



Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.



Clinical usefulness

## Pediatric lung function testing during a pandemic: An international perspective



N. Beydon<sup>a</sup>, L. Gochicoa<sup>b,\*</sup>, M.J. Jones<sup>c</sup>, L.C. Lands<sup>d</sup>, E. Lombardi<sup>e</sup>, M. Rosenfeld<sup>f</sup>, P.D. Sly<sup>g</sup>, D.J. Weiner<sup>h</sup>, O. Yilmaz<sup>i,\*</sup>

<sup>a</sup>Unité Fonctionnelle de Physiologie-Explorations Fonctionnelles Respiratoires, AP-HP, Hôpital Armand-Trousseau, Paris, France

<sup>b</sup>National Institute of Respiratory Diseases, Dept. of Pulmonary Physiology, Mexico City, Mexico

<sup>c</sup>School of Medicine, Pontifical Catholic University of Rio Grande do Sul (PUCRS), Brazil

<sup>d</sup>Department of Pediatrics, Montreal Children's Hospital, McGill University Health Centre, Montreal, Quebec, Canada

<sup>e</sup>Pediatric Pulmonary Unit, Meyer Children's Hospital, Florence, Italy

<sup>f</sup>Department of Pediatrics, University of Washington School of Medicine, Seattle Children's Research Institute, Seattle, WA, United States

<sup>g</sup>Child Health Research Centre, The University of Queensland, South Brisbane, Queensland, Australia

<sup>h</sup>UPMC Children's Hospital of Pittsburgh, Division of Pediatric Pulmonology, Pittsburgh, United States

<sup>i</sup>Celal Bayar University Medical Faculty, Department of Pediatric Allergy and Pulmonology, Manisa, Turkey

### EDUCATIONAL AIMS

The reader will be able to:

- Summarize different practices of pediatric pulmonary lung function testing laboratory management in different countries.
- Identify the change in indications of pulmonary lung function testing in pediatric patients during and right after the pandemic.

### ARTICLE INFO

#### Keywords:

COVID-19

Pediatric pulmonary function testing

Pandemic

### ABSTRACT

The COVID pandemic has passed its first peak for now in many countries while some are still on the rise, with some facing a second wave of cases. Precautions and infection control measures for both pediatric and adult pulmonary function testing (PFT) have been a topic of debate during the pandemic. Many centers had to close their PFT laboratories during the initial periods of the pandemic and are reopening as the numbers of new cases are decreasing. This review aims to summarize different practices of PFT laboratory management in different countries, including patient appointments, personal protective equipment, testing room requirements and telemedicine during and immediately following the COVID pandemic.

© 2020 Published by Elsevier Ltd.

### INTRODUCTION

The World Health Organization reported nearly 13 million cases of COVID-19 worldwide as of July, 2020 [1]. Children constitute a small proportion of people diagnosed with COVID-19 and generally have a more benign disease and course compared to adults [2–4]. The main features in children have been fever, cough and the diagnosis of pneumonia [2].

Considering that there is a possibility of disease transmission to the patients and staff from asymptomatic carriers, precautions for pulmonary function testing (PFT) laboratories have been contro-

versial [5]. Many professional societies have published recommendations for precautions during PFT [6–9]. These include postponing testing in non-urgent cases, personal protective equipment (PPE) for the respiratory technicians and PFT lab room characteristics such as negative pressure and adequate ventilation, HEPA filters, extensive hygiene measures and social distancing [6–9]. Moreover, PFT must be avoided in suspected or confirmed COVID-19 cases [7]. Pediatric PFT labs have been closed during the pandemic in most hospitals except for emergency cases but are reopening in countries with a decrease in the number of cases.

This review summarizes the international practice in different centers around the world aiming to emphasize similarities and differences in regional barriers and opportunities.

\* Corresponding authors.

E-mail addresses: [drgochis@gmail.com](mailto:drgochis@gmail.com) (L. Gochicoa), [oyilmaz\\_76@hotmail.com](mailto:oyilmaz_76@hotmail.com) (O. Yilmaz).

