

Measuring Oxygen Access: lessons from health facility assessments in Nigeria.

Authors: Hamish R Graham*^{1,2}, Omotayo E Olojede², Ayobami A Bakare^{3,4}, Agnese Iuliano⁵, Oyaniyi Olatunde², Adamu Isah⁶, Adams Osebi⁶, Tahlil Ahmed⁷, Rochelle Ann Burgess⁵, Eric D McCollum⁸, Tim Colbourn⁵, Carina King^{4,5}, Obioma C Uchendu^{2,9}, Adegoke G Falade^{2,10} on behalf of the INSPIRING Project Consortium**

Supplemental material

Supplemental table 1: Healthcare worker knowledge and experience with oxygen, pulse oximetry and related clinical practices

Supplemental table 2: Results from testing of pulse oximeter in 58 health facilities in Ikorodu local government area, Lagos state, Nigeria

Supplemental table 3: Results from testing of oxygen concentrators in 58 health facilities in Ikorodu local government area, Lagos state, Nigeria

Supplemental table 4: Results from testing of oxygen cylinders in 58 health facilities in Ikorodu local government area, Lagos state, Nigeria

Supplemental table 5: Triangulation of pulse oximetry and oxygen access to ward areas in 58 health facilities in Ikorodu local government area, Lagos state, Nigeria

Supplemental table 1: Healthcare worker knowledge and experience with oxygen, pulse oximetry and related clinical practices

General characteristics	Secondary health facility	Government PHC	Private PHC	Overall
Facilities	N=1 ¹	N=28	N=27	N=56
Participants	9	96	64	169
Sex, F:M (% female)	8:1 (89%)	91:5 (95%)	50:14 (78%)	149:20 (88%)
Role				
- doctor	2 (22%)	5 (5%)	16 (25%)	23 (14%)
- nurse/midwife	2 (22%)	49 (51%)	37 (58%)	88 (52%)
- other	5 (56%)	42 (44%)	11 (17%)	58 (34%)
Median years of work				
- at any health facility	7 (3-15)	15 (6-29)	8 (4-15)	12 (5-25)
- at this facility	1 (1-3)	1 (1-2)	1 (1-8)	2 (1-3)
Training				
- IMCI	2 (22%)	62 (65%)	21 (33%)	85 (50%)
- ICCM	0 (0%)	4 (4%)	7 (11%)	11 (7%)
- ETAT	1 (11%)	5 (5%)	13 (20%)	19 (11%)
- Oxygen	1 (11%)	9 (9%)	30 (47%)	40 (24%)
- Pulse oximetry	0 (0%)	4 (4%)	27 (42%)	31 (18%)
- CPAP	1 (11%)	5 (5%)	15 (23%)	21 (12%)
- Resuscitation	4 (44%)	27 (28%)	35 (55%)	66 (39%)
- Infection control	4 (44%)	41 (43%)	40 (63%)	85 (50%)
- Baby friendly initiative	5 (56%)	35 (36%)	31 (48%)	71 (42%)
Child pneumonia care				
Ever provided				
- antibiotic for pneumonia	7 (78%)	70 (73%)	56 (88%)	133 (79%)
- IV antibiotic	6 (67%)	39 (41%)	57 (89%)	102 (60%)
- oxygen therapy	7 (78%)	32 (33%)	58 (91%)	97 (57%)
- resuscitate child	7 (78%)	67 (70%)	59 (92%)	130 (79%)
Past 2 weeks provided				
- antibiotic for pneumonia	5 (56%)	35 (36%)	16 (25%)	56 (33%)
- IV antibiotic	4 (44%)	8 (8%)	11 (17%)	23 (14%)
- oxygen therapy	3 (33%)	2 (2%)	9 (14%)	13 (8%)
- resuscitate child	3 (33%)	10 (10%)	15 (23%)	28 (17%)
Oxygen knowledge				
Mean score (95% CI)				
- Total score (max. 40)	17.8 (12.1-23.5)	6.7 (5.2-8.3)	14.9 (13.3-16.4)	10.4 (9.1-11.6)
- Yes/No (max. 20)	10.0 (6.7-13.3)	4.4 (3.4-5.3)	10.9 (9.9-11.9)	7.1 (6.3-8.0)
- Scenarios ² (max. 20)	7.8 (4.4-11.2)	2.3 (1.6-3.1)	4.0 (3.1-4.9)	3.3 (2.6-3.9)
Sample questions	3 (33%)	7 (7%)	27 (42%)	37 (22%)
- Correctly identify that pulse oximeters provide heart rate, SpO ₂ and not blood pressure or respiratory rate ³				
- Correctly identify that a 2-year-old child with fast breathing and SpO ₂ of 87% should be started on oxygen	6 (67%)	18 (19%)	24 (38%)	48 (28%)
- Correctly identify that a small newborn baby with SpO ₂ 99% on oxygen should have the oxygen flowrate reduced	3 (33%)	11 (11%)	18 (28%)	32 (19%)

