lek. Piotr Jankowski

Zastosowanie przenośnych spirometrów w diagnostyce obturacyjnych chorób płuc.

Rozprawa na stopień doktora nauk medycznych i nauk o zdrowiu

w dyscyplinie nauki medyczne

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1. Wykaz publikacji składających się na pracę doktorską

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   Przegląd systematyczny Punktacja MEiN: 40 IF: 1,8

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2. Wykaz stosowanych skrótów

Skrót	***Wyjaśnienie j. angielski*** **Wyjaśnienie j. polski**
ATS	*American Thoracic Society*
BEV	*back extrapolated volume* objętość wstecznie ekstrapolowana
CAT	*COPD Assessment Test* test oceny POChP
COPD	*chronic obstructive pulmonary disease* przewlekła obturacyjna choroba płuc
COVID-19	*coronavirus disease 2019*
ERS	*European Respiratory Society*
FET	*forced expiratory time* czas natężonego wydechu
GINA	*Global Initiative for Asthma*
GLI	*Global Lung Initiative*
FEV_1	*forced expiratory volume in 1 second* natężona objętość wydechowa pierwszosekundowa
FVC	*forced vital capacity* natężona pojemność życiowa

ILD	*interstitial lung diseases* śródmiąższowe choroby płuc
mMRC	*modified Medical Research Council dyspnea scale* zmodyfikowana skala duszności mMRC
NLHEP	*National Lung Health Education Program*
POChP	przewlekła obturacyjna choroba płuc
PS	*portable spirometer* przenośny spirometr
RV	*residual capacity* objętość zalegająca płuc
USPSTF	*U.S. Preventive Services Task Force*
VC	*vital capacity* pojemność życiowa płuc
WHO	*World Health Organization* Światowa Organizacja Zdrowia

3. Streszczenie w języku polskim

Spirometria odgrywa kluczową i dobrze udokumentowaną rolę w rozpoznawaniu i monitorowaniu obturacyjnych chorób płuc – przewlekłej obturacyjnej choroby płuc (POChP) oraz astmy. Pomimo to, potencjał spirometrii jako narzędzia diagnostycznego oraz monitorującego u osób z tymi chorobami nie jest w pełni wykorzystany. Wynika to z wciąż ograniczonej dostępności spirometrów, zwłaszcza w placówkach ochrony zdrowia na terenach wiejskich, presji czasowej w pracy lekarzy, braku regularnych szkoleń personelu medycznego, problemów technicznych (np. nieregularnego serwisowania i kalibracji urządzeń), stosowania nieaktualnych wartości referencyjnych oraz obaw przed niespełnieniem standardów badań zgodnych z aktualnymi wytycznymi.

W XXI wieku rozwój technologii umożliwił stworzenie przenośnych spirometrów (PS), które charakteryzują się lekkością, prostotą obsługi oraz stosunkowo niskim kosztem. Dzięki technologii *Bluetooth* (technologia bezprzewodowa krótkiego zasięgu) urządzenia pomiarowe mogą łączyć się z telefonami komórkowymi, co pozwala na ich zastosowanie niemal wszędzie – zarówno w niewielkich placówkach podstawowej opieki zdrowotnej, jak i w domach pacjentów. Niektóre modele PS oferują funkcję automatycznej analizy poprawności przeprowadzanego badania zgodnie z wytycznymi American Thoracic Society/ European Respiratory Society (ATS/ERS), wskazując błędy, które wpływają na ostateczny wynik i jego interpretację. Co więcej, większość PS wykorzystuje najnowsze wartości referencyjne Global Lung Initative (GLI) 2012, a niektóre modele nie wymagają regularnego serwisowania ani kalibracji. Istotne jest również to, że dokładność PS jest porównywalna z wynikami uzyskiwanymi przy użyciu stacjonarnych spirometrów stanowiących wyposażenie pracowni spirometrycznych. Szerszy dostęp do PS może znacząco przyczynić się do wcześniejszego rozpoznawania chorób obturacyjnych w podstawowej opiece zdrowotnej, co umożliwi wdrożenie wczesnej interwencji terapeutycznej.

PS znajdują zastosowanie także w monitorowaniu innych chorób płuc poza obturacyjnymi. Dzięki możliwości wykonywania pomiarów w domu pacjenta, PS pozwalają na monitorowanie przebiegu mukowiscydozy, ocenę skuteczności leczenia lekami antyfibrotycznymi u pacjentów z chorobami śródmiąższowymi płuc, wczesne wykrywanie powikłań płucnych u biorców allogenicznych przeszczepów komórek hematopoetycznych oraz kontrolę funkcji płuc u pacjentów po przeszczepieniu płuc.

Wychodząc poza stacjonarne pracownie spirometryczne, PS mogą wspierać rozwój proaktywnych strategii w zakresie wczesnego rozpoznawania POChP. Dzięki mobilności tego typu urządzeń przesiewowe badania spirometryczne mogą być przeprowadzane w miejscach publicznych jak lotniska, dworce kolejowe czy centra handlowe.

Zagadnienia związane z wykorzystaniem przenośnego spirometru w diagnostyce POChP stanowiły temat przewodni wszystkich czterech publikacji, które złożyły się na niniejszą rozprawę doktorską. Trzy publikacje przedstawiają wyniki badań oryginalnych, natomiast jedna ma charakter przeglądu systematycznego.

Szczegółowe cele badania obejmowały:

1. ocenę skuteczności proaktywnych strategii wykorzystujących przenośny spirometr w rozpoznawaniu POChP u osób z grupy wysokiego ryzyka,
2. ocenę możliwości zastosowania przenośnego spirometru w różnych warunkach:
    a) w podstawowej opiece zdrowotnej na skalę krajową,
    b) u pacjentów hospitalizowanych w oddziałach pulmonologii i kardiologii,
    c) w akcji badań spirometrycznych przeprowadzonych poza placówkami ochrony zdrowia,
3. oszacowanie częstości występowania POChP zdiagnozowanego za pomocą przenośnego spirometru u pacjentów z czynnikami ryzyka oraz porównanie tych wyników z częstością występowania choroby, odnotowywaną w badaniach z wykorzystaniem konwencjonalnych spirometrów,
4. analizę poprawności badań przeprowadzanych z użyciem przenośnego spirometru oraz identyfikację najczęściej popełnianych błędów.

Badanie opisane w publikacji *Public spirometry campaign in chronic obstructive pulmonary disease screening - hope or hype?* (doi:10.5603/ARM.2017.0024) miało na celu ocenę skuteczności publicznej akcji badań spirometrycznych w identyfikacji osób z obturacją dróg oddechowych, sugerującą POChP. Akcja spirometryczna została przeprowadzona wśród przechodniów na terenie jednego ze stołecznych dworców kolejowych. W badaniu wzięły udział osoby powyżej 40. roku życia z wywiadami palenia papierosów przekraczającymi 10 paczkolat, które zaproszono do wypełnienia ankiety i wykonania spirometrii. Spośród 905 zaproszonych jedynie 178 osób (19,6%) zgodziło się na udział. U 22 (12,3%) osób wykryto obturację dróg oddechowych, a u 37 (20,7%) stwierdzono wyniki zbliżone do dolnej granicy normy. Jedynie 15 (25,4%) pacjentów zgłosiło się na wizytę kontrolną do stacjonarnej pracowni spirometrycznej w celu potwierdzenia wyniku. Ekstrapolacja danych sugerowała, że zdiagnozowanie obturacji było możliwe u 10,7% uczestników badania. Wyniki badania wskazują, że publiczne kampanie spirometryczne są mało skuteczne w wykrywaniu POChP, a osoby palące, nawet przy obecności wyraźnych objawów oddechowych, niechętnie korzystają z możliwości wykonania spirometrii.

Celem badania stanowiącego podstawę publikacji *Active screening for COPD among hospitalized smokers - a feasibility study* (doi:10.1177/2040622320971111) była ocena skuteczności wykorzystania przenośnego spirometru w rozpoznawaniu POChP u pacjentów z czynnikami ryzyka, hospitalizowanych na oddziałach pulmonologii i kardiologii. Do badania zakwalifikowano 188 pacjentów w wieku ≥40 lat z wywiadami palenia papierosów (≥10 paczkolat); spośród nich 116 osób (62%) zgodziło się na udział w badania. Badanie przeprowadzano bezpośrednio przy łóżku chorego. Spirometria z wykorzystaniem przenośnego spirometru została poprawnie wykonana u 94 z nich (81%). POChP rozpoznano u 32 (34%) osób, w tym u 9 po raz pierwszy. Nowo zdiagnozowani pacjenci byli młodsi, mieli dłuższy okres abstynencji od palenia papierosów oraz łagodniejsze objawy w porównaniu z osobami, u których choroba była już wcześniej rozpoznana. Większość nowych przypadków charakteryzowała się łagodnym lub umiarkowanym ograniczeniem przepływu powietrza. Podsumowując wyniki badania zasugerowano, że taka strategia wykonywania badań spirometrycznych może skutecznie zwiększyć wykrywalność POChP w szpitalach, szczególnie u byłych palaczy z łagodnymi objawami.

Kolejna publikacja *The use of a mobile spirometry with a feedback quality assessment in primary care setting - A nationwide cross-sectional feasibility study.* (doi:10.1016/j.rmed.2021.106472) opisuje badanie, którego celem była ocena przydatności przenośnych spirometrów w podstawowej opiece zdrowotnej w Polsce. W okresie od września 2018 do września 2019 roku przeprowadzono 10 936 spirometrii u 9 855 pacjentów. Wszyscy członkowie personelu medycznego wykonujący badania przeszli krótkie, dwugodzinne szkolenie. Spirometrię wykonywano u pacjentów zgłaszających objawy ze strony układu oddechowego lub należących do grupy ryzyka chorób obturacyjnych. W badaniu analizowano najczęstsze błędy popełniane podczas wykonywania spirometrii. Spośród wszystkich badań 49% spełniało kryteria technicznej poprawności, a najczęstszym błędem było nieuzyskanie plateau w końcowej fazie wydechu (17,7%). Wyższy odsetek poprawnych badań odnotowano, gdy były one wykonywane przez osoby z personelu medycznego w wieku >40. r.ż. oraz gdy badanie było powtórzone podczas tej samej wizyty. Obturację dróg oddechowych stwierdzono w 17% technicznie poprawnych badań. Wyniki badania sugerują, że przenośne spirometry mogą być skutecznie wykorzystywane w podstawowej opiece zdrowotnej. W celu poprawy jakości badań konieczne jest wprowadzenie intensywniejszych i regularnych szkoleń dla personelu medycznego.

Czwarta praca wchodząca w skład niniejszej rozprawy, ma charakter przeglądu systematycznego: *How to enhance the diagnosis of early stages of chronic obstructive pulmonary disease (COPD)? The role of mobile spirometry in COPD screening and diagnosis-*

a systematic review. (doi:10.3390/arm92020018). Miała ona na celu ocenę częstości występowania POChP zdiagnozowanego za pomocą przenośnych spirometrów u pacjentów z grupy wysokiego ryzyka oraz porównanie tych wyników z danymi uzyskanymi przy użyciu tradycyjnych spirometrów stacjonarnych. Przeprowadzono systematyczny przegląd literatury w celu zidentyfikowania odpowiednich badań w języku angielskim, opublikowanych w okresie od 1958 roku do 7 grudnia 2021 roku. Źródłem danych były bazy: PubMed, Cochrane Central Register of Controlled Trials oraz Embase. Słowa kluczowe użyte w wyszukiwaniu obejmowały kombinację terminów związanych z POChP, spirometrią oraz badaniami przesiewowymi.

Do analizy zakwalifikowano badania spełniające następujące kryteria:

a. spirometria została wykonana u osób w wieku >35. r.ż. z wywiadami palenia papierosów (≥10 paczkolat),
b. w badaniu wykonano próbę rozkurczową z użyciem przenośnego lub tradycyjnego spirometru,
c. celem badania była ocena częstości występowania utrwalonej obturacji.

Ostatecznie w analizie uwzględniono 28 prac opublikowanych w latach 2007 – 2021. Średnia częstość rozpoznania POChP przy zastosowaniu przenośnych spirometrów wynosiła 20,27%, co było nieco niższym wynikiem w porównaniu do tych, uzyskanych przy użyciu tradycyjnych spirometrów (24,67%). W 11 analizowanych publikacjach próbę rozkurczową przeprowadzono za pomocą przenośnego spirometru. Wyniki przeglądu systematycznego wskazują, że przenośne spirometry charakteryzują się jedynie nieznacznie niższą skutecznością w przesiewowym wykrywaniu POChP w porównaniu z tradycyjnymi spirometrami. Tego typu urządzenia mogą stanowić wiarygodne narzędzie diagnostyczne, umożliwiające przeprowadzenie próby rozkurczowej i potwierdzenie nieodwracalnego ograniczenia przepływu powietrza, które u osób palących jest podstawą rozpoznania POChP.

Przeprowadzone badania pozwoliły na sformułowanie następujących wniosków odpowiadających celom badawczym:

1. przenośne spirometry mogą być skutecznie wykorzystywane w proaktywnych strategiach diagnostycznych, ukierunkowanych na wykrywanie POChP u osób z grupy wysokiego ryzyka;
2. przenośne spirometry mogą być z powodzeniem stosowane w diagnostyce POChP w różnych warunkach klinicznych, w tym w podstawowej opiece zdrowotnej, u pacjentów hospitalizowanych oraz w ramach badań przesiewowych prowadzonych poza placówkami medycznymi;

3. częstość występowania POChP, zdiagnozowanego za pomocą przenośnego spirometru u pacjentów z czynnikami ryzyka wynosi około 20% i jest jedynie nieznacznie niższa niż odsetek rozpoznań uzyskiwanych przy użyciu konwencjonalnych spirometrów;
4. analiza najczęściej popełnianych błędów w badaniach spirometrycznych wykazała, że kluczowym czynnikiem wpływającym na jakość wyników jest odpowiednie przygotowanie techniczne oraz doświadczenie personelu medycznego. W celu poprawy precyzji pomiarów konieczne jest wprowadzenie regularnych szkoleń oraz procedur kontrolnych.

4. Streszczenie w języku angielskim

The use of portable spirometers in the diagnosis of obstructive lung diseases

Spirometry plays a crucial and well-documented role in the diagnosis and monitoring of obstructive lung diseases, including Chronic Obstructive Pulmonary Disease (COPD) and asthma. Despite this, the full potential of spirometry as a diagnostic and monitoring tool for individuals with these conditions is not yet fully utilized. This is due to the still limited availability of spirometers, especially in healthcare facilities in rural areas, time pressure on doctors, lack of regular staff training, technical issues (e.g., irregular servicing and calibration of devices), the use of outdated reference values, and concerns about meeting the standards of tests according to current guidelines.

In the 21st century, the development of technology has made it possible to create portable spirometers (PS), which are characterized by their lightness, ease of use, and relatively low cost. Thanks to Bluetooth technology (short-range wireless technology), measuring devices can connect to mobile phones, making them usable almost anywhere – in small primary healthcare facilities or even in patients' homes. Some models of PS offer automatic analysis of test accuracy according to the American Thoracic Society/European Respiratory Society (ATS/ERS) guidelines, indicating errors that affect the final result and its interpretation. Moreover, most PS devices use the latest Global Lung Initiative (GLI) 2012 reference values, and some models do not require regular servicing or calibration. It is also important to note that the accuracy of PS is comparable to the results obtained using stationary spirometers found in spirometry laboratories.

Wider access to PS could significantly contribute to earlier diagnosis of obstructive diseases in primary healthcare settings, enabling the implementation of early therapeutic interventions. Portable spirometers are also used for monitoring other lung diseases beyond obstructive ones. By allowing measurements in the patient's home, PS devices enable the monitoring of cystic fibrosis, the assessment of the effectiveness of antifibrotic treatment in patients with interstitial lung diseases, early detection of pulmonary complications in recipients of allogeneic hematopoietic stem cell transplants, and lung function monitoring in patients who have undergone lung transplants.

Beyond stationary spirometry labs, PS can support the development of proactive strategies for the early detection of COPD. Due to the mobility of these devices, spirometry screening tests can be conducted in public places such as airports, train stations, or shopping malls. The issues related to the use of portable spirometers in the diagnosis of COPD were the central theme of all four publications that make up this doctoral dissertation.

The specific objectives of the publications included:

1) evaluating the effectiveness of proactive strategies using portable spirometers for diagnosing COPD in high-risk individuals,

2) assessing the feasibility of using portable spirometers in different settings:

a) in primary healthcare on a nationwide scale,

b) in hospitalized patients in pulmonology and cardiology departments,

c) during spirometry screening campaigns conducted outside healthcare facilities.

3) estimating the prevalence of COPD diagnosed using portable spirometers among patients with risk factors and comparing these results with the prevalence observed in studies using conventional stationary spirometers,

4) analyzing the accuracy of tests conducted using portable spirometers and identifying the most common errors.

The first three publications present original research results, while the fourth publication is a systematic review.

The first study, *Public spirometry campaign in chronic obstructive pulmonary disease screening - hope or hype?* (doi:10.5603/ARM.2017.0024), aimed to evaluate the effectiveness of a public spirometry screening campaign in identifying individuals with airway obstruction suggesting COPD. The spirometry campaign was conducted among passers-by at a major city railway station. The study included individuals over 40 years of age with a smoking history exceeding 10 pack-years, who were invited to complete a questionnaire and perform spirometry. Of the 905 invited individuals, only 178 (19.6%) agreed to participate. Airway obstruction was detected in 22 (12.3%) participants, and 37 (20.7%) had results close to the lower limit of normal. Only 15 (25.4%) patients attended a follow-up visit at a stationary spirometry laboratory to confirm the result. Data extrapolation suggested that airway obstruction was detectable in 10.7% of participants. The study results indicate that public spirometry campaigns are ineffective in detecting COPD, and smokers, even with clear respiratory symptoms, are reluctant to undergo spirometry.

The second study, *Active screening for COPD among hospitalized smokers - a feasibility study* (doi:10.1177/2040622320971111), aimed to evaluate the effectiveness of using portable spirometers to diagnose COPD in high-risk patients hospitalized in pulmonology and cardiology departments. The study included 188 patients aged ≥40 years with a smoking history (≥10 pack-years); 116 individuals (62%) agreed to participate. Spirometry was conducted at the patient's bedside. Spirometry using portable spirometers was performed correctly in 94 individuals (81%). COPD was diagnosed in 32 (34%) of them, including 9 for the first time.

Newly diagnosed patients were younger, had a longer period of smoking cessation, and had milder symptoms compared to those with a prior diagnosis. Most new cases showed mild to moderate airflow limitation. In conclusion, the study suggested that this spirometry screening strategy could effectively increase COPD detection in hospitals, especially among former smokers with mild symptoms.

The third study, *The use of mobile spirometry with feedback quality assessment in primary care setting - A nationwide cross-sectional feasibility study* (doi:10.1016/j.rmed.2021.106472), aimed to assess the feasibility of portable spirometers in primary healthcare in Poland. Between September 2018 and September 2019, 10,936 spirometries were performed on 9,855 patients. All medical personnel performing the tests underwent a brief, two-hour training session. Spirometry was performed on patients presenting respiratory symptoms or belonging to a high-risk group for obstructive diseases. The study analyzed the most common errors made during spirometry. Among all tests, 49% met the technical accuracy criteria, with the most frequent error being the failure to achieve a plateau in the final phase of exhalation (17.7%). A higher percentage of accurate tests was noted when performed by medical personnel over 40 years old and when the test was repeated during the same visit. Airway obstruction was found in 17% of technically accurate tests. The study's results suggest that portable spirometers can be effectively used in primary healthcare. To improve test quality, more intensive and regular staff training is necessary.

The final, fourth publication in this dissertation is a systematic review: *How to enhance the diagnosis of early stages of chronic obstructive pulmonary disease (COPD)? The role of mobile spirometry in COPD screening and diagnosis - a systematic review* (doi:10.3390/arm92020018). It aimed to evaluate the prevalence of COPD diagnosed with portable spirometers among high-risk patients and compare these results with data obtained from traditional stationary spirometers. A systematic review of the literature was conducted to identify relevant studies published in English from 1958 to December 7, 2021. Data sources included PubMed, the Cochrane Central Register of Controlled Trials, and Embase. Keywords related to COPD, spirometry, and screening were used in the search.

