates; δ tolerance error < 10%; ‡ listed in order from highest perceived importance from our survey (see supplementary figure 6 for details); # apart from suction, all these monitoring priorities match the recent recommended standards of monitoring during anaesthesia and recovery;[9] † calibration and testing systems need to consider environmental conversion factors (e. g. high altitude).

AC: Alternating current; DC: Direct current; CE: Conformitè Europëenne; FDA: United States Food and Drug Administration; PEEP: positive end-expiratory pressure.

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SUPPLEMENTARY DATA

SUPPLEMENTARY METHODS

The Survey and Participants

The survey was open from October 2020 to January 2021, available on Microsoft Forms in English, French and Spanish, and consisted of 63 questions. It was tested with internal and external peer review, both by experts and potential respondents to confirm content and face validity respectively, and by potential respondents, where it was found to take 10-15 minutes to complete.

The survey form is available at https://forms.office.com/Pages/ResponsePage.aspx?id=AKImixdsUkOPBZt34Saze_s_BToYM9BCt9x04h-Ys0tUNksySVJYT1RSN0dGVktRMlpCNUlDTEpOWC4u

The target respondents were healthcare professionals, specifically physicians and nurses with mechanical ventilation expertise, and who work or have worked in low and middle income country (LMIC) hospitals. The survey was advertised via LinkedIn and social media, and shared via email to anaesthesia and critical care national and international societies and healthcare institutions. These type of target respondents and societies were chosen because they were deemed to be most likely to offer an informed response based on direct experience, overall facilitating a more representative outcome. The list of LMICs for inclusion in the study was taken from the World Bank.

Data processing and analysis

Data were exported to Microsoft Excel 2016 (Microsoft, Seattle, WA), which was used for analyses. Responses from participants who completed the survey in less than 8 minutes, and/or completed less than 33 of the 63 questions, were deemed insufficiently complete and excluded from analysis, as were duplicate responses and those from countries other than LMICs.

SUPPLEMENTARY RESULTS

A total of 60 responses were received from 23 (28%) of the 81 LMICs reached out to. Two responses were identified as duplicates, 4 were insufficiently complete, and 4 from non-LMIC countries, and were excluded.

Of the three possible responses offered, and an option to respond with free text, a lack of funds and technical maintenance support combined was the most frequent reason for non-functioning or not used ventilators, where a lack of funding was cited in 74% (34/46) of responses; the distribution of these responses is presented in Supplementary Figure 3.

Supplementary Figure 7 shows the proposed sustainable costs of consumables per patient per day; 57% (21/37) of respondents reported that these costs should be contained to US$ < 50, while 32% (12/37) responded that these costs could be US$ > 100.

SUPPLEMENTARY DISCUSSION

This study provided an overview of mechanical ventilation capacity in 50 hospitals from 23 LMICs, investigating the infrastructure and resources available, and the perceived need and the sustainable costs for mechanical ventilation. All of this information could help inform the design of a novel context-specific and sustainable mechanical ventilator for LMICs.

Infrastructure, environment and equipment

Our work provides new information on mechanical ventilation capacity, expanding on the limited data available on intensive care units in LMICs.[1] The majority of respondents were specialised physicians, with several years of work in LMICs; they worked in relatively larger hospitals, where the survey identified at least some mechanical ventilation capacity and supporting infrastructure.

Combining evidence on limited mechanical ventilation availability from our survey and on human resources from the literature[2] highlights a vicious cycle between lack of sustainable equipment and clinical training for its use. Even when equipment is acquired with donations, it may not necessarily be usable and, when it is, its use may not be sustainable.[3] For example, a generous but not sufficiently well-planned donation resulted in 20 oxygen concentrators being donated with the wrong voltage and frequency, resulting in overheating and breakdown, highlighting the need for a technical context-specificity.[4] Examples that highlight the need for sustainability come from a report of limited local capacity to repair equipment (36%),aa[5] and from a continuous positive airway pressure trial, where the trial equipment was donated, but within 16 months had failed and was not repaired (e. g. 3 in 4 generators and portable pulse oximeters).[6] This limited sustainability is in line with the findings of our survey, which identified the presence of some functioning mechanical ventilators, but also several non-functioning or not used ventilators, with lack of funds or replacement components and lack of technical engineering maintenance support being the most common barriers (64%).

