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Practical considerations for Spirometry during the COVID-19 outbreak: Literature Review and Insights

Claudia Crimi[1], Pietro Impellizzeri[2], Raffaele Campisi[1], Santi Nolasco[2], Antonio Spanevello[3], Nunzio Crimi[1,2]

[1] Respiratory Medicine Unit, A.O.U. "Policlinico-Vittorio Emanuele", Catania, Italy
[2] Department of Clinical and Experimental Medicine, Section of Respiratory Medicine, A.O.U. "Policlinico-Vittorio Emanuele", University of Catania, Italy
[3]Istituti Clinici Scientifici Maugeri IRCCS, Tradate, Italy

Claudia Crimi: Respiratory Medicine Unit, A.O.U. "Policlinico-Vittorio Emanuele", Catania, Via Santa Sofia, 78, Catania, Italy. Email: dott.claudiacrimi@gmail.com
Pietro Impellizzeri: Department of Clinical and Experimental Medicine, Section of Respiratory Medicine, A.O.U. "Policlinico-Vittorio Emanuele", University of Catania, Via Santa Sofia, 78, Catania, Italy. Email: pietroimpellizzeri2018@gmail.com
Raffaele Campisi: Respiratory Medicine Unit, A.O.U. "Policlinico-Vittorio Emanuele", Catania, Via Santa Sofia, 78, Catania, Italy. Email: raffaelemd@hotmail.it
Santi Nolasco: Department of Clinical and Experimental Medicine, Section of Respiratory Medicine, A.O.U. "Policlinico-Vittorio Emanuele", University of Catania, Via Santa Sofia, 78, Catania, Italy. Email: nolascos@hotmail.it
Antonio Spanevello: Istituti Clinici Scientifici Maugeri IRCCS, Via Crotto Roncaccio, 16, 21049 Tradate, VA, Italy. Email: antonio.spanevello@icsmaugeri.it
Nunzio Crimi: Respiratory Medicine Unit, Department of Clinical and Experimental Medicine, Section of Respiratory Medicine, A.O.U. "Policlinico-Vittorio Emanuele", University of Catania, Via Santa Sofia, 78, Catania, Italy. Email: crimi@unict.it

*Corresponding Author
Claudia Crimi
Respiratory Medicine Unit
A.O.U. "Policlinico-Vittorio Emanuele",
Via Santa Sofia, 78

Catania, 95123, Italy
Tel: +390953781423
Fax: +390953781423
E-mail:dott.claudiacrimi@gmail.com

Words: 3581

Abstract

Background: As the Coronavirus disease 2019 (COVID-19) is spreading worldwide, countries are dealing with different phases of the pandemic.

Lately, scientific evidence has been growing about the measures for reopening respiratory outpatient services during the COVID-19 pandemic. We aim to summarize the key differences and similarities among recommendations by different national and international organizations.

Methods: We searched on Google and Pubmed for recently published National and International Recommendations/Guidelines/Position Papers from professional organizations and societies, offering a guidance to physicians on how to safely perform pulmonary function testing during COVID-19 pandemic. We also searched for spirometry manufacturers' operational indications.

Results: Indications on spirometry were released by the Chinese Task force, the American Thoracic Society, the European Respiratory Society, the Thoracic Society of Australia and New Zealand, the Société de Pneumologie de Langue Française, the Spanish Societies (Sociedad Espanola de Neumologia y Cirugia Toracica, Sociedad Espanola de Alergologia e Inmunologia Clinica, Asociacion de Especialistas en Enfermeria del trabajo, Asociacion de Enfermeria Comunitaria), the Sociedade Portuguesa de Pneumologia, the British Thoracic Society/Association for Respiratory Technology & Physiology, the Irish Thoracic Society, the Sociedad Uruguaya de Neumologia, the Italian Thoracic Society and the Italian Respiratory Society, Cleveland Clinic and Nebraska Medical Center. Detailed technical recommendations were found on manufacturers' websites.

We found several similarities across available guidelines for safely resuming pulmonary function services, as well as differences in criteria for selecting eligible patients for which

spirometry is deemed essential and advice which was not homogenous on room ventilation precautions.

Conclusions: This study shows a synthesis of national/international guidelines allowing practicing physicians to adapt and shape the way to organize their outpatient services locally. There is generally good agreement on the importance of limiting pulmonary function testing to selected cases only. However, significant differences concerning the subsets of candidate patients, as well as on the management of adequate room ventilation, were observed.