The review included studies meeting the following criteria:

a. spirometry was performed on individuals aged >35 years with a smoking history (≥10 pack-years),

b. the study included a bronchodilator test using either a portable or traditional spirometer,

c. the aim was to assess the prevalence of persistent airway obstruction.

A total of 28 studies published between 2007 and 2021 were included in the analysis. The average COPD diagnosis rate using portable spirometers was 20.27%, slightly lower than

the 24.67% obtained using traditional spirometers. In 11 of the analyzed publications, the bronchodilator test was conducted with a portable spirometer.

The results of the systematic review indicate that portable spirometers have only a slightly lower effectiveness in screening for COPD compared to traditional spirometers. These devices can be a reliable diagnostic tool, enabling the bronchodilator test and confirming irreversible airflow limitation, which, in smokers, is the basis for diagnosing COPD.

In conclusion, the results of the conducted studies and the systematic literature analysis indicate that portable spirometers can be successfully used for detecting COPD in various clinical and population settings.

The conducted research allowed for the formulation of the following conclusions corresponding to the research objectives:

1. portable spirometers can be effectively used in proactive diagnostic strategies aimed at detecting COPD in high-risk individuals.
2. portable spirometers can be successfully applied in COPD diagnostics across various clinical settings, including primary healthcare, hospitalized patients, and screening programs conducted outside medical facilities.
3. the prevalence of COPD, diagnosed using a portable spirometer in patients with risk factors, is approximately 20% and is only slightly lower than the detection rate obtained with conventional spirometers.
4. an analysis of the most common errors in spirometric examinations has shown that proper technical preparation and the experience of medical personnel are crucial for result quality. To improve measurement accuracy, regular training and control procedures should be implemented.

5. Wstęp

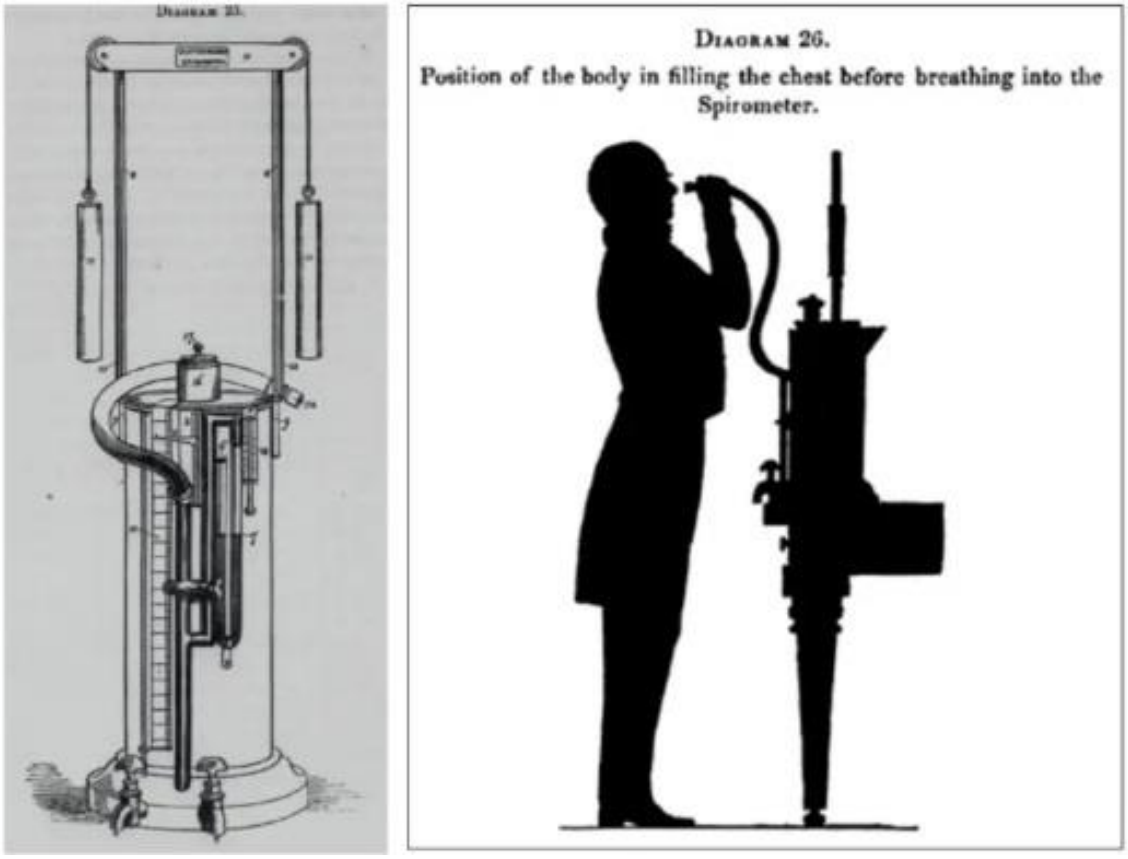
Poniżej zaprezentowano zarys historii spirometrii – od pierwszych prototypów stworzonych przez Hutchinsona po nowoczesne, mobilne spirometry elektroniczne [1]. Przedstawiono również zalety PS oraz ich zastosowanie w praktyce klinicznej.

5.1 Od wodnego spirometru Hutchinsona do wielofunkcyjnego przenośnego spirometru elektronicznego – krótka historia spirometrii

Spirometria stanowi podstawowe badanie czynnościowe układu oddechowego, którego historia sięga pierwszej połowy XIX wieku. Prześledzenie jej rozwoju ukazuje, jak w niezwykły sposób technologia zmieniła oblicze medycyny na przestrzeni ostatnich 180 lat, pozwalając jednocześnie docenić zalety współczesnego sprzętu diagnostycznego.

5.1.1 Pierwsze spirometry

Pierwsze próby pomiaru objętości oddechowych podejmowane były już w XVII i XVIII wieku przez naukowców takich jak Giovanni Alfonso Borelli i Jan Ingenhousz, którzy badali mechanizmy oddychania. Choć ich metody były niedoskonałe, stanowiły ważny krok w kierunku zrozumienia fizjologii układu oddechowego. Za twórcę pierwszego spirometru uznaje się brytyjskiego chirurga Johna Hutchinsona, który w 1846 roku opublikował wyniki swoich prac nad urządzeniem służącym do pomiaru podstawowych parametrów czynnościowych układu oddechowego [2]. Spirometr Hutchinsona pozwalał na pomiar pojemności życiowej płuc (*ang. VC, vital capacity*). Ponadto, to właśnie Hutchinson wprowadził do powszechnego użycia pojęcie objętości zalegającej płuc (*ang. RV, residual volume*). Do wykonywania swoich pomiarów Hutchinson wykorzystywał spirometr wodny (dzwonowy) (rycina 1). Co ciekawe, początkowo badania prowadził na zwłokach. Wynalazek Hutchinsona, choć dość powszechnie użytkowany przez długi czas, miał ograniczone zastosowanie. Pojemność życiowa płuc może pozostawać prawidłowa nawet w ciężkich chorobach płuc. Dlatego jeszcze w XX wieku do oceny przepływu powietrza przez drogi oddechowe wykorzystywano znacznie prostsze narzędzia, takie jak próba gaszenia płonącej świecy lub zapałki.



Rycina 1. Diagramy 25. i 26. z oryginalnej publikacji Hutchinsona opisującej spirometr. Diagram 25. przedstawia wewnętrzne mechanizmy spirometru, a diagram 26. demonstruje, w jaki sposób ustawić pacjenta w stosunku do urządzenia. Zaadaptowano z: Hutchinson J. *On the capacity of the lungs and on the respiratory functions, with a view of establishing a precise and easy method of detecting disease by the spirometer.* Med Chir Trans. 1846;29:137–252.

Możliwość pomiaru natężonej objętości wydechowej pierwszosekundowej (*ang. FEV_1, forced expiratory volume in 1 second*) pojawiła się wraz ze skonstruowaniem w 1920 roku przez Alfreda Fleischa pneumotachometru, który umożliwił rejestrację szybkości przepływu gazu w drogach oddechowych.

Kolejnym krokiem milowym w rozwoju spirometrii było opisanie w 1947 roku podstawowego sposobu oceny drożności dróg oddechowych za pomocą pomiaru natężonej objętości wydechowej pierwszosekundowej odniesionej do pojemności życiowej (FEV_1/VC). Pomiarowi temu, wykorzystywanemu do dzisiaj, nadano nazwę wskaźnika Tiffeneau, na cześć jednego z jego twórców [3].

Prawdziwa rewolucja w historii spirometrii dokonała się jednak dopiero w latach siedemdziesiątych ubiegłego stulecia. Wprowadzono wówczas spirometr elektroniczny. To właśnie masowa produkcja elektronicznego spirometru działającego na zasadzie

pneumotachometru przyczyniła się do rozpowszechnienia badań spirometrycznych w Polsce i na świecie [4].

5.1.2 Standaryzacja spirometrii

W kolejnych latach zaczęto wykorzystywać spirometr do przeprowadzania badań populacyjnych [5]. Przeszkodą w stosowaniu spirometru na szerszą skalę była jednak szeroka różnorodność dostępnych spirometrów oraz brak standardowych metod testowania, co powodowało znaczną zmienność pomiarów. Z tego powodu największe światowe towarzystwa chorób płuc - American Thoracic Society oraz European Respiratory Society zorganizowały spotkania badaczy mające na celu opracowania w formie wytycznych, pierwszych standardów dotyczących spirometrii (ATS – 1979; ERS – 1983) [6]. Wytyczne te opisywały specyfikację sprzętu, kontrolę jakości badań, wykonania manewrów, standardów akceptowalności i powtarzalności, a także określiły wartości referencyjnych poszczególnych parametrów. Aktualizacje wytycznych przygotowane przez oba towarzystwa zostały opublikowane w roku 2005 oraz 2019 [7, 8].

Opracowanie równań referencyjnych, uwzględniających różnice w oczekiwanych wartościach spirometrycznych związanych z wiekiem, wzrostem, płcią oraz pochodzeniem etnicznym okazało się kwestią nie mniej istotną w prawidłowej interpretacji spirometrii niż standaryzacja. Pierwsze powszechnie wykorzystywane równania referencyjne opracowano w 1983 roku w Europejskiej Wspólnocie Węgla i Stali, w skład której wchodziło sześć państw (Belgia, Francja, Holandia, Luksemburg, Niemcy i Włochy) [9, 10]. Równania te, choć stosowane przez wiele lat, posiadały wiele wad, między innymi zaniżały prognozowane wartości FEV_1 i FVC i nie uwzględniały różnorodności etnicznej. Stało się to przyczynkiem do opracowania przez ERS oraz ATS własnych równań referencyjnych [11-13]. Obecnie wykorzystywane są równania referencyjne opracowane w 2012 r. przez Global Lung Function Initiative (GLI). Równania te zostały przygotowane na podstawie danych spirometrycznych pochodzących od ponad 74 tysięcy bezobjawowych niepalących osób z 26 państw [14].

5.1.3 Era przenośnych spirometrów

W kolejnych latach głównym problemem we wdrażaniu spirometrii w rutynowej opiece nad pacjentami z chorobami układu oddechowego była wielkość tradycyjnych aparatów spirometrycznych, wykorzystywanych przede wszystkim w pracowniach szpitalnych. Możliwość wykonania badania spirometrycznego w warunkach szpitalnych oznaczało jego mniejszą dostępność dla pacjentów, co prowadziło do opóźnienia w rozpoznawaniu chorób płuc. Wprowadzenie mniejszych, przenośnych spirometrów elektronicznych oznaczało kolejny

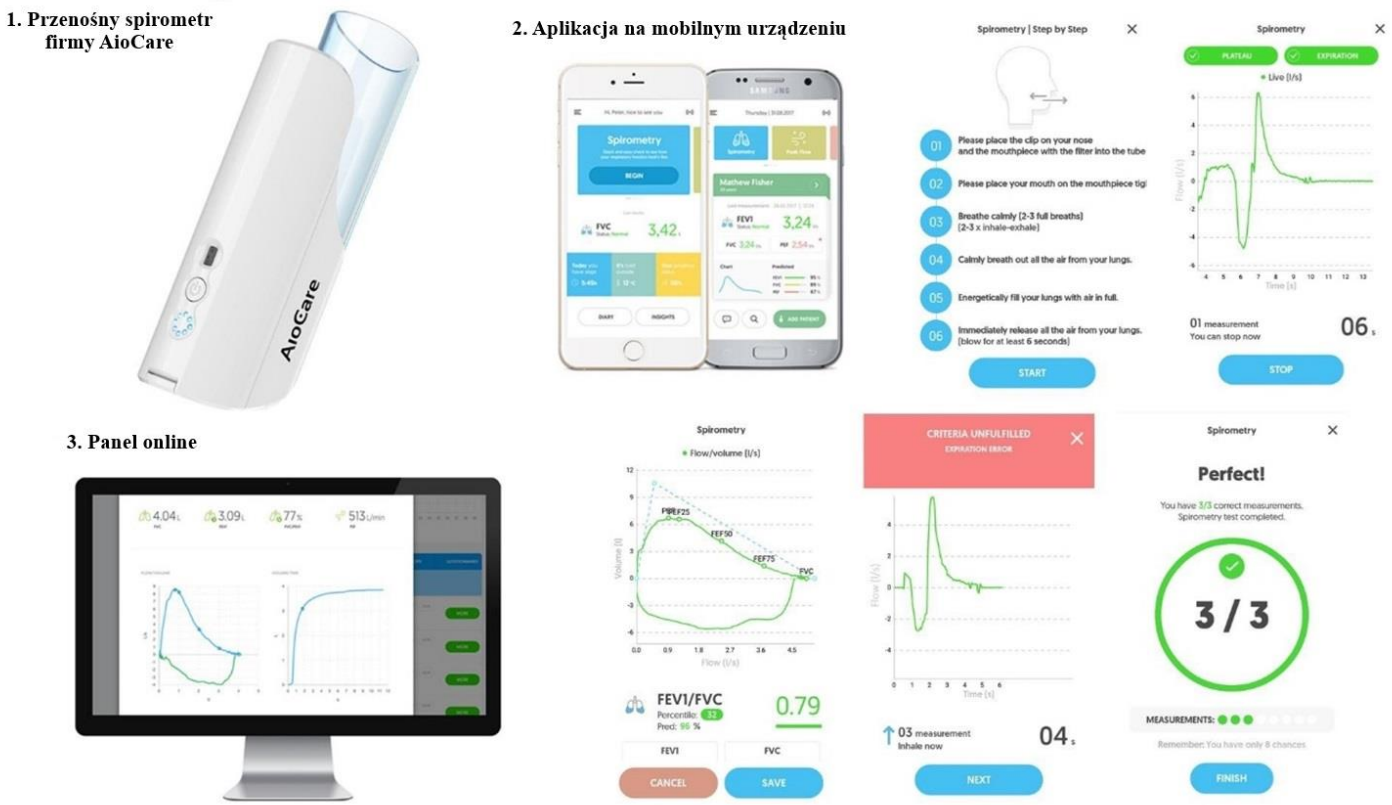
przełom w diagnostyce chorób płuc, umożliwiając „wyprowadzenie” spirometru ze szpitali do podstawowej opieki zdrowotnej. Wyniki pierwszych publikacji z lat 90-tych ubiegłego stulecia, porównujących dokładność pomiarów spirometrycznych wykonywanych przez spirometr przenośny z tradycyjnym spirometrem, okazały się obiecujące [15].

W roku 1996 r. w Stanach Zjednoczonych Ameryki Północnej została powołana inicjatywa NLHEP (*ang. National Lung Health Education Program*). Opublikowana przez nią rekomendacja podkreślała potencjał spirometrii ambulatoryjnej w zakresie wczesnej identyfikacji pacjentów zagrożonych POChP. [16]. Kluczowymi przeszkodami w powszechnym wykonywaniu spirometrii w warunkach ambulatoryjnych, zgodnie z wynikami badań ankietowych przeprowadzonych w kolejnych latach, okazały się niewystarczające szkolenia oraz brak umiejętności poprawnej interpretacji badania [17, 18]. Nowsze generacje elektronicznych PS, które pojawiły się w ciągu ostatniej dekady, rozwiązały część problemów technicznych, które występowały w starszych modelach.

5.2 Zalety przenośnego spirometru

Współczesne elektroniczne PS posiadają liczne zalety. Wiele z nich umożliwia łączność z telefonami komórkowymi lub tabletami za pomocą technologii Bluetooth. Osoba z personelu medycznego wykonująca badanie może śledzić jego przebieg na ekranie swojego urządzenia – przedstawiane są niezbędne krzywe objętość-czas oraz przepływ-objętość (rycina 2). Przy takim rozwiązaniu przenośny pneumotachograf pełni jedynie funkcję dedykowanego rejestratora danych. Zgromadzone informacje są przesyłane do mobilnego urządzenia, które dzięki odpowiedniej aplikacji, dokonuje ich dalszego przetwarzania. Takie podejście pozwala zredukować wymagania dotyczące mocy obliczeniowej, elementów interfejsu, rozmiarów i kosztów samego spirometru [19]. Przesyłanie danych na zewnętrzne urządzenie typu tablet lub telefon komórkowy umożliwia również ich zaawansowaną analizę za pomocą nowoczesnych algorytmów, w tym tych opartych na sztucznej inteligencji. Dzięki temu możliwe jest wykonywanie bardziej złożonych zadań, takich jak identyfikacja wzorców spirometrycznych czy, po uwzględnieniu danych klinicznych, diagnozowanie POChP [20]. Aplikacje opracowane dla niektórych przenośnych spirometrów oferują funkcję automatycznej analizy jakości technicznej badań spirometrycznych w czasie rzeczywistym, zgodnie z obowiązującymi standardami ATS/ERS [21]. Takie rozwiązanie nie tylko wspiera personel medyczny w podnoszeniu jakości wykonywanych badań, lecz także umożliwia pacjentom samodzielne przeprowadzanie spirometrii w warunkach domowych przy zachowaniu wysokich standardów technicznych. Co więcej, przesyłanie danych w czasie rzeczywistym pozwala na zdalny nadzór nad badaniem wykonywanym przez pacjenta. Za pośrednictwem internetowej platformy w

chmurze technicy mogą szczegółowo analizować krzywe przepływ-objętość oraz objętość-czas między kolejnymi manewrami spirometrycznymi [21].



Rycina 2. Przenośny system spirometryczny AioCare, składający się z: (1) przenośnego spirometru, (2) aplikacji mobilnej oraz (3) panelu online przeznaczonego dla personelu medycznego. Adaptacja z publikacji: Jankowski P, Górska K, Mycroft K, et al. *The use of a mobile spirometry with a feedback quality assessment in primary care setting - A nationwide cross-sectional feasibility study. Respir Med.* 2021;184:106472. System AioCare został wykorzystany do przeprowadzenia 2 oryginalnych badań wchodzących w skład cyklu publikacji.

Kolejną z zalet nowoczesnych PS jest wyeliminowanie konieczności kalibracji, ponieważ jednorazowe turbiny z wbudowanym tachografem są fabrycznie skalibrowane [22]. Istotne jest również to, że dokładność PS jest porównywalna z wynikami uzyskiwanymi przy użyciu spirometrów w stacjonarnych pracowniach spirometrycznych [23].

5.3 Zastosowanie przenośnych spirometrów w praktyce klinicznej

5.3.1 Wykorzystanie przenośnych spirometrów w rozpoznawaniu i monitorowaniu astmy i POChP

A) Astma

Astma należy do najczęstszych chorób przewlekłych. Według danych WHO, na świecie chorują na nią 262 miliony osób [24]. Mimo, że w większości przypadków przebieg choroby jest łagodny lub umiarkowany, jej objawy znacząco wpływają na codzienne życie pacjentów, utrudniając funkcjonowanie, aktywność społeczną oraz zawodową. Diagnostyka astmy często stanowi wyzwanie, szczególnie w podstawowej opiece zdrowotnej [25]. Postawienie prawidłowej diagnozy podczas jednej wizyty jest trudne z uwagi na dużą zmienność objawów w czasie oraz obecność różnych fenotypów choroby. Charakterystyczną cechą astmy jest zmienność obturacji dróg oddechowych, co od lat znajduje odzwierciedlenie w wytycznych GINA (ang. Global Initiative for Asthma) i zaleceniach ERS, wskazujących na konieczność wykonywania spirometrii w celu oceny tej zmienności [26, 27].