Notes: CI = confidence interval; CPAP – continuous positive airway pressure; ETAT – emergency triage, assessment, and treatment; ICCM – integrated community case management; IMCI = integrated management of childhood illness; IQR = inter-quartile range, 25th to 75th centiles; SpO₂ – peripheral oxygen saturation. (1) Two secondary health facilities did not do the knowledge test; (2) 5-option best answer scenario with pulse oximetry result displayed; (3) Composite from 4 individual true/false questions.

Supplemental table 2: Results from testing of pulse oximeter in 58 health facilities in Ikorodu local government area, Lagos state, Nigeria

Facility	Device	Type	Location	Usage (times in prior day)	Oximeter Function			
					Turns on	Fluke test 1 (SpO ₂ 95%)	Fluke test 2 (SpO ₂ 85%)	Fit for use
Secondary health facilities								
SHF 1	BCI*	Handheld	Ward (child)	10	Y	-	-	N ³
SHF 2	BCI*	Handheld	Ward (child)	0	N	-	-	N
	Oxi-Go	Finger tip	Ward (child)	~100	Y	96	90	N
	Mindray*	Handheld	Ward (child)	0	Y	-	-	N ³
SHF 3	"Medi Industries"	Finger tip	Ward (child)	2	Y	96	86	Y
	"Pediatric"	Finger tip	Ward (child)	0	Y	93	NR	N
Private primary care facilities								
PRV 1	unknown	Finger tip	Clinic	0	N	-	-	N
	unknown*	Finger tip	Clinic	0	N	-	-	N
	Contec	Desktop	Theatre	0	N ¹	-	-	N ¹
PRV 4	Edan*	Handheld	Clinic	30	Y ²	NR	NR	?
	Edan*	Desktop	Theatre	5	Y	96	87	Y
PRV 6	Drive	Finger tip	Clinic	50	Y ²	NR	NR	?
	Contec*	Finger tip	Emergency	0	Y ²	NR	NR	?
PRV 7	Edan*	Desktop	Theatre	0	Y	96	88	Y
PRV 8	unknown	Finger tip	Ward (general)	20	Y ²	NR	NR	?
PRV 9	unknown	Finger tip	Clinic	0	Y	96	NR	N
PRV 10	Schiller*	Handheld	Other	0	Y	96	86	Y
PRV 14	Ana Wiz*	Finger tip	Clinic	0	Y ²	NR	NR	?
PRV 16	EcoMed	Finger tip	Clinic	0	Y	96	85	Y
PRV 18	Blue Jay	Finger tip	Clinic	0	Y	95	85	Y
PRV 19	FaceLake	Finger tip	Clinic	4	Y	-	-	N ³
	FaceLake	Finger tip	Clinic	0	N	-	-	N
PRV 22	Promise Technology*	Finger tip	Clinic	5	Y	96	NR	N
PRV 24	"Fabrication Enterprises"*	Finger tip	Ward (general)	3	Y	95	85	Y
PRV 25	"Medline"	Finger tip	Delivery	0	Y	97	92	N
PRV 27	Datascope*	Desktop	Theatre	0	Y	96	84	Y
	"iHealth"*	Finger tip	Clinic	0	Y	96	87	Y
TOTAL					22/27 (81%)	14/27 (52%)	9/27 (33%)	9/27 (33%)

Notes: Fluke test 1 simulate normal person, set to 95% with good perfusion. Fluke test 2 simulate sick person, set to 85% with reduced perfusion. Considered "pass" if within +/-3%. (1) unable to test due to power outage; (2) unable to test with Fluke device; (3) missing probe or other defect preventing use. NR = no result.

