ERS International Congress 2022: highlights from the Respiratory Clinical Care and Physiology Assembly

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In this article, @ThomasGILLE_MD and co-authors provide an overview of some of the highlights from @ERSAssembly1 (Respiratory Clinical Care and Physiology) presented during the last #ERSCongress held in Barcelona in September 2022 https://bit.ly/43Bfm25

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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 the laboratory-based science, clinical trials and qualitative research that were presented during the 2022 European Respiratory Society International Congress within

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the sessions from the five groups of 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, mobile/electronic health (m-health/e-health), clinical respiratory physiology, exercise and functional imaging.

Introduction

The 2022 European Respiratory Society (ERS) International Congress was held in hybrid format. It provided a much-valued occasion to meet in person again, 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, 3540 abstracts were accepted for presentation and 20 709 delegates attended some of the 360 sessions (14 159 on site in Barcelona and 6550 online).

Assembly 1 (Respiratory Clinical Care and Physiology) is the largest of the 14 ERS assemblies, comprising 7756 members, 38% of them being under 40 years old (early career members). During the 2022 International Congress, Assembly 1 was proud to honour Robin Vos with an ERS Mid-Career Gold Medal in Respiratory Clinical Care and Physiology. Among the 727 abstracts submitted across the five groups within the assembly, 545 were accepted for presentation. Although the virtual platform allowed presentations to be replayed, it can be challenging to keep up to date with all the scientific and clinical advances. This article, therefore, aims to share some of the highlights from the Respiratory Clinical Care and Physiology assembly.

Group 1.01: clinical problems

The ERS International Congress highlighted novel findings regarding frequent respiratory diseases, such as airway diseases and coronavirus disease 2019 (COVID-19).

Management of exacerbations in airway diseases

Patients with COPD often need to be hospitalised due to exacerbations of their underlying disease, imposing a significant clinical and economic burden on the healthcare system [1]. Hence, it is crucial to apply evidence-based strategies for preventing these hospital readmissions. Burns *et al.* [2] (Glasgow, UK) utilised machine learning models to predict 3-month readmission of COPD patients following a respiratory hospitalisation, based on previous clinical data from patients' health records. Using data from a Scottish nationwide cohort of 33 148 patients, the researchers concluded that the artificial intelligence (AI)-based 3-month respiratory readmission prediction model performance was promising and that it could be used in the clinical practice.

Acute exacerbations of COPD may lead patients to severe respiratory failure, requiring mechanical ventilation and prolonged stays in an intensive care unit (ICU) [3]. The outcome of prolonged weaning in patients with COPD is still uncertain. Wollsching-Strobel *et al.* [4] (Cologne, Germany) analysed 2937 COPD patients from the WeanNet cohort of specialised German weaning centres. Increased mortality due to weaning failure was associated with advanced age and duration of mechanical ventilation. It was demonstrated that transfer from the ICU to a specialised weaning centre could result in successful weaning in >60% of cases. Furthermore, they showed that tracheostomy status and initial destination following discharge greatly depend on the weaning outcome.

In the Middle Eastern cohort SABINA III, a cross-sectional study demonstrated that 38% of 8351 asthmatic patients across 23 countries were prescribed ⩾3 canisters of short-acting β-agonists (SABAs) per year [5]. According to Global Initiative for Asthma (GINA) guidelines, this treatment plan is no longer recommended without the concomitant use of inhaled corticosteroids (ICS) [6]. Through a univariate *post hoc* analysis, Alzaabi *et al.* [7] (Abu Dhabi, United Arab Emirates) showed that a significantly higher percentage of patients prescribed ⩾3 *versus* 1–2 SABA canisters per year had uncontrolled asthma (35.6% *versus* 21.2%), and reported one (24.6% *versus* 21.0%), two (14.2% *versus* 9.3%) or ⩾3 severe asthma exacerbations (18.0% *versus* 11.0%). Therefore, it is important for clinicians to identify this group of patients who are at risk of SABA overuse, in order to ameliorate asthma outcomes globally.

Cancer risk in patients with asthma–COPD overlap

Chronic inflammation is the main underlying pathophysiological mechanism in COPD and asthma. Tobacco consumption and COPD are associated with an increased risk of malignancy [8], but the effect of asthma on cancer incidence is as yet inconclusive. Bonnesen *et al.* [9] (Copenhagen, Denmark) aimed to determine whether asthma was associated with an increased risk of cancer among COPD patients and the role of ICS as anti-inflammatory agents. A total of 50 897 COPD patients from Danish registries were included in the study and separated into two groups: COPD without asthma, and COPD with concomitant asthma (based on the diagnosis of a respiratory medicine physician). Their risk for any cancer diagnosis was evaluated within the following 2 years. Results showed that there was no association between asthma–COPD overlap and cancer, and that ICS use did not seem to modify the risk for malignancy.

