ERS International Congress 2021: highlights from the Respiratory Clinical Care and Physiology Assembly

Thomas Gille [1,2], Pradeesh Sivapalan [3], Georgios Kaltsakas [4,5,6], Shailesh B. Kolekar [7,8], Matthew Armstrong [9], Rachel Tuffnell [10], Rachael A. Evans [11,12], Guido Vagheggini [13,14], Luiza Helena Degani-Costa [15], Cláudia Vicente [16], Nilakash Das [17], Vitalii Poberezhets [18], Camille Rolland-Debord [19], Sam Bayat [20,21], Ioannis Vogiatzis [22], Frits M.E. Franssen [23,24,25], Hilary Pinnock [26] and Lowie E.G.W. Vanfleteren [27,28]

[1]Service de Physiologie et Explorations Fonctionnelles, Centre Hospitalier Universitaire Avicenne, Hôpitaux Universitaires de Paris Seine-Saint-Denis, Assistance Publique-Hôpitaux de Paris, Bobigny, France. [2]Inserm U1272 "Hypoxia and the Lung", UFR Santé – Médecine – Biologie Humaine Léonard de Vinci, Université Sorbonne Paris Nord, Bobigny, France. [3]Section of Respiratory Medicine, Herlev-Gentofte University Hospital, Hellerup, Denmark. [4]Lane Fox Respiratory Service, Guy's and St Thomas' NHS Foundation Trust, London, UK. [5]Centre of Human and Applied Physiological Sciences, Faculty of Life Sciences and Medicine, King's College London, London, UK. [6]1st Respiratory Medicine Dept, "Sotiria" Hospital for Diseases of the Chest, National and Kapodistrian University of Athens, Athens, Greece. [7]Dept of Internal Medicine, Zealand University Hospital, Roskilde, Denmark. [8]Dept of Clinical Medicine, University of Copenhagen, Copenhagen, Denmark. [9]Dept of Rehabilitation and Sport Sciences, Bournemouth University, Poole, UK. [10]Cambridge University Hospitals NHS Foundation Trust, Cambridge, UK. [11]NIHR Leicester Biomedical Research Centre – Respiratory, University Hospitals of Leicester NHS Trust, Leicester, UK. [12]Dept of Respiratory Sciences, University of Leicester, Leicester, UK. [13]Dept of Medical Specialties, Chronic Respiratory Failure Care Pathway, Azienda USL Toscana Nordovest, Volterra, Italy. [14]Fondazione Volterra Ricerche Onlus, Volterra, Italy. [15]Hospital Israelita Albert Einstein, São Paulo, Brazil. [16]Araceti Family Health Unit, Coimbra, Portugal. [17]Laboratory of Respiratory Diseases and Thoracic Surgery, Chronic Diseases and Metabolism, KU Leuven, Leuven, Belgium. [18]Dept of Propedeutics of Internal Medicine, National Pirogov Memorial Medical University, Vinnytsya, Ukraine. [19]Service de Pneumologie, Hôpital Gabriel Montpied, CHU Clermont-Ferrand, Clermont-Ferrand, France. [20]Service de Pneumologie et de Physiologie, CS10217, CHU Grenoble, Grenoble, France. [21]Univ. Grenoble Alpes, Inserm UA07 STROBE, Grenoble, France. [22]Dept of Sport, Exercise and Rehabilitation, Northumbria University Newcastle, Newcastle upon Tyne, UK. [23]Dept of Research and Development, Ciro, Horn, the Netherlands. [24]Dept of Respiratory Medicine, Maastricht University Medical Centre (MUMC+), Maastricht, the Netherlands. [25]NUTRIM School of Nutrition and Translational Research in Metabolism, Maastricht, the Netherlands. [26]Allergy and Respiratory Research Group, Usher Institute, The University of Edinburgh, Edinburgh, UK. [27]COPD Center, Dept of Respiratory Medicine and Allergology, Sahlgrenska University Hospital, Gothenburg, Sweden. [28]Dept of Internal Medicine and Clinical Nutrition, Institute of Medicine, Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden.

Corresponding author: Thomas Gille (thomas.gille@aphp.fr)

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This article provides an overview of some of the highlights from @ERSAssembly1 presented during the #ERSCongress 2021 https://bit.ly/3KPWZOc

Cite this article as: Gille T, Sivapalan P, Kaltsakas G, *et al*. ERS International Congress 2021: highlights from the Respiratory Clinical Care and Physiology Assembly. *ERJ Open Res* 2022; 8: 00710-2021 [DOI: 10.1183/23120541.00710-2021].

