

RECOMMENDATIONS FOR PULMONARY FUNCTION LABORATORIES IN THE COVID-19 ERA

JUAN J. RODRÍGUEZ MONCALVO, JAVIER C. BREA FOLCO, SANTIAGO C. ARCE, ROQUE A. BALDASARIA,
ORLANDO LÓPEZ JOVE, MIRIAM G. MARCOS, CARLOS G. DI BARTOLO

Sección Fisiopatología Respiratoria y Laboratorio Pulmonar, Asociación Argentina de Medicina Respiratoria

Abstract The airborne spread is the main route of human-to-human transmission of coronavirus, including the SARS CoV-2 virus causing the disease known as COVID-19. The implicit risk of aerosolization of SARS CoV-2 infective microdroplets while carrying out respiratory function tests has caused a significant limitation of activity in most Pulmonary Function Laboratories since the beginning of the pandemic. This document aims to update the recommendations for the management of Pulmonary Function Laboratories in the context of the COVID-19 outbreak in Argentina. New recommendations include ways to carry out pulmonary function testing during the context of a high and low community viral spread phase, the evaluation of post-COVID-19 patients, as well as several aspects of biosafety for patients and operators. Measures consist of promoting air circulation in the environment, the use of antimicrobial filters, the protection of airways and mucous membranes, and hand washing.

Key words: COVID-19, SARS CoV-2, pulmonary function tests, biosafety, aerosol sprays

Resumen *Recomendaciones para el laboratorio de función pulmonar en la era COVID-19.* La diseminación aerógena del virus SARS CoV-2 es la principal forma de transmisión interhumana de este coronavirus causante de la enfermedad conocida como COVID-19. El riesgo implícito de la aerosolización de microgotas infectantes del SARS CoV-2 durante la ejecución de las pruebas funcionales respiratorias ha provocado una importante limitación de la actividad en la mayoría de los laboratorios de función pulmonar desde el inicio de la pandemia. Este documento tiene por objetivo actualizar las recomendaciones para el manejo del laboratorio de función pulmonar en el contexto de la epidemia COVID-19 en Argentina. Se incorporan nuevas recomendaciones para realizar pruebas funcionales respiratorias en el contexto de una fase alta y baja de circulación viral comunitaria, para pacientes post COVID-19, así como para la bioseguridad de pacientes y operadores. Las medidas incluyen la ventilación del ambiente, el uso de filtros antimicrobianos, la protección de vía aérea y mucosas y el lavado de manos.

Palabras clave: COVID-19, SARS CoV-2, pruebas de función pulmonar, bioseguridad, aerosoles

The airborne spread is the main form of interhuman transmission of coronavirus, including the novel virus SARS CoV-2, which causes the disease known as COVID-19¹⁻³. Contagion can occur through direct transmission of contaminated respiratory secretions from the patient to an uninfected subject, or, potentially, through unnoticed contact with these secretions deposited on inert objects⁴. The implicit risk of aerosolization of the SARS CoV-2 infective microdroplets while carrying out pulmonary function

testing (PFT) has restricted significantly the activities in most Pulmonary Function Laboratories (PFL) since the start of the COVID-19 pandemic^{5, 6}. For these reasons, and because of the importance of PFTs for diagnosis, assessment, and follow-up of numerous respiratory and systemic diseases; it is necessary to agree on strategies that allow adapting PFL activities to the demands posed by the COVID-19 pandemic.

The purpose of this document is to update the recommendations for the management of PFL in the context of the epidemic in Argentina, the initial version of which was timely published through the website of the Asociación Argentina de Medicina Respiratoria⁷, and the website COVID-19: Guidelines and Recommendations Directory of the European Respiratory Society⁸.

Received: 8-XII-2020

Accepted: 5-I-2021

Postal address: Juan José Rodríguez Moncalvo, Av. de los Incas 3129, 1426 Buenos Aires, Argentina
email: juanjosemoncalvo@hotmail.com

KEY POINTS Current knowledge

- The COVID-19 pandemic has had a great impact in the field of lung function tests, due to the high capacity of SARS CoV2 infected patients to generate potentially infectious aerosols.

Contribution of the article to current knowledge

- New recommendations are incorporated to carry out PFTs in the context of a high and low phase of circulation of SARS CoV2 in the community for biosafety of both, patients and operators, as well as post-COVID-19 patients. Measures include ventilation of the environment, use of antimicrobial filters, protection of airways and mucous membranes, and hand washing.

This document addresses essential aspects that should be considered for a rational basis of those recommendations, including the COVID-19 epidemiological evolution, the clinical condition of patients who require exploration of respiratory function during the epidemic, the PFTs recommended for their usefulness and safety, and the strategies to carry out them while minimizing the risk of the procedures. This document also includes the guidelines for the study of patients recovered from COVID-19.

Methodology

For these recommendations, similar documents were examined, including those issued by various respiratory medicine societies and institutions related to PFL activities⁵⁻¹⁵, government health and epidemiological agencies, and basic research studies on the dissemination of SARS CoV-2 and its conditioning factors. All the recommendations emanating from these documents were evaluated, in successive meetings, regarding their quality and relevance. A committee was formed to draft the present recommendations, which were subsequently evaluated by an independent review committee.

These suggestions apply to any epidemiological phase, should it be primary or due to a new infectious outbreak. Reports of confirmed reinfection in the same patient are rare, so each case must be considered in particular^{16, 17}.

Conceptual bases for recommendations

1. Considerations about the epidemic evolution of COVID-19

To determine the feasibility of PFL activities, the local epidemiological evolution of COVID-19 must be taken into account, which might vary significantly, even between adjacent geographic regions and cities. For this reason,

the situation in each different area must be carefully considered when deciding the level of PFL activity. In Argentina, this data is published on the website of the National Ministry of Health and also on regional health organizations, like the Argentine website of the WHO/PAHO^{14, 18}, where information can be obtained on the evolution of disease prevalence and incidence rates, the curve of progression of confirmed cases by region, the basic reproductive number (R0) of the infection (which estimates the speed of spread of the disease in the population), and the expected time for cases duplication^{14, 18, 19}. These and other variables should be analyzed jointly with the local infection control committee to define the epidemiological phase of the disease and agree on strategies to develop PFL activities.

For this work, the **High Phase** was defined as the local increasing or high stable epidemic situation (high plateau) of the disease, characterized by a high circulation of the virus in the community. The **Low Phase** was defined as the local decrease in the number of new confirmed cases or low stable situation (low plateau) when the probability of spread of the infection is lower.