Coagulation impairments in COVID-19

The coagulation patterns present during COVID-19 pneumonia are not necessarily reflected in regularly used coagulation tests, which may not offer sufficient information on the haemostasis process in these patients. Therefore, Loutsidi *et al.* [10] (Glyfada, Greece) explored an alternative in their study including 22 patients. Using rotational thromboelastometry (ROTEM), they monitored blood coagulation of patients hospitalised with COVID-19 at admission, during clinical deterioration, at discharge, and at 1-month follow-up. They found that changes in the ROTEM variables were correlated with disease severity, and that the disease course followed changes seen in ROTEM. This is in line with other studies that used similar methods, including thromboelastography, which were able to detect and diagnose hypercoagulability in patients with COVID-19, enabling relevant treatment [11].

During hospitalisation with COVID-19, biomarkers may help in either determining relevant treatment or being able to predict patient outcomes. One such possible biomarker is the plasminogen activator inhibitor-1 (PAI-1). Bielosludtseva and Pertseva [12] (Dnipro, Ukraine) investigated the potential of PAI-1 to predict prognosis and risk of mortality in 85 patients admitted with COVID-19 pneumonia (40 moderate, 25 severe, 20 critical). They showed that the risk of mortality was 219-fold higher (95% CI 8–6224) in patients with increased PAI-1 on admission above 20.6 $ng \cdot L^{-1}$, compared to the others, with good sensitivity and specificity of this cut-off level (area under the receiver operating characteristic (ROC) curve 0.78). Furthermore, when analysing autopsies, they showed that defects in fibrinolysis may play a role in thrombogenesis in COVID-19 patients. In a previous study conducted in the USA, investigators had also shown that elevated PAI-1 level was associated with hospitalisation due to COVID-19 and worse respiratory status. They also found that a higher level of tissue-type plasminogen activator was correlated to mortality [13]. These works strongly suggest an imbalance between fibrinolysis and coagulation in COVID-19 patients that requires further research.

Consequences of COVID-19 inflammation

A Polish study, conducted in 77 patients by Martusewicz-Boros *et al.* [14] (Warsaw, Poland), aimed to determine risk factors for myocarditis shortly after hospitalisation for COVID-19. The investigators used cardiac magnetic resonance imaging (MRI) and discovered that 43% of patients had signs of active myocarditis at 1-month follow-up. Risk factors associated with developing this condition were male sex and ever smoking, as well as low transfer capacity of the lung for carbon monoxide (T_{LCO}). A review focusing on post-COVID-19 myocarditis found that between 8% and 30% of patients showed myocarditis on cardiac MRI following infection by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) [15]. The differences in disease severity, as well as whether the patients were hospitalised or not, and the criteria to define myocarditis on MRI, could explain the prevalence discrepancies. The study by Martusewicz-Boros *et al.* [14], for example, included patients with moderate-to-severe COVID-19 who had needed hospitalisation.

O. Elneima and co-workers (Leicester, UK) presented their study in which they used proteomics to compare the inflammatory markers and profiling of 626 patients following hospitalisation for COVID-19, in order to further investigate the characteristics and mechanisms of having post-COVID-19 condition [16, 17]. They divided patients into four clusters of different severity based on clinical data, 5 months after hospitalisation, and assessed 296 proteins. 13 of these proteins were significantly increased in the group of patients with very severe post-COVID-19 condition, and two proteins were elevated in the moderate/cognitive cluster, when compared to the mild cluster. Subsequent studies assessing these proteins might help to predict people at risk of poor long-term outcome and better understand the pathophysiology of persistent post-COVID-19 symptoms.

Take-home messages

- Machine learning prediction models and AI might be a reliable method to predict the 3-month hospital readmission rate of COPD patients due to exacerbations.
- Transfer of mechanically ventilated patients from the ICU to a specialised weaning centre may result in successful weaning in >60% of cases.
- Patients with uncontrolled asthma who were prescribed ⩾3 SABA canisters per year reported more severe asthma exacerbations per year.

- Cancer incidence in patients with the asthma–COPD overlap phenotype was not increased compared to COPD patients, and the use of ICS did not modify the risk for malignancy.
- In COVID-19, ROTEM variables are related to disease severity.
- PAI-1 is a possible prognostic biomarker in patients admitted with COVID-19 pneumonia.
- A single-centre observational study showed that using cardiac MRI, 43% of COVID-19 hospitalised patients had signs of active myocarditis at 1-month follow-up.

Group 1.02: rehabilitation and chronic care

The session entitled "Best abstracts in pulmonary rehabilitation and chronic care" included nine state-of-the-art abstracts that covered a broad range of topics including exercise training, pulmonary rehabilitation (PR), COVID-19 and telemonitoring.

Exercise training and PR in chronic respiratory diseases

Ward *et al.* [18] (Leicester, UK) conducted a network meta-analysis of 28 randomised controlled trials (RCTs) to understand the effectiveness of different components of exercise training programmes to improve cardiorespiratory fitness. High-intensity aerobic exercise training was shown to be more effective at improving maximal oxygen uptake ($V'_{O_2 max}$) in COPD patients, compared to stair climbing and low-intensity training. However, the specific type and intensity of exercise to optimise training adaptations remain to be established. This study underlines the importance of prescribing aerobic exercise for COPD, and the use of component network analysis to understand which types of exercise training in the PR setting are effective.

