Importance of the Department of Biomedical Engineering in the Conversion of a High Specialty Hospital to a COVID-Hospital

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Abstract. The National Institute of Respiratory Diseases (INER, its Acronym in Spanish) is a Mexican tertiary-care-hospital specialized in respiratory diseases. On February 27, 2020, the first case of COVID-19 in Mexico was confirmed at the INER. As of this date, the Institute began its conversion process to a COVID hospital. The challenge was to achieve the maximum capacity of 250 beds for the care of critical patients and turn the Institute into a 100% COVID hospital, becoming the largest Intensive Care Unit in the country. The participation of the Department of Biomedical Engineering (DBE) in this process was crucial; since it re-engineered a set of processes related to the planning, installation, training, use and management, maintenance and performance of medical technology. The DBE defined the technological and logistical changes to increase the capacity for intensive care in each of the clinical areas. It evaluated aspects related to infrastructure, supply of medicinal gases and medical equipment; particularly ventilators, which were the most demanded equipment for the care of COVID patients. This paper presents the process of converting the INER to a COVID-Hospital accompanied by the functions performed by the Biomedical Engineering Department in said process.

Keywords: Biomedical Engineering Department · COVID-Hospital · National Institute of Respiratory Diseases

1 Introduction

The National Institute of Respiratory Diseases (INER, its Acronym in Spanish) is a tertiary-care-hospital specialized in respiratory diseases. Its primary objectives are scientific research, the formation and training of qualified human resources as well as the provision of highly specialized medical care services in respiratory system diseases throughout the Mexican territory. The INER is the main institution in Mexico that treats respiratory diseases such as tuberculosis, Chronic Obstructive Pulmonary Disease (COPD), lung cancer, asthma, interstitial diseases and other diseases of the upper airway through specialists in Otorhinolaryngology [1].

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On January 7, 2020, Chinese health authorities reported that a new coronavirus (SARS-CoV2) had been identified as a possible origin of the COVID-19 disease. On February 27, 2020, the first case of COVID-19 in Mexico was confirmed and it was treated at the INER [2]. As of this date, the Mexican Government mandated the Institute begin its hospital reconversion process, following the guidelines for the implementation of temporary COVID-19 care centers and mobile hospitals, whose objective is to establish the technical foundations necessary for the care of patients with COVID. To contribute in a comprehensive and timely response to the provision of health services for the population infected by SARS-COV-2 with criteria based on the quality and safety of patient care, with respect to the rights human beings and with a focus on the preservation of life, the well-being of people and mental health [3, 4].

It is through this undertaking that the Department of Biomedical Engineering (DBE) participated in the reengineering of processes related to planning, installation, training, use and management, maintenance and optimal functionality of medical technology. This paper presents the activities subscribed for converting the INER to a COVID-Hospital and the functions performed by the DBE in this process.

2 Background (Before COVID-19)

On April 24, 2020, the Government of Mexico City decreed the INER to become a COVID-Hospital. The challenges were to achieve the conversion of beds with all the infrastructure and equipment for the care of COVID patients, reach the maximum capacity of 250 beds for the care of patients in critical condition due to SARS-CoV2, refer patients with other pneumological and otorhinolaryngology diseases (non-covid patients) to other hospitals and, convert the Institute into a 100% COVID-Hospital. It would become the largest Intensive Care Unit in the country.

2.1 Department of Biomedical Engineering

In order to increase the physical and technical capacity of intensive care, the Biomedical Engineering Department (DBE) defined the medical technology, healthcare facilities and logistical changes in each of the clinical areas of the Institute. The DBE considered the following aspects: infrastructure, supply of medicinal gases, and medical equipment, in particular those related to ventilatory support; monitoring, and diagnostic imaging, since these were the highest demanded equipment in relation to the care of COVID patients [5]. The DBE is a member of the Infection Prevention and Control Committee as well as the Biosafety Committee, which is why it was also involved in cleaning and disinfection protocols, both for medical technology and for the physical spaces of the Institute's clinical areas.

2.2 Infrastructure

The Institute has a horizontal architecture distributed in six independent buildings corresponding to different clinical services, which facilitated the conversion and adaptation of the hospital's infrastructure. The fourteen clinical areas and the total distribution of the 250 beds is shown in Table 1.