During the High Phase, it is generally recommended not to perform PFTs. Only exceptional cases could be considered, in which functional examination is essential to take urgent therapeutic measures. While in the Low Phase, it is recommended to consider a gradual opening of the PFL, maintaining the concept of performing only those PFTs that are necessary for the diagnosis or to make medical decisions that cannot be postponed.

In both phases, it is advisable to defer all non-essential PFTs, postponing those requested for routine control of a known condition or that do not modify the clinical management. As it will be seen below, there must be written operating procedures including strategies to prevent a potential viral spread during the studies, as well as the use of personal protective equipment (PPE) elements and decontamination of equipment, according to local institutional and health policies regarding the management of communicable infections.

2. Clinical conditions for conducting PFTs during the COVID-19 epidemic

It is not recommended to carry out PFTs to any patient with a diagnosis of COVID-19, symptomatic or not, nor in those patients who meet clinical criteria for a suspicious case according to the definition of the National Ministry of Health in any of the epidemiological phases of the disease. There is evidence that 95% of patients who have suffered COVID-19 and have recovered (post-COVID) have a very low contagious potential beyond 20 days from the symptomatic onset of the disease and for a period of at least 3 months²¹. In this context, it is reasonable to indicate a respiratory functional evaluation starting 30 days after the

onset of COVID-19 symptoms based on a careful clinical evaluation and the absence of signs and symptoms of reinfection^{18, 22}, without further tests to exclude the presence of SARS-CoV-2. However, immunodeficient patients who have suffered from COVID-19 should be evaluated individually to exclude persistent infection²³.

Presumably, the evaluation of pulmonary function can be indicated in a post-COVID patient in at least two scenarios: 1) to determine the functional condition and its potential impact due to the sequelae of the disease in patients without previous respiratory disease and, 2) to evaluate an acute exacerbation or deterioration of a previously known concurrent disease (chronic obstructive pulmonary disease, pulmonary interstitial diseases, bronchiectasis, etc.). For the first scenario, evidence shows that an acute deterioration of the respiratory function can occur within the first 30 days from the onset of symptoms, and a slight improvement or stabilization is reached at around 3 months²⁴. To know the remaining lung function, it is ideally suggested to assess it after 3 months of disease evolution²⁵. In the second scenario, whenever possible, it is advisable to wait at least 30 days from the onset of symptoms²⁴⁻²⁶.

In patients who have not suffered from COVID-19 and require a PFT during the Low Phase, it is recommended to perform a triage questionnaire 24 to 48 hours before PFT execution to examine criteria for a suspected case of COVID-19. After an interrogation directed by trained PFL personnel, cases considered suspicious will not be able to access the functional study until the SARS-CoV-2 infection has been excluded. Directed questioning is intended to discriminate between the usual symptoms of the patient's underlying disease from those potentially linked to COVID-19 (Fig. 1).

The course of the epidemic varies temporarily and geographically, with periods of high and low local transmission rates that may differ between nearby regions. This reality must be recognized and evaluated with data provided by the local health authority to decide the conduct regarding carrying out PFTs. During the High Phase, in a patient with new or exacerbated respiratory symptoms, diagnosis of COVID-19 should be excluded using any of the validated and approved diagnostic tests such as nasopharyngeal swab and real-time polymerase chain reaction (RT-PCR), saliva tests, etc. within 72 hours before the study^{6, 11}. During the Low Phase, following the healthcare center's

Fig. 1.– Patient selection for pulmonary function testing

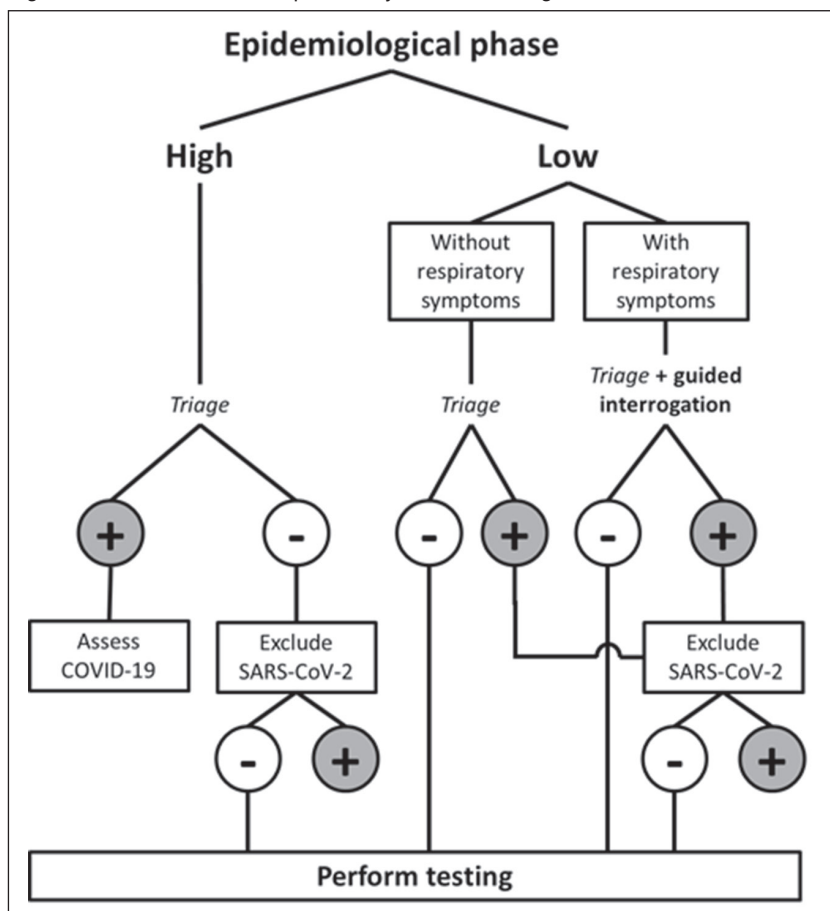


TABLE 1.— *Conditions that may require a pulmonary function test during the COVID-19 pandemic*

-
- Preoperative risk assessment for lung resection
 - Major surgical procedures in patients with pre-existing respiratory disease
 - Unavoidable evaluation of exacerbation or progressive deterioration of a known respiratory disease
 - Assessment of respiratory function before bone marrow or solid organ transplantation
 - Implementation and control of therapy with drugs potentially toxic for the respiratory system
 - Other considered clinically priorities at the discretion of the professional in charge of the LFP
-

experience and the institutional infection committee recommendations, the absence of criteria for a suspected case of COVID-19 through a remote evaluation 24 to 48 hours before the study and the confirmation in person by trained personnel could be considered enough to perform a simple PFT with low contaminating potential. In contrast to the use of direct methods of exclusion of SARS CoV-2 infection, the success of this strategy will depend on the experience and the resources of the center as well as on the local prevalence of the infection⁵ (Fig. 1). It should be borne in mind that rapid tests, such as the nasopharyngeal swab and RT-PCR test, can have a false-negative rate of up to 30%²⁷, depending on the moment in which they are performed and on some technical aspects of their obtention. Therefore, it is advisable to maintain certain protection and hygiene measures during the study as if it were a potentially infectious case.