There is a need to personalise and adapt exercise modalities for patients with severe COPD. Eccentric training has gained interest in recent years, as it is less demanding on the cardiorespiratory system but effective in improving muscular strength and functional performance [19]. 12 subjects suffering from severe COPD were enrolled in a 3-week PR programme and randomly allocated to either downhill walking with 10% inclination and eccentric resistance training, or to standard PR with a cycle ergometer and conventional resistance training. The preliminary results of this pilot study conducted by Pancera *et al.* [20] (Manerbio, Italy) suggested that low-load eccentric training may lead to improved functional performance and be safely prescribed in people with severe COPD.

In people suffering from idiopathic pulmonary fibrosis, PR is known to improve functional exercise capacity, dyspnoea and health-related quality of life (HRQoL). However, the impact on patient mood has yet to be determined [21]. Of 235 patients referred for an 8-week PR programme in the study presented by Edwards *et al.* [22] (Ilford, UK), 35% had symptoms of anxiety and 37% depression using the Hospital Anxiety and Depression Scale (HADS). The programme included an educational session focusing on psychological well-being. Symptoms of depression improved in the 166 patients (64%) who completed the programme, whereas anxiety symptoms only improved in those with HADS anxiety score ⩾8 points. Using an anchor-based statistical method, improvements of −2.0 points for anxiety scores and −1.2 points for depression scores were considered as the minimal clinically important differences.

Grosbois *et al.* [23] (Lille, France) aimed to evaluate the impact of a home-based PR programme on the well-being of 138 caregivers of COPD patients involved in an 8-week programme of 90-min sessions. Caregivers received education on healthy behaviours, motivation and psychosocial support, and physical activity promotion, using the same methods as for patients. Baseline anxiety/depression symptoms and high burden were reported by 40% of caregivers, and 50% had abnormal fatigue. The intervention resulted in a significant improvement of all these descriptors. This study highlights the burden in caregivers and family members of patients with chronic respiratory diseases, and the importance of integrating caregivers into PR.

Biomarkers, long-term consequences, and management of COVID-19

Identifying novel biomarkers to improve our understanding of COVID-19 remains a key priority. Shchudro and Konopkina [24] (Dnipro, Ukraine) conducted a study to assess the role of surfactant protein-A (SP-A), measured in 75 COVID-19 survivors at 6 weeks after the infection and 15 healthy controls. No significant difference was observed in SP-A between patients with moderately severe COVID-19 and controls ($p>0.05$), whereas SP-A was significantly higher in those with severe or critical COVID-19 ($p<0.01$). A strong positive correlation was observed between SP-A and the severity of dyspnoea. Interestingly, another recent study suggested that SP-A could be a useful predictor of lung lesion after COVID-19 [25].

A UK-based multicentre study presented by Baldwin *et al.* [26] (Leicester, UK) evaluated exercise tolerance 5 and 12 months after COVID-19 hospitalisation discharge and assessed self-reported reasons for intolerance. This interim analysis (n=378) indicated that 12 months after discharge, 75% of patients had impaired exercise capacity (⩽80% predicted in the incremental shuttle walk test). Exercise capacity remained unchanged between 5 and 12 months, independent of the limiting symptom. These findings underline the importance of developing effective rehabilitation strategies to increase exercise capacity in people recovering from COVID-19.

Post-COVID-19 condition remains a major public health issue, and there is still a lack of evidence-based interventions to rehabilitate this population [27]. Philip *et al.* [28] (London, UK) presented findings from a parallel-group, single-blind, RCT that aimed to evaluate, in 158 patients with persisting symptoms after COVID-19, the impact of an online breathing and well-being programme including singing exercise (ENO Breathe) on persistent symptoms and HRQoL. The results indicated that ENO Breathe was a safe and well-tolerated intervention that improved the mental component of the Short Form 36 (SF-36) questionnaire and elements of breathlessness (as assessed by a visual analogue scale and the Dyspnoea-12 questionnaire).

Telemonitoring for non-invasive ventilation

Pontier-Marchandise *et al.* [29] (Toulouse, France) presented a retrospective study that evaluated the quality of ventilation (good quality defined as compliance >4 h·day^{-1}, non-intentional leaks <24 L·min^{-1}, apnoea–hypopnea index <10 events·h^{-1}) in patients receiving home non-invasive ventilation (NIV) as part of a telemonitoring programme. In total, 155 COPD and 187 non-COPD (*i.e.* obesity, hypoventilation syndrome, restrictive lung disease) patients were included in the analysis. At baseline, 76% of patients had good quality ventilation, which improved to 87% following 1 year of telemonitoring. The authors concluded that NIV telemonitoring may improve ventilation quality, even in patients who had used NIV for several years.

