

Redesign of the COVID-19 ICUs to Save the Corona Warriors

Ramakrishnan Angarai Ganesan
*Medical Intelligence and Language
Engineering (MILE) Laboratory,
Department of Electrical Engineering,
Indian Institute of Science,
Bangalore, India*
agr@iisc.ac.in

Kanishka Sharma
*Medical Intelligence and Language
Engineering (MILE) Laboratory,
Department of Electrical Engineering,
Indian Institute of Science,
Bangalore, India*
kanishkas@iisc.ac.in

Abstract— It is of utmost importance to protect our health-care professionals, who are the most important resources for any country today. The commitment behind this article and proposal is to ensure that we do not lose even one more doctor or nurse to COVID-19. In the opinion of the authors, the current design of most of the ICUs, where the air is recirculated through the air-conditioning, is not suited for treating the highly infectious patients of COVID-19, and may be one of the causes of the thousands of infections among the healthcare workers, which has also led to the death of more than two thousands of them around the world. One is not sure whether this is the reason behind the unusual death rate of patients put on ventilators too. This article proposes a cost-effective redesign of the existing ICUs and suggestions for choosing the buildings intended to be converted to makeshift hospitals to take care of the patients infected by the corona virus. Also, where the personal protective equipment is in shortage, certain possible alternatives are suggested. There is also the need to revise the curricula for medicine and nursing to make them sufficiently aware of the risks posed by ICUs and also about lifestyle changes for positive health and prevention, rather than purely for patient care.

Keywords—SARS-CoV; SARS-CoV-2; COVID-19; Intensive care units (ICU); air-conditioning; personal protective equipment; infectious medical waste; disposal; disinfection; health worker; safety; air filter; shoes; doormat, medical curriculum, school curriculum.

I. BACKGROUND AND CURRENT STATUS

In 2003, the SARS outbreak in Hong Kong became a global threat affecting 30 countries [1]. At that time too, people at the greatest risk were health workers exposed to the patients or by procedures such as intubation, aerosolized medication and laboratory people handling human secretions [2]. A study on healthcare workers exposed to SARS-CoV patients made a shocking revelation that 56 % (n=80) of them were found to be asymptotically infected even while using N95 masks, gloves and gowns [3]. Further, in the case of SARS-CoV in Hong Kong, the frontline health workers were found with psychological stress and formed as much as thirty percent of the total infected population [4]. Thus, we need to have a

close look at the conditions in the intensive care units meant for such highly infectious diseases.

The present situation is worse than that of the 2003 SARS CoV disease. Around the world, more than two thousand doctors, nurses and other health care professionals have died of COVID-19 infection, while serving patients at the ICUs [5]. While there are definitely other reasons such as lack of protective equipment, exhaustion, etc., we seriously think that the way the ICUs are designed today, may act against the health of the health workers themselves. We strongly feel that by immediately redesigning the ICUs, we can save or minimize the health workers from getting infected. While the normal death rate of patients put on ventilators is high (~50%), with COVID-19 patients, it is reported to be much higher (>80%) [6,7]. In fact, since nearly 50% of the patients do not exactly match the criteria for acute respiratory distress syndrome, there is naturally a difference of opinion among the doctors on the use and the time of application of the only treatment strategy, namely, the ventilator [8]. Mortality rate is eventually higher in ICU patients aged more than 60 years, who have co-morbid conditions such as hypertension [9,10].

II. ICUS ARE NOT DESIGNED FOR DOCTOR SAFETY

By now, we clearly know that exposure time to the virus is an important factor. Being in an enclosed space for hours together with someone infected significantly increases the risk. However, when medical experts have flagged bars, gyms and sports stadiums as high risk areas [11], they seem to be unaware of the high risk posed by air-conditioned ICUs, where one is sure of the infected air being circulated, causing the viral load to systematically increase with time. The ICUs were originally designed to prevent external factors from causing increased infection to the patients. Hence, they turn out to be really bad designs, when the health works need to be prevented from the risk of infection from the in-patients, whose very breathing and speaking are constantly adding to the infection in the air. Thus, ICUs for taking care of patients with highly infectious diseases need a completely different

design. Medical education also needs to be updated to appraise the budding doctors and nurses of these factors.