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Received: 23 Dec 2021
Accepted: 6 April 2022

Abstract

It is a challenge to keep abreast of all the clinical and scientific advances in the field of respiratory medicine. This article contains an overview of laboratory-based science, randomised controlled trials and qualitative research that were presented during the 2021 European Respiratory Society International Congress within the sessions from the five groups of the Assembly 1 – Respiratory clinical care and physiology. Selected presentations are summarised from a wide range of topics: clinical problems, rehabilitation and chronic care, general practice and primary care, electronic/mobile health (e-health/m-health), clinical respiratory physiology, exercise and functional imaging.

Introduction

Because of the coronavirus disease 2019 (COVID-19) pandemic, the 2021 edition of the European Respiratory Society (ERS) International Congress was held virtually once again. Nevertheless, it provided a much-valued occasion to come together in times of travel restrictions and social distancing, as well as an important opportunity to hear about the latest developments in research and clinical practice in the world's largest scientific and educational conference in the field of respiratory medicine. This year, 3293 abstracts were accepted for presentation and 22 925 delegates attended some of the 171 sessions.

Assembly 1 – Respiratory clinical care and physiology is the largest of the 14 ERS assemblies, comprising 6983 members, 38% of them being under 40 years old (early-career members). During the 2021 International Congress, Assembly 1 was proud to honour Paolo Palange with an ERS lifetime achievement award. Among the 557 abstracts submitted across the five groups within the assembly, 448 were accepted for presentation. Although the virtual platform allowed presentations to be replayed, it can be difficult to keep up to date with all the scientific and clinical advances on offer. This article, therefore, aims to share some of the highlights from the Respiratory Clinical Care and Physiology Assembly.

Group 1.01: Clinical problems

Sessions: "Emerging evidence on subacute and long COVID-19" and "Highlights in COVID-19 diagnosis and treatment"

The effects of COVID-19 were broadly addressed during the 2021 International Congress. We report hereinafter some of the evidence regarding short- and long-term implications of COVID-19 reported in two sessions from Group 1.01.

Management of COVID-19 during the acute phase

Oliveira *et al.* [1] found that early endothelial dysfunction, evaluated by flow-mediated dilation, was more frequent in 98 COVID-19 patients as compared to 82 non-COVID-19 controls. Moreover, the presence of endothelial dysfunction in COVID-19 patients was associated to higher mortality and longer hospital stay. From a pathophysiological point of view, it could partly explain the observed discrepancy between profound hypoxaemia and relatively preserved lung mechanics.

Instead of relying only on a single evaluation of the ratio between oxygen partial pressure and fraction (P_{aO_2}/F_{iO_2}), Raimondi *et al.* [2] proposed a two-step method using dedicated software to estimate the shunt fraction and the ventilation/perfusion (V'_A/Q') mismatch, based on data from 12 patients in a semi-intensive respiratory care unit. They recommended a first measurement at low oxygen saturation (S_{pO_2}) providing the actual O_2 requirement taking into account both V'_A/Q' mismatch and shunt, and then a second measurement performed at high F_{iO_2} (>70%) to evaluate the magnitude of the shunt.

Ali *et al.* [3] presented the results of their retrospective study (n=217) investigating whether better than anticipated survival during hospitalisation was correlated with higher readmission or death rates. At follow-up, death rates increased from 28% to 38%, with most deaths registered shortly after hospitalisation. Overall, 32.5% of initial survivors were readmitted, suggesting that both deaths and readmissions often occur early after discharge. The study also found that disease severity, based on radiograph changes and respiratory dependency, might be used as predictor of survival.

In a retrospective study comparing 80 COVID-19 patients with negative first polymerase chain reaction (RT-PCR) to 80 matched controls with positive first RT-PCR, Lascarrou *et al.* [4] observed that laboratory markers of inflammation (higher C-reactive protein and platelet count) were associated with a greater risk of false-negative first RT-PCR, indicating that diagnosis and treatment cannot be based solely on RT-PCR test results. Moreover, only 11 out of 80 patients with negative first RT-PCR had a subsequent positive test, sometimes despite multiple samples.

Long-term outcomes of COVID-19

Sykes *et al.* [5] investigated persistent symptoms and identified that 86% of 134 hospitalised patients had at least one symptom at follow-up, with breathlessness being the most common (60% of patients). Higher body mass index was associated with myalgia and fatigue, with female patients more likely to manifest both symptoms. In this study, there was no correlation between symptom burden and initial illness severity or radiographic/laboratory test abnormalities. The frequency of residual symptoms may vary from one study to another. In a previous Chinese study having enrolled 1733 COVID-19 patients from Wuhan, 76% reported at least one symptom at follow-up, fatigue/muscle weakness and sleep difficulties being the most common [6]. A correlation was found between initial severity and the presence of fatigue/muscle weakness or the extension of radiological lung sequelae. Two other observational cohort studies found respective incidence of 87% and 47% of at least one symptom at follow-up, with fatigue and dyspnoea/breathlessness being the most common [7, 8]. In the latter study, female patients were more likely to have persistent symptoms [8]. These discrepancies may indicate that the frequency and type of residual symptoms are not only dependent on initial severity but also on biopsychosocial factors. Indeed, SYKES *et al.* [5] recorded many neuropsychiatric sequelae in their study. This aspect of COVID-19 has been noted previously. In a prospective cohort study, patients with at least one post-COVID persistent symptom had reduced mental quality of life. These neurocognitive symptoms persisted for at least 1 year and were most common in female patients [9].