Bronchoscopic lung volume reduction in COPD

Bronchoscopic lung volume reduction (BLVR) with endobronchial valves is an established treatment option to reduce pulmonary hyperinflation in COPD [30]. However, the impact on cardiac preload and pulmonary artery pressure remains unknown. Van der Molen *et al.* [31] (Groningen, the Netherlands) presented novel data from 24 patients with severe COPD who had undergone cardiac MRI pre- and 8 weeks post-BLVR. They observed a significant reduction in hyperinflation (as assessed by the residual volume/total lung capacity ratio) after the procedure, which resulted in a clinically meaningful improvement in preload, stroke volume, cardiac output and contractility (for both ventricles). Interestingly, no change in pulmonary artery pressure was observed, and the researchers hypothesised that the increase in blood flow following BLVR was related to the reduction of extravascular pressure, due to improved hyperinflation.

Take-home messages

- In COPD patients, high-intensity aerobic exercise was more effective than stair climbing and low-intensity training. Low-load eccentric training can be effective and safely prescribed in people with severe COPD.
- An online breathing and well-being programme with singing exercises was safe and improved mental status and breathlessness.
- Home-based PR programmes may improve burden, mood and fatigue of informal caregivers of patients with COPD.
- NIV telemonitoring may improve the quality of ventilation, even in patients receiving NIV for several years.
- BLVR may improve cardiac preload, stroke volume, cardiac output and contractility in patients with particular forms of emphysema.
- The minimal clinically important differences in HADS anxiety and depression scores for PR of patients with idiopathic pulmonary fibrosis were defined as −2.0 and −1.2 points, respectively.
- In patients with severe or critical COVID-19, higher blood levels of SP-A were strongly correlated with the severity of dyspnoea.
- An impairment in exercise capacity was reported in most patients 12 months after hospitalisation due to COVID-19.

Group 1.03: general practice and primary care

Important topics aiming to improve respiratory management in general practice and primary care were reviewed in the 2022 ERS Congress.

Rationale for a closer follow-up of COPD patients

As outlined in the 2022 report of the Global Initiative for Chronic Obstructive Lung Disease (GOLD), the risk of future exacerbations in newly diagnosed COPD can be difficult to predict [32]. Løkke *et al.* [33] (Aarhus, Denmark) presented the outcomes of an observational cohort study comparing 3958 GOLD A0 (with no exacerbations) and 3233 GOLD A1 (with one moderate exacerbation within the previous year) COPD patients followed over 3 years in Denmark. The investigators concluded that "Even in COPD patients with a low symptom burden, one moderate exacerbation increases the odds of subsequent exacerbations and death" (odds ratio for death 1.91 (95% CI 1.58–2.31)). This study, highlighting the importance of prevention, treatment and yearly control in GOLD A patients, was awarded the best abstract for ERS Assembly 1.

Sandelowsky *et al.* [34] (Uppsala, Sweden) retrospectively analysed Swedish nationwide data about 19 857 patients with a first-time COPD diagnosis between 2006 and 2017. Over the 11-year study period, the probability of having a follow-up visit within 15 months post-diagnosis increased from 17.4% in 2006 to 53.4% in 2017. In the 15 095 patients who experienced their first COPD exacerbation, the overall probability of having a post-exacerbation visit within 6 weeks was 7%, rising to 29.4% when extending the follow-up period to 15 months. The latter increased from 11.0% in 2006 to 38.3% in 2017. Despite the fact that follow-up visits have become more frequent over the last decade, there is still room for improvement in adherence to guidelines in COPD management.

Supported self-management in asthma

In the UK, asthma causes 6.3 million general practitioner (GP) consultations a year and 100 000 hospital admissions. Supported self-management for asthma reduces attacks and improves asthma control [35]. The IMP^2ART programme (IMPlementing IMProved Asthma self-management as RouTine) in primary care is a three-level implementation strategy that includes providing patient resources, developing professional skills and influencing organisational priorities and routines [36]. The pilot phase reported by McClatchey *et al.* [37] (Edinburgh, UK), having randomised 12 GP practices (implementation arm or usual control arm), showed that IMP^2ART was acceptable and feasible.

Nested within the IMP^2ART programme, Kinley *et al.* [38] (Edinburgh, UK) explored the differences in delivery of supported self-management between five practices of the implementation arm and five controls, using video-recorded asthma reviews and interviews with healthcare professionals. Implementation practices delivered a more patient-centred review, used more behaviour change techniques, and spent more time within consultations discussing supported self-management-related strategies.