Table 1 shows a list of situations proposed for the carrying out of PFTs. Each request must be evaluated by the professional in charge of the PFL, who will determine its feasibility based on biosafety regulations and will decide to accept or reject any or all of the requested tests. In the Low Phase, other indications for functional evaluation could be considered, such as clinical trials not related to COVID-19 or occupational health examination²⁸.

3. Which PFTs can be performed during the COVID-19 pandemic?

The risk of contagion for the operator depends on factors such as ventilation and ambient air exchange, distance from the patient, proper use of PPE, the number of infectious particles in the environment, and the possibility of their deposition in the airways and other mucous membranes, infectious inoculum, among other factors²⁹⁻³¹. Forced exhalation during PFTs generates the dissemination of respiratory secretions in the form of microparticles with a size of up to 20 µm in the environment close to the patient²⁹. While the largest particles can be expelled up to 2 meters, the smallest (less than 5 µm) can remain temporarily suspended in the air, especially when the ventilation of the room is inadequate. During forced respiratory maneuvers, an expiratory flow greater than

700 L/min can be generated, with high dissemination of respiratory secretions in the form of microdroplets³²⁻³⁴. This phenomenon may be more accentuated with coughing and during the performance of PFTs characterized by a sustained increase in ventilation³⁴.

When considering the performance of PFTs during the COVID-19 epidemic, those studies that provide the most useful and specific information for the case being explored, and that at the same time are the simplest, shortest, and with the least respiratory secretions aerosolization should be indicated. Among them, spirometry, arterial blood gas, and measurement of carbon monoxide diffusing capacity (DLCO), which provide the most relevant information for clinical decision-making, can be carried out with the appropriate precautionary measures for the epidemiological situation³⁵. Practices such as bronchial provocation tests and cardiopulmonary exercise testing, which include repetitive forced breathing maneuvers or a sustained increase in ventilation, should not be performed during the High Phase of the pandemic. Some international recommendations^{5, 6, 9-11} maintain that these examinations should be postponed until the COVID-19 epidemic is in the phase of defervescence and epidemiological control. The measurement of total lung capacity (TLC) by any of its techniques can rarely be considered essential³⁶, and it is advisable to be postponed until reaching the Low Phase (Table 2).

Regarding the 6-minute walk test, this working group recommends carrying it out preferably in external open spaces meeting the technical conditions required for this functional test (patios, open galleries, etc.)^{37, 38}. The use of corridors where patients and personnel circulate should be avoided to carry out the test; these could be considered to be performed in patients who meet post-COVID criteria. Depending on the risk assessment of contagion for the operator and third parties, the test could be carried out with or without a mask. When one of the previous options is chosen, the report should detail this modality, its influence on the Borg dyspnea scale, and the limitations of its interpretation against commonly used reference values.

In the Low Phase, the rest of the usual PFTs could be reintroduced, but always considering the absence of suspicion of viral infection, the use of appropriate PPE by

TABLE 2.— Recommended tests according to the epidemiological phase and condition of the patient

Test	High Phase		Low Phase	
	No evidence of SARS-CoV-2 infection	Post-COVID	No evidence of SARS-CoV-2 infection	Post-COVID
Spirometry	+	++	+	++
Lung volumes	–	++	+	++
DLCO	+	++	+	++
Six-minute walk test	–	+	+	++
Maximal static pressures	+	++	+	++
Arterial blood sampling	++	++	++	++
Maximum voluntary ventilation	–	+	+	++
Cardiopulmonary exercise testing	–	+	+	++
Bronchial provocation testing with non-nebulized challenge	–	+	+	++
Bronchial provocation testing with nebulized challenge	–	–	–	(*)

DLCO: diffusing capacity for carbon monoxide

– not recommended, very high risk of contagion

+ recommended, moderate risk of contagion

++ recommended, low risk of contagion

* there is insufficient evidence to date on the safety of this procedure³⁹

Other studies can be considered, according to the criteria of the legal person in charge and according to similarity with the practices detailed above

the intervening health personnel, the hygiene measures of the equipment, and the execution of the studies in a place following the sanitary measures recommended below.

4. How to perform PFTs to reduce the risk of SARS-CoV-2 spread

4a. Conditioning of the waiting room and management of shifts: it is recommended that scheduling and pre-study indications should be done remotely (telephone, cell phone applications, web portals). It is also suggested to administer an evaluation questionnaire (triage) by telephone 24-48 hours before the study. A medical professional should repeat the questionnaire when the patient presents for testing. Having a form for registration and control of canceled and deferred appointments is advisable. At all times, social contact between staff and patients should be minimized. Spaced appointments must be granted, estimating a minimum time of 30 minutes from the end of the previous study to the beginning of the next one, to carry out the conditioning and hygiene of the study room.

Adequate ventilation and air renewal in the waiting room and study premises are important to reduce the permanence of infectious particles in the environment^{32, 33}. The waiting room must be ventilated through windows or forced ventilation of air to the outside. Air recirculation systems (fans, split-type air conditioning units) should not be used without adequate external ventilation, even at the

cost of lower energy efficiency. Central air conditioning systems with an outside air intake are acceptable⁴⁰.