Data on long-term radiological abnormalities were also presented and discussed. SYED *et al.* [10] found that 17% of 695 patients had persistent radiological abnormalities, but most abnormalities were minor and were present in older patients. There were no differences in physiological or psychological function between patients with persistent and resolved radiological abnormalities, suggesting that radiological improvement was not correlated with less anxiety or greater ability to perform activities. Similarly, a 3-month follow-up study by JOHNSEN *et al.* [11], based on computed tomography (CT), found that 67% and 53% of patients had symptoms and abnormal CT scan results, respectively. Hospitalised patients had higher frequency of CT abnormalities and lower diffusing capacity of lung for carbon monoxide (D_{LCO}) values than non-hospitalised patients, and most patients had objective functional, radiological and cognitive abnormalities at follow-up. These rates of radiological abnormalities are higher than in other published studies that typically have reported abnormal scan results at 2-month follow-up in 38% of participants, with 9% of these participants having deteriorated since hospitalisation [12]. VIAN *et al.* [13] investigated whether lung involvement on CT scans correlated with the results of a 6-min walk test (6MWT) at 3-month follow-up. The CT scans were stratified into <25%, 25–50% and >50% lung involvement. There was a significant correlation between the degree of lung involvement and oxygen saturation decline during the 6MWT, but not with walking distance.

Pulmonary function may also be affected long-term following COVID-19. ORZES *et al.* [14] investigated correlations between lung function and CT-scan results at 3-month follow-up. Patients with no lung function abnormalities (48% of the total) were less likely to have a cough and had less oxygen therapy and mechanical ventilation during hospitalisation than those with abnormalities, indicating a correlation between increased severity of disease and reduced lung function. Among the patients with abnormalities, 70% had persistent alterations at 6 months. SEEBACHER *et al.* [15] investigated pulmonary abnormalities in 38 patients who had experienced very severe COVID-19 by assessing spirometry, 6MWT and CT scan. At 6 months, only forced vital capacity (FVC) had improved, whereas 48% of the patients had lung function impairments, 94% had pathological 6MWT results and 86% showed persistent radiological abnormalities. Indeed, the incidence of lung function abnormalities is very dependent on the chosen population (*e.g.*, initial severity). A previous study found persistent abnormal pulmonary function in only 25% of participants, primarily reductions in D_{LCO} values [16]. Similarly, a meta-analysis concluded that COVID-19 affected pulmonary function in 20% of patients [17].

Two studies about the safety of convalescent plasma were presented. In the first one, Salazar *et al.* [18] enrolled 25 patients with severe COVID-19. The administration of convalescent plasma was deemed to be safe (primary end-point), with no serious adverse event related to the treatment. 19 patients (76%) clinically improved from baseline to day 14, but there was no control group [18]. The other one focused on long-term safety, as convalescent plasma may have a long-term negative effect by downregulating the inflammatory response. In the original work, the administration of convalescent plasma to 80 COVID-19 patients had reduced disease progression to severe respiratory disease, as compared to the placebo group [19]. In the follow-up study presented during the congress, PANIGHETTI *et al.* [20] found no differences, from 7 until 11 months after randomisation, in the number of new acute respiratory infections between the two groups. However, a recent meta-analysis having included 18 randomised controlled trials, comprising 16 608 hospitalised patients (8702 having received convalescent plasma), found no significant mortality benefit from convalescent plasma in COVID-19, and no significant reduction in mechanical ventilation requirement nor hospital stay length [21].

Finally, insights from treating COPD may also be used to treat COVID-19. AUL *et al.* [22] hypothesised that COPD assessment test (CAT) scores could be used to predict post-COVID-19 persistent symptoms by focusing on the following three outcomes: post-COVID-19 pulmonary fibrosis, myalgia and fatigue. Patients with one of these three outcomes had higher CAT scores, suggesting that CAT scores may be useful in the assessment of patients with COVID-19. Similarly, CAT scores were used to assess symptoms at follow-up in an observational cohort study and may be useful for monitoring recovery from COVID-19 [23]. PAVITT *et al.* [24] presented the results of a study that investigated the survival of patients with COVID-19 who had the following COPD phenotypes: frequent exacerbators, predominant emphysema, chronic bronchitis and eosinophilic. There were no differences in survival among these phenotypes, and the COVID-19 survival rate of patients with COPD was higher than the overall survival rate.