Additional presentations

The ageing population and its burden on healthcare systems warrant early detection of patients at risk of functional decline and mortality. Wijnant *et al.* [39] (Rotterdam, the Netherlands) reported the outcomes of a Dutch population-based study (n=5442) assessing frailty transitions and their accuracy for mortality prediction in subjects with impaired spirometry. Patients with either a decreased ratio of forced expiratory volume in 1 s (FEV_1) to forced vital capacity (FVC) <0.7, or FEV_1 <80% of mean predicted value, were less likely to recover from frailty, and more likely to progress from any frailty state towards death, compared to individuals with normal spirometry. The accuracy of a statistical model (including age, sex and smoking status) to predict mortality in patients with FEV_1/FVC <0.7 was significantly improved when incorporating frailty score (area under ROC curves 90.5 (95% CI 82.3–98.8) *versus* 77.9 (95% CI 67.2–88.6)).

Finally, G. Doe and co-workers (Leicester, UK) presented a feasibility study investigating the impact of a structured diagnostic pathway designed to confirm or exclude the five most common causes of chronic breathlessness in patients over 40 years old: COPD, anxiety, anaemia, heart failure and obesity/deconditioning [40, 41]. 48 patients were included from 10 GP practices [41]. At 1 year, a coded diagnosis was reached in 44% of patients in the intervention group *versus* 26% in the usual care group, with a significant improvement in patient-reported outcome measures, paving the way for an adequately powered, forthcoming RCT.

Brief report of the symposium "Forgotten issues in COPD: a primary care perspective"

Many of the difficulties faced by patients suffering from COPD are under-investigated, with few recommendations in guidelines, and neglected by physicians, due to lack of confidence and skills in these specific issues [42]. In too many cases, the management of COPD is considered to be limited to inhalation therapy [43].

COPD and mental health

30% of patients with COPD suffer from depression (increasing to 80% in severe COPD) and 10–50% suffer from anxiety [42, 44] with a huge impact on HRQoL and disease control [45]. In order to break the vicious cycle between physical and mental symptoms, addressing the psychological burden could improve not only HRQoL but also treatment adherence [46]. Physicians should adopt a patient-centred approach that focuses on its desires, goals and preferences using OARS skills (Open questions, Affirmations, Reflection and Summary). A number of non-pharmacological approaches proved their efficacy in the management of mental health disorders, specifically cognitive behavioural therapy [47–49], mindfulness [50, 51] and PR [42, 52–54]. The systematic review and meta-analysis of Taylor *et al.* [55] (Birmingham, UK) demonstrated that, contrary to popular belief, quitting smoking is associated with an improvement in mental health. More information about the topic is available in the International Primary Care Respiratory Group desktop helper number 12 [56].

Home-based PR in a digital world: an alternative for low-to-middle-income countries?

Despite its importance in the management of chronic respiratory diseases [57, 58], the access to PR is limited in the context of low-to-middle-income countries (LMICs). In the review of Cox *et al.* [59] (Melbourne, Australia), no differences were found between telerehabilitation and centre-based rehabilitation. Similarly, Uzzaman *et al.* [60] (Edinburgh, UK) concluded that home-based PR is as effective as centre-based PR in terms of functional exercise capacity and HRQoL, and is an option to enhance access to PR in low-resource settings.

COPD and sexual health

Sexual dysfunction in patients with COPD is the result of interaction between hormonal, physiological, psychological, sociological and pharmaceutical factors [61]. The prevalence is high in this patient group, especially erectile dysfunction [62, 63]. Sexual dysfunction in women has rarely been studied, although women with COPD have also been reported to have lower frequency of sexual intimacy [63, 64]. The first step in managing sexual health disorders is to approach the discussion within the patient's cultural context, avoid moral or religious judgement, and normalise the conversation. This requires communication skills. Primary care professionals could play a crucial role by promoting adherence to inhalation therapy and giving practical tips, like advising sexual positions that are less likely to cause dyspnoea [65].

A palliative approach to COPD

Although COPD is responsible for a prolonged substantial burden, in comparison to cancer, access of patients with COPD to palliative care is very restricted [66], and often takes place only within weeks of death [67, 68]. In the study of Bloom *et al.* [67] (London, UK), only 6% had access *versus* 50% of patients suffering from both COPD and lung cancer. Primary care physicians are urged to implement palliative care early by initiating the discussion with their patients about their needs and concerns, and to use a multidisciplinary approach involving palliative care specialists as appropriate.

Take-home messages

- Close monitoring and annual control of patients with COPD are important because even in patients with a low symptom burden, one moderate exacerbation increases the odds of subsequent exacerbations and death.
- Supported self-management for asthma reduces attacks and improves asthma control.
- COPD, anxiety, anaemia, heart failure and obesity/deconditioning are the five most common causes of chronic breathlessness in patients over 40 years old.
- OARS skills (Open questions, Affirmations, Reflection and Summary) are an important tool to approach patients with COPD suffering from mental health difficulties. Non-pharmacological approaches proved their efficacy in mental health management, specifically cognitive behavioural therapy, mindfulness and PR.
- Home-based PR is as effective as centre-based PR in terms of functional exercise capacity and HRQoL, and could be an interesting option in low-resource settings.
- Sexual dysfunction is highly prevalent in patients with COPD. Primary care professionals play a crucial role in its detection and management.
- Palliative care should be implemented early in patients with COPD by initiating the discussion with patients about their needs and concerns.