The virus can remain viable on various inert materials⁴¹. Several reports have found viral particles on various surfaces exposed to aerosols generated by patients with COVID-19⁴¹, and this route of infection is experimentally possible. However, there are no documented cases to date of transmission by fomites⁴². The virus present on these surfaces can be eliminated with the use of the frequently recommended decontaminants^{41, 43}. To make the room easy and quick to clean, it is advisable to avoid the presence of non-essential items such as brochures, posters, cushions, covers, curtains, decorations, water dispensers, etc.^{4, 44}. Seats and other surfaces must be made of washable material. Alcohol-based hand sanitizer or a washbasin with liquid soap and disposable paper towels should be accessible to waiting patients. Do not use bar soap or cloth towels. The number of people gathering simultaneously in the room must be kept to a minimum (a single companion per patient when necessary), with a distance of no less than 2 meters between patients (markings can be used on the seats) and ample circulation spaces. When this is not possible, the other patients will have to wait in another area of the center, or appointments will need to be granted at staggered hours. Patients and those accompanying them must wear a social mask at all times covering the nose, mouth, and chin^{45, 46}. It is advisable to place an information poster about hygiene measures in a visible place.

4b. Conditioning of the PFL or the room where PFTs are carried out: as well as the waiting room, it must be ventilated to the outside or have forced air ventilation to the outside. It is recommended that the windows are completely open, to guarantee the highest possible air exchange rate^{32, 33}. Recirculation systems, such as fans, should not be used without adequate ventilation to the outside. Centralized air conditioning systems with external air intake are acceptable, to which high-efficiency filters with the capacity to retain viruses and bacteria (HEPA) can be added and/or the installation of germicidal lamps of ultraviolet light type C⁴⁰.

Locally installed air conditioning equipment (split type) could be used if it is possible to have external ventilation, as well as proper and regular maintenance and cleaning of filters. Consider maintaining temperatures between 24-27° C with relative humidity between 50-60%^{40, 47}. Ventilation towards internal corridors or waiting rooms is not acceptable. Poorly ventilated rooms pose a high risk of contagion, especially for staff; in these cases, health institutions should consider moving the PFL to other areas of the building that meet the ventilation conditions mentioned.

Although the ventilation of the test area is important, it is advisable not to carry out studies with flow sensors in the open air or areas with air currents, since air currents can generate artifacts in measurements due to instantaneous changes in BTPS (body temperature, pressure, water vapor saturated) correction.

It is convenient to minimize the number of exposed surfaces to facilitate cleaning and decontamination of the rooms where the PFTs are carried out. Sodium hypochlorite, quaternary ammonium, or 70% alcohol solutions may be used. It is recommended that furniture is limited to the minimum, such as two chairs, a desk, and the equipment for measuring lung function, avoiding non-essential elements^{45, 46}. When entering the laboratory, the patient and his eventual companion should clean hands with alcohol-based hand sanitizer or soap and water.

There is evidence of airborne emission of particles from talking and breathing normally⁴⁸. The permanent use of a mask can help minimize this aerosolization. The patient must be at all times with the facemask in place, removing it only to perform the maneuvers. In exceptional cases, the presence of a second operator may be considered.

Maneuvers necessary to carry out functional tests can spread a large number of infective viral particles into the environment³², thus the use of antimicrobial filters is essential for containing them⁴⁹⁻⁵¹. The antimicrobial filter must be specifically designed for pulmonary function tests, and be for single patient and study use⁵¹. The operator must control the correct labial occlusion over the interface with the filter to minimize the possibility of air leakage during the maneuver.

During the pandemic period, multiple devices have been developed to limit the risk of contagion for operators

and patients. Among them, the use of sanitizing showers, carpets with disinfectants, ozonizers, etc. can be mentioned. However, at present, we did not find evidence to support their usefulness, and the application of some of such devices has been discouraged⁵². Also, the use of bulkheads has been suggested as a physical barrier between the operator and the patient at the time of testing; although they have disseminated both in the commercial and health fields, no literature supports them and their implementation emanates from common sense. Its use would prevent the projection of large particles, but not of small particles that float in the environment and can reach the operator's mucosae. Additionally, they can hinder interaction with certain populations that require assistance for mouthpiece placement or for achieving an adequate mouth closure, such as children, elderly, or neuromuscular patients. Therefore, their implementation is left to the criterion of the person in charge of the PFL and the institution. Their use does not prevent the need for ventilation, the use of antimicrobial filters, or the use of appropriate PPE for each situation, as we will see in the next section.

4c. Recommended protective equipment to carry out PFTs: the operator must use the PPE recommended for physical contact with a suspected COVID-19 patient following the regulations of the health authorities^{53, 54}.

PPE may include some or all of the following components, depending on the risk of exposure:

- Scrub set for exclusive use in the PFL
- Closed footwear
- Long hair tied
- Disposable cap and boots
- Disposable water-repellent gown
- N95 or FFP2 face mask
- Three-layer surgical mask
- Closed goggles
- Facial shield
- Disposable gloves

In high-risk scenarios (High Phase or with highly aerosolizing tests), the use of PPE level 3 is recommended, which is intended for assistance and physical contact with symptomatic respiratory patients and exposure to potentially infectious respiratory secretions. This includes an N95 (or FFP2) and surgical mask over the former to prolong its durability, eye or face protection, gown, gloves, cap, and disposable boots. In the Low Phase, it could be considered to dispense some components of the PPE (Table 3). However, its implementation must be agreed upon with the institutional and/or local health authority.

The use of gloves is not essential unless the operator has skin lesions on his hands or wrists. Proper handwashing between patients with soap and water or alcohol-based hand sanitizer is sufficient to eliminate the virus.

If more than one study needs to be carried out, more complete PPE should be used (Table 3).

TABLE 3.— Recommended protective equipment according to test and local transmission phase

Test	High Phase									Low Phase								
	Scrub set	Closed footwear	Disposable cap	Disposable boots	Gown	N95 facemask	Surgical facemask	Eye protection	Gloves	Scrub set	Closed footwear	Disposable cap	Disposable boots	Gown	N95 facemask	Surgical facemask	Eye protection	Gloves*
Spirometry	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓				✓	✓	✓	
Lung volumes	–	–	–	–	–	–	–	–	–	✓	✓				✓	✓	✓	
DLCO	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓				✓	✓	✓	
Six-minute walk test	✓	✓				✓	✓	✓		✓	✓					✓		
Maximal static pressures	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓				✓	✓	✓	
Arterial blood sampling							✓	✓	✓							✓	✓	
Maximum voluntary ventilation	–	–	–	–	–	–	–	–	–	✓	✓				✓	✓	✓	
Cardiopulmonary exercise testing	–	–	–	–	–	–	–	–	–	✓	✓				✓	✓	✓	
Bronchial provocation testing with non-nebulized challenge	–	–	–	–	–	–	–	–	–	✓	✓				✓	✓	✓	

DLCO: diffusing capacity for carbon monoxide

– the study is not available

Empty cells indicate that this guideline must be agreed upon with the local infection committee.