Group 1.02: Rehabilitation and chronic care

Session: "Best abstracts in pulmonary rehabilitation and chronic care"

Six state of the art abstracts were presented in the ERS group 1.02 traditional main session. Key topics covered by these thought-provoking pieces of work included target mechanisms for future interventions, pulmonary rehabilitation (PR) in chronic lung disease and recovery after COVID-19.

Target mechanisms for interventions in patients with chronic lung disease

VAES *et al.* [25] updated our understanding of the association between physical activity and mortality, investigating whether changes in physical capacity "can do" and daily physical activity "do do" influenced all-cause mortality in a cohort of 829 patients with COPD. The combination of low physical activity defined as <5000 steps per day and low physical capacity defined as 6MWT distance of <70% predicted were associated with higher mortality over 55 months.

The biochemistry of skeletal muscle in patients with COPD compared to healthy controls was explored by POMIÈS *et al*. [26] who investigated the calcium response in myotubes after KCl-induced depolarisation. Patients with COPD had a similar resting intracellular Ca^{2+} compared to healthy controls but a reduced Ca^{2+} response. As the Ca^{2+} response was positively correlated with walking distance and quadriceps strength, these alterations could reflect *in vivo* muscle dysfunction in COPD patients.

A study with novel methodology by LOVELL *et al.* [27] addressed breathlessness perception and modulation. A "live science experiment" involved 300 healthy individuals listening to four short recordings of breathlessness caused by anxiety, COPD, exercise and end of life. Self-reported breathlessness was recorded before and after listening to the recordings. Listening to audio recordings of breathlessness increased self-reported breathlessness, with higher adverse response to breathlessness caused by anxiety. The observed response is particularly relevant to people caring for someone who is breathless. This study demonstrated excellent recruitment of healthy participants through an open public research event.

Pulmonary rehabilitation for chronic lung disease

To date, the addition of a physical activity intervention to PR has led to conflicting results. ARMSTRONG *et al.* [28] therefore investigated the effect of a physical activity behavioural modification intervention to PR *versus* PR alone in 48 patients with COPD with low physical activity. The addition of the physical activity behavioural modification led to improvements in physical activity experiences, daily step count and quality of life.

The target population of PR has expanded to patients undergoing lung transplantation and SCHNEEBERGER *et al.* [29] reported the effectiveness of a comprehensive inpatient PR programme in reducing frailty in a longitudinal uncontrolled cohort study. Following PR completion, the short physical performance battery improved, frail patients improved to either pre-frail or not frail (n=4 out of 6) and the majority of pre-frail changed to not frail (n=12 out of 16). These promising results need confirmation in an adequately powered controlled trial.

Exercise-induced hypoxaemia is a frequent challenge to the delivery of PR in patients with idiopathic pulmonary fibrosis (IPF). HARADA *et al.* [30] therefore examined the effect of high-flow nasal cannula oxygen therapy (HFNC) compared to Venturi mask (VM) on exercise tolerance in patients with IPF during constant-load symptom-limited exercise tests at 80% of peak work rate in a randomised crossover trial. Compared to VM, HFNC significantly improved endurance time, and minimum peripheral oxygen saturation and leg fatigue at isotime and end exercise. Whether training with HFNC in IPF during PR improves exercise capacity compared to other oxygen delivery systems could be tested in a randomised controlled trial.

Recovery and COVID-19

Healthcare pathways for the aftercare of those hospitalised with COVID-19 are urgently needed, and AHMED *et al.* [31] reported the outcomes of a multi-disciplinary team comprehensive post-hospitalisation with COVID-19 follow-up pathway in 420 patients at 6 months. Only 28% felt fully recovered, 60% of patients experienced persisting shortness of breath and 44% suffered fatigue or lack of energy, which was comparable to other cohorts [32]. Fatigue is therefore an outcome of interest for COVID-19 rehabilitation, and GERLIS *et al.* [33] presented an early analysis for the minimal clinically important difference (MCID) for two widely used fatigue scores: the Functional Assessment of Chronic Illness Therapy (FACIT)–Fatigue Scale and visual analogue scale (VAS). In a 6-week face-to-face comprehensive PR programme, the proposed MCID scores were between 2.7 and 3.6 points for FACIT, and 0.6 and 1.1 points for the VAS fatigue scores. Although helpful early data, the cohort of n=32 is small, and the MCIDs need confirming in larger datasets.

Healthcare resource for comprehensive rehabilitation is a challenge and as a late-breaking abstract, McNarry *et al.* [34] presented exciting early data (n=87) from an ongoing randomised controlled trial of Inspiratory Muscle Training (IMT) delivered as an 8-week home-based intervention *versus* usual care. Participants in the IMT group had significantly reduced breathlessness compared to baseline with a higher maximal inspiratory pressure, fatigue index and fitness assessed by chair step test. The results of the full trial (n=250) are awaited, but IMT as a therapy for post-COVID-19 breathlessness is intriguing.