Abbreviations:

ACH: air changes per hour

ARTP: Association for Respiratory Technology and Physiology

BTS: British Thoracic Society

COVID-19: Coronavirus disease 2019

WHO: World Health Organization

ANZSRS: Australian and New Zealand Society of Respiratory Science Ltd

AET: Asociacion de Especialistas en Enfermeria del trabajo

AEC: Asociacion de Enfermeria Comunitaria

ATS: American Thoracic Society

CLEVELAND: Respiratory Institute Cleveland Clinic

COPD: Chronic obstructive pulmonary disease

ERS: European Respiratory Society

HCWs: health care workers

ITS: Irish Thoracic Society

IRS/SIP: Italian Respiratory Society/Società Italiana di Pneumologia

ITS/AIPO: Italian Thoracic Society/Associazione Italiana Pneumologi Ospedalieri

PFTs: pulmonary function tests

PPE: personal protective equipment

SEAIC: Sociedad Espanola de Alergologia e Inmunologia Clinica

SEPAR: Sociedad Espanola de Neumologia y Cirugia Toracica

SPLF: Société de Pneumologie de Langue Française

SPP: Sociedade Portuguesa de Pneumologia

SUNEUMO: Sociedad Uruguaya de Neumologia

TSANZ: Thoracic Society of Australia and New Zealand

UV: ultraviolet

Keywords: COVID-19, SARS-CoV-2, pulmonary function test, spirometry, outpatient clinic, safety, guidelines.

INTRODUCTION

Coronavirus disease 2019 (COVID-19) has spread worldwide, becoming a public health emergency of international concern [1], officially designated as a pandemic by World Health Organization (WHO) on March 11 [2]. COVID-19 has had a high impact on the health care system, necessitating unprecedented measures for containing the infection, shutting down all the outpatient activities and providing treatment only for emergency cases [3].

The infection is mainly transmitted by respiratory droplets [4] and close contacts, so both pulmonologists and their patients are at high risk of COVID-19 transmission during the outpatient visit and the pulmonary function testing procedures.

Therefore, in the early phases of the pandemic some International Societies such as the Chinese expert consensus [5], the American Thoracic Society (ATS) [6], the Thoracic Society of Australia and New Zealand (TSANZ/ANZSRS) [7], the Sociedade Portuguesa de Pneumologia (SPP) [8], the Société de Pneumologie de Langue Française (SPLF)[9], the Spanish Societies [Sociedad Espanola de Neumologia y Cirugia Toracica (SEPAR), Asociacion de Enfermeria Comunitaria (AEC), Asociacion de Especialistas en Enfermeria del trabajo (AET), Sociedad Espanola de Alergologia e Inmunologia Clinica (SEAIC)][10] and the Irish Thoracic Society (ITS) [11], recommended stopping or postponing pulmonary visits and pulmonary function tests (PFTs) during the pandemic surge unless deemed clinically essential [5-8, 11, 12].

Nevertheless, PFTs cannot be delayed for a long time in some patients' groups. Moreover, a respiratory follow-up of patients who recovered from COVID-19 pneumonia is crucial in the monitoring of a possible fibrotic complication of the disease which could lead to a reduction of the pulmonary function [1, 5].

Entering the second phase of the COVID-19 pandemic, we need to consider that the infection will remain endemic and we have to coexist with the disease, which will

become a part of the routine practice. Therefore, hospitals have to be prepared to safely bring back regular ambulatory services and PFT labs, especially to assess patients suffering from pre-existing chronic respiratory diseases, to prevent their risk of mortality and disability.

To date, several official Recommendations/Guidelines from National and International Societies, hospitals or professional organizations have been released on this topic with operational indications during the COVID-19 surge [5-11, 13]. Some Organizations updated their own documents [14-16], and other Societies, such as the European Respiratory Society (ERS) [17], the British Thoracic Society/Association for Respiratory Technology & Physiology (BTS/ARTP) [12], the Sociedad Uruguaya de Neumologia (SUNEUMO) [18], the Italian Thoracic Society (ITS/AIPO) [19], and the Italian Respiratory Society (IRS/SIP) [20], as well as renowned medical centers such as Cleveland Clinic [21], recently published statements.

We aim to summarize the available official recommendations on the use of spirometry in the context of COVID-19 infection and to compare them, reviewing in detail the most important aspects, such as eligible patients, health-care workers' and patients' protection, equipment, and environmental management to prevent COVID-19 transmission. These results will help practicing physicians make decisions on how to safely reshape and reopen ambulatory services, tailoring measures to the specific context of their needs, and organizational issues [22].

METHODS

We searched and reviewed all recent Guidelines, Consensus documents, Statements, and Position Papers from National and International Societies or local policies of medical centers on how to perform spirometry during COVID-19, published on official websites in four languages: English, Italian, French and Spanish.

To increase the search strategy's sensitivity, we also searched on Google the websites of the spirometer manufacturers using the following terms: COVID-19, Sar-Cov-2, spirometry, pulmonary function test.

RESULTS

We considered the challenging issues related to performing spirometry and the solutions that may be adopted, as suggested by official Recommendations.

Table 1 summarizes Societies' Recommendations on performing PFTs.

Eligible patients

There was an overall good agreement among Guidelines on limiting PFTs to patients really needed them, weighing the benefits of ongoing care and clinical evaluation with "exposure risk" to COVID-19 for individuals coming to the hospital. Nevertheless, we found heterogeneous indications on the subgroup of patients considered a priority.