W praktyce klinicznej wielu lekarzy stosuje leczenie empiryczne bez wcześniejszego wykonania badań czynnościowych płuc oraz bez udokumentowania zmienności przepływu powietrza [28]. Jednym z powodów tego podejścia jest ograniczony dostęp do spirometrii, nie wspominając już o niewielkim dostępie do innych metod diagnostycznych, takich jak próba prowokacyjna z metacholiną. Diagnostyka oparta wyłącznie na objawach klinicznych może prowadzić zarówno do zbyt rzadkiego, jak i nadmiernego rozpoznawania astmy, co skutkuje opóźnieniem w postawieniu właściwej diagnozy lub nieskutecznym leczeniem [29]. Wczesne rozpoczęcie terapii kontrolującej astmę ma kluczowe znaczenie nie tylko dla łagodzenia objawów, ale również dla zapobiegania zaostrzeniom oraz remodelowania dróg oddechowych, które może prowadzić do trwałej obturacji.

PS aktualnie odgrywają rolę zarówno w poprawie procesu diagnostycznego astmy, jak i w jej monitorowaniu. Zgodnie z zaleceniami ERS, przenośne spirometry, tańsze od stacjonarnych urządzeń, mogą poprawić dostępność badań czynnościowych płuc w podstawowej opiece zdrowotnej, szczególnie w krajach o niskim i średnim poziomie rozwoju [27]. Nowoczesne mobilne urządzenia mogą być również wykorzystywane w nowatorskich rozwiązaniach diagnostycznych, takich jak „spirometryczny holter” [30]. Technologia ta umożliwia codzienne pomiary spirometryczne wykonywane przez pacjenta w warunkach domowych przez okres 30 dni, co pozwala uchwycić zmienność przepływów w drogach oddechowych. Pacjent, korzystając z dedykowanej aplikacji, odnotowuje w tym czasie objawy ze strony układu oddechowego (rycina 3). Zgodnie z wynikami badania Korczyńskiego i wsp.,

codzienne pomiary spirometryczne umożliwiły wykrycie obturacji u wszystkich pacjentów do 21. dnia trwania obserwacji [30]. Co istotne, ponad połowa spirometrii przeprowadzonych w warunkach domowych spełniała kryteria akceptowalności i powtarzalności określone przez ERS/ATS. Po przeprowadzeniu dalszych badań, oceniających dokładność diagnostyczną oraz efektywność kosztową tej metody, „spirometryczny holter" mógłby w przyszłości stać się szerzej stosowanym narzędziem w diagnostyce astmy. Domowa spirometria, wykonywana za pomocą przenośnych spirometrów, może być również skutecznym narzędziem w ocenie kontroli astmy, w przyszłości służąc do wczesnego rozpoznawania zaostrzeń tej choroby [31-32].

B) POChP

POChP jest jedną z najczęściej występujących chorób na świecie. Szacuje się, że dotyka od 7,6% do 10,3% populacji w wieku 30–79 lat [33]. We wczesnych stadiach choroba zazwyczaj przebiega łagodnie, co sprawia, że nawet do 80% osób nią dotkniętych nie zdaje sobie sprawy z jej obecności [34]. POChP jest jednak chorobą postępującą i potencjalnie śmiertelną. W 2021 roku zajmowała czwarte miejsce wśród najczęstszych przyczyn zgonów na świecie [35].

Spirometria pozostaje złotym standardem diagnostycznym – stwierdzenie utrwalonej obturacji dróg oddechowych umożliwia rozpoznanie POChP u osób z istotną ekspozycją na czynniki ryzyka (przeważnie dym tytoniowy) [36]. Chociaż spirometria jest łatwym i tanim badaniem, jest metodą niedocenianą [37]. Podobnie jak w przypadku diagnostyki astmy, wynika to prawdopodobnie z ograniczonej dostępności spirometrii w gabinetach, braku odpowiednio przeszkolonego personelu oraz obaw lekarzy przed błędną interpretacją wyników. Dodatkowo, pacjenci z POChP są trudną psychologicznie grupą, często niechętną do poddawania się badaniom. Ta grupa pacjentów zazwyczaj niechętnie korzysta z pomocy medycznej, a trudności z uzyskaniem porady w placówce ochrony zdrowia mogą stanowić dodatkowy czynnik utrudniający diagnostykę.

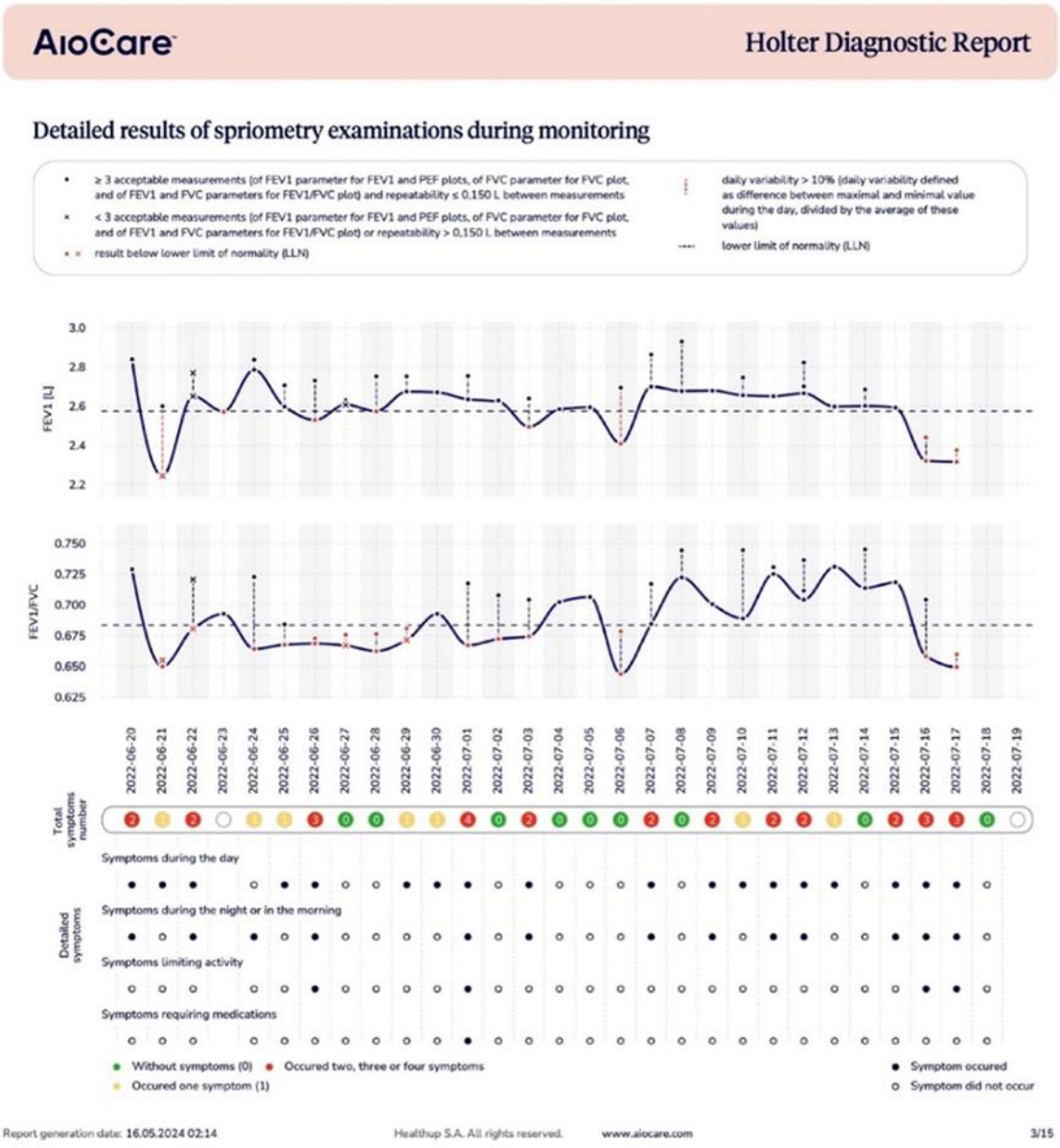
Z drugiej strony, terminowe rozpoznanie i leczenie POChP ma kluczowe znaczenie dla spowolnienia progresji choroby, szczególnie że spadek natężonej objętości wydechowej pierwszosekundowej (FEV1) jest zwykle bardziej znaczący we wczesnych stadiach choroby [38]. Zaostrzenia POChP mogą również występować na jej wczesnym etapie, co potencjalnie prowadzi do hospitalizacji i zwiększa ryzyko zgonu [39]. Z tego względu identyfikacja i leczenie osób z POChP, zwłaszcza w jej wczesnych fazach, może przyczynić się do poprawy ogólnego stanu zdrowia pacjentów.

Tak jak w przypadku astmy, wykorzystanie przenośnych spirometrów może mieć znaczenie w poprawie dostępu do diagnostyki POChP w warunkach podstawowej opieki

zdrowotnej, umożliwiając wczesną interwencję terapeutyczną i spowolnienie postępu choroby. Wczesne wykrywanie i leczenie pozwala zmniejszyć liczbę zaostrzeń, co przynosi korzyści zarówno medyczne, jak i ekonomiczne. Wykazano, że nowoczesne PS mogą być z powodzeniem wykorzystywane u chorych z POChP w warunkach ambulatoryjnych. Szczególnie ważne są wyniki badań wskazujące na dokładność PS w rozpoznawaniu POChP w porównaniu z konwencjonalnymi spirometrami [23, 40].

Zgodnie z zaleceniami amerykańskiego panelu ekspertów zajmującego się oceną i rekomendowaniem działań profilaktycznych w ochronie zdrowia USPSTF (ang. U.S. Preventive Services Task Force) rutynowe badania przesiewowe w kierunku POChP u pacjentów bezobjawowych nie są zalecane ze względu na ich nieskuteczność [41]. Diagnostyka w kierunku POChP jest zalecana u osób wykazujących objawy ze strony układu oddechowego, takie jak przewlekły kaszel, wykrztuszanie wydzieliny czy zmniejszenie tolerancji wysiłku. Taka strategia stwarza szansę na wdrożenie interwencji na wczesnym etapie choroby, co może zapobiec jej postępowi [42]. Dodatkowo, raport USPSTF wskazuje, że badania przesiewowe w kierunku POChP w grupach wysokiego ryzyka charakteryzują się stosunkowo wysoką opłacalnością [43].

Umożliwiając zastosowanie spirometrów poza tradycyjnymi pracowniami spirometrycznymi, PS mogą wspierać rozwój proaktywnych strategii wczesnego wykrywania POChP. Mobilność takich urządzeń pozwala na wykonanie badania spirometrycznego u osób z grup ryzyka w miejscach do których trudno dotrzeć z klasycznym spirometrem, np. bezpośrednio przy łóżku chorego czy w miejscach publicznych. Właśnie zagadnienia związane z wykorzystaniem przenośnych spirometrów w diagnostyce POChP w różnych warunkach klinicznych stanowiły główny temat czterech publikacji, które składają się na tę rozprawę doktorską.



Rycina 3. Przykład raportu z tzw. holtera spirometrycznego, przedstawiającego wyniki codziennych badań spirometrycznych, samodzielnie wykonywanych przez pacjenta, wraz ze zgłaszanymi objawami ze strony układu oddechowego. Zaadoptowano za zgodą z: Korczyński P, Basza M, Górska K, et al. 30-day Spirometry Holter: method design and prospective observational study. Sci Rep. 2024;14:26204.

5.3.2 Wykorzystanie przenośnych spirometrów w monitorowaniu chorób innych niż astma i POChP.

A) Mukowiscydoza

Badania wykazały, że PS mogą być z powodzeniem wykorzystywane do zdalnego wykonywania spirometrii u pacjentów z mukowiscydozą, szczególnie w trudnych warunkach obostrzeń związanych z pandemią COVID-19 [44, 45]. Rozwiązanie to pozwala na skuteczne monitorowanie postępu choroby, co jest niezwykle istotne w codziennej opiece nad pacjentami. Dodatkowo, domowa spirometria znalazła zastosowanie w monitorowaniu funkcji płuc u osób z mukowiscydozą po przeszczepieniu płuc, umożliwiając wczesne wykrywanie zespołu zarostowego zapalenia oskrzelików [46].

B) Śródmiąższowe choroby płuc (*ang. ILD, interstitial lung diseases*)

W ostatnich latach pojawiły się badania nad zastosowaniem przenośnych spirometrów do monitorowania ILD w warunkach domowych. Choć przeprowadzono je na niewielkich grupach pacjentów, wyniki wskazują na wysoką zgodność pomiędzy wynikami spirometrii domowej a spirometrii wykonywanej w stacjonarnych pracowniach spirometrycznych. Sugeruje to, że obie metody mogą być porównywalnie skuteczne [47]. Co więcej, domowa spirometria okazała się szczególnie użyteczna w monitorowaniu pacjentów z ILD poddawanych terapii pirfenidonem [48]. Warto podkreślić, że zgodnie z wynikami cytowanego badania zdecydowana większość pacjentów (90%) stosowała się do zaleceń dotyczących wykonywania codziennej spirometrii w domu.

C) Transplantologia

Spirometria domowa wykonywana z wykorzystaniem mobilnych spirometrów elektronicznych została uznana za skuteczną metodę w rozpoznawaniu wczesnych stadiów zespołu zarostowego zapalenia oskrzelików u biorców przeszczepów płuc i jest obecnie standardem w monitorowaniu funkcji płuc po transplantacji. Wyniki badań potwierdzają dużą biegłość pacjentów w wykonywaniu natężonych manewrów spirometrycznych w warunkach domowych [49, 50].

Wczesne wykrywanie zaburzeń czynności płuc pozostaje również istotnym wyzwaniem w opiece nad pacjentami z późnymi powikłaniami płucnymi po allogenicznym przeszczepieniu krwiotwórczych komórek macierzystych. Także w tej grupie pacjentów wykazano wysoką zgodność wyników spirometrii domowej z wynikami uzyskiwanymi za pomocą konwencjonalnych spirometrów [51]. Jest to szczególnie istotne z klinicznego punktu widzenia, ponieważ prospektywne badania potwierdzają, że wczesna interwencja medyczna po

rozpoznaniu zespołu zarostowego zapalenia oskrzelików może prowadzić do poprawy funkcji płuc [52].

5.4. Osiągnięcia naukowe kandydata na tle dotychczasowego stanu wiedzy

Temat przenośnych spirometrów w diagnostyce POChP zainteresował mnie jeszcze podczas studiów, gdy pracowałem w Studenckim Kole Naukowym *Alveolus* działającym przy Klinice Chorób Wewnętrznych, Pneumonologii i Alergologii Warszawskiego Uniwersytetu Medycznego. W 2016 r. w konkursowej sesji pulmonologicznej 12th Warsaw International Medical Congress (międzynarodowy kongres studenckich kół naukowych z uczelni medycznych) prezentowany przeze mnie plakat pt. *The prevalence of airway obstruction among smoking passers-by at the Eastern Warsaw Railway Station – pilot study* zdobył I miejsce. Wyniki zaprezentowanego wówczas badania stały się podstawą publikacji zatytułowanej *Public spirometry campaign in chronic obstructive pulmonary disease screening – hope or hype?*, której jestem współautorem i która jest częścią tej rozprawy doktorskiej.

Doniesienia z moim udziałem prezentowane na ERS International Congress 2020 (*Screening for COPD with a portable spirometer among hospitalised smokers* oraz *Primary care spirometry with a new mobile phone-linked spirometer – a feasibility study*) wzbudziły zainteresowanie w środowisku naukowym zajmującym się nowatorskimi narzędziami diagnostycznymi w POChP. Wyniki tych badań opublikowano jako drugą i trzecią pracę wchodzącą w skład cyklu publikacji będących podstawą niniejszej rozprawy doktorskiej.

Ostatnia publikacja cyklu, składającego się na niniejszą rozprawę jest przeglądem systematycznym. Jest to według mojej wiedzy pierwsza analiza oceniająca możliwość zastosowania kieszonkowych spirometrów w badaniach przesiewowych w grupie ryzyka POChP. Publikacja ta zawiera również porównanie wyników przesiewowych badań POChP z użyciem PS i urządzeń konwencjonalnych. Wnosi istotne informacje na temat skuteczności PS i wpisuje się w aktualną dyskusję nad ich rolą w diagnostyce POChP. Jednocześnie stanowi przyczynek do dalszych badań nad wykorzystaniem nowatorskich urządzeń w rozpoznawaniu jednej z najczęstszych chorób cywilizacyjnych.

6. Założenia i cele pracy

W obliczu częstości występowania astmy i POChP oraz związanych z tymi chorobami wyzwań diagnostycznych, szybki rozwój przenośnych spirometrów w ciągu ostatniej dekady stał się impulsem do przeprowadzania badań nad skutecznością tych urządzeń w diagnostyce obturacyjnych chorób płuc. Celem niniejszej pracy było zbadanie efektywności przenośnych spirometrów w diagnostyce obturacyjnych chorób płuc, w szczególności POChP w populacjach wysokiego ryzyka.

W szczególności, praca miała na celu:

1. ocenę skuteczności proaktywnych strategii wykorzystujących przenośny spirometr w rozpoznawaniu POChP u osób z grupy wysokiego ryzyka,

2. ocenę możliwości zastosowania przenośnego spirometru w różnych warunkach klinicznych:

   a) w podstawowej opiece zdrowotnej na skalę krajową,

   b) u pacjentów hospitalizowanych w oddziałach pulmonologii i kardiologii,

   c) w akcji badań spirometrycznych przeprowadzonych poza placówkami ochrony zdrowia.

3. oszacowanie częstości występowania POChP zdiagnozowanego za pomocą przenośnego spirometru u pacjentów z czynnikami ryzyka oraz porównanie tych wyników z częstością występowania choroby, odnotowywaną w badaniach z wykorzystaniem konwencjonalnych spirometrów.

4. analizę poprawności badań przeprowadzanych z użyciem przenośnego spirometru oraz identyfikację najczęściej popełnianych błędów.

7. Materiał i metody

Na rozprawę doktorską składa się jeden systematyczny przegląd piśmiennictwa i trzy badania oryginalne. Celem przeglądu systematycznego była synteza dostępnych w bazach publikacji medycznych badań dotyczących zastosowania przenośnego spirometru w ocenie częstości występowania przewlekłej obturacyjnej choroby płuc (POChP). Trzy badania oryginalne, które stały się podstawą trzech publikacji miały charakter prospektywny, a ich celem była ocena możliwości wykorzystania przenośnego spirometru w różnych warunkach klinicznych, takich jak miejsca publiczne (np. dworzec), przyłóżkowa diagnostyka pacjentów hospitalizowanych oraz gabinet lekarza pierwszego kontaktu. Badania te przeprowadzono wśród osób z czynnikami ryzyka obturacyjnych chorób płuc.

7.1 Grupy badane

Ze względu na charakter publikacji – obejmujących zarówno systematyczny przegląd literatury, jak i badania prospektywne prowadzone u pacjentów z czynnikami ryzyka POChP, oraz zróżnicowane warunki kliniczne, w których oceniano osoby zagrożone POChP (pacjenci hospitalizowani i ambulatoryjni), badana grupa cechuje się znaczną heterogennością.

Łącznie analizą objęto 33 781 pacjentów. Zdecydowaną większość (23 632 osoby) stanowili uczestnicy badań uwzględnionych w systematycznym przeglądzie literatury. Istotną grupę badanych (10 149 osób) stanowiły natomiast osoby, które wzięły udział w badaniach, w których bezpośredni udział miał autor niniejszej rozprawy. Najliczniejszą grupę wśród tych pacjentów stanowili uczestnicy ogólnopolskiego badania wieloośrodkowego (*The use of a mobile spirometry with a feedback quality assessment in primary care setting – A nationwide cross-sectional feasibility study*.), w którym przebadano 9 855 osób. Spirometrię wykonywano u nich na zlecenie lekarza pierwszego kontaktu, przy czym wskazania do badania były zróżnicowane. Średni wiek uczestników wynosił 47,8 ± 16,3 lat, a 2 990 osób (30,3%) deklarowało aktywne palenie papierosów. Grupa ta była zróżnicowana również pod względem miejsca zamieszkania – 58,1% spirometrii wykonano w miastach liczących ponad 100 000 mieszkańców.