Group 1.03: General practice and primary care

Session: "Highlights for primary care in 2021"

The ERS congress once more offered many opportunities to review topics of importance to general practice and primary care, such as the diagnosis and management of asthma and COPD, or smoking cessation. Moreover, this session highlighted novel perspectives on some topics that occur less frequently in primary care.

Inhaled treatments for asthma and COPD

The 2021 GINA guidelines [35] reinforced the importance of single-inhaler Maintenance-and-Reliever Therapy (MART) as the gold standard treatment for asthma, on the grounds of reduced exacerbation rates, compared to regimens with separate controller and short-acting β-agonist (SABA) treatments. Nevertheless, in practice, many physicians still prescribe alternative regimens based on personal preference or outdated guidelines. Crooks *at al.* [36] presented early findings from the SENTINEL (SABA rEduction Through ImplemeNting Hull Asthma guidELines) project in the UK showing that the implementation of systematic healthcare provider and patient education programmes together with real-time data monitoring of asthma care metrics in GP practices allowed two-thirds of the patients to be switched from other alternative regimens to MART. This bold quality improvement project resulted in a significant and sustained reduction of SABA prescriptions, potentially reducing exacerbation rates. There may be wider benefits for society, as Wilkinson *et al.* [37] reported that greenhouse gas emissions are three times higher for poorly controlled asthma compared to well-controlled asthma in the UK. Impressively, the excess carbon footprint due to suboptimal asthma control is equivalent to the total greenhouse gas emission of 140 000 houses in the UK between 2019 and 2020, and 90% of it is estimated to be related to SABA use.

Prescribing the correct medication is only the first step to achieve disease control. It is of the utmost importance that patients are correctly instructed on how to use their inhalers as a systematic review published in 2016, comprising 144 articles and reporting a total of 54 354 patients, confirmed that >30% of them make at least one technique mistake, and that inhaler technique has not improved over the past 40 years [38]. However, it seems that all technique mistakes are of different importance. In a more recent study conducted by Kocks *et al.* [39, 40], 29% of 1434 COPD patients showed suboptimal peak inspiratory flow rate (PIFR) for their dry powder inhalers. Although many of them did not generate a high enough PIFR, more than half of those patients could do so (and might be receptive to some training then). Breathing in incorrectly was associated with a worse clinical COPD questionnaire score, but other inhalation technique mistakes were not.

In another work by Kendall *et al.* [41] using data from the INTREPID trial [42] and UK cost data, single-inhaler triple therapy with fluticasone, umeclidinium and vilanterol was found to be cost-effective and cost-saving in several estimated scenarios compared to non-Ellipta multiple-inhaler triple therapy.

Taken together, the results of these studies highlight the importance of educating patients and, if possible, minimising the number of different types of inhalers to avoid inappropriate drug delivery. Physicians often lack the time to check and demonstrate inhaler technique, so the observation by Rodrigues *et al.* [43] that a pharmacist-led inhalation technique intervention significantly decreased patient numbers at a 6-month follow-up is encouraging.

Healthcare providers' views on electronic cigarettes

An interesting systematic review pointed to the fact that the use of electronic cigarettes as smoking cessation aids still divides opinions of general practitioners – both on paper and on screen! By analysing the results of 25 studies carried out mainly in Europe and in the USA, Selamoğlu *et al.* [44] found that most general practitioners lacked confidence and knowledge about the efficacy and safety of e-cigarettes for smoking cessation, although some were in favour of their use. This stimulated a heated debate during the Q&A session, with some panellists considering that e-cigarettes were potential "tobacco harm reduction tools", while others reminded participants of the potential harms of e-cigarettes, the role of Phillip Morris in the e-cigarette industry and the official ERS position statements against the use of e-cigarettes for smoking cessation [45, 46]. While it is still unknown to what extent healthcare providers endorse e-cigarettes for smoking cessation regardless of the official advice of medical societies against it, the debate is likely to continue until more evidence on the short- and long-term effects of e-cigarettes is collected.

Finally, as the International Primary Care Respiratory Group (IPCRG) global e-Delphi highlighted that the top research needs were in the areas of diagnosis and management of asthma, COPD and chronic cough [47], we should expect next year's congress to bring more studies aiming to develop prediction models and ultimately artificial intelligence programmes or electronic calculators such as the one presented by Daines *et al.* [48, 49], which could assist front-line physicians in decision making processes from diagnosis to management of diseases.