The guidelines of the *Indian Society of Critical Care Medicine* recommend that the ICUs serving the critically ill patients have a filtering efficiency of 99% for particles above the size of 5 microns [6]. Negative air pressure is suggested as a necessity in these units dealing with infectious disease spread through airborne droplets with microbes of size less than 5 microns [12,13]. Even with these guidelines, the filter efficiency dealing with the smaller size of SARS CoV-2 is questionable. WHO guideline now says air travel has high risk mainly because of this recirculation of same air, with no filtering possible for any virus in the air within the aircraft. However, an aircraft will never have a high number of COVID-19 patients, since the passengers are tested before they board a plane. On the other hand, an ICU meant for the COVID-19 patients has a high number of patients, leading to a high viral load in the air within the ICU. Unfortunately, almost all the ICUs are air-conditioned and ***the same air is recirculated through the air-conditioner and it does not effectively get filtered for viruses of smaller size.*** Of course, some companies do have products with HEPA filters of those capabilities, but most hospitals do not have these models installed today.

From the Japanese simulation study [15] on how the virus spreads in a closed room, and how it quickly disperses in a room with windows, it is very clear that the ICUs as they exist today are a matter of concern not only for the patients, but also for the health workers. A recent study at MIT showed that arbitrary droplet size cut-offs and the social distancing of a minimum of one meter may not provide efficient protection from respiration emission for SARS-CoV2 [10]. With fast track experimental research on COVID-19, the recommended safety measures as well as the critical information about the infection spread are rapidly changing [17,18].

In the considered opinion of the authors, the recirculation of the air by the centralized air-conditioning systems is what has led to the significant infection of our committed medical fraternity and has also led to deaths of doctors and nurses. It is also our considered opinion that none of the masks will be fully protective, if the air around is fully infected by the diffusion of the air constantly being breathed out by the patients, when a large number of patients are being taken care of in a (makeshift) ICU.

We suggest the following possible solutions, depending upon the density of patients being attended to, availability of personal protective equipment (PPE), availability of sufficient number of health workers, whether it is a regular or a make-shift hospital, available funds, etc.

III. EFFECTIVE MEASURES

A. *Cost-effective solutions for some countries, say in Africa, lacking ICU, etc.*

Instead of converting buildings into makeshift hospitals, it is preferable to convert big, open grounds for monitoring infected patients, who have no complications and are only under observation, probably with oxygen saturation being monitored.

B. *If air-conditioning is NOT a must: Create a forceful, unidirectional flow of air in the ICU. Let the exhaust*

air bubble through a disinfecting soap or sodium hypochlorite solution or very hot water.

Studies clearly show that higher the temperature, faster the corona virus becomes inactive [18]. Thus, the authors suggest that air-conditioning can be dispensed with. In this case, the fundamental change we are suggesting for ICUs taking care of COVID-19 or other such contagious patients is that there must be a swift draft of air through the ICU in a single direction. On the entry side of the air, there must be active pushing in of the air with powerful (industrial type, with low noise) fans. On the exit site of the air, there must be powerful exhaust fans pulling the air out, and we must design in such a way that this air passes through a tube and bubbles through multiple chambers of a solution of simple soap (in simple water) or sodium hypochlorite to assure that any virus in the air gets disintegrated or disinfected by the time the air finally comes out of the multiple bubbling chambers. Soap is the best way of eliminating the virus from the infected air [19]. Soap and surfactants have a property to form micelles and to wedge themselves into the protein, lipid bilayer in the case of infectious bacteria and virus. The soap action on H1N1 [20], influenza [21] and Ebola [22] has been found to be very effective and established as one of the best ways of disinfection, with consistent results. However, the soap solution has the problem of frothing, which needs to be suitably managed. Chemical engineers need to give an appropriate solution to this, if possible. It may be possible to direct the air stream alternately through two sets of soap solution chambers and eliminate the froth in the inactive chambers suitably, when the air is made to pass through the other set of chambers.