*Only recommended if there are skin lesions on hands and wrists

#there is insufficient evidence to date on the safety of this procedure³⁹

During the administration of inhaled bronchodilators and in the waiting period between the pre- and post-bronchodilator phase, the operator must remain with the PPE on and inside the study room. The administration of inhaled bronchodilators carries a high potential for aerosolization of viral particles. The use of spacers or air chambers does not prevent the emission of microdroplets into the environment. If the patient comes into contact with the aerosol actuator (canister holder), it must be decontaminated after use. Spacers and air chambers must also be discarded or decontaminated following the regulations of the center⁵⁵. The patient should stay in the study room between the phases of the study, and it is not recommended to intersperse patients between the phases of the bronchodilator test, as this implies decontamination and replacement of a new PPE for each phase.

Once the study is finished, the work area and any surface that may have come into contact with the operator or the patient should be cleaned. This cleaning can be carried out by the operator himself or by dedicated cleaning personnel, especially within a radius of two meters from the patient, taking into account the potential contamination with microdroplets of respiratory secretions. It should be clarified that the cleaning personnel

should enter the area with PPE identical to the one used by the operator. After cleaning the surfaces, the PPE components such as gloves, surgical mask, gown, cap, and boots should be discarded, and the goggles and face shield should be decontaminated with 70% alcohol or other suitable solutions⁵⁶. A period of at least 30 minutes must elapse between patients to allow ventilation, cleaning, and the change of PPE. Surface cleaning can be done with sodium hypochlorite solutions. The correct dilution of sodium hypochlorite for disinfection of critical areas is 1000 ppm and is dependent on the initial chlorine concentration. For example, starting from an initial concentration of 55 g of chlorine per liter, make the following count: $1000 \text{ (ppm)} \times 1000 \text{ (ml of water in the sprayer)} / 55000 \text{ (g of chlorine to mg)} = 20 \text{ ml of chlorine in 1 liter of water}$. Chlorinates are used on surfaces that have already been cleaned and rinsed. They are only used in sprayers. The minimum concentration for virus elimination is 500 ppm⁵⁷. This solution can be applied with a cloth and at least 5 minutes should be allowed to pass to achieve the elimination of the virus. For surfaces that could be damaged by sodium hypochlorite, it is recommended to use a concentration of 70% ethanol or quaternary ammonium solution, which are less corrosive.

Discussion

The COVID-19 pandemic has posed a significant challenge to biosafety during the performance of PFTs. Since airborne dissemination is the main form of interhuman transmission of this coronavirus, the implicit risk of the aerosolization of infecting droplets during the execution of PFTs has caused a significant limitation of activity in most of the PFL throughout the world. During the initial epidemic phase, the restriction of PFL activities was widely adopted as the best option (and perhaps the only one) to reduce the spread of the disease and the possibility of disease transmission to health personnel and patients^{5, 6, 58}. However, the value of PFTs for the diagnosis, evaluation, and control of the evolution of respiratory and systemic conditions, has prompted the need to agree on strategies aimed at adapting the activities of PFLs to the requirements of the COVID-19 pandemic. However, to date, there is still no consensus on a solid and uniform way to maintain the biosafety of PFLs in this situation⁵⁻¹⁵. In fact, in some international guidelines and recommendations, decision-making is delegated to the experience and operational availability of each PFL unit¹⁵. This shortcoming is due, at least partially, to the fact that even today the most important approach to PFL biosafety was focused on the cross-transmission of respiratory infections through the equipment⁵⁹, relegating patient to operator transmission, as well as the indirect spread of potentially infectious secretions to other patients and health personnel from contaminated inert surfaces of the equipment and the place where PFTs are performed.

The objective of this document is to update the recommendations for the management of PFLs in the context of the COVID-19 epidemic in Argentina based on an extensive review of other similar documents, published experimental and clinical studies, as well as on our initial recommendations issued in May 2020^{7, 8}. New recommendations have been incorporated in this edition for the management of PFTs in patients recovered from COVID-19, the performance of PFTs in the context of a High and Low Phase of community viral circulation, as well as biosafety of the procedures involving patients, operators, and health personnel. However, the review of the information consulted to support these recommendations shows the difficulty in obtaining a desirable level of category and quality degree. We think that this is partially due to the ethical limitation to carry out case-control studies to investigate the infectious potential of some PFL operating procedures, but also to the fact that in the last 20 years the PFL, in general, have relied on the biosafety of procedures in the very few reports of infections acquired through PFTs performance^{36, 59}. The reality of COVID-19 has abruptly ended with this fact, and, until we obtain more information about its impact in the field of PFL, the best available tools to conduct our task are the recommendations based on

the quality of the available evidence, mostly indirect, as well as on the adherence to basic and rational measures for the prevention of transmission of respiratory infections.

Summary of recommendations for PFLs in the COVID-19 era

The following recommendations may vary after the issuance of this document depending on new evidence and/or the local evolution of the epidemic, and eventual changes or modifications may be required in agreement with the institutional and/or local health authority, to adapt them to the reality of each workplace. For clarifications and annexes, refer to the full text.

a. To determine the feasibility of PFL activities, the local epidemiological evolution of COVID-19 must be taken into account, which may differ significantly, even between adjacent geographic areas and cities. For this reason, the situation in each different area must be carefully considered when defining the level of activity of the PFL.

b. Prevalence and incidence rate of the disease, curve progression of confirmed cases by region, basic reproductive number (R_0) of the infection (which estimates the speed of spread of the disease in the population), and time expected for duplication of cases should be analyzed together with the local infection control committee to define the epidemiological phases of the disease and agree on the strategies to develop the PFL activities.

c. The **High Phase** is defined as the local increasing or stable epidemic situation (high plateau) of the disease, characterized by a high circulation of the virus in the community. The **Low Phase** is defined as the local decrease in the number of new confirmed cases or low stable situation (low plateau) when the probability of spread of the infection is low.

d. During the High Phase, it is generally recommended not to perform PFTs. Only exceptional cases could be considered in which functional examination is indispensable to take urgent therapeutic measures.

e. During the Low Phase, it is suggested to consider the gradual opening of the PFL, maintaining the concept of performing only those PFTs necessary for the diagnosis or to decide on medical decisions that cannot be postponed.

f. It is recommended to defer all PFTs that are not essential for diagnosis or when indicated for routine monitoring of a known condition.