Table 1. Clinical areas and distribution of the 250 beds.

Clinical Area	Beds
Clinical Service 1. Interstitial diseases (CS1)	28
Clinical Service 2. Tuberculosis (CS2)	28
Clinical Service 3. Oncology (CS3)	30
Clinical Service 4. Pneumology (CS4)	27
Clinical Service 5. COPD (CS5)	29
Clinical Service 6. Pharmacological Research (CS6)	10
Surgery Unit (UQX)	4
Recovery of Surgery (REC)	20
Intensive Care Unit (ICU)	15
Otolaryngology (ORL)	12
Pneumopediatrics (UNP)	29
Emergency Room (ER)	18
Total	**250**

2.3 Medicinal Gases

The Institute had 250 hospital beds with medical gas intakes distributed in clinical areas as shown in Table 2. Note that, despite having the capacity to supply medical gases, a ventilator was not available in all cases. For example, in Clinical Service 1. Interstitial Diseases, there are 28 beds with intakes, but only eight have an associated ventilator; while critical areas (Intensive Care Unit (ICU), Surgery Unit (UQX) and Emergency Room (ER)) have a ventilator for each oxygen intake.

2.4 Mechanical Ventilators

At the end of 2019 the Institute had 66 ventilators and 113 vital sign monitors available. Of the total, six ventilators (9%) were over 15 years old; 46 ventilators (70%) were between 15 and 10 years of age; nine ventilators (14%) had an antiquity between 10 and 5 years; and five ventilators (7%) less than five years (Table 3). The largest number of ventilators acquired coincides with the declaration of the H1N1/09 virus pandemic in Mexico in 2009. Regarding the vital signs monitors, there were 113 devices of which 22 (20%) presented functional problems due to deterioration as a result of their intensive use.

3 Reconversion Covid Hospital (Results)

3.1 Department of Biomedical Engineering

The reconversion to a COVID-Hospital required a vast quantity of human, material and financial resources. The Institute hired more medical and paramedical personnel. To meet the permanent high demand for medical services, work shifts were increased in the

Table 2. Medicinal intakes and oxygen consumption per ventilator in the clinical areas of INER, prior to conversion.

				O_2 consumption (L/min)	
Clinical service	Gas intake	Intake+V	%Beds+V	For V	Total for intake+V
CS1	28	8	29	60	480
CS2	28	8	29	60	480
CS3	30	10	33	60	600
CS4	27	15	56	60	900
CS5	29	10	34	60	600
CS6	10	10	100	60	600
UQX	4	6	100	60	360
REC	20	10	50	60	600
ICU	15	15	100	60	900
ORL	12	4	33	60	240
UNP	29	13	45	60	780
ER	18	18	100	60	1080
Total	**250**	**127**	**50.8**		**7,620**

clinical areas, respiratory therapy, radiology and biomedical engineering. The hospital staff increased 60% and in the specific case of the Department of Biomedical Engineering (DBE), the staff increased by 300%. Since prior to the conversion there were only six biomedical engineers and, 18 additional ones were hired to cover all hospital operating shifts (Table 4). This growth derived from the great demand of technical support required for the optimal functionality of medical technology, since all the hospital beds were converted to intensive care beds. The DBE collaborated with the medical area in order to identify the medical equipment needed for the care of COVID patients in critical condition. The technological capacity increased globally by 119%. Equipment such as: infusion pumps, beds, stretchers, electrocardiographs, X-ray equipment, immunology analyzers, blood gas analyzers, bariatric lifts, hemodialysis machines, vital signs monitors, deep freezers, refrigerators, ultrasounds, video laryngoscopes and ventilators where acquired.

Each of the hospital beds was equipped with monitoring, ventilation, electrocardiography and drug infusion devices. The increase in the amount of medical equipment for the care of critical patients due to SARS-CoV2 is shown in Table 5. In some types of medical equipment, such as ventilators, monitors and beds, it was possible to have a surplus that provided a technological reserve for the hospital.

Due to the increase in the technological capacity, the personnel and the medical services of the Institute, the DBE also increased and modified the technical service routines. In order to promptly detect operating problems in both, the critical equipment and in the medical gas supply. Continuous tours were implemented during all work shifts.