W przypadku dwóch pozostałych badań składających się na niniejszą rozprawę – *Public spirometry campaign in chronic obstructive pulmonary disease screening – hope or hype?* oraz *Active screening for COPD among hospitalized smokers – a feasibility study* – uczestnicy stanowili bardziej homogenną grupę. Zarówno osoby poddane badaniu spirometrycznemu w miejscu publicznym, jak i pacjenci hospitalizowani byli osobami o podwyższonym ryzyku POChP, spełniającymi kryteria: wiek > 40 lat oraz wywiady aktywnego palenia papierosów wynoszące co najmniej 10 paczkolat. Średnia liczba paczkolat była zbliżona w obu badanych

grupach – 28 (mediana: 18–38) w jednej grupie oraz 30 (mediana: 20–40) w drugiej. W porównaniu z pacjentami hospitalizowanymi, uczestnicy badania przeprowadzonego w miejscu publicznym (dworzec kolejowy) byli młodsi – ich średni wiek wynosił 56 lat (mediana: 48–61) w porównaniu do 66 lat (mediana: 59–73) w grupie hospitalizowanej.

7.2 Metody

Ze względu na różnorodny charakter badań składających się na niniejszą rozprawę oraz odmienne cele poszczególnych publikacji, zastosowana metodyka pracy cechuje się znaczną heterogennością.

Badanie w miejscu publicznym

Pierwsza publikacja, *Public spirometry campaign in chronic obstructive pulmonary disease screening – hope or hype?*, dotyczyła badania przeprowadzonego na dworcu kolejowym. Wszyscy uczestnicy wypełnili autorski kwestionariusz zawierający m.in. dane demograficzne oraz ilościową ocenę nasilenia objawów ze strony układu oddechowego (skale CAT i mMRC). Ponadto, każda osoba poddała się badaniu spirometrycznemu z użyciem przenośnego spirometru (MicroLab 3500, CareFusion, USA).

Na podstawie wyników spirometrii uczestników podzielono na trzy grupy:

1) Grupa N (no airflow limitation, n = 119) – osoby bez cech obturacji dróg oddechowych ($FEV_1/FVC \geq 0,7$) i bez objawów ze strony układu oddechowego.
2) Grupa AO (airway obstruction, n = 22) – osoby ze spirometrycznymi cechami obturacji ($FEV_1/FVC < 0,7$).
3) Grupa PAO (possible airway obstruction, n = 37) – osoby zgłaszające objawy ze strony układu oddechowego, które nie były w stanie wykonać spirometrii dobrej jakości.

Wszystkie osoby z grup AO i PAO zaproszono do Pracowni Badań Czynnościowych Układu Oddechowego Warszawskiego Uniwersytetu Medycznego celem weryfikacji obturacji za pomocą konwencjonalnego spirometru, a w przypadku jej potwierdzenia – wykonania próby rozkurczowej.

W analizie statystycznej zastosowano:

- Test chi-kwadrat – dla zmiennych kategorycznych.
- Testy U Manna-Whitneya oraz Kruskala-Wallisa – dla zmiennych ciągłych.

Badanie wśród pacjentów hospitalizowanych

W kolejnej publikacji, *Active screening for COPD among hospitalized smokers – a feasibility study*, badaniem objęto hospitalizowanych pacjentów. Podobnie jak w poprzednim

badaniu, uczestnicy wypełnili autorski kwestionariusz zawierający dane demograficzne oraz ocenę nasilenia objawów oddechowych (skale CAT i mMRC). Spirometrię – zarówno badanie wyjściowe, jak i próbę rozkurczową w przypadku wykrycia obturacji – przeprowadzono przy łóżku pacjenta, wykorzystując przenośny spirometr (AioCare®, HealthUp, Polska).
Analiza statystyczna obejmowała:

- Test chi-kwadrat lub test Fishera – dla zmiennych kategorycznych.
- Test U Manna-Whitneya – dla zmiennych ciągłych (szczegółowy opis: rozdział *Patients and Method, Statistical analysis,* str. 45).

Badanie w podstawowej opiece zdrowotnej

Trzecia publikacja, *The use of a mobile spirometry with a feedback quality assessment in primary care setting – A nationwide cross-sectional feasibility study*, przeprowadzona została w wielu ośrodkach podstawowej opieki zdrowotnej w Polsce. W ramach badania do placówek dostarczono przenośne spirometry (AioCare®, HealthUp, Polska), a personel medyczny przeszedł dwugodzinne szkolenie z wykonywania spirometrii.

Spirometrię wykonywano u pacjentów zgłaszających się na wizyty kontrolne z objawami ze strony układu oddechowego lub czynnikami ryzyka chorób obturacyjnych dróg oddechowych. Badanie uznawano za technicznie poprawne, jeśli co najmniej trzy manewry spełniały kryteria akceptowalności i powtarzalności zgodnie z wytycznymi ATS/ERS.

W analizie statystycznej zastosowano krokową regresję logistyczną w celu identyfikacji czynników wpływających na jakość wykonania spirometrii (rozdział *Materials and Methods, Statistical analysis,* str. 56).

Systematyczny przegląd literatury

Ostatnia publikacja składająca się na rozprawę – *How to enhance the diagnosis of early stages of chronic obstructive pulmonary disease (COPD)? The role of mobile spirometry in COPD screening and diagnosis – a systematic review* – stanowi systematyczny przegląd literatury, przeprowadzony zgodnie z wytycznymi PRISMA 2020. Protokół badania został zarejestrowany w bazie PROSPERO (ID CRD42022337420).

Przeszukiwanie literatury objęło badania opublikowane w języku angielskim w okresie od 1958 roku do 7 grudnia 2021 roku. Dane pozyskano z baz PubMed, Cochrane Central Register of Controlled Trials oraz Embase, a wyszukiwanie przeprowadzono z wykorzystaniem kombinacji słów kluczowych związanych z POChP, spirometrią i badaniami przesiewowymi. Selekcja badań oraz zastosowane kryteria włączenia i wykluczenia zostały szczegółowo

opisane w rozdziale *Materials and Methods, Selection criteria, Study selection* (str. 65–66) oraz przedstawione na Ryc. 1, str. 66.

Na podstawie rodzaju spirometru użytego w badaniach przesiewowych i diagnostycznych wyróżniono trzy grupy:

Grupa A – badania, w których zarówno spirometrię przed, jak i po podaniu leku rozszerzającego oskrzela wykonano za pomocą przenośnego spirometru.

Grupa B – badania, w których obie spirometrie wykonano za pomocą konwencjonalnego spirometru.

Grupa C – badania, w których wstępną spirometrię wykonano za pomocą przenośnego spirometru (lub urządzenia przesiewowego, np. COPD-6), natomiast spirometrię potwierdzającą przeprowadzono z użyciem konwencjonalnego spirometru.

8. Kopie opublikowanych prac

8.1 Publikacja nr 1

VIA MEDICA

ORIGINAL RESEARCH

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Public spirometry campaign in chronic obstructive pulmonary disease screening — hope or hype?

The authors declare no financial disclosure

Abstract

Introduction: Underdiagnosis of COPD seems to be a relevant clinical and social problem. We hypothesized that active public spirometry campaign may help identify subjects with airflow limitation consistent with COPD.
The aim of the study was (1) to evaluate the willingness of random smokers to undergo public spirometry, (2) to assess the ability to obtain an acceptable quality spirometry during a public campaign, and (3) to assess the relationships between the presence and severity of respiratory symptoms and readiness to undergo spirometry.
Material and methods: Pedestrians aged > 40 years and a smoking history > 10 pack-years were recruited by medical students to fill a questionnaire and perform spirometry. Those with obstructive or borderline ventilatory insuffciency were invited and encouraged to undergo stationary spirometry in a pulmonary outpatient department.
Results: Nine hundred and five subjects meeting the inclusion criteria were invited to the study. Only 178 subjects agreed to complete the questionnaire and undergo spirometry. Airway obstruction and borderline spirometry result (classified as possible airway obstruction) were found in 22 and 37 subjects, respectively. Of these, only 15 patients attended follow-up visit to verify public spirometry results. Extrapolation of the limited data showed the incidence of newly diagnosed airway obstruction as 10.7%.
Conclusions: Public spirometry campaign does not seem to be an effective way of COPD screening. Smokers are reluctant to undergo complimentary spirometry even in the presence of pronounced respiratory symptoms. Our observations may be helpful in elaborating future screening programs for COPD.

Key words: airway obstruction, chronic obstructive pulmonary disease, public spirometry

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Introduction

Chronic obstructive pulmonary disease (COPD) is a common entity characterized by persistent airflow limitation and respiratory symptoms [1]. According to one recent meta-analysis of 123 studies, the prevalence of COPD in people aged 30 years or older was approximately 11.7% (95% confidence interval [CI] 8.4–15.0%) [2]. With more than 3 million people dying of COPD every year [3] the disease is currently the fourth world leading cause of death and is estimated to become the third in the next several years [1].

Polish epidemiological data on COPD are consistent with those reported from other countries. Three studies showed the prevalence of COPD in Polish population aged > 40 years ranging between 10.7 and 22.1% [4–6]. As in other countries, an early diagnosis seems to be one of the major issue in management of COPD. Bednarek *et al.* [5] showed that in primary care setting only less than 20% of patients with COPD had been diagnosed. Most of these patients had severe and very severe airflow limitation. Thus, it might be estimated that about 80% of COPD patients in Poland suffered

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from mild or moderate disease and had been underdiagnosed [7].

As smoking is a major risk factor for COPD, it may seem that the identification of the population at particular risk of COPD development should be relatively simple. One recent Polish study showed that approximately 30% of men and 21% surveyed in 2014 were current smokers [8]. These patients should probably be a target for screening campaigns aimed at an early diagnosis of airway obstruction and COPD. However, it has been well documented that asymptomatic smokers or smokers with mild symptoms only rarely seek medical attention. Moreover, primary care providers do not always have access, enough time or adequate training to use spirometry, which is crucial for diagnosis of persistent airflow limitation. Thus, albeit early detection and proper intervention for COPD could potentially slow the progression of the disease and minimize its negative consequences [9], spirometry is probably still performed too rarely to significantly increase the proportion of patients diagnosed with early COPD stages. We believe that social campaigns, including those carried out by medical students, may increase public awareness of COPD, contribute to more effective smoking cessation and more effective COPD diagnosis in patients with mild symptoms.

Therefore, we undertook a study aimed at:

1. The evaluation of willingness of random smokers to undergo public spirometry.
2. The assessment of ability to obtain an acceptable quality spirometry during a public campaign, which could be a prerequisite for the diagnosis of airway obstruction and COPD.
3. The assessment of the relationships between readiness to undergo free of charge spirometry and the presence and severity of respiratory symptoms.

Material and methods

Study design and patient characteristics

This prospective, cross-sectional study was conducted between January and May 2016. The recruitment to the study was performed at the Warsaw East Railway Station and included pedestrians who were asked and encouraged to participate in the study. The specific inclusion criteria were as follows: 1) age > 40 years; 2) a smoking history > 10 pack-years; 3) consent to take part in the study. Subjects with symptoms of acute respiratory tract infection in the previous 6 weeks and those who did not give their consent to participate in the study were excluded. The participants who were active smokers or who had quitted smoking in the last 12 months were classified as current smokers. Subjects who had a smoking history > 10 pack-years but who had not smoked for more than 12 months were classified as ex-smokers.

A stand was prepared and driven by the medical students. The students actively searched and recruited the study participants. All subjects who met the inclusion criteria and signed the informed consent to participate in the study were asked to fill a questionnaire that contained questions on demographic data, exposure to active and passive smoking, comorbidities and respiratory symptoms. Participants who agreed to perform spirometry, but were non-smokers or < 40 years of age were excluded from study. Quantitative assessment of symptoms included the COPD Assessment Test (CAT) and the modified Medical Research Council (mMRC) dyspnea scale. Based on the results of the above tests, the patients were classified as having low (mMRC score 0–1 and CAT score < 10) or high level of symptoms (mMRC ≥ 2 or CAT score ≥ 10, respectively) [1]. A portable spirometer (MicroLab 3500, CareFusion, San Diego, California) was used to perform a public spirometry. The measurements were performed by properly trained medical students in accordance with the recommendations of the European Respiratory Society (ERS) and American Thoracic Society (ATS) [10, 11]. Reference values published by the European Coal and Steel Community (ECCS) were applied [12].

To simplify the assessment of public spirometry fixed FEV_1/FVC ratio below 0.7 was used to diagnose airway obstruction. This approach was concordant with GOLD recommendations [1]. However, to minimize the risk of false negative diagnosis of airway obstruction, the spirometry results with FEV_1/FVC ratio ≥ 0.7 but only in subjects with symptoms suggestive for COPD and at the same time unable to perform good quality spirometry were also considered as probable airway obstruction. Thus, based on public spirometry the patients were classified as follows: no airflow limitation group (N) characterized by FEV_1/FVC ratio ≥ 0.7 and no respiratory symptoms, airway obstruction group (AO) defined as FEV_1/FVC ratio < 0.7 and possible airway obstruction group (PAO) defined as FEV_1/FVC ratio < 0.7 and FEV_1/FVC ratio ≥ 0.7 and below LLN in symptomatic patients unable to perform spirometry of good quality.

In order to verify the results of public spirometry all participants from AO and PAO groups were strongly encouraged to visit a Pulmonary Function Test (PFT) Unit of the Medical Universi-

ty of Warsaw in order to undergo a free of charge spirometry carried out by qualified medical staff and to be seen by pulmonary specialist. The subjects asked to consult the doctor at the medical centre were inhabitants of the city, where the test was performed. They initially declared the responsible will to come for the check-up and they could select the appointment date. The authors made every effort to motivate the planned group to come for a control spirometry tests. In patients who accepted the invitation, spirometry with flow-volume curve was performed (Lungtest 1000, MES, Cracow, Poland) in accordance with the recommendations of the ERS/ATS [10, 11]. In case of airflow limitation (defined as $FEV_1/FVC < LLN$), the bronchial obstruction reversibility test was performed according to the respective guidelines [11].

The study was approved by the institutional review board of the Medical University of Warsaw.

Data presentation and statistical analyses

Statistical analysis was performed using Statistica 12.5 (StatSoft Inc., Tulsa, OK, USA) and MedCalc 13.2.2 (MedCalc Software bvba, Ostend, Belgium) statistical software packages. Data are expressed as medians and interquartile ranges (IQRs, 25^{th} to 75^{th} percentiles) or numbers and percentages. The distribution of categorical variables in the independent groups was compared using Fisher's exact or Chi square tests. The differences between continuous variables in two or more groups were tested with the use of nonparametric Mann-Whitney U-test or Kruskal-Wallis test with the subsequent use of the post-hoc Dunn test (for multiple comparisons), respectively. Statistical significance was accepted at p-value less than 0.05.

Results

One thousand fifty five passers-by were asked to participate in the study, 150 of them were unsuitable (age under 40 years, non-smokers, no answer). Finally, nine hundred five persons who were smokers and aged above 40 years were invited to the study. One hundred seventy eight subjects agreed to stop for a while to complete the questionnaire and undergo spirometry. These patients formed a baseline study group. The remaining 727 subjects (80%) refused to collaborate. A detailed characteristic of the study group is presented in Table 1. Based on the results of public spirometry AO and PAO was diagnosed in 22 (12%) and 37 (21%) patients, respectively. In the remaining 119 cases (67%), spirometry showed normal results. Comparative data of patients with normal spirometry, AO and PAO are shown in Table 1.

Only 15 (25%) of 59 patients with AO and PAO attended the visit in the PFT Unit: 6 participants from the AO group (27%) and 9 from the PAO group (24%) (Fig. 1). In 5 patients from the AO group (83%) and 2 patients from PAO group (22%) the airway obstruction was confirmed by second spirometry. Thus, airway obstruction was confirmed in 7/15 patients with positive screening by public spirometry. All patients with confirmed airflow limitation had persistent ("fixed") airway obstruction.

The participants who came for a check-up visit were significantly older than subjects who did not seek further medical attention. Also, the percentage of ex-smokers was significantly higher among patients attended follow up visit (Table 2).

In all 5 patients with known COPD, airway obstruction was demonstrated in public spirometry. Two of these patients came for a second assessment and persistent airflow limitation was confirmed in a repeated spirometry. In 2 of 5 patients with known asthma, airway obstruction was found in public spirometry, while 3 asthmatics had normal spirometry. One of them attended the check-up visit and had normal second spirometry. Thus, 5 of 7 (71%) patients with confirmed airflow limitation had newly diagnosed airway obstruction consistent with diagnosis of COPD.

The similar severity of bronchial obstruction in the public spirometry and stationary spirometry was observed. FEV_1 and FVC were not significantly different during the test performed on the railway station and in the PFT Unit ($n = 15$; $p = 0.16$ and 0.64, respectively).

Analysis of symptoms in the study group

Seventy one (40%) and 107 (60%) patients who underwent public spirometry had CAT score ≥ 10 and < 10 points, respectively. The proportion of patients with CAT score ≥ 10 points in AO and PAO groups was significantly higher than in N group (56% vs. 32%, respectively, $p = 0.003$) (Fig. 2). Ten of 15 patients who attended follow up visit and underwent second spirometry reported CAT score ≥ 10 points, while the remaining 5 patients < 10 points ($p = 0.381$). Only 2 of these 15 patients had severe dyspnea according to mMRC scale. The differences between the results of scoring patients with mMRC and CAT are presented in Figure 3. Among AO and PAO patients, the proportion of symptomatic patients evaluated in CAT was significantly higher than

Table 1. Comparison of study groups classified according to the results of public spirometry

	All subjects n = 178	N group n = 119	AO group n = 22	PAO group n = 37	p (Kruskal-Wallis or Chi square test)	p for multiple comparisons: N-AO (a), N-PAO (b), AO-PAO (c)
Age (years)	56 (48–61)	55 (47–60)	60.5 (51–64)	59 (52–63)	0.022	0.08[a], 1.0[b], 0.13[c]
Sex (F/M)	65/113	49/70	7/15	9/28	0.157	
BMI (kg/m^2)	27.7 (24.6–30.5)	28.1 (24.7–31.0)	26.3 (22.5–30.0)	26.1 (24.3–30.8)	0.298	
FEV_1 (L)	2.70 (2.14–3.34)	2.89 (2.38–3.66)	2.04 (1.48–2.58)	2.44 (2.02–3.05)	0.000	0.015[a], 0.16[b], < 0.001[c]
FEV_1 (% of predicted)	91.5 (76–103.5)	96 (85–110)	71 (56–79)	82 (72–102)	0.000	0.01[a], 0.01[b], <0.001[c]
FVC (L)	3.78 (3.16–4.56)	3.84 (3.16–4.80)	3.73 (2.50–4.26)	3.65 (3.25–4.41)	0.406	
FVC (% of predicted)	102 (91–115.5)	104 (92–116)	99 (90–102)	103 (87–120)	0.106	
FEV_1%FVC	73 (67–78)	76 (72–80)	56 (51–65)	69 (66–70)	0.000	< 0.001[a], 0.05[b], < 0.001[c]
Ex-smokers/ /current smokers (n)	39/139	26/93	2/20	11/26	0.179	
Pack-years	28 (18–38)	22.5 (15–36)	33.5 (30–40)	30 (22–40)	0.003	0.01[a], 0.19[b], 1.0[c]
CAT (points)	8 (3–13)	6 (3–12)	11 (8–17)	9 (4–16)	0.013	0.43[a], 0.52[b], 0.02[c]
mMRC	0 (0–1)	0 (0–1)	0.5 (0–1)	0 (0–1)	0.580	
COPD n (%)	5 (3)	0	5 (23)	0 (0)	0.000	
Asthma n (%)	5 (3)	3 (2.5)	2 (9)	0	0.174	
Hypertension n (%)	67 (39)	45 (38)	7 (32)	15 (40.5)	0.798	
Ischemic heart disease n (%)	20 (12)	12 (10)	1 (4.5)	7 (19)	0.170	

The results are presented as median (IQR) or numbers. For comparisons with no significance in the Kruskal–Wallis test, only one p-value is shown, the left p column; for comparisons with significance, p-values are shown for each compared pair, the right p column: a (N vs AO); b (N vs PAO); c (AO vs PAO).
AO — airway obstruction; BMI — body mass index; CAT — COPD Assessment Test; FEV_1 — forced expiratory volume at 1 second; FVC — forced vital capacity; mMRC — Medical Research Council scale of dyspnea; N — normal; PAO — possible airway obstruction

patients evaluated according to the mMRC dyspnea scale ($p < 0.001$).