This lack of sustainable equipment, technical support and training forms the basis of a vicious cycle that could be broken if more affordable technology was available, potentially increasing mechanical ventilation capacity and access to surgery and critical care in LMICs.[7] While improved and more widely available training remains necessary,[5] access to technology is likely going to contribute to improve healthcare in LMICs. Internet connectivity was available to 75% of hospitals, with 25% having no or frequently disrupted availability. This finding is a substantial increase compared with a reported 4% in a cross-sectional survey in Sri Lanka in 2014, although only asymmetric digital subscriber line for internet connection was reported.[8] With increased internet connectivity, the cost of remote technical assistance and training can be reduced dramatically. Based on the published literature and on our survey, internet connectivity may enable a system to support sustainability via training, technical support, ventilator monitoring and recalls, all of which should be recorded.[6 9] This approach would facilitate initial training, remote technical support, identification of hardware or calibration faults, firmware updates, and data collection on location and usage of the ventilator (e. g. days per week, hours per day, settings).

However, for a longer-term solution, building local manufacture, assembly capacity and technical support will be required, also to break the dependency from HICs. In this longer-term perspective, internet connection will also facilitate the application of artificial intelligence to the management of mechanical ventilation therapy, where local experience and expertise could be complemented with guidance made available through algorithms based on approaches and outcomes measured on thousands of mechanically ventilated patients globally.[10]

Patient monitoring

Among monitoring techniques (Supplementary Figure 6), pulse oximetry is relatively economical. Its availability was limited in LMICs, but has become more widely available since being successfully introduced in LMICs with the Global Oximetry Project and the Lifebox Foundation.[11–13] Capnography is relatively more expensive and not as widely available in LMICs, but its introduction was recently demonstrated as feasible in Malawi, where it enabled early recognition of critical airway incidents,[14] contributing to saving lives and further highlighting the priority this monitoring technology should be given. Overall, the results on monitoring priorities from our survey largely overlap with the most recent recommendations for standards of monitoring during anaesthesia and recovery from the Association of Anaesthetists in the UK,[15] further supporting the validity of the survey.

Strengths and limitations

Our survey presents results from a broad geographical area reaching LMICs across Africa, Asia, Central and South America. To the best of our knowledge, this is the first study to specifically and systematically survey environment and infrastructure to provide information for a context-specific and sustainable mechanical ventilator design.

The response rate was only 28% of all LMICs that were reached out to, and the majority of respondents worked in larger hospitals. This respondents' self-selection intrinsically presents a degree of bias, where our results could over- or underestimate the information applicable to a wider scenario. Nevertheless, where the areas of investigation in this survey overlapped with published surveys with larger sample sizes,[5 8 16 17] the results were largely in agreement, supporting the validity in the approach to target experienced responders and of our results.

While our survey explored the nurse-to-patient ratio, more information is required on trained staff capacity. The availability of clinical staff trained to use mechanical ventilators is an important consideration in design, perhaps pointing to the need for design that is simple to understand and use.

Supporting the quality of the work presented here, the parameters and requirements identified by our survey are in line with the current United States Food and Drug Administration, Emergency Use Authorization guidelines for ventilators and ventilator accessories,[18] with the United Kingdom Medicines and Healthcare products Regulatory Agency guidelines for Rapidly Manufactured Ventilator Systems,[19] and with the recommendations from the Association of Anaesthetists of Great Britain & Ireland.[15]

Supplementary Table 1. Characteristics of respondents and associated LMIC institutions.

Variable [number of respondents]	Number of respondents (% of total)
Role [n=49]	
Physician	38 (78)
Nurse	8 (16)
Other *	3 (6)
Specialty [n=47]	
Anaesthesia	21 (45)
Emergency	11 (23)
ICU	10 (21)
Other ‡	5 (11)
LMIC work experience [n=50]	
0-2 years	6 (12)
3-5 years	8 (16)
6-8 years	9 (18)
9-11 years	8 (16)
12-20 years	12 (24)
> 20 years	7 (14)
Hospital type [n=49]	
Teaching	25 (51)
Public	12 (25)
Regional	6 (12)
District	4 (8)
Other	2 (4)
Hospital beds [n=49]	
Unsure	4 (8)
<50	4 (8)
51-100	5 (10)
101-200	7 (14)
201-300	7 (14)
301-400	4 (8)
>400	18 (37)
ICU beds [n=49]	
Unsure	5 (10)
<3	5 (10)
4-6	17 (35)
7-9	5 (10)
10-12	4 (8)
13-15	4 (8)
16-18	3 (6)
19-21	3 (6)
>21	3 (6)
Nurse-to-patient ratio [n=50]	
1:1 - 1:3	42 (84)
1:4 - 1:6	5 (10)
Other	3 (6)