Table 3. Number of mechanical ventilators and monitors available at INER in 2019

Purchase year	Number of ventilators	Number of monitors	Antiquity
1998	1		22
1999		1	21
2001	1		19
2002	1		18
2003	1	2	17
2005	2	3	15
2006	3	2	14
2007	6	9	13
2008	1	4	12
2009	35	14	11
2010	1	8	10
2011	3	6	9
2012	1	4	8
2013	5	21	7
2014		31	6
2015	2		5
2016	3	2	4
2018		6	2
Total	66	113	

Table 4. Distribution of Biomedical Engineering staff in shifts

Shift	**M**	**E**	**N_A**	**N_B**	**D_W**	**N_W**	**Total**
Pre-Conversion	6	0	0	0	0	0	6
Post-Conversion	7	5	3	3	4	2	24

M. Morning N_A Night A D_W Day weekend
E. Evening N_B Nigth B N_W Night Weekend

Preventive maintenance was advanced before the Hospital conversion, and a calendar of preventive services based on the surplus of medical equipment was programmed on a rotating basis, so as not to deter from bed care.

On the other hand, the DBE participated in the development of protocols for the disinfection of medical devices and clinical areas in conjunction with the Hospital Epidemiological Surveillance Unit (UVEH). It also developed the methodology for the internal and external cleaning of medical equipment, and medium and high level disinfection. It trained workers, internal technical staff and suppliers in the use of personal protective equipment (PPE). A biological safety strategy was carried out in the maintenance of medical equipment and its accessories, as well as the safe disposal of its consumables.

Table 5. Growth of medical equipment to attention of COVID19 critical patients.

Medical equipment	Before	After	Growth
Video-laryngoscopes	0	14	
Mechanical ventilators	66	240	264%
Ultrasound	6	19	217%
Hemodialysis machines	2	6	200%
Vital Signs Monitor	113	324	187%
Portable X-rays	4	11	175%
Gasometer	4	11	175%
Infusion pumps	650	1400	115%
Electrocardiograph	17	30	76%
Hospital beds	230	314	37%
Defibrillators	50	51	2%
Total	**1142**	**2499**	**119%**

Regarding the processes of acquisition, delivery and installation of new medical equipment, execution times had to be shortened due to the urgency of requiring immediate equipment for intensive care beds. In this sense, the installation and operation tests of the medical equipment, as well as training of the user personnel had to be carried out in parallel and in compliance with the biosafety protocols in the corresponding clinical areas.

3.2 Medicinal Gases

In order to have a homogeneous distribution of constant gas supply (without saturation in critical points of the network) the pneumatic load of the medical gas supply network (oxygen and medical air) was distributed in the critical areas: ICU, UQX and ER in addition to inpatient clinical services in the first stage of conversion.

Initially, a physical separation of the hospitalization areas was made to distribute and separate the supply lines in each clinical service. The supply lines were changed, the electrical capacity of each building was adapted, and the spaces were distributed to ensure the safe accommodation of medical equipment and furniture.

Using an oxygen and nitrogen mixing system in proportions of 21% and 79% respectively, synthetic air (free of moisture and particles) was supplied to the clinical areas. Simultaneous pneumatic support was guaranteed for 100 mechanical ventilators with a safety margin of at least 10%. In an extreme case, the maximum gas capacity would allow feeding at least 10 additional ventilators; considering a consumption average of 3,600 L per hour. The synthetic air production capacity is limited to a production of up to 480,000 l/h. The oxygen is limited by the storage capacity of up to 6,500 gallons of liquid oxygen. This allows for the use of 100 ventilators for 48 continuous hours without recharging gas. However, a five-hour backup was also envisaged in the event of a main supply system failure.

In the second stage of conversion—named "Magna Hospital Reconversion" by the Mexican government, the medical gas supply network was divided into three blocks, each with its own gas supply plant. This division guaranteed the pneumatic oxygen and air support for 200 ventilators to its maximum capacity. Out of the three plants supplying medicinal gases, one already existed prior to the first stage of conversion; subsequently, two more with mobile oxygen units and medical grade compressors were implemented. Table 6 shows the distribution of the oxygen and medical air supply network into these three blocks of hospital services that ensured an adequate supply of medicinal gases for each clinical service.

Table 6. Segmentation of the medical oxygen and air supply network into three blocks of hospital services.