Group 1.04: m-health/e-health

The thematic poster session "Digital health interventions in respiratory practice" highlighted a wide range of digital health interventions to support patients' self-management and encourage patients' and providers' adoption of digital technologies. These novel digital health interventions in respiratory practice correspond with the call to action published by the m-health/e-health group in 2020 [69]. Presenters raised the importance of prioritising the end-users' needs, involving them in co-designing the solutions early in their development to ensure the technologies are accurate and fit the users' preferences/habits and routine workflow. Moreover, compared to the topics highlighted during the previous ERS Congresses by this group [70–72], these presentations showed the evolution of the topics that group members considered as clinically relevant during the last years.

Digital health

The definition of digital health is broad, encompassing use of a mobile phone, smart devices (sensors), AI, big data and robotics to support patients' healthcare [73].

Ferreira-Cardoso *et al.* [74] (Porto, Portugal) showed the feasibility of using a smartphone microphone to record the quality of lung sounds and to capture adventitious sounds to support remote monitoring and healthcare.

A recent prospective study from Cerdán-de-Las-Heras *et al.* [75] (Aarhus, Denmark) with 54 COPD patients showed that telerehabilitation with a virtual autonomous physiotherapist agent (TR-VAPA) was non-inferior to traditional hospital-based PR, as assessed by improvement of exercise performance and HRQoL questionnaires. Additionally, complementary data were presented during the Congress showing that TR-VAPA was more cost effective [76].

Digital therapeutics

Digital therapeutics products must be certified by regulatory bodies [77] and are defined as "evidence-based therapeutic interventions that are driven by high quality software programs to treat, manage, or prevent a disease or disorder" [78].

Häussermann *et al.* [79] (Munich, Germany) tested Kata, an app aiming to optimise inhalation technique in patients with COPD or asthma. It uses the camera and microphone built into a mobile phone, and augmented reality, to analyse images and sounds of inhaler technique. In a proof-of-concept study with eight people with asthma, the app reduced overall handling errors and critical errors per inhalation.

An Internet-of-things platform connected with several CE-marked smart devices (smart-inhaler, smart-peak-flow meter, smart-watch) from various brands was developed by Hui *et al.* [80] (Edinburgh, UK) to support asthma self-management. In a proof-of-concept study with 10 people with asthma, they found that perceived accuracy of the technology determined adherence to using the technology, and highlighted the need to make digital technologies interoperable.

Finally, Glyde *et al.* [81] (Bristol, UK) showed the potential of using machine learning on real-world data collected through the myCOPD app to predict future exacerbations. These works demonstrate the relevance of conducting proof-of-concept studies with end-users to make digital technologies more accurate and attractive to support healthcare.

AI and machine learning

Three types of AI were presented in the session, for three distinct purposes: diagnosis, classification and prediction.

Chest radiographs were used as the input to an AI algorithm to diagnose pulmonary embolism [82] and detect pneumothorax, airspace opacity, and mass or nodule [83, 84]. Verdi *et al.* [83] (Ankara, Turkey) used deep learning and multicentre datasets in a pneumothorax detection algorithm (PDA-alpha) to improve the model generalisability. Similarly, deep learning was used by Gana *et al.* [84] (Harare, Zimbabwe) in another model that achieved a high performance, comparable to radiologists or other models approved for clinical use [85, 86].

By analysing respiratory sounds captured by an electronic stethoscope with convolutional neural networks, Sourour *et al.* [87] (Sfax, Tunisia) were able to automatically classify and assign them the correct auscultation.

Gonzalez Colom *et al.* [88] (Barcelona, Spain) used registry data, clinical/functional status information and social care data to generate a predictive model of patients' mortality and readmission risk at 90 days after hospital discharge, and were able to stratify risk profiles into four different clusters.

All three approaches show promise as early warning systems to support clinical decisions and remote care in the future. Further development and validation were highlighted as the natural next steps.

Electronic Health Record

The Electronic Health Record (EHR) contains rich data and information about patients' conditions and health outcomes after treatments. Several works were presented, by A. Morra and co-workers and M. Moloney and co-workers (Kingston, ON, Canada), suggesting that a standardised data structure is needed to ensure data interoperability between different healthcare organisations, and allow healthcare evaluation across them. A rule-based algorithm was developed to categorise confirmed and suspected asthma patients in an observational study, and support asthma educators to adhere to the best practice guidelines in recognising and managing uncontrolled severe asthma. The authors showed that a machine learning algorithm can be used to classify asthma patients in a future clinician decision support system, improving asthma underdiagnosis/misdiagnosis, and operating as a surveillance system [89–92].

These works demonstrated the potential of real-world data based on EHR to improve delivered care, but also as a powerful tool to evaluate healthcare quality.

Perceived facilitators, barriers and caveats

Many digital tools exist at present, but engaging patients to adopt and use them to manage their conditions is challenging.