g. PFTs are not recommended in any patient with a current diagnosis of COVID-19, as well as in those who meet clinical criteria for a suspected case, in any of the epidemiological phases of the disease.

h. During the High Phase, in a patient with new or exacerbated respiratory symptoms, the diagnosis of COVID-19 should be excluded using any of the validated and approved diagnostic tests (nasopharyngeal swab and

RT-PCR test, saliva, etc.), considering the possibility of performing them within 72 hours before the functional test.

i. In patients who have not suffered from COVID-19 and require a PFT during the Low Phase, it is recommended to perform a triage questionnaire 24 to 48 hours before the execution of the PFT to examine criteria for a suspected case of COVID-19. Suspected cases will not be able to access the functional study until the SARS CoV-2 infection has been excluded.

j. Patients who have suffered from COVID-19 present very low infectious potential after 20 days of the symptomatic onset of the disease, for which its functional assessment is recommended starting 30 days from the onset of symptoms based on a careful clinical evaluation and the absence of signs and symptoms that could render suspicion of reinfection, without the need for further tests to exclude SARS CoV-2 infection.

k. During the Low Phase, following the healthcare center's experience and the institutional infection committee, the absence of criteria for a suspected case of COVID-19 through a remote evaluation 24 to 48 hours before the study followed by the confirmation in person by trained personnel could be considered enough to perform a simple PFT with low contaminating potential. In contrast to the use of direct methods of exclusion of SARS CoV-2 infection, the use of this strategy will depend on the experience and resources of the center, as well as the local prevalence of the infection.

l. When considering carrying out PFTs during the COVID-19 epidemic, those studies that provide the most useful and specific information for the case being explored and that at the same time are simple and brief examinations with the least possible respiratory secretion aerosolization should be indicated.

m. Spirometry, arterial blood gas, and measurement of CO transfer with single breath (DLCO) are examinations considered simple and can be performed with the appropriate precautionary measures for the epidemiological situation. The possibility of carrying out the 6-minute walk test is considered when external open spaces are available that meet the technical conditions required for this functional test.

n. Some conditions that may require PFTs include pre-operative risk assessment of lung resections, major surgical procedures in patients with pre-existing respiratory diseases, evaluation of an exacerbation or progressive deterioration of known respiratory diseases, evaluation before a bone marrow or solid organ transplantation, and the implementation and control of therapy with potentially toxic drugs for the respiratory system.

o. Bronchial provocation testing and cardiopulmonary exercise testing, which include repetitive forced breathing maneuvers or a sustained increase in ventilation, should not be performed during the High Phase of the COVID-19 epidemic.

p. In post-COVID or Low Phase patients, the rest of the usual PFTs could be reintroduced, but always considering the absence of suspicion of viral infection, the use of appropriate PPE by the intervening health personnel, the hygiene measures of the equipment, and carrying out the studies in a place following the recommended sanitary measures.

q. Scheduling and pre-study indications to perform PFTs must be managed remotely (telephone, cell phone applications, web portals). It is recommended to administer an evaluation questionnaire (triage) by telephone 24-48 hours before the study.

r. Spaced appointments should be granted, estimating a minimum time of 30 minutes from the end of the previous study to the beginning of the next one to carry out the conditioning and hygiene of the study room.

s. The waiting room and the PFL or the place where the PFTs are carried out must have ventilation towards the exterior. Air recirculation systems should not be used. Likewise, there must be elements for hand washing or alcohol-based hand sanitizer and respect the general biosafety regulations at all times: social distance, chin-strap or mask, staggered appointments, ample circulation spaces.

t. Furniture limited to a minimum is recommended in the PFL, such as two chairs, a desk, and lung function measurement equipment, avoiding non-essential items. Upon entering the laboratory, patients should sanitize their hands with alcohol-based hand sanitizer.

u. The operator and the patient are the only ones who must remain in the PFL unless a companion is essential. The patient must be with the face mask in place, removing it only to perform the maneuvers required for PFT. In exceptional cases, the presence of a second operator may be considered necessary.

v. All PFTs must be performed with disposable antimicrobial filters. The antimicrobial filter must be specifically designed for pulmonary function testing, and be single patient and study use.

w. In the High Phase, the use of level 3 PPE is recommended, which is intended for assistance and physical contact with symptomatic respiratory patients and exposure to potentially infectious respiratory secretions. In the Low Phase, it could be considered to dispense with some components of the EPP in agreement with the institutional and/or local health authority.

x. During the administration of an inhaled bronchodilator, and in the waiting period between the pre and post-bronchodilator phase, the operator must remain with the PPE on.

y. After each patient, the study area should be cleaned within a radius of at least 2 meters using disinfectant solutions. The operator can remove PPE only after cleaning is completed.

Acknowledgments: To Eduardo L. De Vito, Hernando Sala Romanó, and Andrea Guzmán, for their expert review of the contents of the document. To the *Asociación Argentina de Medicina Respiratoria* for their support in the distribution of the document, to the colleagues with whom we had the opportunity to debate the various topics that make up this document.