Supplemental table 3: Results from testing of oxygen concentrators in 58 health facilities in Ikorodu local government area, Lagos state, Nigeria

Facility	Device type	Location	Concentrator Function ¹						
			Turns on	Gas flow	Air	22-49%	50-84%	≥85%	Fit for use
Secondary health facilities									
SHF 1	"LuFaith Y007-3"*	Ward (child)	Y	Y		○			N
SHF 2	DeVilbiss*	Ward (child)	N	N					N
SHF 3	unknown	Ward (child)	Y	Y		○			N
Private primary care facilities									
PRV 1	Longfe+B2+E6:M41	Theatre	N ²	-					N ²
PRV 2	Weinmann	Theatre	Y	N					N
PRV 4	Longfei*	Theatre	Y	Y	○				N
PRV 4	Draeger*	Emergency	Y	N					N
PRV 4	Longfei*	Delivery	Y	Y	○				N
PRV 6	unknown "7F-3"	Emergency	Y	Y			○		N
PRV 7	unknown	Theatre	Y	Y	○				N
PRV 8	"Leap Medical 7F-3"	Ward (general)	Y	Y ⁴					? ⁴
PRV 10	"Elgil LFY-I-3A-W"*	Delivery	Y	Y	○				N
PRV 10	"Globe Health 7F-3"	Ward (general)	Y	Y				○	Y
PRV 12	Philips*	Delivery	N ²	-					N ²
PRV 13	Invacare	Emergency	Y	Y				○	Y
PRV 13	Longfei*	Theatre	N	N					N
PRV 14	Microfield*	Ward (general)	N ²	-					N ²
PRV 14	Microfield*	Ward (general)	N ³	N					N
PRV 15	Zhengzhou Olive*	Theatre	Y	Y				○	Y
PRV 17	"Shulte-Deme"*	Store	Y ²	-					N ²
PRV 18	DeVilbiss*	Theatre	Y ²	-					N ²
PRV 19	Microfield*	Theatre	Y ²	-					N ²
PRV 20	"Globe Health"*	Clinic	Y	Y	○				N
PRV 21	Puritan Bennett	Theatre	N	N					N
PRV 22	Philips*	Theatre	N ²	-					N ²
PRV 20	DeVilbiss*	Theatre	N ²	-					N ²
PRV 23	Jiangsu Folee*	Theatre	Y	Y	○				N
PRV 23	Jiangsu Folee*	Theatre	Y	Y	○				N
PRV 24	unknown*	Theatre	N	N					N
PRV 26	Airsep*	Theatre	N	N					N
PRV 27	Invacare	Theatre	Y	Y	○				N
Government primary health care facilities									
PHC 1	"Axiom"	Delivery	Y	N					N
PHC 3	"MA-Donax"*	Delivery	N ²	-					N ²
PHC 11	Microfield*	Delivery	N	N					N
PHC 14	unknown	Delivery	Y	N					N
PHC 14	unknown	Delivery	Y	Y	○				N
PHC 16	unknown	Store	Y	N					N
PHC 16	unknown	Store	Y	Y				○	Y
PHC 21	Microfield*	Delivery	Y	N					N
PHC 21	unknown	Emergency	Y	N					N
PHC 23	"Axiom"	Delivery	Y	Y				○	Y
PHC 27	"VINS"*	Delivery	N ²	-					N ²
TOTAL		N=42	28 (67%)	17 (40%)	9 (21%)	2 (5%)	1 (2%)	5 (12%)	5 (12%)

Notes: LPM = litres per minute. (1) tested at 5LPM or specified maximum; (2) unable to fully tested due to power outage; (3) missing electrical cable and/or other essential parts; (4) unable to be tested as it was being used for a critically ill patient at the time of survey; (*) had visible Conformaté Européenne CE marking indicating compliance with the Declaration of Conformity to ISO 8359.