Alcohol is preferably not used in this application, since we need large quantities of the same, where it is highly inflammable. Sodium hypochlorite solution of a suitable dilution can be used, but needs to be refreshed every day [23]. However, at high concentration, it is corrosive and can cause nasal and skin irritation, sore throat and coughing and hence, the personnel handling it need proper training and protection equipment. Indian society of heating, refrigerating and air conditioning engineers (ISHRAE) suggests the use of high efficiency particulate air (HEPA) filters, but unless they are certified for this (at least H13 (EN1822-1) filter class) [24], HEPA filters will NOT be able to filter out the SARS CoV2 virus, which is 0.08 to 0.16 micrometer in size [25]. Further, HEPA filters only filter the virus based on its size, leaving the live virus on the filter, to be disinfected periodically later. Thus, they are again not advisable. On the other hand, sodium hypochlorite [23] or soap chemically annihilate the virus [19] by destroying their structural integrity and thus are preferable. The disinfected air can again be sent through one or two chambers of water to remove the soap or chemical molecules in the air. This clean air can again be circulated OR left into the atmosphere, depending upon what works. Clearly, these solutions require the design and expertise of fluid mechanics engineers.

The third alternative is to pass the exhaust (virus-laden) air through very hot water, being continuously heated by coils, similar to a geyser. It has been reported that at a temperature of 70 degree Centigrade, the virus gets inactivated within 5 minutes [18]. Hence, it is likely to get inactivated even faster with the use of near-boiling water. In

this case, it is preferable to let the disinfected air into the atmosphere, since it is hot. Figure 1 gives a tentative schematic diagram, illustrating the method suggested for disinfecting the exhaust air from ICU.

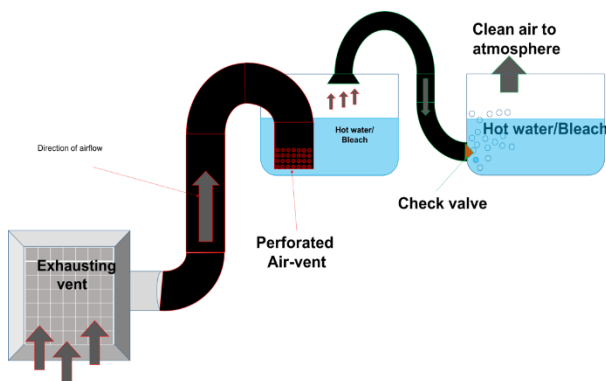


Fig. 1. A conceptual diagram illustrating the possible disinfection of ICU exhaust air, by a sequence of chambers containing a disinfecting solution or near-boiling water.

C. If air-conditioning is a must: No forceful flow; Let the exhaust air go through an appropriate disinfecting solution.

In this case, it is really important to ensure that the air-conditioning of the COVID-ICU is delinked from that of the other (non-COVID-19) ICUs in the hospital to avoid the air that comes out of the COVID-19 ICU from being recirculated to the other ICUs. We do not need the fans that forcefully send air into the ICU. The exhaust fans and the filtering by making the air pass through multiple chambers of disinfecting solution remain, as in the case (B) above.

D. If a new area is converted into a makeshift COVID-19 ICU or if there are closed windows in the ICU: Open all the windows of the ICU or choose a place with as many windows as possible, so that the aerosols (and hence the virus) disperses as fast as possible.

The latest review published after the current pandemic outbreak has recommended to have a single room with proper ventilation for each critically ill patient, if no negative pressure infrastructure is available [13]. However, this may be impractical and expensive, if we need to modify an existing ICU facility. However, in case the hospital ICU has a number of windows that have been closed for increasing the efficiency of A/C cooling, then all the windows must be opened and the air-conditioning switched off. If a makeshift hospital or ICU is planned, then one must choose a hall or a building, which has a lot of windows and ventilation, and if needed, both blow-in and exhaust fans may be used to create a constantly moving, unidirectional flow of air.