Group 1.04: M-health/e-health

Session: "Remote monitoring of respiratory patients"

In the era of COVID-19, there has been an explosion of interest in remote monitoring of patients, including those with respiratory ailments. This session, organised by the recently formed ERS group 1.04 – m-health/e-health [50], saw several research presentations covering an interesting spectrum of remote monitoring applications such as medication adherence, virtual consultation and advanced data analytics. Topics dedicated to remote healthcare that were previously raised during ERS International Congress 2020 were analysed and elaborated by researchers from Europe and USA [51].

Medication adherence

Medication adherence is defined as the extent to which a patient takes his prescribed medication. Poor adherence can adversely affect the trajectory of the disease and lead to suboptimal clinical benefits together with inefficient utilisation of healthcare resources. Remote monitoring m-health/e-health technologies provide patients with the tools they need to improve adherence such as regular reminders, usage monitoring, medication-specific education and facilitating virtual visits [52, 53].

This session included several talks on adherence monitoring among patients with respiratory diseases like COPD and asthma. Jácome *et al.* [54] explored patient characteristics that were associated with low engagement with a m-health app called InspirerMundi, which monitors adherence in asthma patients. Of the 107 invited patients, 93% installed the app. Patients with a low engagement rate were mostly male, had worse outcomes including poor self-reported health, higher exacerbations and unscheduled medical visits. A similar study was reported by Woehrle *et al.* [55], who investigated the potential of a digital companion on adherence to Breezhaler asthma inhaler therapy. This digital companion comprises a sensor and a smartphone app and can be prescribed alongside inhaler therapy. The researchers showed that patients using a digital companion had a high medication adherence of 82% at baseline that was sustained after 3 months. Schnoor *et al.* [56] studied the effects of an e-Health intervention called SARA to improve the correct use of medication among asthma and COPD patients. SARA helps patients by providing information, support and instructions on inhalation medication. In an observational study involving Dutch pharmacy dispensing data of 32 000 patients, exacerbation rates lowered significantly after implementation of SARA when compared to a control group. Finally, Kaye *et al.* [57] reported that in the USA, patients who enrolled in a digital self-management platform to manage their asthma and COPD maintained an increased controller medication adherence throughout 2020. Such a trend was seen initially at the onset of COVID-19 [58].

Virtual consultation

Virtual consultation using tele-conferencing technologies provides a safe and convenient modality to monitor the health of patients, especially during a pandemic [52]. Harkness *et al.* [59] demonstrated the clinical usefulness of "virtual wards" in the UK to facilitate the safe discharge of COVID-19 patients. A virtual ward allows the patient to be monitored in the community using pulse oximetry, a mobile app and telephone consultations. The researchers analysed 161 patients discharged to a virtual ward of which 68% were discharged with an oxygen concentrator. The study reported a saving of 1263 hospital inpatient days, with 1003 of these reflecting days when patients needed oxygen.

Celan *et al.* [60] studied the benefit of a video-supported treatment system to facilitate directly observed therapy in drug-resistant tuberculosis patients in Moldova. The study, perfectly timed during COVID-19 restrictions, was carried out with 225 patients, and further demonstrated a high overall adherence rate of 89% with an increased level of patient satisfaction.

In a small cohort of COPD patients, Frerichs *et al.* [61] explored the feasibility of a telemonitoring system that comprised a tablet system connected to Bluetooth devices that measured several physiological parameters, allowed self-reporting of symptoms and scheduled weekly video calls with nurses. The researchers identified an incorrect Bluetooth connection, incomplete data transfer and issues with video-connection stability as the top three barriers to implementation.

Advanced analytics

One of the key features of a remote monitoring system is the volume of data gathered by the multitude of sensors involved. Extracting clinical insights from such datasets necessitates the application of advanced modelling techniques such as signals processing and machine learning.

Buekers *et al.* [62] modelled the kinetics of heart rate and oxygen uptake (V'_{O_2}) from COPD patients, determined by a wearable data outside of clinical/laboratory settings, during outdoor walks. They demonstrated that estimated kinetics were valid when starting/finishing an outdoor walk and were comparable to the standard 6MWT.

Swaminathan *et al.* [63] developed a machine learning software called Vironix that provides real-time risk stratification for COVID-19 and provides decision support for return-to-work initiatives. In a pilot study, 11 participants received daily personalised recommendations on the risk of COVID-19 infection, while their managers received work-from-home recommendations for 4 months. The app released 14 stay-at-home and 10 escalation recommendations with a high user retention rate.

Lastly, Roberts *et al.* [64] described a fully automated machine learning approach to quantify CT airway volumes in IPF patients. When applied to 31 unseen IPF patients with two CT scans each, the difference in median airway volume was observed to be larger in subjects with >10% change in FVC between the two scans (progressive) than those with <10% change (stable).

Overall, during this session, numerous important questions focused on remote monitoring of respiratory patients were raised and discussed. It provided insights into various digital health technologies implemented all across Europe, as well as approaches to make obtained data more valid and improve the engagement of patients in these new technologies.