Conflict of interest: None to declare

References

- Liu J, Liao X, Qian S, et al. Community transmission of severe acute respiratory syndrome coronavirus 2, Shenzhen, China, 2020. *Emerg Infect Dis* 2020; 26: 1320-3.
- Chan J F-W, Yuan S, Kok K-H, et al. A familial cluster of pneumonia associated with the 2019 novel coronavirus indicating person-to-person transmission: a study of a family cluster. *Lancet* 2020; 395: 514-23.
- W. Guan, Z. Ni, Yu Hu, W. Liang, C. Ou, J. He, L. Liu, et al. The China Medical Treatment Expert Group for Covid-19* Clinical Characteristics of Coronavirus Disease 2019 in China. *N Engl J Med* 2020; 382: 1708-20.
- Kampf G, Todt D, Pfaender S, Steinmann E. Persistence of coronaviruses on inanimate surfaces and their inactivation with biocidal agents. *J Hosp Infect* 2020; 104: 246-51.
- ATS. Pulmonary Function Laboratories: Advice Regarding COVID-19. In: <https://www.thoracic.org/professionals/clinical-resources/disease-related-resources/pulmonary-function-laboratories.php>; accessed December 2020.
- Recommendation from ERS Group 9.1 (Respiratory function technologists/Scientists). Lung function testing during COVID-19 pandemic and beyond. In: <https://ers.app.box.com/s/zs1uu88wy51monr0ewd990itoz4tsn2h>; accessed December 2020.
- Recomendaciones para el laboratorio de función pulmonar en la era COVID-19. Sección Fisiopatología Respiratoria y Laboratorio Pulmonar Redactores: Juan J. Rodríguez Moncalvo, Javier C. Brea Folco, Santiago C. Arce, Roque A. Baldasaría, Orlando López Jove, Miriam G. Marcos, Carlos G. Di Bartolo. Revisores: Eduardo L. De Vito, Hernando Sala Romanó, Andrea Guzmán, 27 mayo 2020. In: https://www.aamr.org.ar/secciones/coronavirus/recomendaciones_laboratorio_funcion_pulmonar_cocov19.pdf; accessed December 2020.
- Recomendaciones para el laboratorio de función pulmonar en la era COVID-19 – AAMR en: COVID-19 Guidelines and Recommendations directory. ERS. In: <https://www.ersnet.org/covid-19-guidelines-and-recommendations-directory>; accessed December 2020.
- Sociedad Española de Neumología y Cirugía Torácica (SEPAR). Recomendaciones de prevención de infección por coronavirus en las unidades de función pulmonar de los diferentes ámbitos asistenciales. In: <https://enfermeriadeltrabajo.com/wp-content/uploads/2020/02/Documento-Recomendaciones-FUNCIO%CC%81N-PULMONAR-6.pdf>; accessed December 2020.
- Association for Respiratory Technology and Physiology. ARTP COVID19 Update -18th March 2020. In: www.artp.org.uk/write/MediaUploads/Standards/COVID19/ARTP_COVID19_Infection_Control_Issues_for_Lung_Function.pdf; accessed December 2020.
- SBAR for Performing Pulmonary Function Test in PFT labs. In: [https://www.nebraskamed.com/sites/default/files/documents/covid-19/Guidance-regarding-pulmonary-function-testing-\(PFT\).pdf?date=04012020](https://www.nebraskamed.com/sites/default/files/documents/covid-19/Guidance-regarding-pulmonary-function-testing-(PFT).pdf?date=04012020); accessed December 2020.
- American Academy Allergy of Asthma & Immunology. Spirometry during COVID-19. In: <https://www.aaaai.org/ask-the-expert/spirometry>; accessed December 2020.
- American College of Occupational and Environmental Medicine. ACOEM Advises Suspension of Routine Occupational Spirometry Testing During COVID-19 Pandemic. In: <https://acoem.org/News/Press-Releases/ACOEM-Advises-Suspension-of-Routine-Occupational-Spirometry-Testing-During-COVID-19-Pandemic>; accessed December 2020.
- OPS/OMS Argentina. Recursos de información relacionados con el nuevo coronavirus. In: https://www.paho.org/arg/index.php?option=com_content&view=article&id=10430:coronavirus&Itemid=226; accessed December 2020.
- Wilson KC, Kaminsky DA, Michaud G, et al. Restoring Pulmonary and Sleep Services as the COVID-19 Pandemic Lessens. From an Association of Pulmonary, Critical Care, and Sleep Division Directors and American Thoracic Society-coordinated Task Force. *Ann Am Thor Soc* 2020; 17: 1343-51.
- European Centre for Disease Prevention and Control. Reinfection with SARS-CoV: considerations for public health response: ECDC; 2020. In: <https://www.ecdc.europa.eu/sites/default/files/documents/Re-infection-and-viral-shedding-threat-assessment-brief.pdf>; accessed December 2020.
- Organización Panamericana de la Salud / Organización Mundial de la Salud. Orientaciones provisionales para la detección de casos de reinfección por el virus SARS CoV-2, 29 de octubre de 2020, Washington, D.C.: OPS/OMS, 2020. In: <https://www.paho.org/es/documentos/orientaciones-provisionales-para-deteccion-casos-reinfeccion-por-sars-cov-2>; accessed December 2020.
- Ministerio de Salud de la Nación. In: http://www.msal.gov.ar/index.php?option=com_bes_contenidos; accessed December 2020.
- Ridenhour B, Kowalik JM, Shay DK El número reproductivo básico (R_0): consideraciones para su aplicación en la salud pública. *American Journal of Public Health*, Supplement 6, 2018; 108.
- Ministerio de Salud. Definición de casos sospechoso. In: <https://www.argentina.gob.ar/salud/coronavirus-COVID-19/definicion-de-caso>; accessed December 2020.
- Centers for Disease Control, USA. Duration of isolation and precautions for adults with COVID-19. In: <https://www.cdc.gov/coronavirus/2019-ncov/hcp/duration-isolation.html>; accessed December 2020.
- Tillett RL, Sevinsky JR, Hartley PD, et al. Genomic evidence for reinfection with SARS-CoV-2: a case study. *Lancet Infect Dis* 2021; 21:52-8.
- Hoon Baang J, Smith C, Mirabelli C, et al. Prolonged