Block	Clinical service	Beds	Beds + V 1st stage	Beds + V Magna R	Total Beds + V per block
Block 1	SC1	28	6	20	**82**
	SC2	28	6	20	
	SC3	30	8	22	
	SC4	27	13	20	
Block 2	SC5	29	8	20	**77**
	SC6	10	8	10	
	UQX	4	4	4	
	REC	20	10	16	
	UCI	15	15	15	
	ORL	12	4	12	
Block 3	UNP	29	13	21	**41**
	URG	18	15	20	
Total		**250**	**110**	**200**	**200**

3.3 Mechanical Ventilators

Owing to the fact that the most demanded medical equipment in critical areas was the mechanical ventilator, another very important area for the reconversion of the Institute was Respiratory Therapy. The availability of this equipment and the control of the consumption of its accessories were essential to guarantee the safety of the patients who required ventilatory support.

Throughout 2020, the Institute bought eleven mechanical ventilators, borrowed 25 and received 138 more ventilators in donation. This raised the ventilatory support capacity by 264% with 240 available ventilators. The existing and newly acquired ventilators are of four types: basic pneumatic (BN), non-invasive (NI), volumetric (VL) and volumetric transfer (VT); distributed in 13 different brands (Table 7). Note that most of the devices (200) are volumetric ventilators, followed by transfer ventilators with 24, twelve basic pneumatic ventilators, and four non-invasive ventilators. In relation to brands, four dominate: the M7 brand totaling 96 devices; the M1 brand with 35; the M12 with 26 and the M4 and M13 brands with 20 ventilators each. The rest of the ventilators (43) are distributed among the nine remaining brands.

The variety of ventilators and brands forced the DBE to oversee the control of accessories and consumables. The design of training and the qualification of technical staff in maintenance procedures, along with the modification and/or updating of preventive maintenance routines adhering to the corresponding calendar. Likewise, respiratory therapy technicians were trained in the use and management of the new ventilators, as well as to keep a record of adverse events derived from the use of a wide variety of equipment.

Table 7. Ventilators available after COVID19 Hospital conversion

Brand	NB	NI	VL	VT	Total
M1	12		23		**35**
M2		4			**4**
M3			1		**1**
M4			20		**20**
M5			5		**5**
M6			12	5	**17**
M7			80	16	**96**
M8			2	1	**3**
M9			4		**4**
M10			6	1	**7**
M11			2		**2**
M12			25	1	**26**
M13			20		**20**
Total	**12**	**4**	**200**	**24**	**240**

3.4 Disinfection Procedures

Other relevant tasks for the reconversion of the Institute included control of infections associated with health care, and scouting of appropriate technologies to carry out the disinfection processes of physical spaces. The DBE worked in conjunction with the Institutional Biosafety Committee to learn about the disinfection protocols for the safe handling of medical equipment, so as to help reduce the risk of cross-infection between patients. Some of the protocols that the DBE participates in are described below:

- Cleaning surfaces by mechanically removing organic matter in equipment and accessories.
- Medium level disinfection by high pressure biphasic mixture spraying of areas including furniture and biomedical equipment.
- Application of a high-level disinfectant using a bactericidal and bacteriostatic film.
- High level disinfection using hydrogen peroxide vapor methods or Ultraviolet-C (UV-C) light irradiation. Evaluation of the effectiveness of the high-level disinfection process (HLD) using surface and environmental (air) cultures.

It is important to mention that the application of the HLD techniques were carried out only in the event that the patient was occupied the bed presented some drug or multidrug resistant bacteria, or in the case of empty clinical services. The selection of the HLD protocol by hydrogen peroxide, or by UV-C irradiation was determined for the emergency services or for the "Field Hospital" (described below) due to its characteristics of being an open space.

4 Covid Hospital Magna Reconversion (Results)

The work of the Department of Biomedical Engineering consisted of planning, implementing and evaluating the hospital reconversion of the Institute in relation to medical technology, medicinal gases and the critical infrastructure. The objective was to increase the physical and technical capacity of the ICU, expanding the intensive care beds to a maximum care capacity of 250 patients in critical condition.