Rounding to 2 sf means percentages may not sum to 100. * Clinical Officers and Emergency Medical Technicians; ‡ Basic Life Support, Obstetrics and Gynaecology, Palliative Care, ICU: Intensive care unit, LMIC: Low and middle income country

Supplementary Table 2. Characteristics of respondents by country

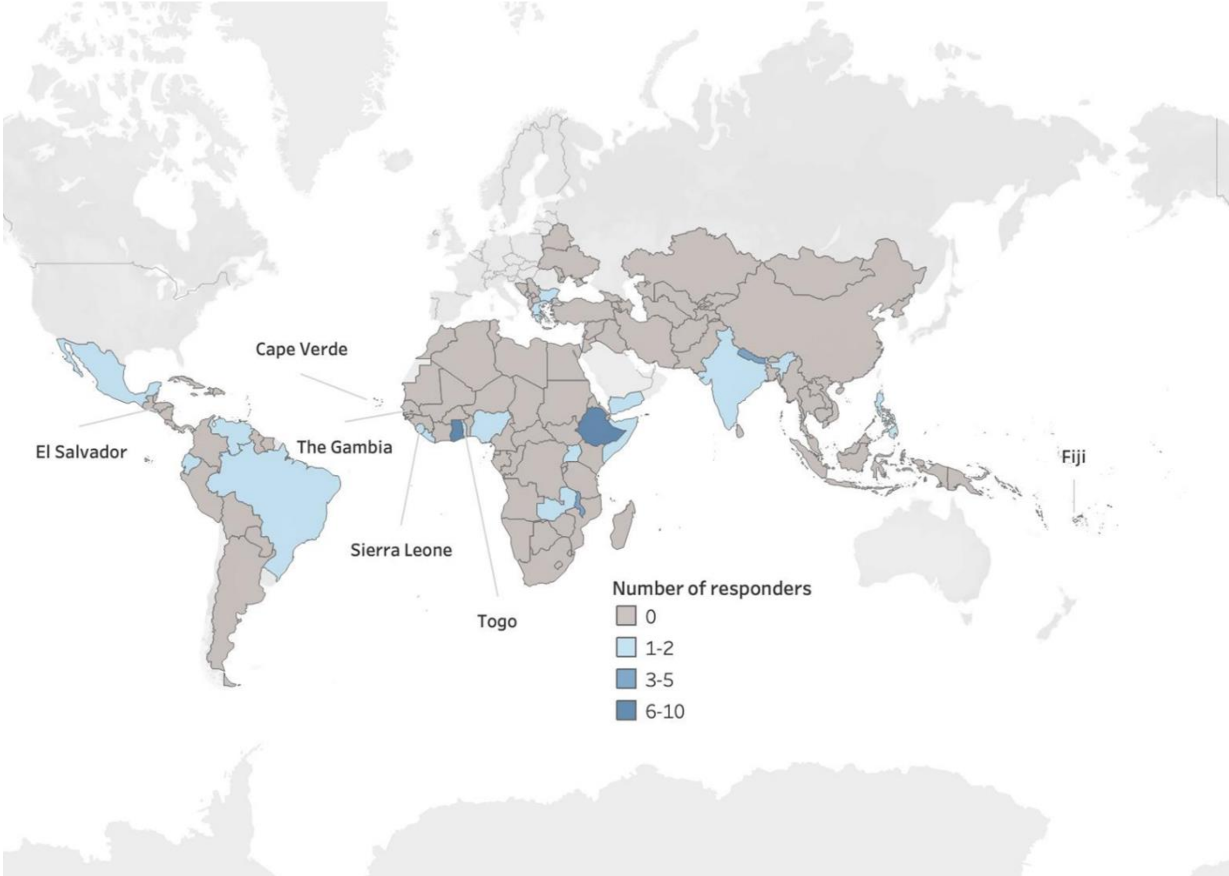
Country	Hospital type	Hospital beds	ICU beds	Respondent specialty	Respondent years of experience in LMIC
Brazil (1)	Private (1)	Unsure (1)	19-21 (1)	ICU (1)	12-20 (1)
Bulgaria (1)	UT (1)	201-300 (1)	16-18 (1)	ICU (1)	9-11 (1)
Cape Verde(1)	Public (1)	101-200 (1)	4-6 (1)	NA (1)	>20 (1)
Ecuador (1)	Public (1)	<50 (1)	<3 (1)	ICU (1)	3-5 (1)
El Salvador (1)	Public (1)	51-100 (1)	7-9 (1)	Nursing (1)	12-20 (1)
Ethiopia (7)	UT (6) Public (1)	>400 (3) 201-300 (1) 301-400 (3)	10-12 (2) 13-15 (1) 16-18 (1) 4-6 (2) 7-9 (1)	Anaest (6) Anaest,ICU (1)	>20 (1) 0-2 (4) 3-5 (1) 6-8 (1)
Fiji (1)	Public (1)	Unsure (1)	7-9 (1)	Anaest (1)	12-20 (1)
Gambia, The (1)	Public (1)	<50 (1)	7-9 (1)	ICU (1)	12-20 (1)
Ghana (10)	District (2) District; Public (1) Regional/Provincial(1) Tertiary (1) UT (2)	<50 (1) >400 (3) 101-200 (3) 201-300 (2) Unsure (1)	<3 (2) >21 (1) 10-12 (1) 13-15 (1) 19-21 (1) 4-6 (2) Unsure (2)	Basic Life Support (1) EM (6) Obstetrics (1) Palliative Care (1) Blank (1)	0-2 (1) 3-5 (2) 6-8 (4) 9-11 (1) 12-20 (2)
India (1)	Private (1)	<50 (1)	<3 (1)	OG (1)	9-11 (1)