The ATS [6] and ERS [17] Recommendations generically advise performance of PFTs when they are essential for immediate treatment decisions of the current illness. At the same time, SPP [16], SPLF [9] and BTS/ARTP guidelines [12] strongly encourage performing essential procedures only in cancer patients or in cases of pre-operative assessments for urgent surgery. In contrast, the recent update of the Australian Guidelines [14] suggests that asymptomatic patients might undergo PFTs, especially in cases of a pre-operative evaluation for elective surgery. The ITS [11] Guidelines recommend performing PFTs in patients with cystic fibrosis and rapid access lung cancer and in those needing a pre-operative assessment for emergency surgery. Furthermore, they recommend spirometry in immunocompromised patients for urgent treatment (e.g. bone marrow transplant, lung transplants, pre-chemotherapy treatments), suggesting testing them first on the day. Conversely, the Chinese expert Recommendations [5] limit PFTs only to patients needing them; moreover, they specify that in patients with asthma and chronic obstructive

pulmonary disease (COPD), the test might be suspended unless urgently needed for diagnosis and treatment, suggesting the use of a peak flow meter for self-monitoring the lung function. Similar indications come from the Position Paper of the ITS/AIPO Italian Society [19], which also prioritizes patients needing thoraco-abdominal surgery. The latest released IRS/SIP Recommendations [20], provide more broad indications, including the diagnosis of COPD and asthma and interstitial lung diseases, the follow-up and the antifibrotic drugs prescription. Cleveland [21] is the only Organization that also mentions patients with pulmonary hypertension, while SUNEUMO [18] also takes into account patients with pneumoconiosis and respiratory drug toxicity. Finally, the SEPAR/AEC/AET/SEAIC[10] Recommendations suggest performing PFTs in negative rooms and postponing them unless urgently needed.

As regards patients recovered from COVID-19 experiencing persistent or evolving respiratory complications, BTS/ARTP [12] Guidelines propose a detailed follow-up: all patients recovered from a severe (hospitalized in Intensive Care Unit/High Dependency Unit, or necessitating protracted dependency on a high fraction of inspired oxygen or noninvasive ventilation during the hospital stay, or discharged with oxygen or with significant ongoing respiratory symptoms*)* or a mild to moderate pneumonia, or clinically improved patients with persistent changes in the chest X-ray 12 weeks post-discharge, should undergo PFTs.

Patients with a previous COVID-19 pneumonia are also mentioned by the ERS[17] Guidelines that only specify that these patients must not be tested for a minimum of 30 days post-infection. The ITS/AIPO [19] Position Paper recommends a documented negative swab test 48-72 h before PFTs or arranging dedicated post-COVID PFTs lab facilities, while IRS/SIP [20] Guidelines state that these patients need to be tested without specifying any strategy. No specific indications for PFTs in COVID-19 recovered patients are mentioned by the other Guidelines.

Patient management: measures to ensure social distancing

To safely restart PFTs services, it is mandatory to appropriately assess each outpatient, considering everyone as a potential symptomatic or asymptomatic COVID-19, avoiding at the same time denying access to many patients. All Guidelines are generally encouraging similar strategies to guarantee health safety, are implementing measures to warrant social distancing and to identify suspected patients for limiting the transmission of the infection, are ensuring the safety of health-care workers (HCWs) with adequate personal protective equipment (PPEs), because subclinical patients may still transmit the virus.

Patient visit

Chinese [5], ITS/AIPO [19], IRS/SIP [20], and Irish Recommendations particularly emphasize that patients should be scheduled for a visit at a specific date and time, in order to avoid early arrival of the patient and crowded waiting rooms.

The Irish Thoracic Society specifies that patients booked for a visit should wait in their own car, entering the department for testing only after a phone call by the administrative team [11]. No mention of scheduled visits was formulated by ATS [6], BTS/ARTP [12], TSANZ/ANZSRS [14], SSP [8], SUNEUMO [18] , SPLF[9], SEPAR/AEC/AET/SEAIC[10] Societies.

Waiting rooms

The Recommendations generally encourage patients to come to the visit alone, without accompanying persons, when possible, or limited to one caregiver if they need support. Maintaining a minimum of 2 meters distance between sitting patients is recommended by Irish [11], Chinese [5], ITS/AIPO [19], ERS [17], and BTS/ARTP [12] Societies, while SEPAR/AEC/AET/SEAIC limit the distance to at least 1 meter.

Furthermore, the Chinese task force [5], and ITS/AIPO [19] Position Paper suggest making a demonstration video focused on the maneuvers for correctly performing spirometry and to project it in the waiting area, enabling patients to be prepared before the visit, while SEPAR/AEC/AET/SEAIC[10] Societies recommend to use educational posters.

Patient entrance

ERS [17] and ITS/AIPO [19], IRS/SIP [20], Portuguese [16], SPLF [9] and Nebraska medical center [15] Guidelines specify that patients coming to their visit should wear a mask, stressing that patients without a mask will not be allowed to enter the outpatient facility.

SEPAR/AEC/AET/SEAIC [10] Societies suggest wearing a mask only if patients have respiratory symptoms.