This stage was consolidated with the installation of a Field Hospital, donated by the Mexican Red Cross, with a capacity of 50 additional beds, of which 30 were enabled for the intensive care of COVID patients. Said hospital was installed in the parking lot next to the Emergency Room and was made up of five tents for medical care, with beds designed to provide intensive care. Furthermore, it required the design and installation of an air conditioning system with filters of High Efficiency Protection Air (HEPA) to ensure a safe environment. Additionally, ambient temperatures were controlled and monitored to ensure the correct functionality of equipment and comfortability of the units. A continuous air and oxygen distribution network was implemented to enable the continuous supply of airflow; assure safe ranges of ventilation and aspiration of patients, as well as the installation, training, operational tests and commissioning of medical equipment.

The supply of medicinal gases was guaranteed and distributed in a total of 250 beds throughout the Institute. This considered 230 beds available for use with a mechanical ventilator and 20 additional beds with low oxygen requirement as nasal tips (Table 8).

Note that in the first stage of the reconversion (R_{1st}) the supply was expanded from 15 to 110 intensive care beds (44%), and in the "Magna Reconversion" (MR) 200 beds (80%) were completed. These were distributed in the three blocks defined: 82, 77 and 41 respectively. Additionally, the "Magna Reconversion" was completed with more than 30 beds of the Field Hospital.

In this way, the largest Intensive Care Unit in Mexico was created, reaching a capacity of 250 beds equipped with the infrastructure requirements, medical equipment and paramedical personnel for the care of critical COVID patients.

Table 8. Total facilities provide by the COVID Hospital Magna Reconversion at the National Institute of Respiratory Diseases from Mexico.

Clinical area	Beds (B)	B+V (R_{1st})	B+V (MR)	%(B+V) By block
Block 1	113	33	82	36%
Block 2	90	49	77	33%
Block 3	47	28	41	18%
INER	**250**	**110**	**200**	87%
Red Cross (Field Hospital)	30	0	30	13%
Total capacity	**280**	**110**	**230**	**100%**

5 Conclusion

The National Institute of Respiratory Diseases (INER) has treated 5,746 critically ill patients with SARS-CoV2 and other coronaviruses. As of February 27, 2020, when the first case was presented in Mexico, the INER treated a monthly average of 60% of patients with ventilatory support. The installed infrastructure has sustained solid care of critically ill patients during the 15 months of pandemic—even in the maximum occupancy in which 200 hospitalized patients were treated, out of which 185 required mechanical ventilatory support. Likewise, the Field Hospital for emergency room care, was reconfigured into a unit for the care of critically ill patients and infectious diseases, thus complementing the Institute's health care capacity.

The planning and execution of the growth of the Institute's infrastructure carried out by the BDE for the "Magna Reconversion", mandated by the Government of Mexico, has correctly covered the care of critically ill patients, placing the INER as the health institution with the highest intensive care capacity in the history of the country.

For all the above, the Department of Biomedical Engineering has become a fundamental piece in regard to the decision-making of all processes that concern medical technology in the National Institute of Respiratory Diseases.

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References

1. National Institute of Respiratory Diseases: Specific Organization Manual for the National Institute of Respiratory Diseases Ismael Cosio Villegas. Ministry of Health, Mexico (2016). http://iner.salud.gob.mx/descargas/normatecainterna/MOdirgeneral/MO_INER_2016-2.pdf
2. Suárez, V., Suárez Quezada, M., Oros Ruiz, S., Ronquillo De Jesús, E.: Epidemiology of COVID-19 in Mexico: from the 27th of February to the 30th of April 2020. Rev. Clin. Esp. **220**(8), 463–471 (2020). (in Spanish)
3. Mexican Health Ministry: Hospital reconversion guidelines (2020). https://coronavirus.gob.mx/wp-content/uploads/2020/04/Documentos-Lineamientos-Reconversion-Hospitalaria.pdf. (in Spanish). Accessed 15 Apr 2021
4. Mexican Health Ministry: Guidelines for the implementation of COVID-19 temporary care centers and Mobile Hospitals (2020). https://coronavirus.gob.mx/wp-content/uploads/2020/04/Lineamientos_Centros_Atencion_Temporal.pdf. (in Spanish). Accessed 15 Apr 2021
5. World Health Organization: Priority medical devices list for the COVID-19 response and associated technical specifications (2020). https://www.who.int/publications/i/item/WHO-2019-nCoV-MedDev-TS-O2T.V2. (in Spanish). Accessed 15 Apr 2021