Liberia (1)	UT (1)	Unsure (1)	Unsure (1)	Anaest (1)	3-5 (1)
Malawi (4)	Regional/Provincial(2) Tertiary Public Hospital (1) UT; Public (1)	>400 (1)	10-12 (1) 4-6 (2) 7-9 (1)	Anaest (2) ICU (2)	>20 (2) 12-20 (1) 6-8 (1)
Mexico (1)	Public (1)	201-300 (1)	4-6 (1)	EM (1)	0-2 (1)
Nepal (5)	Public (1) Regional/Provincial(1) United Mission (1) UT (2)	>400 (1) 101-200 (3) 51-100 (1)	>21 (2) 4-6 (2) Unsure (1)	Anaest (3) ICU (1) NA (1)	3-5 (1) 6-8 (2) 12-20 (1) >20 (1)
Nigeria (1)	UT; Public (1)	>400 (1)	4-6 (1)	Anaest (1)	12-20 (1)
Philippines (1)	Public (1)	>400 (1)	13-15 (1)	OG (1)	>20 (1)
Sierra Leone (1)	UT (1)	201-300 (1)	4-6 (1)	Infectious diseases (1)	3-5 (1)
Somalia (1)	UT; Private (1)	51-100 (1)	<3 (1)	Anaest (1)	6-8 (1)
Togo (1)	UT (1)	>400 (1)	13-15 (1)	Anaest (1)	9-11 (1)
Uganda (2)	District (1) UT; Public (1)	201-300 (1) 51-100 (1)	4-6 (1) Unsure (1)	Anaest (2)	3-5 (1) 9-11 (1)
Venezuela (2)	Regional/Provincial; public (2)	>400 (1) 301-400 (1)	4-6 (2)	ICU (2)	>20 (1) 9-11 (1)
Yemen (1)	District (1)	51-100 (1)	4-6 (1)	Anaest (1)	12-20 (1)
Zambia (2)	UT (1) UT; Public; National Referral Hospital (1)	>400 (2)	16-18 (1) 19-21 (1)	Anaest (2)	12-20 (2)

"Private" hospitals were not-for-profit and/or faith based; (n): number of respondents [most, but not all respondents had a specialty]; Anaest: Anaesthesia; EM: Emergency Medicine; ICU: Intensive Care Unit; OG: Obstetrics and Gynaecology; UT: University and Teaching hospital; NA: not applicable.