Group 1.05: Clinical respiratory physiology, exercise and functional imaging

Session: "New insights into the pathophysiology and prognosis of COPD"

This session from Group 1.05, which recently joined Assembly 1, mainly focused on new ways to improve the assessment of COPD patients and understand the consequences of the disease.

Muscle dysfunction in COPD

As muscle fatigue and oxygenation may contribute to reduced exercise capacity in COPD, Gephine *et al.* [65] measured the surface electromyography signals (sEMG) and oxygenation response of the quadriceps during the 1-min sit-to-stand (1STS) in 14 COPD patients compared to 12 paired healthy controls. During the 1STS, they observed a progressive deceleration only in COPD patients, associated with a sEMG fall in quadriceps median frequency suggestive of fatigue. No major difference in quadriceps oxygenation was noted between groups, although quadriceps oxygen extraction was increased during the first 15 s of 1STS in COPD patients.

Kharat *et al.* [66] investigated the evolution of diaphragm thickening fraction (TF) by ultrasound, during acute exacerbation (AE) and its predictive value as a marker of early readmission, in 28 COPD patients. Diaphragmatic thickening ratio (TF%max: ratio of tidal to maximal inspiratory–expiratory thickening fraction) was increased in AE. Its change between admission and discharge differed depending on clinical evolution, with a decrease only in patients without treatment failure. Upon discharge, TF%max was significantly higher in readmitted patients, suggesting its role as a predictive marker of treatment failure.

Finally, Louvaris *et al.* [67] investigated the effects of 4 days in-hospital nocturnal noninvasive ventilation (NIV) initiation on respiratory muscle performance, activation and oxygenation during a maximal incremental inspiratory load test, in seven stable COPD patients with chronic hypercapnic respiratory failure (CHRF). Five patients improved their maximal inspiratory load capacity and strength. At equal inspiratory load between pre- and post-NIV measures, patients exhibited greater inspiratory muscle activation and less systemic and respiratory muscle deoxygenation post-NIV. The authors suggested that short-term nocturnal NIV can improve respiratory muscle function in COPD patients with CHRF, but any clinical extrapolation must remain cautious with such a small number of explored patients.

Dyspnoea and exercise

Increased dyspnoea may be an important signal for reduced exercise tolerance and survival in COPD. Neder *et al.* [68] evaluated implications of exertional dyspnoea on exercise tolerance and survival in 300 patients with COPD. Severe dyspnoea during cardiopulmonary exercise testing (CPET) at standardised minute ventilation (V'_E 25 $L \cdot min^{-1}$) was found in 56% of subjects, who presented with greater inspiratory constraints due to higher operating lung volumes at low V'_E, poorer exercise tolerance and more cardiovascular comorbidities. Regardless of the Global Initiative for Chronic Obstructive Lung Disease (GOLD) stage, these patients had poorer survival up to 20 years after CPET. Severe dyspnoea-$V'_{E_{25}}$ may identify patients at risk of poorer outcome across the spectrum of COPD severity.

Evaluating the quality as well as the intensity of dyspnoea is potentially important in patients with COPD. Phillips *et al.* [69] examined associations between exercise capacity and descriptors of dyspnoea using a 15-item questionnaire in 261 COPD patients and 94 matched controls. Patients reporting "unsatisfied inspiration" had an increased frequency of inspiratory mechanical constraints and low exercise capacity, regardless of COPD severity or peak dyspnoea intensity. Reporting descriptors complemented traditional assessments of dyspnoea during CPET and helped identify patients with critical mechanical abnormalities related to exercise intolerance.

Assessing airway diseases with functional explorations

Ventilation inhomogeneity is a cardinal feature of airway diseases. Pisi *et al.* [70] assessed the poorly communicating fraction (PCF) defined by the ratio of total lung capacity to alveolar volume measured by inert gas dilution, in 35 patients with asthma and 45 patients with COPD. PCF was compared to multiple breath nitrogen washout, which provides indices of conductive (Scond) and acinar (Sacin) heterogeneity as well as the lung clearance index (LCI). In both patient groups, PCF showed a positive correlation with LCI and Sacin, but not with Scond. COPD patients with PCF>30% were highly likely to have a modified Medical Research Council (mMRC) score $\geqslant$2. The authors concluded that PCF can provide a comprehensive measure of ventilation inhomogeneity in asthma and COPD patients.

D_{LCO} is modestly associated with emphysema in mild–moderate COPD. Elbehairy *et al.* [71] investigated the association between D_{LCO} and total pulmonary blood volume measured by segmenting the vascular tree in lung CTs of 65 smokers with no or mild–moderate airflow obstruction. Among smokers with mild emphysema quantified by CT low attenuation per cent, and mild–moderate airflow obstruction, low resting D_{LCO} was associated with reduced pulmonary blood volume, independently of emphysema. Low D_{LCO} was also associated with increased intensity of exertional dyspnoea and greater ventilatory requirements during exercise, independently of airflow obstruction and emphysema severity.