- SARS-CoV-2 replication in an immunocompromised patient. *J Inf Dis* 2020; jiaa666. doi: 10.1093/infdis/jiaa666. Online ahead of print.
24. George PM, Barrat SL, Condliffe R, et al. Respiratory follow-up of patients with COVID-19 pneumonia. *Thorax* 2020; 75: 1009-16.
 25. Ong K-C, Ng AW-K, Lee LS-U, et al. Pulmonary and exercise capacity in survivors of severe acute respiratory syndrome. *Eur Res J* 2004; 24:436-42.
 26. Zhao Y, Shang Y, Song W, et al. Follow-up study of the pulmonary function and related physiological characteristics of COVID-19 survivors three months after recovery. *E Clinical Medicine* 2020; 25: 100463.
 27. Kinloch NN, Ritchie G, Brumme CJ, et al. Suboptimal biological sampling as a probable cause of false-negative COVID-19 diagnostic test results. *J Inf Dis* 2020; 222: 899-902.
 28. Inicio o reinicio del reclutamiento de personas sanas para estudios de farmacología clínica. In: <https://www.argentina.gob.ar/noticias/inicio-o-reinicio-del-reclutamiento-de-personas-sanas-para-estudios-de-farmacologia-1>; accessed December 2020.
 29. Tellier R. Aerosol transmission of influenza A virus: a review of new studies. *J R Soc Interface* 2009; 6: S783-90.
 30. Brusasco V, Crapo R, Viegi G, et al. ATS/ERS Task Force: Standardization of Lung Function Testing: general considerations for lung function testing. *Eur Respir J* 2005; 26: 153-61.
 31. Tran K, Cimon K, Severn M, et al. Aerosol generating procedures and risk of transmission of acute respiratory infections to healthcare workers: A Systematic Review. *PLoS ONE* 2012; 7: e35797.
 32. Bourouiba L, Hu DL, Levy R. Surface-tension phenomena in organismal biology: an introduction to the symposium. *Integr Comp Biol* 2014; 54: 955-8.
 33. Bourouiba L. Turbulent gas clouds and respiratory pathogen emissions: potential implications for reducing transmission of COVID-19. *JAMA* 2020; 323: 1837-8.
 34. Kendrick AH, Johns DP, Leeming JP. Infection control of lung function equipment: a practical approach. *Respir Med* 2003; 97: 1163-79.
 35. Miller MR, Crapo R, Hankinson J, et al. General considerations for lung function testing. *Eur Respir J* 2005; 26: 153-61.
 36. Enright P. Body plethysmography is not helpful for COPD diagnosis, Determination of severity, phenotyping, nor response to therapy. *COPD* 2015; 12: 595-7.
 37. ATS Committee on Proficiency Standards for Clinical Pulmonary Function Laboratories. ATS statement: guidelines for the six-minute walk test. *Am J Respir Crit Care Med* 2002; 166: 111-7.
 38. Holland AE, Spruit MA, Troosters T, et al. An official European Respiratory Society/ American Thoracic Society technical standard: field walking tests in chronic respiratory disease. *Eur Respir J* 2012; 44: 1428-46.
 39. Amirav I, Newhouse MT. Transmission of coronavirus by nebulizer: a serious, underappreciated risk. *CMAJ* 2020; 192: E346.
 40. Comunicado Capítulo Argentino ASHRAE/AADAIH. In: <https://ashraeargentina.com/wp-content/uploads/Comunicado-ASHRAE-Argentina-21102020.pdf>; accessed December 2020.
 41. van Doremalen N, Bushmaker T, Morris DH, et al. Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1. *N Engl J Med* 2020; 382: 1564-7.
 42. Magurano F, Baggieri M, Marchi A, et al. SARS-CoV-2 infection: the environmental endurance of the virus can be influenced by the increase of temperature. *Clin Microbiol Infect* 2020. S1198-743X(20)30688-1. doi: 10.1016/j.cmi.2020.10.034.
 43. CDC Guidance for cleaning and disinfecting. CS316485C September 16, 2020 10:42 AM. In: https://www.cdc.gov/coronavirus/2019ncov/community/pdf/Reopening_America_Guidance.pdf; accessed December 2020.
 44. Ren SY, Wang WB, Hao YG, et al. Stability and infectivity of coronaviruses in inanimate environments. *World J Clin Cases* 2020; 8: 1391-9.
 45. Protocolo de manejo de individuos que requieran consulta ambulatoria programada en el contexto de la pandemia Covid-19 del Gobierno de la Ciudad de Buenos Aires. In: <https://www.buenosaires.gob.ar/coronavirus/protocolo-de-manejo-frente-casos-confirmados-y-sospechosos-de-coronavirus-covid-19-2>; accessed December 2020.
 46. Buenos Aires Ciudad. Protocolo para la atención odontológica de urgencia. In: <https://www.buenosaires.gob.ar/coronavirus/protocolos-coronavirus-covid-19/protocolo-de-manejo-de-individuos-que-requieren-atencion>; accessed December 2020.
 47. World Health Organization. Coronavirus disease (COVID-19): Ventilation and air conditioning. In: <https://www.who.int/news-room/q-a-detail/coronavirus-disease-covid-19-ventilation-and-air-conditioning>; accessed December 2020.
 48. Asadi S, Wexler AS, Cappa CD, Barreda S, Bouvier NM, Ristenpart WD. Aerosol emission and superemission during human speech increase with voice loudness. *Sci Rep* 2019; 9: 2348.
 49. Hazaleus RE, Cole J, Berdischewsky M. Tuberculosis skin test conversión from exposure to contaminated pulmonary function testing apparatus. *Respir Care* 1981; 26: 53-5.
 50. Gough J, Kraak WAG, Anderson EC, Nichols WW, Slack MPE, McGhie D. Cross-infection by nonencapsulated Haemophilus influenzae. *Lancet* 1990; 336: 159-60.
 51. Zhang Y. High justification for universal stringent precautions in lung function testing. *Respir Med* 2005; 99: 1064-6.
 52. ANMAT informa. Acerca de las cabinas sanitizantes o túneles de desinfección. In: <https://www.argentina.gob.ar/noticias/acerca-de-las-cabinas-sanitizantes-o-tuneles-de-desinfeccion>; accessed December 2020.
 53. Buenos Aires Ciudad. Recomendaciones para el uso de los equipos de protección personal (EPP). In: <https://www.buenosaires.gob.ar/coronavirus/protocolos-coronavirus-covid-19/recomendaciones-para-el-uso-de-los-equipos-de-proteccion>; accessed December 2020.
 54. Recomendaciones para el uso de los EPP del Ministerio

- de Salud de la Nación. In: <https://www.argentina.gob.ar/salud/coronavirus-COVID-19/recomendaciones-uso-epp>; accessed December 2020.
55. Arce SC, Baldasaria RA, Brea Folco JC, Rodríguez Moncalvo JJ. Bioseguridad y prevención de infecciones cruzadas durante la realización de estudios de función pulmonar. *Rev Am Med Respir* 2020; Supl. Especial Covid-19: 25-31.
 56. Ong SWX, Tan YK, Chia PY, et al. Air, surface environmental, and personal protective equipment contamination by Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) from a symptomatic patient. *JAMA* 2020; 323: 1610-2.
 57. Ministerio de Salud de la Nación. COVID-19. Limpieza y Desinfección del Material Sanitario, Superficies y Ambientes. In: <http://www.msal.gob.ar/images/stories/bes/graficos/0000001899cnt-covid-19-recomenedaciones-limpieza-desinfeccion.pdf>; accessed December 2020.
 58. Burgos Rincón F, Martínez Llorens J, Cordovilla Pérez R. Impact of the COVID-19 pandemic on lung function laboratories: considerations for “today” and the “day after”. *Arch Bronconeumol* 2020; 56: 611-2.
 59. Sylvester KP, Clayton N, Cliff I, et al. ARTP statement on pulmonary function testing 2020. *BMJ Open Respir Res* 2020; 7: e000575.