Supplementary Table 3. Power and gas availability details

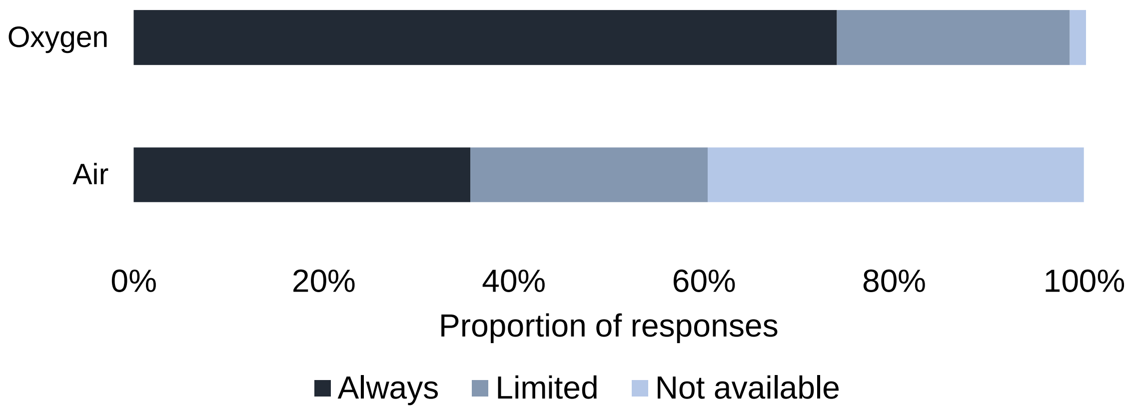
Variable [total respondents]	Number of respondents (% of total)
Power outage frequency [n=48]	
Unsure	4 (8)
Daily	9 (19)
Weekly	12 (25)
Monthly	5 (10)
Other	18 (38)
Power cut duration [n=44]	
Unsure	3 (7)
<1 hour	21 (48)
1-2 hours	10 (23)
3-8 hours	6 (14)
>8 hours	3 (7)
Back-up power supply time [n=44]	
Unsure	2 (5)
<30 min	34 (77)
30 – 60 min	6 (14)
No access	2 (5)
Back-up supply source [n=44]	
Fossil fuel	36 (82)
Fossil fuel and Battery	5 (11)
Other	3 (7)
Oxygen availability [n=49]	
Always	36 (73)
Limited	12 (24)
Not available	1 (2)
Compressed air availability [n=48]	
Always	17 (35)
Limited	12 (25)
Not available	19 (40)

Supplementary Figure 1. LMICs and associated number of responses included in the analysis