Discussion

Our study is one of the few reports, which show the results of public spirometry carried out outside a health care setting. We demonstrated that despite an active search for individuals at risk, the readiness to take part in a simple screening program that involved a questionnaire and public spirometry reached only 20%. In 178 subjects who entered the screening program realized by medical students trained to perform and interpret spirometry, airway obstruction and possible airway obstruction were found in 33% of the respondents. Importantly, only 25% of those who were informed about an abnormal spirometry result, and were invited to a reference pulmonary center to undergo stationary spirometry and to be consulted by pulmonary specialist, attended the visit. Those patients, who followed the students' advice and came for a second assessment were older and were ex-smokers rather than active smokers. We did not demonstrate that the severity of symptoms was associated with the attendance at the follow-up visit in the reference health care pulmonary center.

It seems that active campaigns including spirometry screening in high risk populations might help to manage the important problem of COPD underdiagnosis and, in consequence, to provide a more efficient health care for COPD patients. We found that our program not only allowed to assess

Table 2. Comparison of the selected clinical data of patients with AO and PAO found in public spirometry who underwent and did not undergo follow up visit

	Not attended follow up visit and spirometry n = 44	Attended follow up visit and spirometry n = 15	p
sex (F/M)	12/32	4/11	1.0
age (years)	57.0 (51.5–61.5)	66.0 (51.0–70.0)	0.02
BMI (kg/m^2)	26.1 (24.7–29.9)	26.9 (21.8–33.2)	0.94
FEV_1 (L)	2.4 (1.8–2.8)	2.3 (1.6–3.0)	0.65
FEV_1 (% of predicted)	76.0 (66.5–91.5)	78.0 (59.0–107.0)	0.55
FVC (L)	3.7 (3.1–4.4)	3.6 (2.6–4.4)	0.61
FVC (% of predicted)	99.0 (87.5–112)	98.5 (88.0–124.0)	0.58
FEV_1%FVC	66.5 (56.5–69.5)	65.0 (52.0–69.0)	0.65
Ex-smokers/smokers	8/36	5 / 10	< 0.001
Pack-years	31.0 (25.0–40.0)	30.0 (20.0–40.0)	0.52
CAT (points)	10.0 (4.5–16.5)	11.0 (8.0–17.0)	0.39
mMRC	0.0 (0.0–2.0)	0.0 (0.0–1.0)	0.51
COPD n (%)	3 (6.8)	2 (13.3)	0.44
Asthma n (%)	1 (2.3)	1 (6.7)	0.42

The results are presented as median (IQR). Results were considered statistically significant at $p < 0.05$. AO — airway obstruction; BMI — body mass index; CAT — COPD Assessment Test; FEV_1 — forced expiratory volume at 1 second; FVC — forced vital capacity; mMRC — Medical Research Council scale of dyspnea; PAO — possible airway obstruction

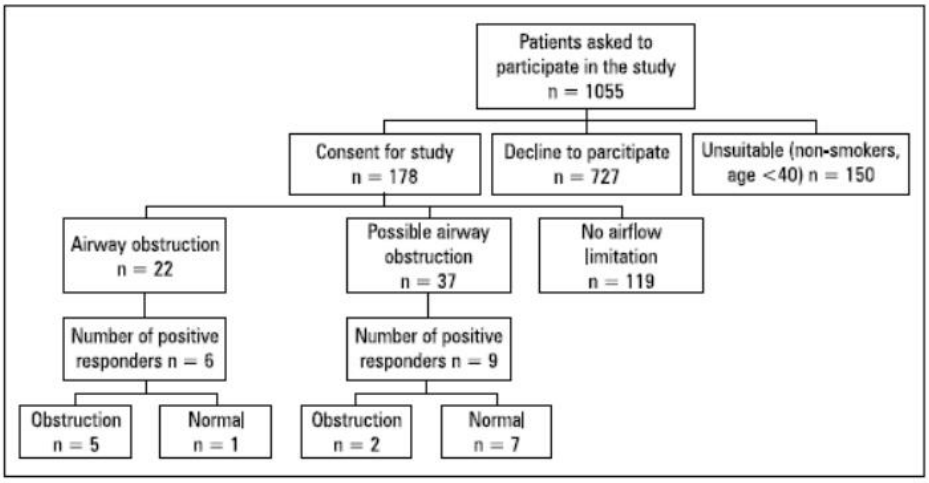

Figure 1. Flow chart presenting the number of patients and the results of spirometry in the subsequent phases of the study

symptoms and perform a screening spirometry, but also to carry out an anti-tobacco educational campaign and to discuss threats related to smoking. To our knowledge, most of the previous studies were performed in primary care setting with active patient recruitment through invitation letters sent by post, telephone calls, advertisements or encouragements during primary care visits [13]. Different patient characteristics and different model of screening can be responsible for significant variability in the response rate found in public campaigns and in screening programs conducted in health care centers. For example, approximately 70% of potentially eligible participants were recruited by general practitioners in one recent Croatian study aimed at the evaluation of the diagnostic accuracy of active screening for COPD [14], while the respective percentage in our public project conducted by medical students was much lower and did not exceed 20%. Acceptable response rates vary depending on the method of recruitment applied.

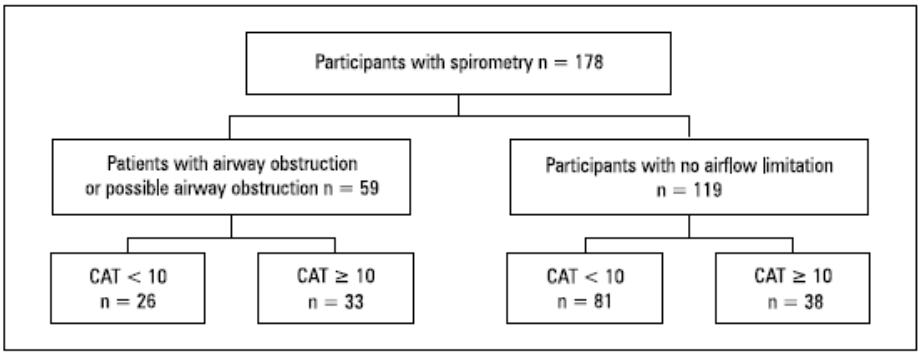

Figure 2. Distribution of the analyzed group depending on the grade of the intensity of the symptoms evaluated in COPD Assessment Test

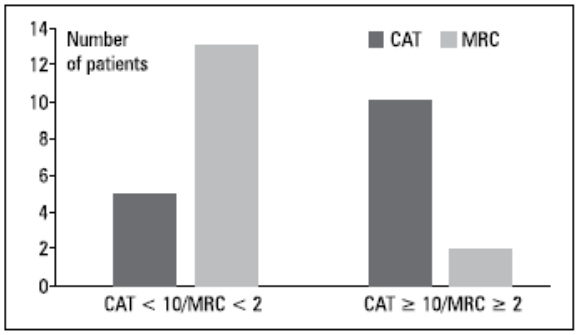

Figure 3. The differences between the results of symptoms scoring with mMRC and CAT in 15 patients who attended follow-up visit

It is thought that 50% is an adequate response rate in patients invited to participate by mail and 80% is considered satisfactory when the recruitment is conducted on a phone call basis. When face-to-face contact is applied in the recruitment phase, the expected response rate can be as high as 80–85% [15]. Thus, it must be admitted that our response rate of 20% was unexpectedly low. This can be explained by several factors. First, the passers-by recruited at the railway station represent a fairly specific study group, not necessarily caring for their health. Second, the railway station is a busy place, where the majority of people are in hurry to catch their trains, trams and buses and, therefore, they were reluctant to stop by in spirometry stand. Third, young medical students might have been considered not competent enough to perform spirometry screening. This might have resulted in lower credibility of the campaign, at least for some people who declined to join the study. Finally, winter and spring months with relatively low external temperature were probably an unfavorable time to convince the passers-by to participate in the project.

Low willingness to participate in screening programs is not a specific feature of patients with high risk of pulmonary diseases. In one Polish study, only 169 of 850 (20%) patients with various gastrointestinal symptoms agreed to undergo gastroscopy. The respective percentage was higher, but still relatively low (62%), in patients with alarming symptoms [16]. As even the risk of malignancy does not prompt patients to accept screening tests, the response rate of 20% found in our study performed in busy area might not be as low as it seems at the first glance.

Numerous previous studies demonstrated a high burden of COPD and emphasized the proportion of undiagnosed patients. In a German cohort, the prevalence of COPD classified as GOLD stage I was estimated at 9%, but in the Hokkaido cohort, this value reached even 26% [17, 18]. In one recent study by Fu *et al.* [10] undiagnosed airway obstruction was demonstrated in 14.6% of patients attending primary care, who had a positive smoking history and were older than 30 years. Lokke *et al.* [20] showed that 21.7% of 4049 subjects at-risk had been newly diagnosed with COPD in a primary care-setting and the majority of these patients had mild to moderate disease. In one earlier Polish study that applied spirometry screening to detect early stages of COPD in high-risk populations (n = 11027), airway obstruction was found in 30.6% of subjects aged > 40 years with a smoking history of 10 pack-years or longer [21]. In our study, the sample size was significantly smaller, but the same inclusion criteria identifying high risk population were applied. Excluding 5 patients with known COPD and 5 patients with asthma and assuming 83% of correct diagnoses of airflow limitation in AO group and 22% of correct diagnoses in PAO group, it may be speculated that simple public spirometry performed by medical students can correctly identify 11–12% of subjects in high risk population who had undiagnosed persistent airway obstruction consistent with COPD.

Spirometry continues to be an underutilized tool, despite its ease of use and increased ava-

ilability in primary care. Portable spirometers can be conveniently used during screening programs and spirometry testing do not necessarily need to be performed indoors [22]. The results of previous studies pointed out that active case finding in a population at risk for COPD should be instituted, even using a pocket screening spirometer/peak flowmeter [14, 23]. High correlations between the results of pulmonary function measured with Spirobank hand-held spirometer and Jaeger MasterScope in a laboratory environment were demonstrated [24]. Although the number of patients who had undergone both screening and stationary spirometry in our study was relatively low, the differences between FEV_1 and FVC measured in these two different settings were irrelevant, $p = 0.30$ and $p = 0.79$ respectively. It is believed that spirometry used for screening purposes requires a verification in a specialized health center. In our study, such approach was particularly important in patients with public spirometry classified as possible airway obstruction. Airway obstruction was confirmed in only 22% of these patients. On the other hand, airflow limitation was confirmed by stationary spirometry in as many as 5/6 (83%) of patients whose earlier public spirometry was classified as airway obstruction. These data show that public spirometry performed with a portable spirometer might be a reliable screening tool for patients with COPD.

Our results indicate that in the population older than 40 years with a smoking history of >10 pack-years, extrapolated prevalence of airway obstruction reaches 14.6%, whereas the percentage of subjects with a new diagnosis of airway obstruction is approximately 10.7%. Dąbrowiecki *et al.* [25] found that airway obstruction is present in 34% of the subjects participating in the Polish Spirometry Day, a national multicenter campaign. Such results point out a significant underestimation of the number of patients with obstructive lung diseases in clinical practice. Knowing how low percentage of people are willing to perform spirometry during a public campaign, it would be advisable to search for more effective methods to recruit high risk patients into spirometry screening programs.

In our study, subjects with airway obstruction or possible airway obstruction had a significantly higher CAT score than those with normal spirometry results. We have also shown that a significantly higher percentage of symptomatic patients were identified with the use of the CAT compared to the use of the mMRC scale. This might be easily explained in the light of the results of earlier studies that found a relatively weak correlation between mMRC and CAT [26, 27] and demonstrated that the CAT score correlates much better with St. George's Respiratory Questionnaire (SGRQ) [26]. Disagreement between CAT and mMRC results is not surprising because these two instruments differ in their purpose and symptom areas that are covered. CAT score and its items "breathlessness" and "phlegm" were significantly related to spirometric diagnosis of COPD in a population-based sample of 532 participants [28].

We are aware about some limitations of the study that should be mentioned. The major limitation is probably one of the study results, i.e. the low percentage of passers-by who agreed to participate in the study. A similar statement refers to the low percentage of patients who attended follow-up visit and underwent stationary spirometry verifying the results of public spirometry. The low number of patients in whom reliable conclusion from pulmonary function testing could have been established (certain airflow limitation or normal spirometry) did not allow to draw any reliable epidemiological conclusions. Possible causes of this situation have already been presented when discussing the low response rate in our study. Complex diagnostic criteria for airway obstruction, with patients classification as having airway obstruction or possible airway obstruction, may be considered as one of the study limitations. We realize that the quality of public spirometry may be suboptimal and the results of $FEV_1/FVC < 0.7$ in symptomatic patients unable to perform spirometry of good quality should be a subject of particular concern. Hence, these cases were classified as possible airway obstruction and were to be verified during the second phase of the study. Unfortunately, the percentage of patients who responded to our invitation to perform high quality stationary spirometry was surprisingly low.

Conclusions

The limited willingness of subjects at risk for COPD development to participate in public spirometry campaign may indicate that this is not an effective form of COPD screening. Smokers are rather reluctant to undergo complimentary spirometry and pulmonary consultation, even in the presence of pronounced respiratory symptoms. Nevertheless, the study showed the incidence of non-diagnosed airway obstruction in smokers aged > 40 years 10.7%. We also demonstrated

that a short training performed by experienced technicians seems sufficient for persons who are not healthcare providers to perform quality spirometry and to obtain reliable results. Our observations may be helpful in elaborating screening programs for COPD.

Conflict of interest

The authors declare no conflict of interest.

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8.2 Publikacja nr 2

Therapeutic Advances in Chronic Disease — *Original Research*

Active screening for COPD among hospitalized smokers – a feasibility study

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Abstract

Background: Spirometry is a primary tool for early chronic obstructive pulmonary disease (COPD) detection in patients with risk factors, for example, cigarette smoking. The aim of this study was to evaluate the strategy of an active screening for COPD among smokers admitted to the pulmonary and cardiology department.

Methods: This prospective study was conducted between February and March 2019. All hospitalized smokers aged 40 years and older completed an original questionnaire and had spirometry measurement with a bronchial reversibility test (if applicable) performed by medical students using a portable spirometer.

Results: One hundred and eighty-eight patients were eligible to participate in the study. Seventy (37%) subjects refused to participate. Eventually, 116 (62%) patients were included in the final analysis and 94 (81%) performed spirometry correctly. In total, 32 (34 %) patients were found to have COPD. Nine (28%) of these patients were newly diagnosed, 89% of them had mild-to-moderate airway obstruction. Patients with newly diagnosed COPD were significantly younger [age 63 (56–64) *versus* 69 (64–78) years], had a longer smoking-free period [17 (13–20) *versus* 9 (2–12) years], had fewer symptoms and had a better lung function compared with patients with a previous diagnosis of COPD ($p < 0.05$ for all comparisons).

Conclusion: The proposed diagnostic strategy can be successfully used to improve COPD detection in the inpatient setting. The majority of the newly diagnosed COPD patients had mild-to-moderate airway obstruction. Patients who should be particularly screened for COPD include ex-smokers with less pronounced respiratory symptoms.

Keywords: chronic obstructive pulmonary disease, fixed airway obstruction, misdiagnosis, portable spirometry, screening

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Introduction

Although chronic obstructive pulmonary disease (COPD) affects approximately one-fourth of the population of smokers aged 40 years and older,[1] most of the affected subjects are unaware of having the disease.[2,3] This is, at least partially, related to the fact that even 80% of undiagnosed subjects have mild-to-moderate disease.[2,3] In particular, early COPD, which is often mildly symptomatic,[4] can hinder patients from seeking medical help and receiving treatment. Underdiagnosis and undertreatment of COPD is critically important as the disease is progressive and leads to continuous lung function decline. It is hypothesized that the annual loss of forced expiratory volume in the first second (FEV_1) is more pronounced in earlier stages of the disease.[5,6] Moreover, early COPD does not exclude the possibility of an exacerbation, which is an important cause of hospital admission and death.[7] Therefore, diagnosing and treating patients with COPD, especially in early stages, can lead to improvement in their health status.[8]

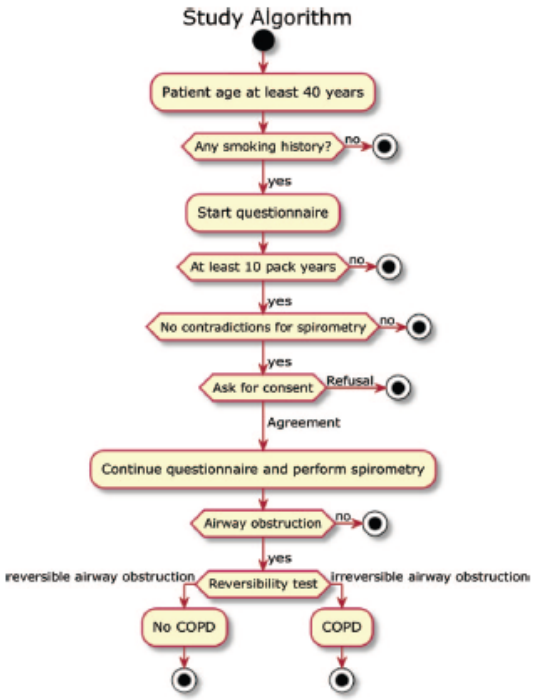

Figure 1. Study algorithm.
COPD, chronic obstructive pulmonary disease.

The gold standard for COPD diagnosis and monitoring is spirometry. Although it is an easy and low-cost method for basic lung function assessment, spirometry is frequently underused both in general practice and hospital settings, leading to underdiagnosis or overdiagnosis of COPD,[9–11] especially in patients with dyspnea related to cardiovascular diseases.[12] In a study by Spero *et al.*, only 8.4% of patients admitted to hospital with a diagnosis of COPD had a spirometry performed at discharge and in more than 30% of these patients spirometry did not confirm the diagnosis. We believe that accessibility to spirometry can be improved by the use of portable devices. It has been shown that portable spirometers linked to a mobile phone could be used as an alternative to laboratory spirometry and performed in the office or at bedside prior to discharge.[13–17] In this study, we propose an active screening strategy for hospitalized smokers to improve the diagnosis of COPD, especially when there is limited accessibility to laboratory spirometry. Briefly, all hospitalized patients with risk factors for COPD (smokers aged ⩾40 years) admitted to the pulmonary and the cardiology departments were questioned on their symptoms and comorbidities and underwent spirometry with the use of a portable spirometer. The choice of these two departments was based on the common risk factor of respiratory and cardiovascular diseases, that is, cigarette smoking. In this study we aimed to evaluate the feasibility of the proposed strategy to assess the prevalence of COPD and to identify under- and overdiagnosed patients with COPD among smokers aged 40 years and older admitted to the pulmonary and the cardiology departments.

Patients and methods

General study design

This was a prospective, cross-sectional study performed at the Central Teaching Hospital of the Medical University of Warsaw, Poland. All patients admitted to the pulmonary and the cardiology departments between February and March 2019 were screened for eligibility to participate in the study. Patient recruitment was performed by trained medical students who were guided on the study algorithm (Figure 1) by an interactive electronic questionnaire (KoBoToolbox, Harvard Humanitarian Initiative, Cambridge, MA, USA) and were working under the supervision of two pulmonologists. The questionnaire consisted of 45 questions on demographic data, smoking history, respiratory symptoms, comorbidities, medications, contraindications to perform spirometry and World Health Organization (WHO) performance status (see Supplemental Material). Patients who met the inclusion criteria (see below) underwent spirometry with a portable spirometer. In both departments, spirometry was carried out by the same group of students. Patients who were hospitalized because of acute medical conditions had spirometry after stabilization, whereas patients who were stable and admitted to perform planned procedures had spirometry on admission. The study project was approved by the Institutional Review Board of the Medical University of Warsaw, Warsaw, Poland (KB/232/2018) and was performed in accordance with the principles stated in the Declaration of Helsinki. All enrolled patients gave their written informed consent to participate in the study. All data were anonymized and treated with confidentiality according to Good Clinical Practice guidelines.