Screening

All the Guidelines besides ATS [6], TSANZ/ANZSRS [14] and BTS/ARTP [12] recommend administering a symptoms screening questionnaire to patient on arrival and checking body temperature, in order to verify if they are likely to have a COVID-19 infection. A sample screening questionnaire is provide by ERS [17], ITS/AIPO [19] and IRS/SIP [20] documents.

ITS/AIPO [19], IRS/SIP [20], Irish [11] and Chinese task force [5] specify that the questionnaire, when possible, might also be administered by telephone (tele-screening) 48-72 hours before the visit. Body temperature detection alone is recommended only by TSANZ/ANZSRS [14] Guidelines: if the temperature is greater than 37.3°C, the visit will be suspended. No information on PPE to be used by the personnel during the triage is provided by any Guidelines.

ITS/AIPO [19] and IRS/SIP [20] Guidelines strongly recommend a documented negative swab test 48-72 h before PFTs for suspected cases, while ITS/AIPO [19] Guidelines encourage physicians to arrange dedicated post-COVID-19 PFTs lab facilities.

Patient preparation

After this screening phase, the patient will perform careful hand hygiene and enter the PFTs operative room; ITS/AIPO [19] Guidelines specify that patients need to wear gloves too.

HCWs protection

There is a lack of evidence about whether the PFTs should be considered aerosol-generating procedures. Nevertheless, HCWs assigned to PFTs lab should adopt all the precautionary measures suggested by WHO, since the procedure needs close contact with the patient and can induce coughing, similar to that induced by collecting diagnostic respiratory samples (e.g. nasopharyngeal swab). All Societies cautiously recommend PPEs use for HCWs performing PFTs, specifying that HCWs should wear filtering facepiece respirators FFP3 or, when not available, FFP2 and eye protection. Only SPLF [9] Guidelines state that HCWs can use a simple surgical mask. Changing disposable gloves between patients is highly recommended and rigorous hand hygiene is essential. BTS/ARTP [12] Guidelines further specify that HCWs also need to wear a fluid-resistant gown and a disposable plastic apron, while IRS/SIP[20], SPLF [9] and SEPAR/AEC/AET/SEAIC [10] Guidelines mention only the gown. However, the Chinese task force [5] and Portuguese [8] Guidelines recommend the use of overshoes and surgical hats and replacing masks, gloves, and protective glasses if contaminated with saliva, sputum, and other secretions.

Furthermore, Chinese task force [5], SEPAR/AEC/AET/SEAIC[10] and ITS/AIPO Position Paper [19] for an additional level of safety consider it appropriate that the chair direction of the PFTs operator should sit beside the patient, facing the same way, and recommend avoiding sitting face to face.

Equipment management

Spirometry systems are not designed to be sterile. There are three main potential sources of cross-contamination when performing the test: skin contact, aerosolized particles and saliva/body fluids; therefore, hygiene measures to protect users are crucial.

Filter

The ERS [17], BTS/ARTP [12], SEPAR/AEC/AET/SEAIC [10] and ITS/AIPO [19] Guidelines specify that in-line bacterial/viral filters should be used to protect the whole circuit from

contamination with exhaled microorganisms, and the patient from inhaling particles from the circuit, while ATS [6], ITS [11] and TSANZ/ANZSRS [14] Guidelines do not specify any precaution in this regard.

To ensure the protective effect, BTS/ARTP [12] Guidelines recommend using in-line filters with a high-quality filtration performance against viruses but with proven evidence of not altering function measurements. Similarly, ITS/AIPO [19] and the Chinese Task force [5] state that verification of the total resistance of the filter and lung respiratory tube function instrument should be < 1.5 cmH_2O at a flow rate of 0-14 $L / s \cdot L^{-1} \cdot s^{-1}$, in order to not affect the results of the lung function test. At the same time, ERS [17] Guidelines suggest selecting a filter with a minimum proven efficiency for a high expiratory flow of 600 to 700 L/min.

Interestingly, only the SPLF [9] Guidelines recommend performing PFTs in a plethysmography boot with a shut door.

Bronchodilator

As far as bronchodilator challenge is concerned, TSANZ/ANZSRS [14] Societies suggest using the patient's own salbutamol inhaler or a single-use inhaler, while ITS [11] Guidelines recommend considering the use of Turbohaler or an aerosol holding chamber (spacer) device (i.e. aerochamber), the latter also endorsed by the Portuguese Society [16].

Equipment Cleaning

The use of in-line filters does not preclude the necessity for thorough cleaning of the equipment. After each use, equipment cleaning with 75 % ethanol for 3 minutes twice is recommended by the Chinese task force [17]. SEPAR/AEC/AET/SEAIC[10] and BTS/ARTP Guidelines [12] also describe in detail the type of disinfectant solution, as shown in **Table 1**. A general statement regarding regular equipment cleaning protocol following local policies is advised by IRS/SIP [20].