Circulation of the air exhaled by infected patients in the ICU or COVID-19 units may contribute to fast transmission of infection as well as severity of already infected patients. Elias and Bar-Yam [27] suggest separate filtration of air exhaled from each patient's lungs in order to reduce the number of virions present in the lung and the upper respiratory tract as well as the immune hyper response associated with cytokine storm. A wearable filter for patients

or patient cohort may be an effective measure to reduce the viral load in the air as well as the patient's body [27].

Indian Railways has converted several railway coaches into temporary ICUs for the care of COVID-19 patients [28], in case required. In this makeshift arrangement, it is ideal to use the conventional non-AC coaches with all the windows open.

1) Requirements in hospital toilets

It is more than clear that the chances of infection are very high in the toilets. Hence, all the water taps in all the toilets must be of the contactless variety, so that neither the doctors, nor the nurses nor patients need to touch any of the taps to open or close them. This shall minimize the viral load on the taps and also the frequency of disinfection needed. Further, when the patient is able enough to visit the toilet himself/herself, it is not advisable to use toilet paper, since it does not lead to any disinfection at all. It is better to provide a warm water jet, with a small amount of soap in it, which can neutralize the virus. Similarly, the flush water may also be loaded with the minimum required concentration of bleach to disintegrate the virus present in the excreta then and there. In case the patient is not in a condition to visit the toilet and is being nursed, appropriately modified procedures may be adopted to ensure disinfection of the patient's body and the refuse, as much as possible. Below, we discuss other connected issues.

2) Keep elderly doctors away from direct patient care

Many senior doctors, with ages much above 60 years, have also sacrificed their lives in the service of Covid-19 patients [5]. This could have easily been avoided. Aged and senior physicians must preferably be used as advisors to young doctors, and current postgraduate students in medical institutions, belonging to every specialty should be utilized by the Governments of every country to serve the COVID-19 patients as part of their training programme. While providing a sufficient number of young skilled professionals, this will also ensure less casualties among the medical fraternity, by keeping the more vulnerable elderly physicians away from directly dealing with the infected patients. This also requires educating the hospital administrators and the health ministries in every country.

3) Reusable, affordable personal protective gowns

The authors are making the following suggestions for poor countries, which could ill-afford single use personal protective gowns or do not have sufficient supplies of them. Ultimately, if this idea works out, it shall lead to a huge environmental benefit to the world, by minimizing the use of all possible single-use materials in hospitals, and hence, the need for expensive disposal mechanisms and technologies for their careful disposal. In many cases, even Governmental regulations and policing are required to ensure the safe disposal of contaminated hospital wastes, and the suggested measures may reduce the strain on even the administration.

Improper removal and disposal of contaminated, disposable personal protective gowns can expose other people to infectious agents. In this context, it is unfortunate that in some hospitals of even advanced countries, the medical

personnel have been asked to use the same mask for three consecutive days, because of inadequate supplies. Since it is clear that the Covid-19 virus does not enter through the intact skin, the hospitals or the health authorities in poor countries can supply easily washable, regular clothes to the HCW, along with the protective mask for the face alone. Once the duty is over, the HCW must directly enter a bathroom, have a shower and leave all his/her clothes in the washing machine. Washing the clothes with soap not only effectively destroys the virus and disinfects the clothes, but also it solves the huge problem of safe disposal of medical waste.