*Preparations before pediatric pulmonary function testing*

Preparations before PFT concern two populations in pediatric care: the parents and the children. In most hospitals, families are screened with questionnaires about cough, shortness of breath, fever, loss of taste or smell, unusual fatigue or rhinitis/sinusitis and exposure to patients with COVID-19. If symptoms suggestive of COVID are reported, the test is re-scheduled until the result of COVID testing is available. The number of patients that can be seen has decreased in all centers owing to the increased time between tests required for adequate decontamination and air exchanges. The patients are usually scheduled with no overlap to avoid congregation in the waiting area. Moreover, only one person is allowed to accompany the child when he or she presents for the appointment.

Patients and visitors to the hospital are questioned about symptoms and contact on arrival, and in many hospitals no-contact temperature is measured at the hospital entrance. Some centers prescreen patients by phone within 48 h prior to appointments. At some centers, a negative COVID test is required within 72 h before performing PFTs.

Patients and visitors are expected to have a face mask/covering to enter the hospital. Moreover, they are asked to use hand sanitizer. Face masks are required for patients and families except for children younger than 6 years (note some places under 10, some under 12 years of age).

In some hospitals patients that arrive for a scheduled PFT are taken directly into the room where testing will be performed. In hospitals where waiting rooms are large enough to organize seats in compliance with social distancing rules or where environmental conditions allow waiting out of the hospital, overlapping of appointments is not a major problem, but the waiting room and door handles still need to be disinfected several times a day. In areas where climate allows waiting outside the hospital, patients may wait in an outdoor area.

In hospitals with negative pressure PFT labs with 8–11 air exchanges per hour, urgent PFTs that cannot be postponed despite COVID suspicion, are performed with the lab personnel wearing full COVID personal protective equipment (PPE).

*The requirements for pediatric pulmonary function testing*

The testing room: Every hospital has different environment conditions that influence the PFT practice. The number of air exchanges determines how quickly aerosol droplets are removed from the environment. With negative pressure rooms providing 8–11 air exchanges per hour or rooms equipped with portable or integrated HEPA filters, a delay is not required between patients. This may not be feasible in all hospitals; at some centers, PFTs are performed in rooms with windows that open outside. If these conditions do not exist, then there should be a 30-min waiting time between patients. Other measures include: continuous air purifying respiratory (CAPRs) use, adding a plexiglass (Perspex)

divider between the patient and therapist (Table 1). All surfaces in the testing room such as the equipment, chairs, tables and plexiglass are wiped down with sanitizers after each patient. The testing equipment: Mouthpiece filters with bacterial and viral filtration efficiency of  $\geq 99\%$  are used for all measurements so the flow sensors do not need to be changed nor cleaned between patients.

Procedures and aerosol generation: There has been a lot of debate regarding which procedures are aerosol generating; and while tidal breathing tests such as oscillometry or Rint and plethysmography are considered as not being aerosol generating, maneuvers that induce cough, including spirometry and bronchial provocation tests, are more likely to generate aerosols. Methacholine challenge testing may not be undertaken in many centers since it typically induces cough and requires nebulization.

Exercise testing is another challenging PFT during the pandemic period since it results in high minute ventilation and may induce cough. Moreover, there is concern that filters may cause resistance during the high minute ventilation with exercise.

Testing order: Independent of the epidemic, tidal breathing tests are done before forced expiration maneuver to prevent changes in static volumes and bronchial caliber. Therefore, during the pandemic tidal breathing tests such as Functional residual capacity (FRC) dilution, resistance, Tlco rebreathing are performed first, followed by slow expiration and inspiration tests such as FeNO, nasal NO, slow vital capacity (SVC), static volumes, TlcoBH,  $P_{max}$  and Sniff nasal inspiratory pressure (Snip). Finally, forced expiration and exercise tests are performed. The main idea is to have more aerosol generating tests, such as inducing sputum, performed after less aerosol generating tests, such as tidal breathing PFTs, in most centers, in order to leave the testing room right after the completion of the former.

Testing personnel: Respiratory therapists or nurses performing all types of pulmonary function testing are screened daily for COVID symptoms by questionnaires and by temperature measurement in many centers. Moreover, home isolation if symptoms of fever, coryza and cough develop and PCR testing is mandatory in some institutions.