Nose-clip

The use of disposable nose clips is strongly recommended by ERS [17], BTS/ARTP [12], ITS/AIPO [19], IRS/SIP[20] and SEPAR/AEC/AET/SEAIC[10] Guidelines.

Environment management

Ventilation

Airborne transmission occurs through the dissemination of droplets from infectious patients; the motion of droplets significantly depends on gravity, direction and strength of local airflow, temperature, and relative humidity. It is crucial, therefore, to perform the spirometry in a properly ventilated room, in order to control any possible cross-infection. Ventilation is defined as the supply/distribution or removal of air from a space by mechanical or natural procedures. The clearance rate of aerosols in a closed space is dependent on the extent of any mechanical or natural ventilation; therefore, the greater the ventilation rate, expressed as the number of air changes per hour (ACH), the sooner any aerosol will be cleared [23]. A single air change is estimated to remove 63% of airborne contaminants: after 5 air changes, less than 1% of airborne contamination is thought to remain [24]. A minimum of 20 minutes, that is 2 air changes, in hospital settings, where most of these procedures occurs, is considered pragmatic [25].

Nevertheless, the issue of adequate ventilation was considered only by ERS [17], ITS/AIPO [19], BTS/ARTP [12], Chinese task force [5], SUNEUMO [18] and Nebraska Medical Center [15] Recommendations. SEPAR/AEC/AET/SEAIC[10] and Portuguese[8] Guidelines generally suggest avoidance of air recycling.

In particular, adequate room ventilation, i.e. at least 15 minutes to ventilate the room (open windows, closed doors), is recommended by SPLF[9], ERS [17] and ITS/AIPO [19] Guidelines. Negative isolation rooms with 6-12 ACH or side rooms with 6 ACH are encouraged by BTS/ARTP [12] Guidelines.

The Nebraska Medical Center [15] states that the procedure room should remain closed for an hour after the PFTs. The Chinese task force [5] recommend maintaining the ventilation of

the lung function examination room, ensuring 12 ACH if operating in a negative isolation room or an air flow of at least 160 L / s per patient or hourly in a naturally ventilated room, as well as opening windows as much as possible for natural ventilation.

Chinese [5], SEPAR/AEC/AET/SEAIC [10] and ITS/AIPO Guidelines [19] proposed separating the test area from the administrative area of the room.

Room and surfaces cleaning and infection control.

All the reviewed Guidelines agreed on the importance of cleaning equipment and surfaces; SEPAR/AEC/AET/SEAIC[10], BTS/ARTP [12] and Chinese [5] Guidelines also recommend the type of cleaning solution to be used, **Table 1**.

Disposable cleaning wipes were strongly recommended by SEPAR/AEC/AET/SEAIC [10] BTS/ARTP [12], ITS [11], and Cleveland Clinic [21] Guidelines, but only TSANZ/ANZSRS and SEPAR/AEC/AET/SEAIC[10] Guidelines expressly recommend the presence of minimal furnishings that can be easily cleaned and disinfected [14].

As regards PFTs operating room cleaning, ERS [17] ITS/AIPO [19] and IRS/SIP [20] Guidelines suggest the use of UV light or ozone room decontamination at intervals, compliant with local infection policies, while more detailed precautions are provided by the Chinese task force [5].

The Chinese task force also recommend switching off the central air conditioner, sanitizing the room at least twice a day, using UV light for at least 30 min a day to clean the air and medical air purification devices for air disinfection during lung function tests.

Waiting time between patients

The suggested time required between visits by ERS [17], BTS/ARTP [12] Guidelines is 30 min for a regular side room and 60 min for a negative isolation room. The Portuguese Society [16] recommends a period time of 60 minutes between visits and the Nebraska medical center [15] specifies that the operating room must be closed for 1 hour after the visit.

Interesting suggestions come from ITS/AIPO [19] and SPLF [9] Guidelines that recommend a new calibration of the spirometer after the cleaning procedures, and from ERS [17], the only Society that takes into account high-risk patients, that suggest performing a remote test with live video instructions in these subgroups of patients.

A plan to manage the respiratory issues of people with acute respiratory symptoms, pre-existing chronic lung diseases or conditions that need adequate pulmonary function assessment to be appropriately diagnosed and treated, is essential to prevent an inevitably indirect effect of COVID-19 on frail patients that could be devastating, increasing death and disability.

Manufacturers' policies

Manufacturers' policies[26-29] are summarized in **Table 2**.

DISCUSSION

The COVID-19 pandemic completely changed the routine of providing health-care services, shifting from elective to essential/acute management and limiting several diagnostic resources for chronic respiratory patients such as pulmonary function labs and sleep labs [30]. We analyzed Society-specific clinical practice Guidelines on how to safely perform PFTs and the recommendation level of consensus for each clinically relevant problem; we found similarities but also several differences. In particular, the Societies' Guidelines on spirometry during the COVID-19 outbreak differ greatly in relation to the subgroup of patients that need to be prioritized for testing.