Study participants

The two major inclusion criteria were age ⩾40 years and smoking history of at least 10 pack-years.

Exclusion criteria comprised contraindications to perform spirometry and refusal or inability to give a written informed consent to participate in the study.

Spirometry and definitions

A portable AioCare® spirometer (HealthUp, Poland) with a wireless connection (*via* Bluetooth) to a dedicated software running on mobile phone operating systems was used to perform spirometry. The AioCare® spirometer meets all performance criteria described in international standards.[18] The device measures all commonly used spirometry parameters including forced vital capacity (FVC), FEV_1 and peak expiratory flow. The measurements were performed in a sitting position with a nose clip clamping the nostrils. In this study, spirometry was defined as a complete spirometry test consisting of at least three maneuvers with the measurement of FVC. If a maneuver was not in line with American Thoracic Society/European Respiratory Society (ATS/ERS) spirometry quality criteria, automatic feedback was provided to the medical students responsible for conducting the test. Spirometry quality assessment and interpretation of the results was performed by two pulmonologists according to the ATS/ERS guidelines.[19,20] In patients with baseline airway obstruction [FEV_1/FVC < lower limit of normal (LLN) according to the Global Lung Initiative reference values], a reversibility test with 400 µg salbutamol *via* a pressurized metered-dose inhaler with a spacer was performed. In patients who received a short- or a long-acting bronchodilator within 6 or 24 h, respectively, before the test was performed, the spirometry was considered a post-bronchodilator examination and a reversibility test was not conducted. COPD diagnosis was made when the post-bronchodilator FEV_1/FVC was below the LLN after the exclusion of other reasons for fixed airway obstruction.[21] The severity of airway obstruction was graded according to Global Initiative for Chronic Obstructive Lung Disease (GOLD) recommendations.[22] COPD overdiagnosis was considered when the study participant reported a diagnosis of COPD, but there was no fixed airway obstruction (post-bronchodilator FEV_1/FVC ⩾ LLN). COPD underdiagnosis was defined as the presence of irreversible airway obstruction in a patient without an earlier diagnosis of COPD.[23]

Statistical analysis

Estimation of the sample size was based on the prevalence of COPD in the Polish population aged ⩾40 years and among smokers, estimated to be 9.3%[3] and 22.95%,[1] respectively. We assumed that the COPD prevalence in our study would be 25% lower than that found in the above cited literature data. Assuming the power of 80% and the significance level of 5%, the sample size was estimated as 92 subjects (46 in the pulmonary and 46 in the cardiology department).

Continuous data are expressed as medians and interquartile ranges (25th to 75th percentiles) and categorical data are presented as numbers and percentages. Statistical analysis was performed using Statistica 13.3 (StatSoft Inc., Tulsa, OK, USA). The differences between continuous variables in two groups were tested using the non-parametric Mann–Whitney *U*-test. The categorical variables were compared using chi-squared test or Fisher's exact test. The statistical significance was accepted at a *p*-value less than 0.05.

Results

Patient characteristics

Four hundred and eighty-five patients were screened and 188 were eligible to participate in the study. Seventy (37%) subjects refused to participate in the study. The data on patient inclusion are presented in Figure 2. Ultimately, 116/188 (62%) patients (51 and 65 in the pulmonary and in the cardiology department, respectively) were included in the analysis. The characteristics of the study group are presented in Table 1. There were no differences in age, body-mass index, smoking history or WHO performance status between patients from the two departments. The cardiology group was characterized by a higher proportion of men compared with the pulmonary group ($p=0.03$). In the pulmonary group, more subjects had had spirometry in the past and had a shorter time interval since the last spirometry compared with the cardiology group ($p=0.005$). In the whole cohort, 92% patients had cardiovascular diseases and 22% had diabetes. Overall, 94 (81%) spirometry measurements were performed correctly and were used for analysis.

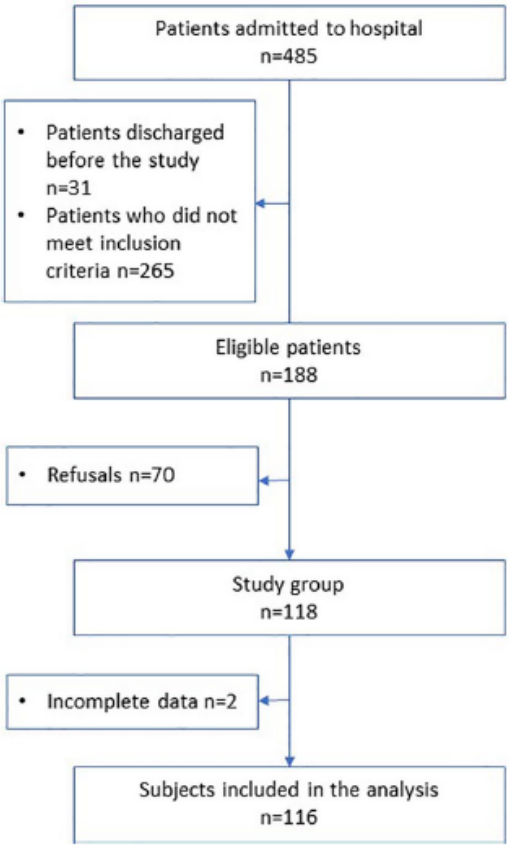

Figure 2. Flow diagram of the subjects screened and included in the full cohort.

Prevalence of COPD and detection of new cases of COPD

Fixed airway obstruction consistent with the diagnosis of COPD was found in 32 (34%) patients: 23/46 in the pulmonary and 9/48 in the cardiology department, respectively, $p=0.019$ (Figure 3). Of those, nine (28%) (four in the pulmonary and five in the cardiology department, respectively) subjects were newly diagnosed with COPD. The proportion of newly diagnosed COPD patients to non-COPD patients was numerically higher in the pulmonary than in the cardiology department but the difference was not statistically significant (17% *versus* 10%, respectively, $p=0.72$)).

Five of the nine newly diagnosed COPD patients had had spirometry in the past (three within the previous year, two more than 1 year prior to the study). Patients with newly diagnosed COPD were significantly younger [age 63 (56–64) *versus* 69 (64–78) years], had a longer smoking-free period [17 (13–20) *versus* 9 (2–12) years], had fewer symptoms and had better lung function compared with patients with earlier COPD diagnosis (Table 2) ($p<0.05$ for all comparisons). Figure 4 presents the prevalence of COPD and airway obstruction severity according to GOLD in the pulmonary and in the cardiology department. The underdiagnosis rate in patients with different airway obstruction severity grades was as follows: 80% for mild, 25% for moderate, 0% for severe and 33% for very severe (Figure 5). In 3/30 (10%) patients (one in the pulmonary and two in the cardiology department) who had reported an earlier COPD diagnosis, there was no fixed airway obstruction and the diagnosis of COPD was excluded. Two of these patients had no airway obstruction in the post-bronchodilator spirometry and one had a normal spirometry without prior bronchodilator intake. All of the overdiagnosed patients had had a spirometry performed in the past.

Acceptability of spirometry examinations in the pulmonary and the cardiology departments and in patients with different performance status

A larger proportion of patients hospitalized in the pulmonary department could perform a spirometry meeting the quality standards compared with the patients treated in the cardiology department: 46 (90%) *versus* 48 (74%) respectively, $p=0.014$. The subjects who performed a quality spirometry were significantly younger and had had spirometry more recently compared with those who did not (Table 3). There were no differences in the smoking history or the WHO performance status between the groups.

We found no difference in the percentage of quality examinations between patients with good (WHO 0–1) and poor (2–4) WHO performance status, 81% *versus* 80%, $p=0.76$. As there were only one and two patients with WHO performance status 3 and 4, respectively, we could not reliably assess and compare the ability to perform spirometry in those patients. Out of these three patients, only one performed spirometry which met the quality standards. The other two patients failed to perform any correct maneuver.

Discussion

The present study showed that active COPD screening in the inpatient setting is feasible. We

Table 1. Characteristics of the study population.

	All *N* = 116	Pulmonary department *n* = 51	Cardiology department *n* = 65	*p*
Age, years	66 (59–73)	66 (59–73)	66 (59–73)	0.76
Male gender	79 (68%)	29 (57%)	50 (77%)	0.03
BMI, kg/m^2)	27.4 (24.2–30.8)	27.3 (23.4–32.0)	27.4 (24.8–29.7)	0.75
Current smoker/ex-smoker	35 (30%)/81 (70%)	18 (35%)/33 (65%)	17 (26%)/48 (74%)	0.31
Pack-years	30 (20–40)	30 (20–40)	30 (20–40)	0.58
Years free from smoking	13 (4–25)	12 (3–22)	14.5 (4–25)	0.60
Spirometry in the past	87 (75%)	45 (88%)	42 (65%)	0.005
Months since the last spirometry	9 (1–60)	1 (0–4)	48 (12–168)	<0.001
Performance status according to the WHO				
Grade 0	54 (46%)	22 (43%)	32 (49%)	0.33
Grade 1	43 (37%)	18 (35%)	25 (38%)	
Grade 2	16 (14%)	9 (18%)	7 (11%)	
Grade 3	1 (1%)	0 (0%)	1 (2%)	
Grade 4	2 (2%)	2 (4%)	0 (0%)	
Previous diagnosis of obstructive lung disease				
COPD	30 (26%)	21 (41%)	9 (14%)	<0.001
Asthma	10 (9%)	6 (12%)	4 (6%)	
None	76 (65%)	24 (47%)	52 (80%)	
Comorbidities				
Cardiovascular diseases	102/111 (92%)	39/46 (85%)	63/65 (97%)	0.031
Diabetes	24/111 (22%)	7/46 (15%)	17/65 (26%)	0.241

Data are presented as median (interquartile range) or *n* (%).
BMI, body mass index; COPD, chronic obstructive pulmonary disease; WHO, World Health Organization.

found that the medical students' involvement allowed to achieve spirometry of sufficient quality and to detect irreversible airway obstruction, which is crucial for COPD diagnosis. Patients with newly diagnosed COPD have mainly mild-to-moderate airway obstruction. Of note, although our study was addressed to hospitalized patients with COPD risk factors, a significant proportion of these patients were unwilling to perform spirometry. Our results demonstrated that COPD screening should be considered not only for active smokers but also for subjects who have a long smoking-free period and report mild or no respiratory symptoms.

To our knowledge, this is one of the few studies in which all patients with COPD risk factors visiting a health center were included in the COPD

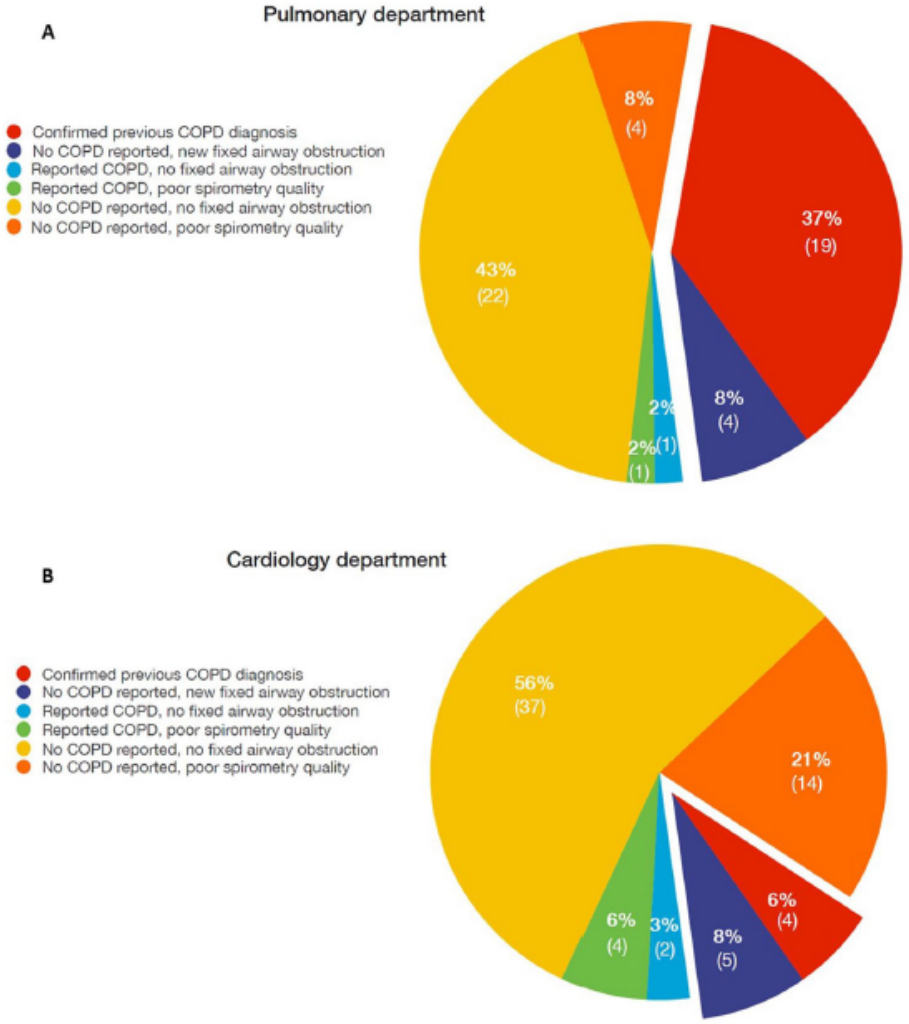

Figure 3. Results of screening for chronic obstructive pulmonary disease (COPD) in the pulmonary (A) and the cardiology (B) departments.

detection program and had spirometry with reversibility test performed. There are still no system solutions which would reduce the COPD underdiagnosis and overdiagnosis rate. It has been shown that active screening for COPD allowed to detect new cases in 22% patients, whereas in the standard care strategy only in 3% of patients could a new diagnosis of COPD be established.[24] Some authors have suggested implementing questionnaires which would help to select at-risk patients for spirometry examination.[25,26] A proposal of an active COPD case-finding strategy for primary care with the use of portable spirometers was presented in a study by Kim *et al.*[27] The authors found that the strategy was feasible in a primary clinical setting and should also include asymptomatic smokers aged ⩾40 years. In another study, a targeted spirometry screening program was implemented within the presurgical clinic and included smokers with respiratory symptoms and patients with a history of COPD or asthma.[28] Although in both of these studies the reversibility test, which is crucial for diagnosis of COPD,[22] was not performed, it was shown that about 25% of smokers had newly diagnosed airflow limitation.[27,28]

We identified COPD in 34% of the evaluated patients. The prevalence of COPD in our study was higher than previously reported (22.1–24.3%)

in the Polish population with risk factors.[1,29] Such a high prevalence of COPD in our study could be related to several factors. Almost half of the study participants were hospitalized in the pulmonary department, where the prevalence of COPD was significantly higher compared with the cardiology department. Moreover, smokers requiring hospitalization are a specific group of patients, probably in a worse health condition than healthy smokers. It has been shown that the COPD population has a significant rate of comorbidity.[30] COPD, especially in more severe stages, is characterized by systemic inflammation and the concurrence of COPD and cardiovascular diseases was shown to be independent of smoking history.[31] Of note, it has been shown that congestive heart failure might cause airway obstruction in patients without COPD and, therefore, poses a diagnostic challenge.[32–34] Brenner *et al.* have demonstrated that in up to 50% of patients, airway obstruction resolved after 6 months of treatment for heart failure.[32] In our study, we found that 10% of the patients who had declared having COPD did not have fixed airway obstruction. Overdiagnosis of COPD should be considered as a serious issue as it is associated with unnecessary and ineffective treatment and might delay the correct diagnosis. On the other hand, patients without fixed airway obstruction could still be at risk of developing COPD in the future and should be, similarly to COPD patients, educated on the harmful effects of smoking, advised on smoking cessation to avoid or delay lung function decline and be regularly followed up to assess lung function.

It is estimated that even 67–81%[2,3,23] of COPD patients are undiagnosed. In our study, the underdiagnosis rate was considerably lower, as 28% of COPD subjects were newly diagnosed. We may assume that a number of patients remained undiagnosed, as a significant proportion of subjects who are at risk of COPD declined participation in the study. Interestingly, the proportion of newly diagnosed to all non-COPD patients was similar in both the pulmonary and cardiology departments. Patients with newly diagnosed COPD had better lung function and reported fewer respiratory symptoms (in particular, less pronounced dyspnea) than those with an earlier diagnosis of COPD, which is consistent with findings from other studies.[35] We also found that newly diagnosed COPD patients had a longer smoking-free period compared with patients with an earlier diagnosis of COPD. All these factors could have contributed to the fact that some of the underdiagnosed patients had not been identified earlier. Patients with mild COPD are often unidentified, as the symptoms often do not interfere with their daily activity[36] and are accepted as a consequence of smoking and aging and, therefore, these patients do not seek medical advice.[37] In our

Table 2. Comparison of patients with a previous *versus* new COPD diagnosis.

	Previous diagnosis of COPD *n* = 23	New COPD diagnosis *n* = 9	*p*
Age, years	69 (64–78)	63 (56–64)	0.005
Male gender	11 (48%)	7 (78%)	0.23
BMI, kg/m^2	24.7 (21.8–29.7)	25.8 (24.7–28.3)	0.52
Pack-years	40 (30–50)	31 (20–46)	0.32
Years free from smoking	9 (2–12)	17 (13–20)	0.03
WHO	1 (0–2)	0 (0–1)	0.06
mMRC	2 (1–3)	1 (0–1.5)	0.03
CAT score	20 (14–23)	6.5 (5.5–9)	0.001
Cough	2 (0–3)	2 (1–3)	0.78
Phlegm	2 (1–3)	1 (0.5–2)	0.14
Chest tightness	0.5 (0–2)	0 (0–1)	0.26
Breathlessness	4 (2–5)	0 (0–1)	0.004
Activities	3 (2–4)	0 (0–1)	0.003
Confidence	2.5 (0–4)	0 (0–1)	0.01
Sleep	2.5 (0–4)	0 (0–1)	0.046
Energy	3 (3–3)	1 (1–2)	0.002
% predicted FEV_1	51 (40–64)	72.1 (55.9–85)	0.01
% predicted FVC	79 (67–94)	93.9 (77–102.6)	0.14
GOLD 1/2/3/4, %	4/52/35/9	44/44/0/12	0.02
GOLD A/B/C/D, %	9/36/9/46	50/13/0/37	0.08

Data are presented as median (interquartile range) or *n* (%).
BMI, body mass index; CAT, COPD Assessment Test scale; COPD, chronic obstructive pulmonary disease; FEV_1, forced expiratory volume in 1 s; FVC, forced vital capacity; mMRC, modified Medical Research Council scale; WHO, World Health Organization.

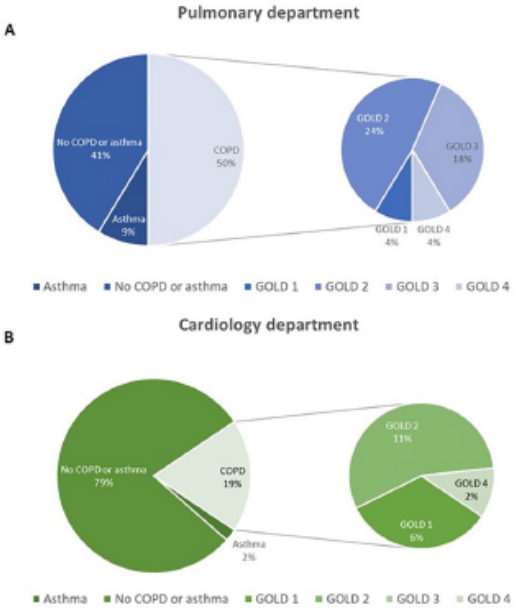

Figure 4. Prevalence of chronic obstructive pulmonary disease (COPD) and airway obstruction severity according to Global Initiative for Chronic Obstructive Lung Disease (GOLD) in the pulmonary (A) and the cardiology (B) departments.

study, 80% of patients with mild COPD were previously undiagnosed. Therefore, we believe it is important to actively search for patients with COPD risk factors and make the COPD diagnosis early to prevent further lung function deterioration and exacerbations and to maintain good quality of life.