Respiratory therapists or nurses performing forced expiration techniques such as spirometry, DLCO and FeNO are required to wear a mask; in some centers or situations, this mask must be a FFP2 (equivalent of N95) mask. Otherwise, in all situations wearing gowns, gloves and face shield or goggles for testing is required in most hospitals. Moreover, testing that is likely to cause cough such as bronchial challenge and testing that leads to high minute ventilation such as exercise testing require full protective measures.

For tidal breathing techniques [helium dilution (FRCh), multiple breathing nitrogen washout (MBNW), interrupter technique (Rint), oscillometry, tidal breathing indices in infants, etc.) or closed plethysmography techniques, the professionals performing the PFT wear surgical face masks, gloves (because of risk of contact with respiratory secretions) with gloves changed between patients (Table 1).

**Table 1**  
Potential measures that can be taken for protection of the lung function test personnel for tidal breathing and forced measurements.

Method	Proposed protection measures for the personnel
Techniques involving larger expiration than tidal volume and/or forced (spirometry, DLCO, FeNO, MIP/MEP etc)	<ul style="list-style-type: none"> <li>Wearing FFP2 (N95) masks, gowns, gloves and face shield or goggles</li> <li>Continuous air purifying respiratory (CAPRs) use</li> <li>Adding a plexiglass (Perspex) divider between the patient and therapist</li> </ul>
Tidal breathing techniques (multiple breathing nitrogen washout, interrupter technique (Rint), oscillometry etc)	<ul style="list-style-type: none"> <li>Wear surgical face masks, gloves</li> </ul>

**Table 2**  
Changes implemented in the pulmonary function testing laboratories that are expected to be permanent even after the pandemic.

Change Implemented	
Before the test	<ul style="list-style-type: none"> <li>• Indications for PFT testing is narrowed</li> <li>• Patient scheduling with compliance expectations for the caregiver</li> <li>• Waiting room restrictions to allow social distancing</li> <li>• Questionnaire and no-contact temperature measurements on the day of the test</li> </ul>
During the Test	<ul style="list-style-type: none"> <li>• Mouthpiece filters with viral and bacterial efficacy</li> <li>• Personal protective requirements for the respiratory technician or nurse performing the test</li> </ul>
After the test	<ul style="list-style-type: none"> <li>• Wiping down all surfaces with sanitizers after each patient</li> <li>• Waiting period between patients depending on the air exchange rate in the room</li> </ul>

*Pediatric pulmonary function testing indications*

The indications for PFT in children do not change with the pandemic as stated in previous guidelines [10]. However, the risk to other patients and staff must be carefully weighed against the benefits to the patient. In many hospital settings the indications for performing PFTs have been narrowed to include only the cases where diagnosis or acute management will change with the results of the PFT.

*Considerations for specific patient groups*

Patients with cystic fibrosis are amongst the most commonly tested in the pediatric pulmonology departments. These patients and their families are already quite familiar with infection control measures such as wearing a mask and practicing social distancing. The decision to perform PFTs in these patients is evaluated on individual basis. While spirometry may be very valuable in guiding treatment, most clinics are postponing plethysmography, cardiopulmonary exercise testing and six-minute walk test in these patients.

Home spirometry is a potentially promising alternative to office/clinic spirometry that can avoid the need for office/clinic visits and allow for more frequent monitoring. There has been rapid uptake of home spirometry in some regions and innovations are accelerating. However, there are still a number of unknowns that must be acknowledged, including accuracy, repeatability, clinical significance of acute declines, need for coaching and long-term patient adherence [11,12]. Home spirometry use for specific populations may be an alternative for selected populations such as the asthmatics in the long term but it will require training of the subjects to fulfill the standards.

The COVID-19 pandemic has also impacted scientific research that requires PFT as part of the protocol. Many researchers postponed PFT measurements in the study population without clinical indications. This will be a major limitation for ongoing research in addition to the cancellation of in-person visits for these subjects.

In conclusion, PFT laboratories are re-opening in areas of the world where there is decreased number of new COVID-19 cases; but generally, with reduced activity at the beginning. As experience and confidence with operating under restrictions is gained, activity increases. If there is a local increase of the case numbers, it is always possible to decrease the activity in an attempt to

decrease contact. However, in the long term, it is probable that some changes implemented in the PFT labs during this pandemic will stay in daily practice even with no or low virus circulation (Table 2).