The Guidelines agreed about prioritizing patients with urgent need to initiate treatment and pre-operative assessment, except Cleveland [21], which takes into account also pulmonary hypertension patients, IRS/SIP [20], which also considered patients with a diagnosis of pulmonary fibrosis and follow-up and for therapy prescription, as well as patients with a

diagnosis of asthma and COPD , and Uruguayans [18] Guidelines, providing indications also for pneumoconiosis and drug toxicity.

We identified a recommendation level of consensus on patient screening, on HCWs protection, and on the use of in-line filters for spirometry, but a little reference to adequate ventilation policies. No details on PPEs that should be worn by the triage personnel were found, as well as no indications on how to safely perform spirometry using point of care portable spirometers with turbines in any National and International Guideline. ERS [17] and BTS/ARTP [12] Guidelines provided detailed information on when to perform PFTs in patients with a previous COVID-19 pneumonia, while IRS/SIP [20] and ITS/AIPO [19] Guidelines strongly recommend nasopharyngeal swab testing before the visit, probably taking into account only in-patients. The Chinese task force [5] and ITS/AIPO [19] Guidelines, interestingly, recommend providing an educational video on how to perform PFTs in the waiting rooms. ERS [17] is the only Society that suggests the possibility of remote testing in very severely ill patients, “untethering” them from physical sites, promoting decentralized medical services. Manufacturers concentrate on in-detail technical issues, such as the type of in-line filters to be used or the cleaning procedures for the equipment of each product.

This review provides a summary of clinical practice Guidelines/Recommendations/Position Papers on practical problems that might arise worldwide during the safe reopening of respiratory outpatient services during COVID-19 pandemic, with a special focus on spirometry, but does not represent a Guideline itself.

The main strength of this research is that all the reviewed Guidelines were published in the restricted time period of the COVID-19 outbreak, with publication dates ranging from 4, March 2020 to 12, May 2020. Therefore, the scientific evidence available when they were developed was almost the same for them all.

Differences in national healthcare systems, resource availability and different times of epidemic evolution might explain any dissimilarity in terms of consensus. However, the lack of specific COVID-19-related evidence could be another reason for heterogeneity of the Guidelines, mainly based on experts' opinions rather than evidence-based recommendations. Furthermore, national and international recommendations may overlap due to the contribution of national representatives who possibly served also as the international experts in the Societies' statement. Finally, although we have searched for national guidelines on spirometry resumption in four common languages (English, Spanish, French and Italian) we might have failed to detect recommendations of some Societies due to language restrictions.

CONCLUSION

The review of Guidelines/Recommendations/Position Papers indicate a good agreement in the need to prioritize patients for PFTs, patients screening, HCWs protection, and in the use of in-line filters for spirometry but poor consensus on the subgroup of patients considered a priority, and few indications on the measures to implement for adequate ventilation. We believe that this summary of the available literature may be a useful guide helping HCWs to select appropriate measures, tailored to the highly specific context in which they will be used, to meet the needs of intended users.

Authors' contribution: CC conceived the content, drafted the manuscript and approved the final version to be submitted. PI drafted the manuscript, approved the final version to be submitted. RC, SN, helped in writing the manuscript and approved the final version to be submitted. AS helped in writing the manuscript, revised it critically for important intellectual content and approved the final version to be submitted. NC conceived the content, revised it critically for important intellectual content and approved the final version to be submitted.

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Table 1: Issues related to safely performing pulmonary function test and proposed solutions by National/International Organizations.