4) *Machine-washable shoes for the HCW and disinfecting doormats at the ICU entrances*

There is recent evidence from the Centre for Disease Control and Prevention (CDC), USA that novel coronavirus can spread through shoes. Once again, we must use easily machine-washable shoes with appropriate materials (if needed, manufacture them in sufficient numbers) so that the HCW dumps the shoes also into the washing machine and goes out with his/her own shoes. Further, the doormat outside the ICU must have a disinfectant, so that the nurses and other health workers disinfect the bottom of their shoes, before walking into the other areas of the hospital. Once again, a simple sponge dipped in soap water, kept in a broad, shallow tub must do the job. There must be another sponge dipped in normal water, to remove the slippery soap from the bottom of the shoes. Once again, we do not recommend the use of corrosive sodium hypochlorite; however, even that is better than not having anything to disinfect the shoes. These are some affordable, simple but very effective measures.

5) *Separate resting chambers for the doctors and nurses post/in-between working hours*

Our medical fraternity goes through extreme stress, exhaustion, etc. So, we need to create a small space, wherein the doctors can go in and refresh and recharge themselves quickly. We can provide (i) availability of hot, tasty soups with turmeric and black pepper added [29], (ii) a water fountain or water flowing down one of the walls, creating negative ions in the air, effective against occupational stress and anxiety [30], (iii) show videos of simple pranayama and yogasanas, which refresh them and increases their immunity [31], (iv) soothing music [32]: preferably, choosable by the health worker based on his/her taste, etc. and so on. Manifold benefits of music listening [32] and music making [33] have been observed on healthcare workers in burnout symptoms, stress reduction as well as surgical efficiency. If possible, the walls may have wallpaper, depicting lush, green, nature.

6) *Possible hypoxia: Rotate the doctors and nurses every few hours*

The N-95 mask is relatively crude, and does not provide clean air to the health worker, when he/she is working for long hours in an atmosphere, where there are a sizeable number of serious COVID-19 patients. Since the air in the ICU may have a high viral load (especially where recirculating air-conditioners are present), the health worker is also inhaling the same air. Further, several physicians have confirmed that

wearing N95 masks makes them fatigued much faster than normal situation. This could be partially due to the possible hypoxia [34] that might result due to the additional effort needed to breathe deeply when one is wearing a tight mask, like the N95.

Many physicians, including specialists in other areas, are relatively free these days, since most people are avoiding going to hospitals (except for emergencies) for fear of infection or due to lock-down. Similarly, independent practitioners and nurses from private hospitals may be free of work. Hospitals can get financial support from the State or Central government and recruit some of the above doctors and nurses, who are ready to come and help (temporarily, till we win over the novel Coronavirus). Since there are no specific medicines and the patients have no other wound born of surgery, etc., any other willing doctor or nurse can be trained to handle these patients in a finite time by someone with experience. Also, in every country, senior, final year medical students can be mandated by the respective Governments to assist in these special COVID-19 intensive care units. This will immediately provide sufficient supply of trained manpower in hospitals; the students can be given some credit in terms of merit points, which can be appropriately recognized later.

This way, there will be adequate availability of doctors, nurses and any other type of support workers. They can be rotated after every 6 or 8 hours, depending upon what works.

7) *Soothing music for the patients too*

The patients are also under extreme stress, normally in any ICU [35], and more so in the COVID-19 case. So, we must think of whatever we could do, to reduce their stress and keep them at relative ease, and one of the things we can think of immediately, is music.

IV. CONCLUSION

The current outbreak has once again made us realize the importance of healthcare workers as the most valuable resource [36] and it is of utmost priority to provide them effective PPEs as well as a safe and disinfected environment and ensure their security. We appeal to engineering design researchers to work on an innovative and effective design for a soap-based air filter in order to treat the infected air in ICU and COVID-19 wards. Strong and prompt measures are needed to be taken at the policy level to implement these designs quickly to stem the infection of healthcare workers.

Finally, a word of caution. The world has been suddenly and unexpectedly attacked by this virus and everything about how to handle the situation, patients, economy, etc. are being actively discussed and changes are being made every day. Similarly, this article has been written with currently available knowledge and a sincere intention to help the medical community handle the patients with best possible caution, with the given facilities and constraints. Hence, some of the suggestions made here are also subject to change with time, in a dynamic manner, with additional knowledge and practical considerations coming in.