The high COPD under- and overdiagnosis rate in the general population could be associated with the poor accessibility to spirometry and the reluctance of smokers to undergo screening. In a study performed outside a healthcare setting aimed to offer spirometry to smoking pedestrians, only 20% agreed to participate.[38] In the present study, the patients' willingness to undergo bedside COPD screening was substantially higher, as 62% of eligible subjects participated in the study. It is likely that hospitalized patients are more willing to participate as they already have other significant comorbidities and a greater health awareness and spirometry is an additional test performed during their hospitalization.

Spirometry of an adequate quality is critical for diagnosing airway obstruction. In our study 19% of participants were unable to perform spirometry of an adequate quality. It cannot be excluded that some of those patients could also suffer from COPD and, therefore, should have spirometry repeated. In our study, patients with poor quality spirometry were older than those who performed spirometry with good quality standards. Based on other reports, the quality of spirometry in elderly patients was found to be similar to that in younger adults.[39] The inability to perform the test could be associated with the deterioration of cognitive function, which, however, was not assessed in this study. On the other hand, it has been shown that the quality of spirometry depends mainly on the skills of the person conducting the examination.[40] In our study, spirometry was conducted by

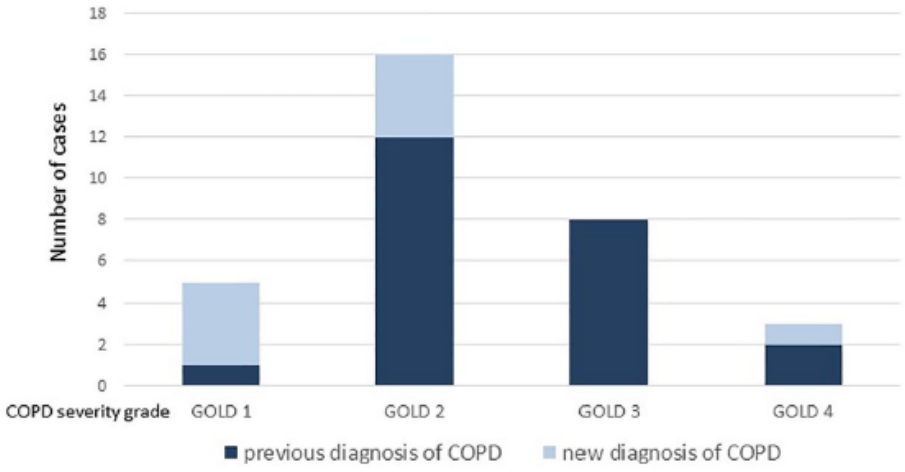

Figure 5. Number of patients with new and previous diagnosis of chronic obstructive pulmonary disease (COPD) according to the Global Initiative for Chronic Obstructive Lung Disease (GOLD) airway obstruction severity grade.

Table 3. Comparison of patients who performed technically correct spirometry and those who did not.

	Patients who performed technically correct spirometry *n* = 94	Patients who did not perform technically correct spirometry *n* = 22	*p*
Age, years	65 (59–71)	77 (67–83)	<0.001
Male gender	64 (67%)	15 (71%)	0.80
BMI, kg/m^2	27.0 (24.3–31.2)	27.7 (24.0–30.5)	0.94
Current smokers	29 (31%)	6 (29%)	1.00
Pack-years	30 (20–40)	30 (20–52.5)	0.79
Years free from smoking	12 (3–25)	15 (7–30)	0.22
Previous diagnosis of an obstructive lung disease	34 (36%)	6 (27%)	0.47
Spirometry in the past	74 (78%)	13 (62%)	0.16
Months since the last spirometry	3.5 (0–48)	36 (24–84)	0.04
Performance status according to the WHO	0 (0–1)	1 (0–1)	0.13

Data are presented as median (interquartile range) or *n* (%).
BMI, body mass index; WHO, World Health Organization.

trained medical students with little experience and this could have impacted the poor quality of some examinations. It has been shown that repeating spirometry by the person conducting the examination resulted in improvement of the quality of spirometry.[41] However, the fact that medical students obtained 81% of spirometry examinations of an adequate quality suggests that portable spirometers can be successfully used by operators with very limited experience and we believe that the device should be considered for the outpatient setting to improve detection of COPD. Moreover, we believe that the standardization of COPD screening during medical students' education may increase the early detection of COPD patients.

We are aware of several limitations in our study. The study group was relatively small; however, it must be emphasized that all patients admitted to the two departments during the study period were included in the analysis and the number of participants was based on the sample size estimation. The study was conducted only in the pulmonary and cardiology departments. The choice of the departments, however, was based on the fact that cigarette smoking is a major risk factor for respiratory and cardiovascular diseases and we aimed to compare the prevalence of undiagnosed COPD in these two departments. Furthermore, in this study, we did not compare the effect of portable spirometry on COPD detection with standard laboratory spirometry. However, it must be emphasized that the device we used was validated,[18] whereas the access to laboratory spirometry can be limited and our target to examine all eligible patients would not be met. We are aware that some of the patients, especially those with airway diseases, for example, asthma, might have suffered from an exacerbation. Therefore, lung function of these patients at the time of spirometry could be deteriorated and could potentially cause COPD overdiagnosis. Moreover, in some patients taking inhaled medication, we did not perform pre-bronchodilator spirometry and, therefore, we could not assess whether these patients had pre-bronchodilator obstruction and whether they were at risk of developing COPD. Also, we did not perform any additional investigations, for example, chest computed tomography scan, exercise tests to assess whether patients with newly diagnosed COPD presented with signs of early disease. Finally, we have no information on the reasons for refusal to participate in the study.

In conclusion, COPD detection strategy with the use of a portable spirometer is feasible in

the inpatient setting and should be also considered in the outpatient setting as it allows to detect patients with COPD under- or overdiagnosis. Patients with newly diagnosed COPD have mainly mild-to-moderate airway obstruction. However, a significant proportion of patients with COPD risk factors were unwilling to perform spirometry.

Author contributions

KG and PK conceived the concept of the study. KM, PJ, LK, GO and RK contributed to the design of the research. MK created the electronic questionnaire and integrated the collected data. OZ, MZ, KW, US performed spirometry examinations and collected the data. KM, PK, PJ and KG analyzed the data. KM and KG prepared the first draft of the manuscript. All authors edited and approved the final version of the manuscript.

Conflict of interest statement

KM, PJ, MK, OZ, MZ, KW, US, GO declare no conflict of interest. PK reports personal fees from Polpharma and Chiesi outside the submitted work. LK is the inventor, founder and shareholder of the AioCare portable spirometry system. RK reports fees for lectures and travel expenses from Boehringer Ingelheim, Chiesi, AstraZeneca and Polpharma, outside the submitted work. KG reports fees for lectures and travel expenses from Boehringer Ingelheim, Chiesi, AstraZeneca, Polpharma and Roche, outside the submitted work. The authors alone are responsible for the content and writing of the paper.

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Original Research

The use of a mobile spirometry with a feedback quality assessment in primary care setting – A nationwide cross-sectional feasibility study

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ABSTRACT

Objectives: Mobile phone-linked portable spirometers are light-weight, easy to use and low cost, with new software to facilitate data collection. In this study we investigated the feasibility of the AioCare® mobile spirometry in primary care.

Methods: In this nationwide, cross-sectional study, AioCare® spirometers (HealthUp, Poland) were distributed among primary healthcare centres across Poland. Operators (primary care professionals) received a 2-h training session, after which spirometry was performed in patients attending routine visits with respiratory symptoms or risk factors for obstructive airway diseases. Spirometry was considered technically correct when at least three manoeuvres met ERS/ATS acceptability and repeatability criteria. The most common spirometry errors were assessed and stepwise logistic regression was applied to identify factors associated with technically correct spirometry. Airway obstruction was defined as FEV_1/FVC below the lower limit of normal. A restrictive pattern was defined as FVC below the lower limit of normal.

Results: Between 1 September 2018 and 1 September 2019, 10,936 spirometry examinations were performed in 9855 patients by 673 operators. 5347 (49%) spirometry examinations met both acceptability and repeatability criteria. The most common error was plateau error (17.7%). Operator age >40 years (OR 1.49, 95% CI 1.35–1.64) and repetition of the examination at the same visit (OR 1.90, 95% CI 1.66–2.16) increased the likelihood of a technically correct examination. Airway obstruction was found in 17% of correctly performed spirometry examinations.

Conclusions: Our nationwide study suggests that use of the AioCare® mobile spirometer in primary care could be feasible. More intensive and continual training should be implemented to improve the quality of spirometry examinations.

1. Introduction

The role of spirometry in diagnosing and monitoring chronic obstructive airway diseases is well established. Demonstration of irreversible airway obstruction is crucial for the diagnosis of chronic obstructive pulmonary disease (COPD), which is the third leading cause of death worldwide according to WHO [1]. It is estimated that up to 67–81% [2–4] of patients with COPD remain undiagnosed. This is due to poor awareness of the condition [5–7], under-recognition of early symptoms among the general public [8] and poor access to spirometry, especially in rural areas [9]. Spirometry may also be useful in asthma diagnosis, as variable airway obstruction in spirometry is a key feature of the disease [10]. Diagnosis of asthma based on clinical symptoms alone can drive underdiagnosis or overdiagnosis, leading to delays in correct diagnosis and ineffective treatment [11,12]. Moreover, spirometry can be used to predict the risk of asthma exacerbation [13].

Abbreviations: AUC, area under the curve; ATS, American Thoracic Society; BEV, back extrapolated volume; BMI, body-mass index; CI, confidence interval; COPD, chronic obstructive pulmonary disease; ERS, European Respiratory Society; FEV1, forced expiratory volume in 1 s; FET, forced expiratory time; FVC, forced vital capacity; GP, general practitioner; IQR, interquartile range; PEF, peak expiratory flow; ROC, receiver operating characteristic; OR, odds ratio; SD, standard deviation.

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However, even when spirometry is available in primary care, clinicians frequently miss opportunities to perform it [14]. This could be due to a shortage of time, a lack of adequate training, technical problems (i.e. lack of a regularly serviced and calibrated spirometer) and reluctance to perform a test that does not fulfil the American Thoracic Society/European Respiratory Society (ATS/ERS) standardisation criteria [15].

Rapid technical progress in the 21st century has enabled the development of portable diagnostic tools, which are lightweight, easy to use and low cost. Mobile phone-linked spirometers can be used almost anywhere - at small primary healthcare centres or even at the patient's home. Improved access to these tools could lead to earlier diagnosis of COPD and asthma, resulting in earlier therapeutic intervention and suppression of disease progression [16]. Early detection and treatment can decrease the number of disease exacerbations, which has a positive medical and economic impact. New software on the devices facilitates data collection from every test and allows disease progression to be monitored.

A new AioCare® portable spirometer was reported to be effective for home self-monitoring in patients with asthma [17]. Up to 96% of participants used the device correctly (i.e. in line with the ATS/ERS acceptability and repeatability criteria) at least once. Our recent study showed that the AioCare® mobile spirometry system can also be used at the bedside to detect airway obstruction in hospitalised patients without the need to transport them to the lung function laboratory [18]. The device measures all commonly used spirometry parameters including forced vital capacity (FVC), forced expiratory volume in 1 s (FEV_1) and peak expiratory flow (PEF). The spirometer communicates wirelessly with the mobile device application via Bluetooth. Here we present complete results of the abovementioned study, which aimed to: 1) assess the feasibility of use of the AioCare® mobile spirometry system in primary care on a national scale; 2) evaluate the acceptability of the performed tests and identify the most common errors; 3) evaluate factors associated with technically correct spirometry examinations; and 4) assess the prevalence of airway obstruction in patients undergoing spirometry in primary care.

2. Materials and methods

2.1. Overall study design

This nationwide, cross-sectional, observational study was conducted in the primary healthcare setting in Poland between 1 September 2018 and 1 September 2019. Mobile spirometers were distributed among primary health centres across Poland that did not have a lung function laboratory and agreed to take part in the project. Devices were distributed with respect to population density (one spirometer for every 100,000 citizens) among the primary healthcare centres that were the first to respond and agree to collaborate. Spirometers were used by healthcare professionals in patients attending routine visits. General practitioners (GPs) were instructed to order spirometry according to the Recommendations of the Polish Society of Lung Diseases [19]. The study was approved by the Institutional Review Board of the Medical University of Warsaw, Poland (AKBE/159/2020).

2.2. Equipment and usage

A total of 382 mobile phone-linked spirometers (AioCare®, Health Up, Poland) (Fig. S1) were distributed throughout Poland (Fig. S2). Spirometry was performed by a specially trained nurse, technician or GP. A 2-h training session was held by representatives of the company that distributed the spirometers. All operators were trained not only in conducting spirometry examinations according to the ATS/ERS criteria, but also in the practical application of the mobile spirometer and the connected mobile device (smartphone or tablet). If a manoeuvre was not in line with ATS/ERS spirometry quality criteria [15] automatic feedback in the form of messages was provided to the operator (Fig. S1). Data were stored on the mobile device and accessed via a web-based platform.

2.3. Spirometry and definitions

A spirometry examination was deemed technically correct if at least three manoeuvres fulfilled acceptability and repeatability criteria according to the ATS/ERS recommendations [15] (Table 1). The incidence and types of the most common spirometry errors were assessed. Airway obstruction was defined as FEV_1/FVC below the lower limit of normal and the severity of airway obstruction was evaluated according to the ATS/ERS spirometry interpretative strategies [20].

2.4. Statistical analysis

Statistical analysis was performed with statistical software package R (Foundation for Statistical Computing, Vienna, Austria). The normality of data distribution was tested using a Shapiro-Wilk test. Normally distributed data are presented as mean ± standard deviation (SD), and non-normally distributed data as median (interquartile range, IQR). Categorical data are presented as n (%). The differences between variables in two different groups were evaluated using a Student's t-test (normally distributed data) or Wilcoxon rank sum test (non-normally distributed data). Categorical data were compared using a Chi-square test.

The percentage of acceptable and repeatable examinations by operator was calculated for each spirometer use. A Chi-square test was used to assess the significance of differences in the percentages of acceptable and repeatable examinations between the first and subsequent (i-th) uses of spirometry.

Stepwise logistic regression was used to identify factors with the greatest impact on achieving a technically correct spirometry examination. One-way analysis was performed for 14 variables: user's age >40 years old and gender (male/female), patient's age >40 years old, patient's gender (male/female), patient's smoking status (smoker), patient's body-mass index (BMI) > 25 kg/m^2, occurrence of back extrapolated volume (BEV) error, FET<6s, cough error and plateau error in at least one examination, number of manoeuvres in examination >4 (binary variable), patient's visit number (1 or 2) and repetition of examination during the same visit. Odds ratios (ORs) were calculated for each factor in the final model. The level of fit of the model was assessed using the v-cross validation method (v = 10) and the area under the curve (AUC) calculated from the receiver operating characteristic (ROC) curve. The Hosmer-Lemeshow test was performed to verify the fit of the model. All P-values were two-tailed and $P < 0.05$ was considered

Table 1
Spirometry errors identified and reported by the portable spirometer.

Type of error		Definition
Acceptability errors	BEV error	BEV value exceeds 5% of the FVC or 0.150 L, whichever is greater
	Plateau error	The volume–time curve shows a change in volume less than 0.025 L in the last 1 s of expiration
	FET<6 s	Duration of the forced expiratory time is less than 6 s
	Cough error	Cough recorded during the expiration manoeuvre
Repeatability errors	Number of manoeuvres	Less than three spirometry manoeuvres performed
	ΔFVC	The difference between the largest and the next largest FVC is ≥ 0.150 L (ΔFVC)
	ΔFEV_1	The difference between the largest and the next largest FEV_1 is ≥ 0.150 L (ΔFEV_1)

BEV - back extrapolated volume, FVC - forced vital capacity, FET - forced expiratory time, FEV_1 - forced expiratory volume in 1 s.

statistically significant.

3. Results

3.1. Study population

A total of 10,936 examinations were performed in 9855 patients (aged 47.8 ± 16.3 years, 5094 (52%) women) by 673 operators (aged 46.8 ± 10.3 years, 404 (60%) women). The mean BMI of patients was 26.55 ± 5.02 kg/m^2, and 2990 (30.3%) patients were current smokers. The majority (58.1%) of examinations were performed in towns with more than 100,000 inhabitants (Table 2.). Operators performed a median of 9 (IQR 3-31) spirometry examinations.

3.2. Acceptability and repeatability of spirometry

Of 10,936 spirometry examinations, 5347 (49%) met both acceptability and repeatability criteria (Fig. 1). In 12.8% of examinations less than three acceptable manoeuvres were performed. Among all spirometry manoeuvres the most common errors were plateau error (17.7%), followed by BEV error (16.5%) and FET<6s (14.3%). The percentage of acceptable and repeatable examinations by operator declined with the increasing number of performed tests, with the difference compared to the first examination reaching statistical significance from the 16th examination (Fig. 2).

3.3. Factors influencing technically correct spirometry

Examinations conducted by an operator >40 years old more often met acceptability and repeatability criteria than those performed by younger operators (≤40 years) (Fig. 3A, operator-associated factors, shown in green). Patient-dependent factors that negatively affected the OR of achieving acceptable and repeatable tests were: current smoking and male sex (Fig. 3A, patient-dependent factors, shown in orange).

Among technical factors, the occurrence of plateau error in at least one manoeuvre had the greatest effect on the acceptability and repeatability of the whole examination (OR 0.28, 95% CI 0.25–0.31) (Fig. 3A, technical factors, presented in blue). The occurrence of FET<6s or BEV error in at least one manoeuvre also significantly impacted the acceptability and repeatability of the examination. Repetition of the spirometry examination at the same visit, after rest, significantly increased the chance of meeting acceptability and repeatability criteria.

Spirometry examinations in female and non-smoking patients were more likely to be affected by BEV error (Fig. 3B). Plateau errors occurred more often in male patients and in patients >40 years old (Fig. 3C). Male and older (>40 years old) operators were more likely to avoid this error. Smoking patients, and operators and patients >40 years old, were also less likely to have an FET<6s (Fig. 3D).

3.4. Spirometry results

Mean spirometry values were: FEV_1 (% of predicted) 91.1 ± 25.3% and FVC (% of predicted) 97.1 ± 23.4%. Airway obstruction was found in 930 (17%) correctly performed spirometry examinations, with severity graded as follows: mild (46.9%), moderate (17.4%), moderately severe (12.8%), severe (15.6%) and very severe (7.3%). Airway obstruction was more prevalent in smokers than in non-smokers (23.8% vs. 14.5%, $p < 0.001$) (Table 3). In patients >40 years airway obstruction was observed in 26.8% of smokers versus 14.2% of non-smokers ($p < 0.001$). The prevalence of airway obstruction was higher among residents of towns with fewer than 40,000 inhabitants than in bigger towns (27.1% vs. 17.3%, $p < 0.01$). A restrictive pattern was observed in 918 (17%) correctly performed examinations.

4. Discussion

Our study demonstrated that portable, mobile phone-linked spirometers can be successfully applied in primary healthcare centres that do not have access to a lung function laboratory, across all regions of Poland. We found that 49% of 10,936 performed tests fulfilled acceptability and repeatability criteria. The most common spirometry errors were plateau and BEV errors, followed by FET<6s. Multiple logistic regression showed that the most important factors that positively impacted the acceptability of spirometry were the operator's age (>40 years old), and patients' smoking status (non-smoking patients) and sex (female). Airway obstruction was found in 17% of correctly performed spirometry examinations, whereas the prevalence of airway obstruction among smokers >40 years was almost 27%.

To our knowledge, this is the first study to address the usefulness of a mobile phone-linked spirometer on a national scale. The results of several studies assessing the quality of portable spirometry examinations performed in primary care have previously been reported. The portable spirometers used in these studies were not mobile phone-linked and were larger than the pocket-sized spirometer used in our study. The studies differ in population characteristics and size, and not all were nationwide. Importantly, as the ATS and ATS/ERS standardisation criteria have changed over time, there are also differences in spirometry quality criteria among studies. The percentage of tests that fulfilled all ATS/ERS criteria in these studies ranged between 3.5 and 80% [21–29] (Table 4). According to previous studies, the percentage of tests performed in the pulmonary function laboratory that fulfilled all ATS/ERS criteria was definitely higher and amounted to 90% of all tests [30].