**DIRECTIONS FOR FUTURE RESEARCH**

The pandemic has necessitated reorganization of the pediatric pulmonary function testing (PFT) laboratories and practice. Future research on the extent of aerosol generation during various PFT techniques is needed for meticulous protection of the patients and health care personnel performing the procedure. Moreover, research to improve implementation of telemedicine in patient care will be important.

**ACKNOWLEDGEMENTS**

This report was based on the webinar recorded by the American Thoracic Society Pediatric Assembly Virtual International Pediatric Pulmonology Network (<https://vipnp.thoracic.org>) and European Respiratory Society. The opinions expressed are those of the authors, and do not represent official respiratory society opinions. All authors contributed equally so all need to be credited as first authors.

**CONFLICT OF INTEREST/FUNDING**

None.

**References**

- [1] WHO Coronavirus Situation Report-166. [https://www.who.int/docs/default-source/coronaviruse/situation-reports/20200704-covid-19-sitrep-166.pdf?sfvrsn=6247972\\_2](https://www.who.int/docs/default-source/coronaviruse/situation-reports/20200704-covid-19-sitrep-166.pdf?sfvrsn=6247972_2).
- [2] Lu X, Zhang L, Du H, Zhang J, Li YY, Qu J, et al. SARS-CoV-2 infection in children. *N Engl J Med* 2020;382:1663–5. <https://doi.org/10.1056/NEJMc2005073>.
- [3] Du W, Yu J, Wang H, Zhang X, Zhang S, Li Q, et al. Clinical characteristics of COVID-19 in children compared with adults in Shandong Province, China. *Infection* 2020;48:445–52. <https://doi.org/10.1007/s15010-020-01427-2>.
- [4] She J, Liu L, Liu W. COVID-19 epidemic: Disease characteristics in children. *J Med Virol* 2020;92:747–54. <https://doi.org/10.1002/jmv.25807>.
- [5] Yu X, Yang R. COVID-19 transmission through asymptomatic carriers is a challenge to containment. *Influenza Other Respir Viruses* 2020;14:474–5. <https://doi.org/10.1111/irv.12743>.
- [6] Pulmonary Function Laboratories: Advice Regarding COVID-19. <https://www.thoracic.org/professionals/clinical-resources/disease-related-resources/pulmonary-function-laboratories.php>.
- [7] Bignamini E, Cazzato S, Cutrera R, Ferrante G, La Grutta S, Licari A, et al. Italian pediatric respiratory society recommendations on pediatric pulmonary function testing during COVID-19 pandemic. *Ital J Pediatr* 2020;46. <https://doi.org/10.1186/s13052-020-00829-0>.
- [8] Recommendation from ERS Group 9.1 (Respiratory function technologists/Scientists) Lung function testing during COVID-19 pandemic and beyond. <https://ers.app.box.com/s/zs1uu88wy51monr0ewd990it0z4tsn2h>.
- [9] Gochicoa-Rangel L, Torre-Bouscoulet L, Rojas AS, Guzman-Valderrabano C, Silva-Ceron M, Benitez-Perez RE, Salas-Escamilla I, Madrid-Mejia W, Grosso-Espinosa JM. Functional respiratory evaluation in the COVID-19 Era: the role of pulmonary function test laboratories. *Rev Invest Clin.* (ahead of print). <https://doi.org/10.1016/j.jaip.2018.01.032>.
- [10] Beydon N, Davis SD, Lombardi E, Allen JL, Arets HG, Aurora P, et al. *Am J Respir Crit Care Med* 2007;175:1304–45. <https://doi.org/10.1164/rccm.200605-642ST>.
- [11] Berlinski A, Chervinskiy SK, Simmons AL, Leisenring P, Harwell SA, Lawrence DJ, et al. Delivery of high-quality pediatric spirometry in rural communities: A novel use for telemedicine. *J Allergy Clin Immunol Pract* 2018;6:1042–4. <https://doi.org/10.1016/j.jaip.2018.01.032>.
- [12] Gerzon FLGR, Jöbsis Q, Bannier MAGE, Winkens B, Dompeling E. Discrepancy between lung function measurements at home and in the hospital in children with asthma and CF. *J Clin Med* 2020;9:E1617.