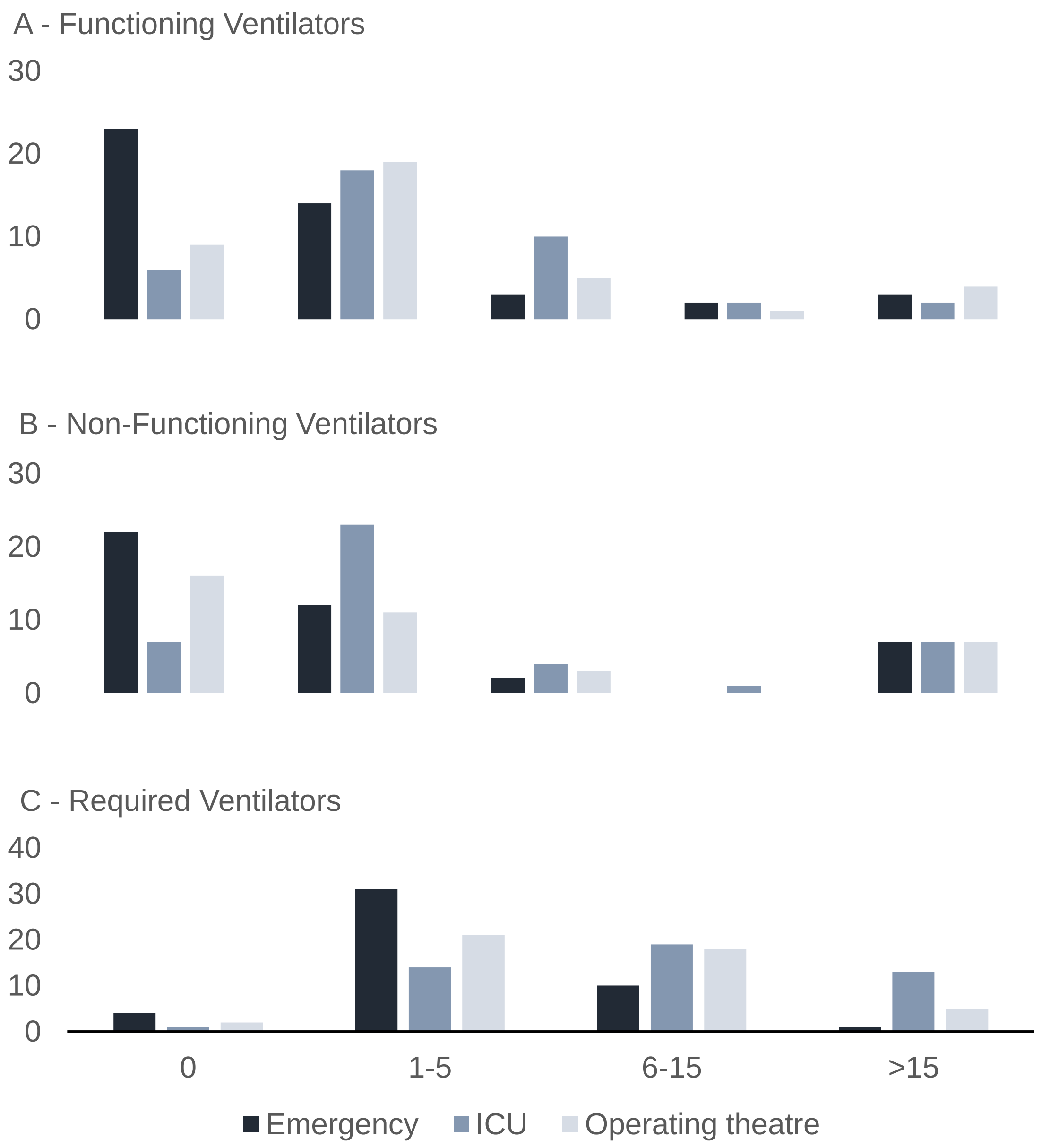
Dark grey and blue shadings visualise the number of responses per LMIC, and light grey indicates non-LMIC. Countries where responses were collected and where land area is smaller than 100,000 sq. km are annotated in the map for clarity.

Supplementary Figure 2. Availability of compressed air and oxygen for typical working patterns.



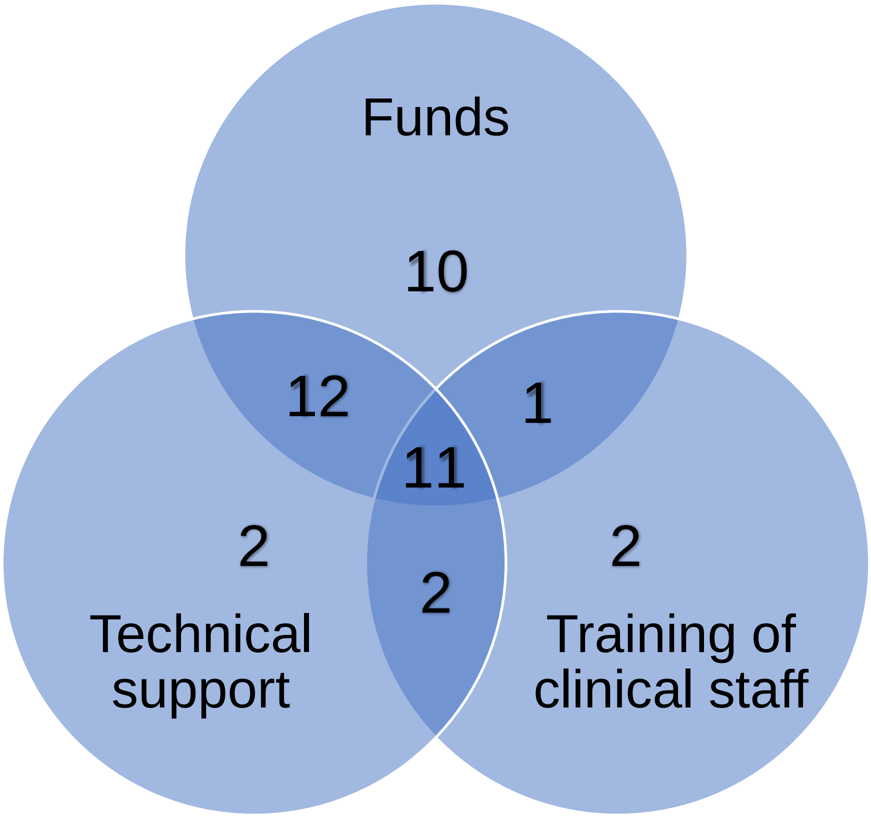
48 responses were received for compressed air and 49 for oxygen availability.