Berton *et al.* [72] investigated whether continuous monitoring of S_{pO_2}during 6MWT as recommended by ERS/American Thoracic Society (ATS) improves the yield of 6MWT-induced desaturation in predicting mortality in COPD. 37% of 399 patients ranging from mild to very severe COPD died during a mean follow-up of 1674±679 days after 6MWT. In 72% of patients who desaturated, the S_{pO_2} nadir was lower than S_{pO_2} at the end of the test. Desaturation detected only by S_{pO_2} nadir was found in 20% of participants and predicted all-cause mortality in patients with COPD, adjusted for sex, body mass index, comorbidities, forced expiratory volume in 1 s (FEV_1 % pred) and 6MWT distance.

Other presentations

Within the SPIROMICS cohort, Suri *et al.* [73] compared functional capacity and health status in 310 COPD patients residing at high altitude (>1250 m) with 400 from sea level. The high-altitude group was younger with more current smokers, less asthma history, higher supplemental oxygen use and more AEs. The high-altitude group had more emphysema percentage on CT, shorter 6MWT distance, poorer health status and had more severe AE in the first year of follow-up; however, without a difference in mortality or FEV_1 decline. The authors concluded that more research is needed to understand the impact of high altitude on COPD outcomes.

Also, reference equations are critical for the correct diagnosis of restrictive lung diseases. MRAZ *et al.* [74] assessed the use of Global Lung Function Initiative (GLI) equations [75] in the Austrian general population. The 2021 GLI equations showed a better fit for static lung volumes compared to the European Coal and Steel Society (1993 ECSC, 18–70 years) and Zapletal (6–18 years) reference equations [76, 77]. However, total lung capacity (TLC) less than the lower limit of normal assessed by 2021 GLI reference equations was lower than the expected 5% for both males (1.4%) and females (0.4%). This was also found for residual volume (RV), functional residual capacity (FRC) and inspiratory capacity (IC). The authors concluded that the 2021 GLI reference equations may underestimate the prevalence of restrictive impairment in the studied population.

Conclusion

We hope that the highlights summarised will help readers to keep up to date with the impressive amount of lung research and advances in pulmonary care presented through the sessions from ERS Assembly 1. A broad number of suggestions for further investigations were highlighted in this article, concerning for example the diagnosis and treatment of asthma, COPD and chronic cough in primary care, the role of e-cigarettes, the management of COVID-19 in the acute phase and its long-term assessment, a better determination of PR target population and maintenance programmes, a better characterisation of dyspnoea, and how to improve patients' education and engagement. We also hope to have encouraged the readership to contribute to Assembly 1 activities, and of course to take part in the 2022 ERS International Congress to be held in Barcelona next September, where further scientific novelties and clinical developments on these topics will be discussed.

Provenance: Commissioned article, peer reviewed.

Conflict of interest: T. Gille reports personal fees from Boehringer Ingelheim and Roche, and nonfinancial support from Oyxvie, LVL Medical and Vitalaire (oxygen providers), outside the submitted work. P. Sivapalan reports personal fees from AstraZeneca, GSK, Boehringer Ingelheim and Chiesi Farmaceutici, outside the submitted work. C. Vicente reports personal fees from AstraZeneca, Boehringer Ingelheim, GlaxoSmithKline and Mylan, outside the submitted work. N. Das owns stock options in ArtiQ, which develops commercial AI software for lung function diagnostics, outside the submitted work. C. Rolland-Debord reports personal fees from Sanofi, Novartis and AstraZeneca, outside the submitted work. I. Vogiatzis is an associate editor of this journal. F.M.E. Franssen reports grants and personal fees from AstraZeneca, and personal fees from Boehringer Ingelheim, Chiesi, GlaxoSmithKline, MSD and Novartis, outside the submitted work. L.E.G.W. Vanfleteren reports personal fees from AstraZeneca, Novartis, GlaxoSmithKline, Resmed, Boehringer Ingelheim, Verona Pharma and AGA, outside the submitted work; and is an associate editor of this journal. G. Kaltsakas, S.B. Kolekar, M. Armstrong, R. Tuffnell, R.A. Evans, G. Vagheggini, L.H. Degani-Costa, V. Poberezhets, S. Bayat and H. Pinnock have nothing to disclose.

Support statement: R. Tuffnell holds a National Institute for Health Research (NIHR) pre-doctoral fellowship. R.A. Evans holds a NIHR clinician scientist fellowship (CS-2016-16-020). Funding information for this article has been deposited with the Crossref Funder Registry.

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