With an online questionnaire sent to users with interstitial lung disease, Parsons *et al.* [93] (Oxford, UK) found that compliance to home spirometry was favoured by greater disease severity and requirement for treatment. Goal setting and a patient-led escalation plan in event of deterioration were facilitators to encourage engagement, whereas a key barrier was the lack of knowledge of spirometry parameters.

Smartphone apps for physical activity are not primarily designed for patients [94]. Dourado *et al.* [95] (Santos, Brazil) assessed which features were attractive to individuals with low cardiorespiratory function. The ability to receive suggestions for activity techniques and to monitor progress with graphs and tables were amongst preferred features, contrary to data sharing through social networks and the possibility to "compete with friends".

Quach *et al.* [96] (Concord, ON, Canada) reviewed 437 COPD Android apps in the Google Play store, with features including disease screening, medication reminders, symptom tracking, goal planning and peer networking. However, none of the apps reported effectiveness, feasibility or usability information to support their use for self-management.

Finally, a scoping review by Hui *et al.* [97] (Edinburgh, UK) revealed that digital health implementation in several LMICs (Bangladesh, India, Indonesia, Malaysia and Pakistan) was restricted by limited skilled labour, lack of legislation/interoperability support, interrupted electricity and internet services, age/gender and geographical disparities.

Take-home messages

- Digital interventions such as AI, smartphone apps, augmented reality, electronic stethoscopes, built-in cameras and microphones on smartphones, home spirometry, smart inhalers, Internet-of-things connected platforms and "big data" in the EHR are technically feasible to be used in supporting respiratory care and can encourage engagement.
- To ensure the interventions are accurate and fit the user's preferences/habits and routine workflow, it is essential to involve end-users to co-design the digital health intervention at the early development stage.
- To ensure effective implementation, several practical issues raised in the studies need to be addressed, including lack of interoperability support to allow effective data exchange across health organisations, limited available datasets to support AI validation and its generalisability to a wider population, unclear quality of the existing apps, and specific concerns in LMICs (interrupted electricity/internet services, limited skilled labour, age/gender and geographical disparities).

Group 1.05: clinical respiratory physiology, exercise and functional imaging

Most abstracts in the session "Expanding the insight into COVID-19 dyspnoea" presented data examining breathing pattern or ventilatory inefficiency during cardiopulmonary exercise testing (CPET), while others investigated resting abnormalities or original strategies to lessen dyspnoea after SARS-CoV-2 infection.

Ventilatory inefficiency and "dysfunctional" breathing

During exercise at moderate intensity (*i.e.* in the absence of metabolic acidosis), minute ventilation (V'_E) is tightly coupled to the rate of carbon dioxide output (V'_{CO_2}) washed out by the lungs, which serves to keep arterial carbon dioxide tension constant [98]. In this context, ventilatory inefficiency refers to excessive ventilatory stimuli relative to metabolic demand (*i.e.* high V'_E/V'_{CO_2} ratio) [99, 100]. Poor ventilatory efficiency is a well-known mechanism of exertional dyspnoea in different respiratory disorders, such as COPD [101]. Dysfunctional breathing (DB) may be defined as dyspnoea found in the presence of an abnormal breathing pattern after excluding other potential contributory causes, such as underlying cardiopulmonary conditions [102–104].

In line with these premises, PIAMONTI *et al.* [105] (Rome, Italy) performed CPET in a group of 20 survivors of moderate-to-critical COVID-19 (n=6 hospitalised in ICU) with residual exertional dyspnoea and/or abnormalities on pulmonary function tests (PFTs) up to 15 months after discharge. At 15 months, V'_E/V'_{CO_2} slope >30, signalling poor ventilatory efficiency, was observed in 13 (65%) out of 20 patients. Importantly, V'_E/V'_{CO_2} slope was related to the severity of lung involvement on high-resolution computed tomography (HRCT) of the chest, and inversely correlated with T_{LCO}. The authors thus concluded that residual exertional dyspnoea and ventilatory inefficiency may reflect damage in the interstitial/pulmonary capillary structure.

LOEW *et al.* [106] (Sion, Switzerland) sought to investigate the perceptual (*i.e.* symptoms and HRQoL) and functional impact in patients diagnosed with DB after COVID-19. In a sample of 48 patients, the authors reported hyperventilation (21%), erratic breathing (46%) and mixed types of DB (33%). Dyspnoea was the most prevalent symptom, while exercise capacity was preserved. In comparison to healthy controls, HRQoL (SF-36, total score and every subdomain) was lower in those previously infected by COVID-19. The same group reported that hyperventilation was associated with greater respiratory rate, while patients showing erratic breathing or mixed types of DB showed greater coefficient of variation in tidal volume and inspiratory time, compared to patients with post-COVID-19 condition but normal CPET. Hyperventilation and mixed types of DB were also associated with steeper V'_E/V'_{CO_2} slopes, signalling excessive ventilation relative to metabolic demand [107], providing potential physiological explanations for dyspnoea in post-COVID-19 condition [108]. These findings were further supported by VAN VOORTHUIZEN *et al.* [109] (Nijmegen, the Netherlands), who found a large prevalence of erratic breathing patterns during exercise after mild COVID-19.