ISSUES	PROPOSED SOLUTIONS													
	CHINESE TASK FORCE[5] **04/03/2020**	**SPLF[9]** **17/03/2020**	**ATS[6]** **20/03/2020**	**SPP[9, 16]** **23/03/2020**	**SEPAR/AEC/AET /SEAIC[10]** **25/03/2020**	**ANZSRS/ TSANZ[7, 14]** **25/03/2020**	**ITS[11]** **30/03/2020**	**NEBRASKA MEDICINE[13, 15]** **01/04/2020**	**CLEVELAND[21]** **13/04/2020**	**SUNEUMO[18]** **13/04/2020**	**BTS/ARTP[12]** **27/04/2020**	**ERS[17]** **09/05/2020**	**ITS/AIPO[19]** **09/05/2020**	**IRS/SIP[20]** **12/05/2020**
Eligible patients	U/ET tests for Dx of current illness COPD/Asthma: postpone or use PFM	U tests for: - PRE-OP - CA - clinical decision	U/ET tests for immediate treatment	U tests for: - PRE-OP - CA - Dx - therapies	Avoid PFT in patients with respiratory Sx unless necessary	Afebrile Asymptomatic	U tests for: - RALC O/P - CF I/P - PRE-OP - ID	ET tests for: - LTP - PRE-OP - CF Pts - IST - Asymptomatic	ET tests for: - LTP - CTX surveillance - Surgery - ILD - PAH	ET tests for: - PRE-OP for LR, CS, OS - ILD Dx - PneumoTox Dx - ID (tested first)	ET tests for: - LTC - CA I/P - PRE-OP for US - ID (tested first)	U/ET tests for immediate Dx	U/ET tests for: - PRE-OP TAS - immediate Dx COPD/Asthma: postpone or use PFM	ET tests for: - PRE-OP TAS - LTPs - COPD Dx - Asthma Dx - ILD (Dx, F/U, drug Rx) - ID (tested first)
Post-COVID-19 pneumonia	- Normal BT (> 3d) - Sx improvement - Imaging improvement - 2 consecutive negative swabs										12-wks after discharge	30d post-infection	30d post-infection dedicated PFT lab	Pts with Sx
Social Distancing/ Prevention	Pts wear mask	Pts wear mask Hand Hygiene		Pts wear mask Pts alone/one caregiver	Hand Hygiene Pts wear mask if have Sx Pts sit >1 m Pts alone/one caregiver		Pts remain in the car RP phone to pts to come for PFT Pts sit >2 m	Pts wear mask			Pts sit >2 m	Pts wear mask Pts sit >2 m Hand hygiene Use gloves Pts alone/one caregiver	Pts wear mask and gloves Pts alone/one caregiver	Pts wear mask Hand hygiene Pts alone/one caregiver
Trace suspicious cases	Risk assessment questionnaire BT detection			Risk assessment questionnaire BT detection		BT detection	Risk assessment questionnaire Hand sanitizer in waiting areas	Risk assessment questionnaire 48-72 h before and the day of the test	Risk assessment questionnaire	Risk assessment questionnaire BT detection	Hand sanitizer BT detection	Risk assessment questionnaire BT detection	Risk assessment questionnaire Evaluate swab 48-72 h before	Risk assessment questionnaire BT detection Evaluate swab 48-72 h before
HCWs protection	PPE: - mask - eye protection - gloves Hand hygiene before and after gloves use Attention to medical staff health	PPE: - surgical mask - eye protection - gloves - gown	PPE Hand hygiene between tests	PPE: - N95/FFP2 (change q4h-q6h or if wet) - eye protection - nitrile gloves - gown - shoe protector	PPE: - FFP2/FFP3 - gloves - eye protection - gowns	PPE	PPE: - FFP2	PPE: - N95 mask - eye protection - gowns - gloves Hand hygiene	PPE: - surgical mask - eye protection - gloves If aerosolization: - gown - gloves - eye protection - N95 - powered air purifying	PPE: - N95/FFP-mask - gloves - eye protection - cap and hair up - eye protection - gowns	PPE: - FFP3 - eye protection Hand hygiene	PPE: - FFP2/FFP3 - gloves - eye protection Hand hygiene	PPE: - FFP3/FFP2 - eye protection - gloves	PPE: - FFP2 - eye protection - gowns - gloves
Testing and equipment	1 exam at time Disposable BVF BVF total resistance <1.5 cmH20 at a flow rate of 0-14 L / s · L -1 · s – 1	Perform the exam inside a plethysmography booth Recalibrate the equipment after decontamination		Disposable BVF BD test: disposable expansion chambers	Separate test/ administrative area Disposable BVF Disposable nose-clips	Disposable BVF BD test: pts' salbutamol inhaler or a single-use inhaler			Disposable BVF		Disposable BVF	Disposable BVF with minimum efficiency for high expiratory flow of 600 to 700 L/min. Single use consumables	1 exam at a time Disposable BVF Total resistance of BVF and tube of spirometer should <1.5 cmH2O · L-1·s	Disposable BVF >99% efficiency for HEF of 600 to 700L/min Disposable nose-clips

	Technician sit in the same direction, never in front of pts Separate test/ admin area Edu program and Telematic report				Technician sit in the same direction, never in front of pts Informational posters	Portable individual patient dedicated spirometers						Telemedicine for high-risk O/P Recalibrate the equipment after decontamination Separate test/ admin area	Disposable nose-clips Technician sit in the same direction, never in front of pts Recalibrate the equipment after decontamination Edu program Separate test/ admin area	BD test: pts' salbutamol inhaler or a single-use inhaler or aero-chamber Separate test/ admin area
Room ventilation	160 l/s for each pt for hour if natural ventilation 12 ACH for hour if negative room Turn off the A/C	15 min open windows closed doors		Ventilated rooms to avoid recirculation	Ventilated rooms to avoid recirculation			Room closed for 1 h after the procedure			30 min for isolation room with 10-12 ACH 60 min for side room with 6 ACH	15 min open windows closed doors Negative pressure room for high-risk pts NO HEPA filters	15 min open windows closed doors	
Environment and surfaces cleaning	Clean external instruments twice with 75% ethanol for 3 min Sanitize the environment at least BID UV light room decontamination for >30 min	Clean equipment and surfaces	Wiping down surfaces with appropriate cleaners	Clean equipment and surfaces	Minimal furniture Clean equipment and surfaces Cleaning solutions: Alcohol 60-70 °, 0.5% hydrogen peroxide or disposable wipes, hypochlorite 0.1%	Minimal furniture Clean equipment and surfaces	Clean contact parts with appropriate wipes between pts		Super Sani-Cloth germicidal disposable wipes (PDI, Woodcliff Lake,NJ) for hard surfaces Sani-Cloth AF3 for glass and other clear surfaces		Clean contact parts with appropriate wipes between pts (alcohol/Clinell wipes) Cleaning solutions: - ethanol >70% - sodium hypochlorite at least 0.21%	Regular equipment cleaning protocols UV light or ozone room decontamination at intervals	Clean equipment and surfaces UV light or ozone room decontamination at intervals Sanitize the environment BID	Clean equipment and surfaces Sanitize according to ecdc indications UV light, ozone/hydrogen room decontamination
Wait time between patients				60 min			30 min	60 min			30-60 min	30- 60 min		