Supplemental table 4: Results from testing of oxygen cylinders in 58 health facilities in Ikorodu local government area, Lagos state, Nigeria

Facility	Device type	Location	Number	Fit for use ¹
Secondary health facilities				
SHF 1	Cylinder + manifold	Various ²	12	12
SHF 2	Cylinder	Various ³	? ³	? ³
SHF 3	Cylinder	Ward (paediatric)	2	2
Private primary care facilities				
PRV 2	Cylinder	Delivery	3	0
	Cylinder	Emergency	1	1
PRV 3	Cylinder	Theatre	1	1
PRV 4	Cylinder	Triage	1	1
PRV 5	Cylinder	Theatre	1	1
PRV 6	Cylinder	Emergency	5	2
PRV 7	Cylinder	Theatre	6	1
PRV 9	Cylinder	Ward (adult)	1	0
	Cylinder	Theatre	2	1
PRV 10	Cylinder	Theatre	3	2
	Cylinder	Clinic	1	1
PRV 11	Cylinder	Store	7	0
	Cylinder	Emergency	1	1
PRV 12	Cylinder + splitter	Delivery	1	1
PRV 13	Cylinder	Emergency	1	1
	Cylinder	Theatre	1	1
PRV 16	Cylinder	Theatre	1	1
PRV 17	Cylinder	Theatre	1	1
PRV 18	Cylinder	Store	1	0
PRV 19	Cylinder	Emergency	1	1
PRV 20	Cylinder	Theatre	1	1
PRV 21	Cylinder	Clinic	1	1
PRV 22	Cylinder + manifold	Theatre	1	1
PRV 24	Cylinder	Clinic	2	1
PRV 25	Cylinder	Store	2	1
PRV 26	Cylinder	Theatre	3	3
PRV 27	Cylinder	Delivery	1	1
Government primary health care facilities				
PHC 1	Cylinder	Delivery	1	1
	Cylinder	Delivery	1	1
PHC 2	Cylinder	Store	1	0
PHC 3	Cylinder	Store	2	1
PHC 11	Cylinder	Delivery	2	1
PHC 14	Cylinder	Clinic	1	0
	Cylinder	Delivery	2	2
PHC 15	Cylinder	Delivery	1	1
	Cylinder	Store	1	1
PHC 16	Cylinder	Delivery	1	1
	Cylinder	Clinic	1	0
PHC 20	Cylinder	Delivery	1	1
PHC 23	Cylinder + splitter	Delivery	1	1
PHC 26	Cylinder	Delivery	1	1
TOTAL	-	-	82 (100%)	53 (65%)

Notes: (1) fit for use defined as the number of cylinders with a regulator apparatus or functional outlets from manifold system. (2) Cylinders supplied outlets in 6 wards: Emergency ward, Operating Theatre, Maternity suite, General ward (M and F), and Paediatric ward. (3) Unable to complete cylinder survey at facility – cylinders were available and being used in multiple ward areas and in store, but missing exact location, quantity, and functional assessment.

Supplemental table 5: Triangulation of pulse oximetry and oxygen access to ward areas in 58 health facilities in Ikorodu local government area, Lagos state, Nigeria