Supplementary Figure 3. Distribution of ventilators' available and requirement in LMIC emergency departments, ICU and operating theatres.

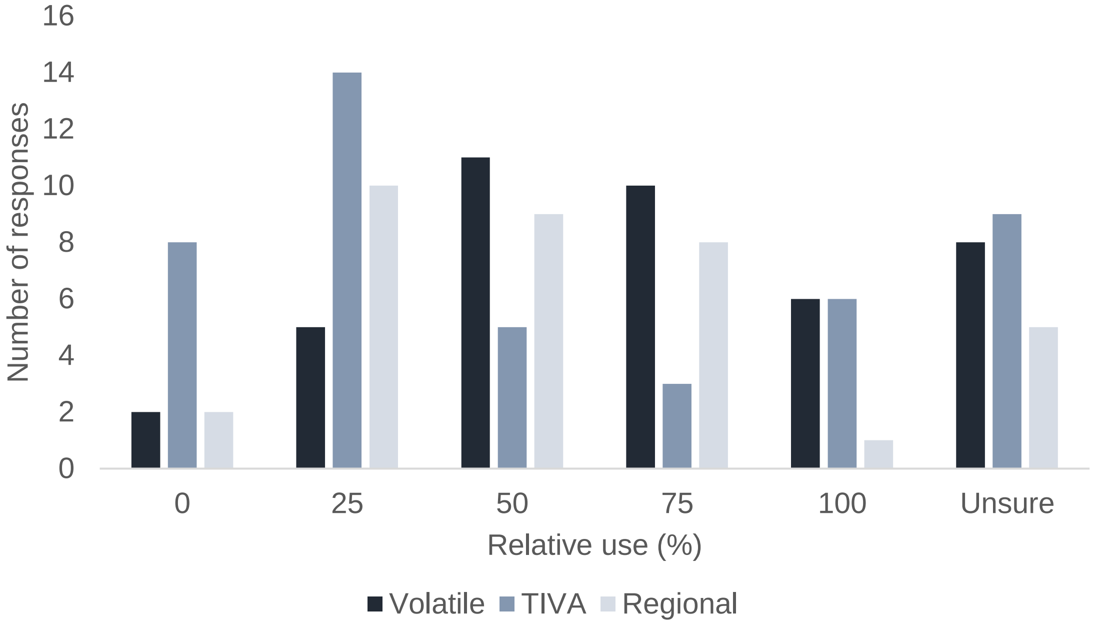


(A) number of functioning ventilators in each department (n = 45, 38, 38 respectively); (B) number of non-functioning ventilators in each department (n = 43, 42, 34) include those not used due to lack of trained clinical staff (Figure 4); (C) number of ventilators perceived as required from each department (n = 46, 47, 46). ICU: Intensive care unit.

Supplementary Figure 4. Number of responses for reasons for non-functioning or not used ventilators across LMICs hospitals surveyed here.