List of Abbreviations:

30d: 30 days

A/C: air conditioner

ACH: air changes per hour

Admin: administrative

AET: Asociacion de Especialistas en Enfermeria del trabajo

AEC: Asociacion de Enfermeria Comunitaria

AS: Asymptomatic

ARTP: Association for Respiratory Technology and Physiology

ATS: American Thoracic Society; ANZSRS: Australian and New Zealand Society of Respiratory Science Ltd

ANZSRS: Australian and New Zealand Society of Respiratory Science Ltd

BD-Test: Post Bronchodilator test

BID: twice a day

BT: Body Temperature

BTS: British Thoracic Society

BVF: Bacterial/viral filter

CA: Cancer Patients

CF: Cystic fibrosis

CLEVELAND: Respiratory Institute Cleveland Clinic

COPD: Chronic Obstructive Pulmonary Disease

CS: Cardiac Surgery

CTX: chemotherapy

Dx: diagnosis

ecdc: European Centre for Disease Prevention and Control

Edu program: Educational program

ERS: European Respiratory Society

ET: essential

FFP: filtering face piece

F/U: follow up

HCWs: Health Care Workers

HEF: High Expiratory Flow

HEPA: High Efficiency Particulate Air filter

I/P: inpatients

ID: Immunocompromised patients

ILD: Interstitial Lung Diseases

IRS/SIP: Italian Respiratory Society/Società Italiana di Pneumologia

IST: Immunosuppressive Therapies

ITS: Irish Thoracic Society

ITS/AIPO: Italian Thoracic Society/Associazione Italiana Pneumologi Ospedalieri

LR: Lung Resection

LTC: long-term conditions

LTP: Lung Transplant Patients

Min: minutes

O/P: outpatients

OS: Oncological Surgery

PAH: Pulmonary Arterial Hypertension

PFM: Peak Flow Meter

PFTs: Pulmonary Function Tests

PneumoTox: Pneumotoxicity

PPE: personal protective equipment

PRE-OP: Preoperative patients

Pt/Pts: patient/patients

q4h: every 4 hour

q6h: every 6 hour

RALC: Rapid Access Lung Cancer Patients

RP: Respiratory Physiologist

SEIAC: Spanish Society of Allergy and Clinical Immunology

SEPAR: Spanish Society of Pneumology and Thoracic Surgery

Sx: symptoms

SPLF: Société de Pneumologie de Langue Française

SPP: Sociedade Portuguesa de Pneumologia (SPP)

SUNEUMO: Sociedad Uruguaya de Neumologia

TAS: Thoraco-Abdominal Surgery

TR: Telematic Reports

TSANZ: Thoracic Society of Australia and New Zealand

U: urgent

US: Urgent Surgery

UV: ultraviolet

Wks: weeks

Table 2: Issues related to safely performing pulmonary function test spirometry manufacturers'' proposed solutions.

Issue	PROPOSED SOLUTIONS			
	Vitalograph[26]	**Morgan Scientific[28]**	**ndd[27]**	**Vyaire[29]**
Cleaning and infection control	New BVF for each pt Clean the exterior surface with a 70% isopropyl alcohol solution The interior of the patient circuit requires no decontamination between tests If internal contamination is suspected, follow appropriate protocol	New BVF for each pt Clean the exterior surface with a 70% isopropyl alcohol solution The interior of the patient circuit requires no decontamination between tests Equipment cleaning and disinfection required after use on infected subjects or prior to use on ID	The ndd hygiene solution, which uses the inserts spirette, FlowTube and bamette, requires no cleaning of internal tubing or sensor Surface cleaning is required Separate test / administrative area Risk assessment questionnaire	Use MicroGard II BVF Minimize contamination performing PFTs Use an enzyme cleaner with neutral pH (pH 6–8) Do not use temperatures above 130 °F
HCWs protection			PPE: - surgical mask - disposable gloves	
Minimum wait time between patients		5 minutes		
Ventilation			Air ventilation and sterilization	
Critical issue			Measurements are influenced by the filter's resistance.	

List of Abbreviations:

BVF: Bacterial Viral Filter

HCWs: health-care workers

ID: Immunocompromised patients

PFTs: Pulmonary Function Tests

PPE: personal protective equipment

Pt: patient

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