By carefully redesigning the ICUs meant for COVID-19 and other infectious patients with respiratory tract related illness, we can minimize the risk of infection to the health care workers. The article gives a number of suggestions in

this direction, based on a study of current ICUs and their constraints especially for less developed countries with dense population and high number of infection-prone communities. With recent empirical evidences about the stability of CoV-2, it is of utmost importance to use novel methods to eradicate the airborne concentration in COVID wards. This paper requests air-conditioning and ventilation engineers to contemplate and work out advanced design with heating chambers for the infectious viral load present in the COVID wards. Also, future designs of wards for care/treatment of respiratory illness and airborne diseases may benefit from the suggestions made in the article.

V. NEED TO REVISE MEDICAL CURRICULA

Allopathic education deals primarily with alleviation of pathology or relief or lessening of disease. While the medical curricula do include study of how the immune system functions and responds to attacks by foreign bodies, they neither include any systematic study of measures for positive health nor a good overview of suggested practices (diet, exercise or pranayama) for improving one's health and immunity [37]. Further, excessive fear also reduces one's immunity, due to factors such as nocebo [38].

As of September 18, 2020, over 4.1 million covid-19 patients in India and over 21.9 million people around the world have recovered fully from the COVID-19 infection. This includes a large number of elderly people, many of them even above 90 years, and some of them even with the so-called comorbidities. This has happened in the absence of any certified vaccine or drugs, which have been unambiguously accepted by the medical administration around the world. This clearly and undisputably demonstrates that the human immune system, when maintained in good condition, can definitely and reliably win over any new and unknown virus [39]. However, unfortunately, there are very few physicians in the world, who have publicly acknowledged this fact, and have decisively spoken about the importance of positive health and advised the general public on methods to improve the readiness level of the immune system of humanity as a whole.

This is clearly because the current medical education system does not teach them about systematic methods of improving the effectiveness of immune response and general health of a person. In the absence of such knowledge, it is not at all surprising that the allopathic practitioners rarely, if at all, talk about methods (diet, exercise and other practices) of improving health. For example, a study by the National Institutes of Health and The National Institute of Allergy and Infectious Disease has well documented that the western diet (ready to eat packaged food rich with refined wheat flour, white sugar, salt and saturated fatty acids; soft drinks) is pro-inflammatory and reduce immunity [40]. One of the causes of the disproportionate mortality rates in United States of America, United Kingdom and several European countries could very well be the diet, as clearly stated by the above study. However, neither such crucial information nor knowledge about lifestyle practices that enhance one's immunity are part of regular medical education.

At a time, when the novel Coronavirus is spreading without any stop despite the efforts by all the Governments of the world in terms of lock-down, face masks and social distancing, it is really crucial that the common man is educated well about the importance of keeping the immune system

combat-ready and taking all the possible steps to improve its effectiveness [41, 42, 43]. Also, while too much has been studied and disseminated about diet and its importance for our health, very little has been done to educate the common man on the extraordinary benefits of controlled, deep breathing exercises [44, 45]. After all, good oxygen supply is crucial for brain function and metabolic activity of the hundred billion cells in the body. There are studies that have clearly demonstrated positive changes in the expression of up to 110 genes after the practice of two hours of certain pranayama and meditation [31]. Thus, there is an urgent need for revising the medical education curricula around the world towards positive health. This shall also reduce the cost of medical care and has the potential to make a country as a whole healthy in time.

VI. NEED TO REVISE SCHOOL CURRICULA

It is also imperative to revise the science syllabus in high schools to teach the children all the scientifically proven knowledge about good dietary habits and deep breathing practices [45] and their crucial importance for great positive health, a quick-to-respond immune system and a brain that works at its best efficiency. This also requires appointing the best of people as teachers, training and paying them well, similar to what is done in Finland. Any country that consciously chooses to do that, is the most advanced country, in the opinion of the authors, which truly serves its citizens.

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