Facility	Oxygen supply ¹								Use ²
	OPD	MAT	ED	GEN	OT	PED	ICU	Store	Oximeter
Secondary health facilities									
SHF 1		>2 outlets	>2 outlets	>2 outlets	>2 outlets	>2 outlets 0 concent	>2 outlets	12-bank manifold	0 paed*
SHF 2	cylinder ³	cylinder ³	cylinder ³	cylinder ³	cylinder ³	cylinders ³ 0 concent	cylinder ³	25 cylinder	0 paed
SHF 3						2 cylinder, 0 concent			1 paed
Private primary care facilities									
PRV 1					0 concent*				0 clinic, 0 OT
PRV 2		0 cylinder no gauges	1 cylinder		0 concent				
PRV 3					1 cylinder				
PRV 4		0 concent	1 cylinder, 0 concent		0 concent				1 theatre, 0 clinic*
PRV 5					1 cylinder				
PRV 6			2 cylinders, 0 concent						0 clinic*, 0 ED*
PRV 7					1 cylinder, 0 concent				1 OT
PRV 8				1* concent					0 ward*
PRV 9				0 cylinder no reg	1 cylinder				0 clinic*
PRV 10	1 cylinder	0 concent		1 concent	2 cylinder				1 everwhere
PRV 11			1 cylinder (more in store)						
PRV 12		1 cylinder + splitter, 0 concent*							
PRV 13			1 cylinder, 1 concent		1 cylinder, 0 concent				
PRV 14				0 concent					0 clinic*
PRV 15					1 concent				
PRV 16					1 cylinder				1 clinic
PRV 17					1 cylinder			0 concent*	
PRV 18					0 concent*			0 cylinder no reg	1 clinic
PRV 19			1 cylinder		0 concent*				0 clinic
PRV 20	0 concent				1 cylinder				
PRV 21	1 cylinder				0 concent*				
PRV 22					1 or more cylinder manifold, 0 concent*				0 clinic
PRV 23					0 concent				
PRV 24	1 cylinder				0 concent				1 gen
PRV 25							1 cylinder		0 matern
PRV 26					3 cylinder, 0 concent				
PRV 27		1 cylinder			0 concent				1 OT, 1 clinic
Government primary health care facilities									

PHC 1		2 cylinder, 0 concent*							
PHC 2								0 cylinder no regulator	
PHC 3		0 concent*						1 cylinder	
PHC 4									
PHC 5									
PHC 6									
PHC 7									
PHC 8									
PHC 9									
PHC 10									
PHC 11		1 cylinder, 0 concent							
PHC 12									
PHC 13									
PHC 14		2 cylinder, 0 concent							
PHC 15		1 cylinder						1 cylinder	
PHC 16	0 cylinder no reg	1 cylinder						1 concent	
PHC 17									
PHC 18									
PHC 19									
PHC 20		1 cylinder							
PHC 21		0 concent	0 concent						
PHC 22									
PHC 23		1 cylinder + splitter, 1 concent							
PHC 24									
PHC 25									
PHC 26		1 cylinder							
PHC 27		0 concent*							
PHC 28									

Notes: * Concentrator unable to be tested due to power failure or in use (PRV 8), or pulse oximeter appeared incompatible with Fluke testing device. (1) Adequate oxygen supply for minimum expected use. Numerical values indicate functional oxygen sources located in each ward area ('0' means none of the sources present were functional), while blank cells indicate no oxygen sources in that ward area. Oxygen supply assumptions: secondary health facilities provide inpatient and outpatient services and must be able to simultaneously provide oxygen to 2 patients in each inpatient ward area with backup supply available; private facilities provide outpatient and inpatient services +/- surgical services, and must be able to provide oxygen to one patient in each inpatient ward area with backup supply available; government primary health care facilities provide outpatient and maternity services and must be able to provide oxygen to one patient with backup supply available.; (2) Ability to triage and monitor patients on oxygen with oximetry for minimum expected demand. Numerical values indicate functional oximeters located in each ward area ('0' means none of the oximeters present were functional), while blank cells indicate no oximeter in that ward area. Oxygen use assumptions: pulse oximetry must be available in every ward area that sees acutely unwell patients. (3) Unable to complete cylinder survey at facility – cylinders were available and being used in multiple ward areas and in store, but missing exact location, quantity, and functional assessment. OPD = outpatient department / clinic; MAT = maternity / birth suite; ED = emergency department; OT = operating theatre; PED = children's / neonatal ward; GEN = general / adult wards; ICU = intensive care unit. **Red** = not available. **Orange** = available but inadequate to meet needs. **Green** = adequate for minimum expected service need. * Device not able to be fully tested (e.g. due to power outage).