Similarly, in a group of 40 male professional soccer players, STAVROU *et al.* [110] (Larissa, Greece) reported greater resting and exertional V'_E in the 20 athletes previously infected by COVID-19, despite strictly similar cardiorespiratory fitness (*i.e.* V'_{O_2max}). The authors also signalled lower breathing reserve (~25%) in the COVID-19 subgroup at exercise cessation, although no indicators of dyspnoea were provided.

PFTs and imaging

Data on long-term sequelae of severe COVID-19 pneumonia beyond clinical follow-up at 6 months are scarce [111, 112]. BARRIA *et al.* [113] (Santiago, Chile) thus described the evolution of pulmonary consequences in 84 severe COVID-19 survivors at 3, 6 and 12 months after discharge. While longitudinal evaluations showed progressively improving values over time for spirometry, T_{LCO} and 6-min walk test, long-term HRCT anomalies and exercise-induced desaturation suggested persistent interstitial phenomena that might contribute to respiratory symptoms.

BALAMUGESH *et al.* [114] (Vellore, India) established a post-COVID-19 respiratory clinic and retrospectively compared clinical, radiological and functional parameters of 100 previously infected patients. Residual dyspnoea was the most common symptom, with a prevalence of 55% ~9 weeks post-infection. Chest radiograph scores for the severity of lung oedema were negatively associated with FVC and T_{LCO}, but none of these measurements were significantly associated with dyspnoea. Similarly, SAHNOUN *et al.* [115] (Ariana, Tunisia) evaluated the frequency of persistent dyspnoea and assessed potential associated factors in patients 6 months after discharge for COVID-19 pneumonia. 62 patients were divided into two groups, according to the presence or absence of persistent dyspnoea. The frequency of persistent dyspnoea was 31%; it was associated with lower FEV_1 and T_{LCO}, together with more persistent dry cough and memory loss. Severe initial pneumonia and the use of NIV during the acute episode were also associated with persistent dyspnoea.

Interventions to reduce persistent dyspnoea

There is an urgent need to offer new non-invasive tools to alleviate persistent dyspnoea in COVID-19 [116, 117]. In this context, Betka *et al.* [118] (Geneva, Switzerland) developed an immersive virtual reality-based digital therapeutic, based on known analogies between pain and dyspnoea [119]. They investigated the effect of synchronous or asynchronous visual–respiratory feedback on persistent dyspnoea, in 26 patients recovering from COVID-19 pneumonia. Synchronous feedback was associated with improved breathing comfort compared to the asynchronous feedback condition. Of note, 91% of patients were satisfied with the intervention and 67% perceived it as beneficial for their breathing, emphasising its potential clinical application to reduce persistent dyspnoea in this population [118].

Reliability of pulse oximetry

Crooks *et al.* [120] (Hull, UK) examined the effect of different haemoglobin levels on pulse oximetry measurements in 1086 patients admitted to hospital with a possible diagnosis of COVID-19 infection. Pulse oximetry and arterial/venous blood gas oxygen saturations were compared. The authors found an inverse and linear association between haemoglobin and measurement error of oxygen saturation as determined by pulse oximetry. This discrepancy was relatively large in patients with anaemia (corresponding to a measurement error of +8.0% if haemoglobin was $70\ \text{g}\cdot\text{L}^{-1}$), suggesting that haemoglobin levels should not be overlooked when establishing treatment decisions on pulse oximetry.

Overall, this session highlighted the presence of persistent respiratory symptoms beyond the acute phase of COVID-19 pneumonia. Persistent dyspnoea, the most prevalent symptom, does not seem to be associated with resting lung function impairments. DB and ventilatory inefficiency during exercise are, however, two potential underlying pathophysiological mechanisms of residual dyspnoea. Innovative strategies are urgently needed to alleviate persistent dyspnoea in post-COVID-19 infection [121].

Take-home messages

- Residual dyspnoea is the most prevalent symptom beyond the acute phase of COVID-19 pneumonia.
- Ventilatory inefficiency (elevated ventilatory stimuli relative to metabolic demand) and DB (abnormal breathing pattern without apparent causes) may assume a prominent role in residual exertional dyspnoea post-COVID-19.
- Abnormalities observed on "resting" investigations (PFTs and imaging) poorly relate to exertional dyspnoea post-COVID-19.
- Innovative strategies, such as immersive virtual reality, are urgently needed to alleviate persistent dyspnoea post-COVID-19.

Conclusion

We hope that the highlights summarised will help update readers on the impressive amount of lung research and advances in pulmonary care presented through the sessions from ERS Assembly 1, alongside suggestions for further investigations. We also hope to have encouraged the readership to contribute to Assembly 1 activities, and to take part in the 2023 ERS International Congress to be held in Milan in September, where further scientific novelties and clinical developments on these topics will be discussed.

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