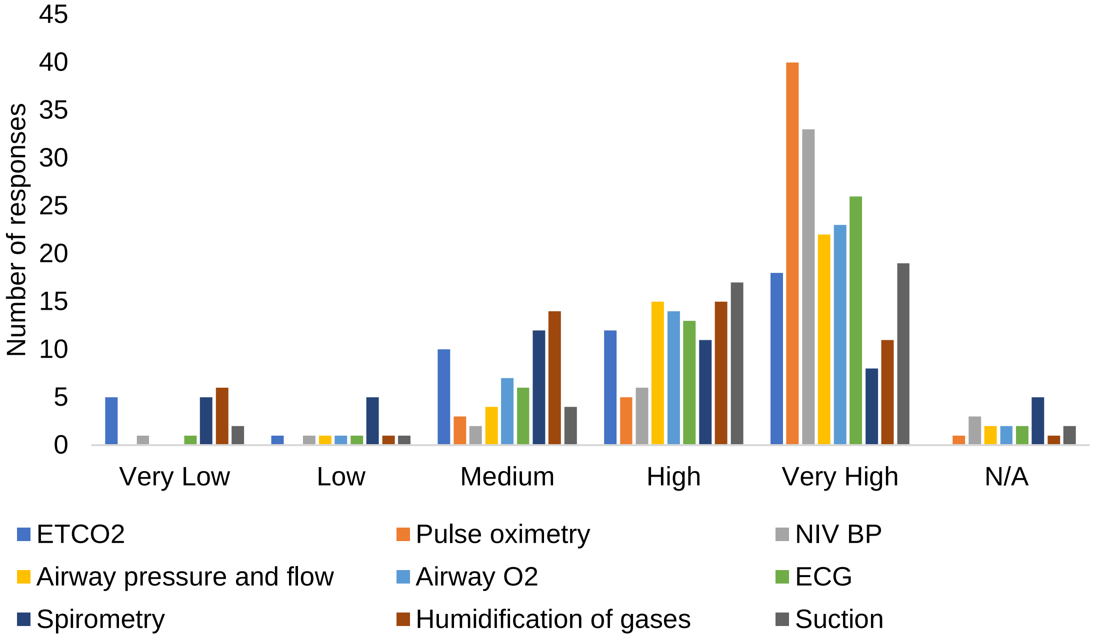


Supplementary Figure 5. Reported methods of anaesthesia.



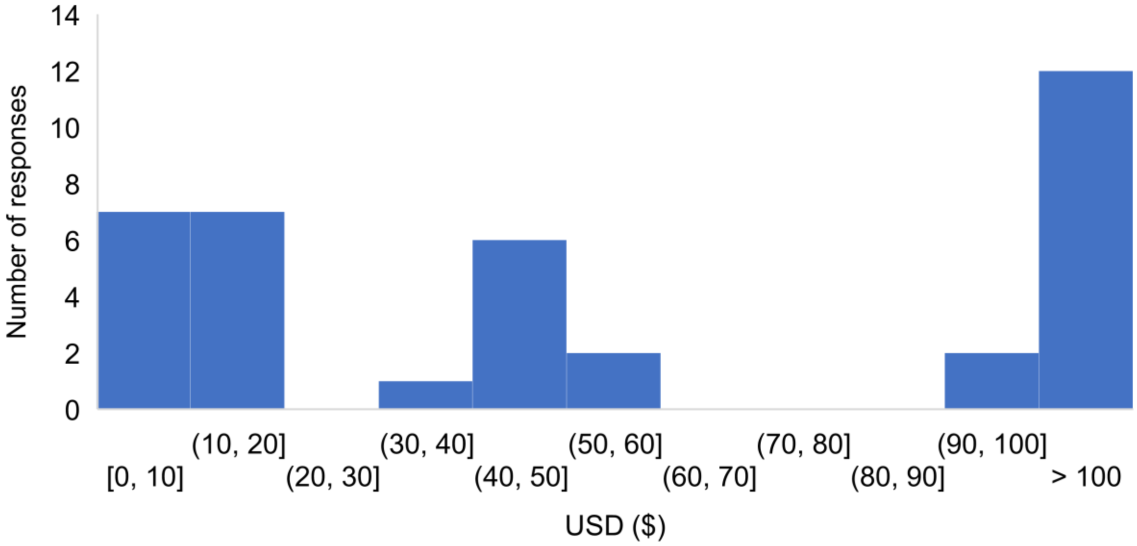
TIVA: Total intravenous anaesthesia.

Supplementary Figure 6. Perceived importance of monitoring techniques.



E_TCO_2: End-tidal CO_2, NIV BP: non-invasive blood pressure.

Supplementary Figure 7. Reasonably sustainable cost of consumables per patient per day in US dollars.



USD: US Dollars

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