Analysis of data from previous studies demonstrated that the following factors are the most important in ensuring good-quality spirometry examinations in primary care: 1) duration of spirometry training, 2) follow-up training and 3) instructor's experience. A 2-h training session was insufficient to achieve a high rate of quality

Table 2
Demographic data for all patients included in the study and a comparison between patients who performed acceptable and repeatable spirometry vs. those who did not.

Variable		Patients			P-value
		All (n = 9855)	Spirometry meeting acceptability and repeatability criteria (n = 4864)	Spirometry not meeting acceptability and repeatability criteria (n = 4991)	
Age (years)		47.8 ± 16.3	47.9 ± 15.7	47.8 ± 16.8	0.880
Female sex, no. (%)		5094 (52)	2649 (54)	2445 (49)	<0.001
BMI (kg/m^2)		26.5 ± 5.0	26.6 ± 5.0	26.5 ± 5.1	0.304
Smokers, no. (%)		2990 (30)	1338 (28)	1652 (33)	<0.001
Place of residence	<10 000 inhabitants, no. (%)	522 (5.3)	268 (5.5)	255 (5.1)	0.469
	10,000–39,999 inhabitants, no. (%)	1951 (19.8)	914 (18.8)	1028 (20.6)	0.076
	40,000–100,000 inhabitants, no. (%)	1656 (16.8)	851 (17.5)	809 (16.2)	0.185
	>100,000 inhabitants, no. (%)	5726 (58.1)	2831 (58.2)	2899 (58.1)	0.96

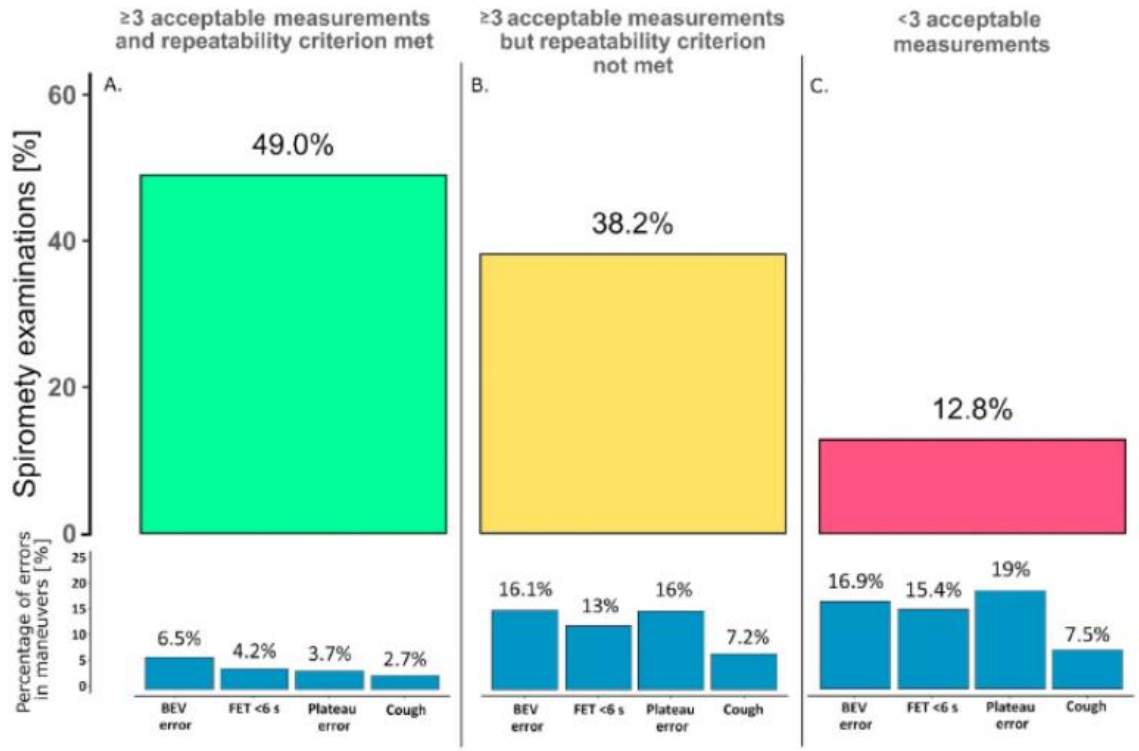

Fig. 1. Percentage of spirometry examinations that met acceptability and repeatability criteria (upper panel), including data on the distribution of different types of errors (lower panel). Upper panel: A. Acceptable spirometry examinations in which at least three acceptable spirometry manoeuvres were recorded while maintaining repeatability criteria. B. Spirometry examinations in which at least three acceptable spirometry manoeuvres were recorded without fulfilling repeatability criteria. C. Spirometry examinations in which fewer than three acceptable spirometry manoeuvres were recorded. Lower panel: percentage of different errors in all spirometry manoeuvres in patients with technically correct versus technically incorrect examinations.

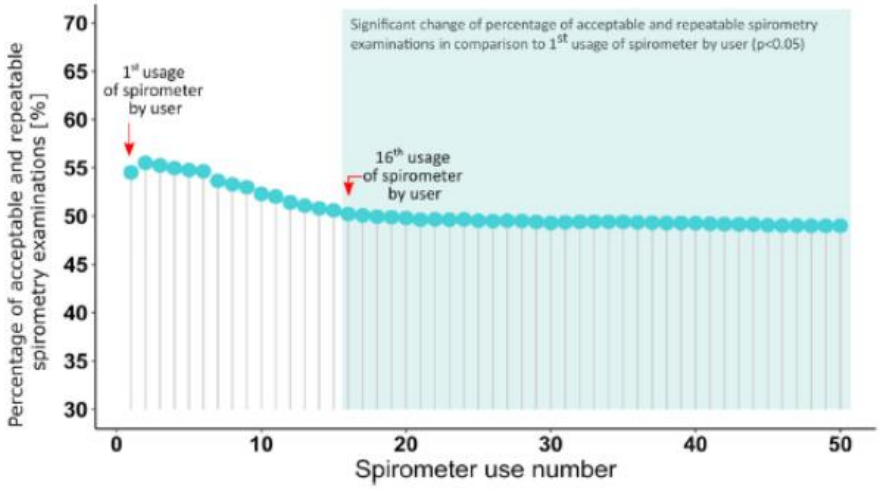

Fig. 2. Percentage of acceptable and repeatable examinations by operator. A significant change in the percentage of acceptable spirometry examinations in comparison to the 1st use of the spirometer is marked with a green box. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

spirometry examinations in several studies [21,24]. Only 13.5% [21] and <34% [24] of tests performed by family physicians who underwent a 2-h training session fulfilled all ATS/ERS acceptability and reproducibility criteria in New Zealand and Switzerland, respectively. By contrast, studies that incorporated intensive training lasting ≥3 h demonstrated that acceptable spirometry could be obtained in over half of patients [25–29]. Interestingly, we found a relatively high percentage of acceptable spirometry examinations despite a short 2-h training course. This might be associated with the technical properties of the new mobile phone-linked spirometer and its software, which serves as a guide in performing spirometry and provides real-time messages on technical errors.

Follow-up training and instructor's experience were not assessed in our project. However, in studies in which follow-up training was applied, technically correct examinations were found in most patients [25,26,28]. Similarly, all except one study [21] in which spirometry

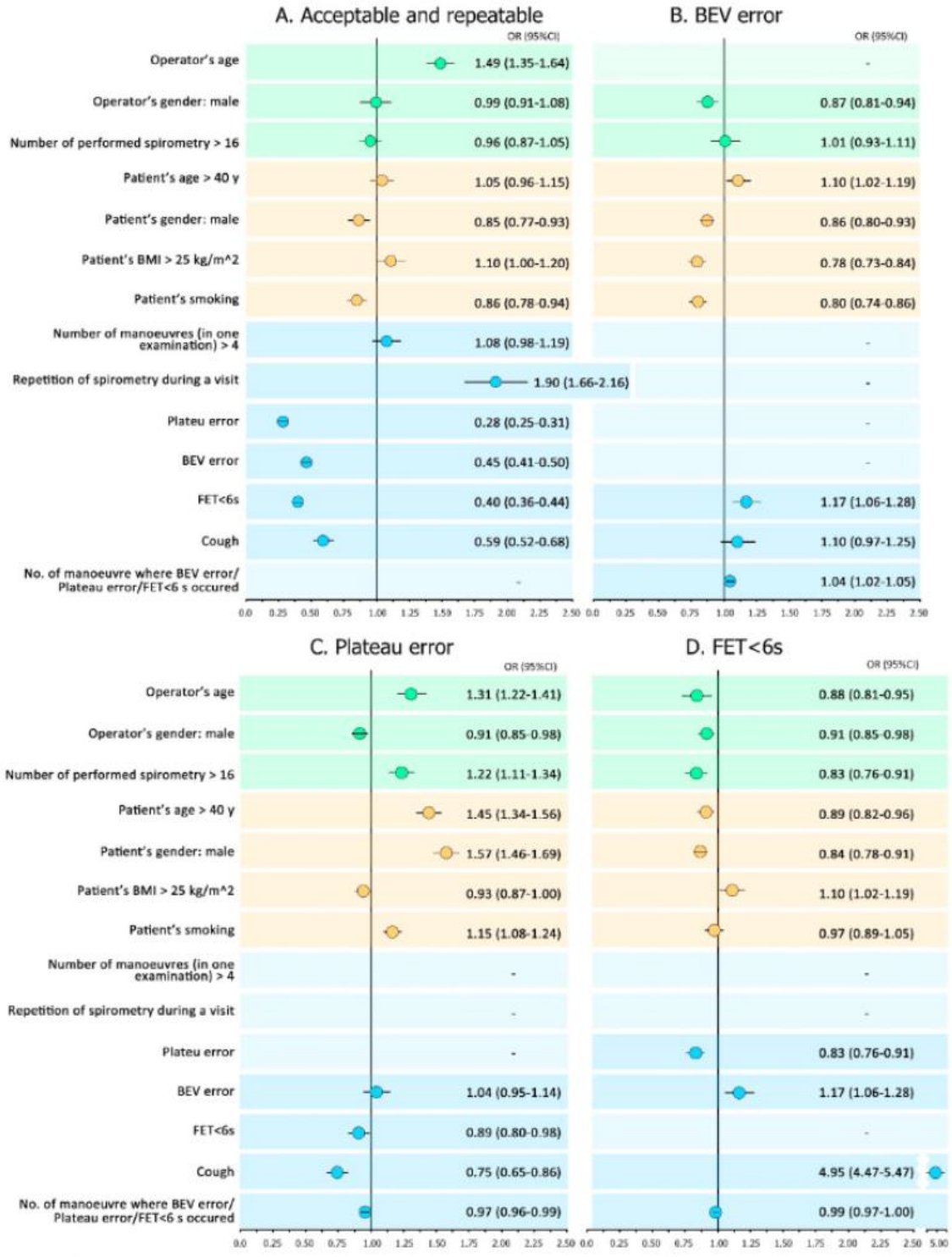

Fig. 3. Factors that affected the achievement of acceptable and repeatable spirometry examinations and different errors expressed as odds ratios (ORs) and 95% confidence intervals (95% CIs). A. Factors associated with the likelihood of obtaining acceptable spirometry examinations. B. Factors affecting the occurrence of back extrapolated volume (BEV) error. C. Factors associated with plateau error. D. Factors influencing a forced expiratory time of less than 6 s (FET<6s). In column A values of OR>1 indicate factors that increase the probability of obtaining a technically correct spirometry examination (meeting acceptability and repeatability criteria). In columns B-D, values of OR>1 indicate factors that increase the probability of individual errors. Operator-dependent factors are marked in green, patient-dependent factors are highlighted in orange and factors associated with technical acceptability criteria are marked in blue. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 3
Comparison of patients with and without airway obstruction.

Variable	Patients		P-value
	With airway obstruction (n = 814)	Without airway obstruction (n = 3955)	
Age (years)	49.2 ± 18.0	47.7 ± 15.2	0.022
Female sex, number (%)	444 (55)	2152 (54)	0.975
BMI (kg/m^2)	26.2 ± 5.1	26.7 ± 4.9	0.006
Smokers, number (%)	314 (39)	1003 (25)	<0.001
FEV_1 (% predicted)	68.5 ± 23.1	96.3 ± 22.8	<0.001
FVC (% predicted)	95.72 ± 25.3	97.4 ± 22.9	0.072
FEV_1/FVC	0.57 ± 0.12	0.796 ± 0.067	<0.001

BMI - Body-mass index, FEV_1 - forced expiratory volume in 1 s, FVC - forced vital capacity.

training courses were conducted by respiratory healthcare professionals achieved relatively high rates of technically correct examinations [21–29]. This might be because experienced clinicians can pass on their clinical knowledge from years of practice.

Surprisingly, we observed a negative correlation between the number of spirometry tests performed by operators and the quality of conducted tests. This is probably because all operators in our study received spirometry training only once, without follow-up training. A decreasing enthusiasm and excitement about the novel device may also have contributed to this relationship. Previous studies report contradictory findings regarding the relationship between the number of performed procedures and their quality. An inverse relationship was reported in two previous studies [24,29]; however, in the study by Leuppi et al. the ability to perform technically correct spirometry initially increased with the first 30 examinations [24]. No 'learning curve' was observed in other studies [22,23,31].

An inability to meet the end-of-test criteria was the most frequent reason for spirometry failure in the present study and in previous studies [23,29,32,33]. In the Polish study in patients aged >70 years a lack of

Table 4
Quality of spirometry in the primary care setting in the present and previously published studies in relation to provided spirometry training.

	Eaton 1999, New Zealand [21]		de Hei 2020*, the Netherlands [22]	Hegewald 2016, USA [23]	Leuppi 2010, Switzerland [24]	Jankowski 2020*, Poland	Burton 2004, Australia [25]	Borg 2010, Australia [26]	Yawn 2007, USA [27]	Zanconato 2005, Italy [28]	Bellia 2000, Italy [29]
	Untrained group	Trained group									
% of tests that fulfilled all ATS or ATS/ERS* criteria	3.5%	13.5% (at 12th week)	13.5%	32%	34%	49%	57% (at 8th week)	62% (at 9th month)	71%	78%	80%
Number of tests	1012		149	153	29,817	10,936	141	60	368	109	1622
Training time	None	2 h	None	None	1-2 h	2 h	3-4 h	14 h	2 days	5 h	15 h
Repetition of training	n/a	None**	n/a	n/a	None	None	Every week	yes (at 5, 7 and 9th of month)	None	yes (at week 12)	None
Instructor	n/a	Experienced respiratory scientists	n/a	n/a	Spirometry sales company rep.	rep. of the company which distributed spirometers	Experienced respiratory scientists	Experienced respiratory scientists	3rvcStudy authors	Pulmonologists	Study authors
Population	pts with clinical indications		pts >18 y.o., with clinical indication	pts >10 y.o.	Current smokers aged ≥40 years	pts with clinical indications	Respiratory pts >7 y.o.	Naive subjects	pts >7 y.o. with asthma or COPD	Children 6-15 y.o. with asthma or persistent cough	≥65 y.o.

A bold line underlines the threshold of 50% of correctly performed tests according to ATS or ATS/ERS criteria. pts - patients, y.o. - years old. *ATS/ERS criteria. **The follow-up training was organised after data collection.

plateau occurred nearly 4 times more often than in our study (60.1% vs. 17.7%) [32]. In another study performed in patients with airflow limitation, plateau error was found in 59.5% of spirometry examinations [29]. Most of the previously published papers did not assess BEV error. In some studies, a common term for both BEV error and time to PEF>0.3s was used, making it impossible to evaluate the occurrence of BEV error alone [22]. In the study by Bellia et al. BEV error was the least common error (13.4–18.2% of all tests) [29]. By contrast, although plateau error was the most common error in all performed examinations in our study, BEV error was the most frequent error among spirometry examinations that met both the acceptability and repeatability criteria or that met acceptability criteria alone.

Although the mobile phone-linked spirometer could be considered easier to use by younger adults, operators >40 years old obtained better quality examinations than their younger colleagues. This is probably because portable spirometers are easy to use regardless of age and more experienced operators are able to obtain more valuable results. Our finding that spirometry was of higher quality in female patients than in male patients has been documented in previous studies [32]. Spirometry examinations were of lower quality in current smokers than in non-smokers, which was also observed in a previous study [34], in which current smoking among women was a key determinant of test failure. However, a few studies have reported higher failure rates in non-smokers than in current smokers [30,35]. Repetition of spirometry during a single visit increased the probability of achieving a technically correct examination. This finding is consistent with the results of previous studies. Perez-Padilla et al. reported that the quality of spirometry improved after repeating the examination on either the same or a different day, supporting the need to perform multiple examinations in some patients [36].

In all technically acceptable tests, the prevalence of airway obstruction among smokers >40 years old was 26.8%. The findings of our study concur with those reported in similar studies [24,37,38].

4.1. Limitations

Our study has several limitations. The device software used at the beginning of the study was less advanced than at present, which resulted in some missing patient data (e.g. comorbidities, previous diagnosis of COPD or asthma). Furthermore, we had no information about whether spirometry tests were used before or after bronchodilator examinations, which made it impossible to use the results in the context of COPD screening. Although this might be considered an important shortcoming, the main aim of this project was to verify that the new spirometry software can be used efficiently on a national scale. Therefore, we concentrated only on the raw spirometry data. Furthermore, we did not compare the results of spirometry examinations with those of the follow-up examinations, which could provide information about the diagnostic utility of portable spirometry in primary care. Nevertheless, many of these limitations can be easily eliminated with new software that is going to be prepared based on this experience. Therefore, our report provides the incentive to introduce mobile spirometers into general practices on a broad scale and will be used to improve the quality of spirometry examinations in primary care. Moreover, we believe that these mobile devices could counteract the reduced availability of spirometry in the outpatient setting during the COVID-19 pandemic, as they have disposable filters, can be easily disinfected and connect via Bluetooth, ensuring the safety of both operators and other patients.

5. Conclusions

A portable, mobile phone-linked spirometer can be successfully implemented as an effective tool for lung function testing in the primary care setting on a national scale. Easy-to-use, operator friendly and guiding software can help to obtain a considerable percentage of technically correct spirometry examinations, even by healthcare professionals who have undergone only one short-course spirometry training session. However, more intensive and continued operator training is probably needed to achieve fully satisfactory spirometry examinations. The most common spirometry error was plateau error. Older operator age, patient's non-smoking status and female sex, as well as repeated examination during the same visit were associated with better spirometry quality. Airway obstruction is a common finding in primary care, present in almost 27% of smokers >40 years old in the study.

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CRediT authorship contribution statement

Piotr Jankowski: Formal analysis, Writing – original draft, contributed substantially to the study design, data analysis and interpretation, and the writing of the manuscript. **Katarzyna Górska:** contributed substantially to the study design, data analysis and interpretation, and the writing of the manuscript. **Katarzyna Mycroft:** Formal analysis, Writing – original draft, contributed substantially to the study design, data analysis and interpretation, and the writing of the manuscript. **Piotr Korczyński:** Formal analysis, Writing – original draft, contributed substantially to the study design, data analysis and interpretation, and the writing of the manuscript. **Mateusz Soliński:** Formal analysis, had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. **Łukasz Kołtowski:** Formal analysis, Writing – original draft, contributed substantially to the study design, data analysis and interpretation, and the writing of the manuscript. **Rafał Krenke:** Formal analysis, Writing – original draft, contributed substantially to the study design, data analysis and interpretation, and the writing of the manuscript.

Declaration of competing interest

PJ, KM and PK declare no conflict of interests. KG reports fees for lectures and travel expenses from Boehringer Ingelheim, Chiesi, AstraZeneca, Polpharma, and Roche, outside the submitted work. MS reports personal fees from HealthUp both during the conduct of the study and outside the submitted work. ŁK reports personal fees from HealthUp outside the submitted work. In addition, ŁK has a patent pending for the AioCare® spirometer and is the inventor of the AioCare® spirometry system. RK reports fees for lectures and travel expenses from Boehringer Ingelheim, Chiesi, AstraZeneca, Roche and Polpharma, outside the submitted work.

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Appendix A. Supplementary data

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8.4 Publikacja nr 4

advances in respiratory medicine

MDPI

Systematic Review

How to Enhance the Diagnosis of Early Stages of Chronic Obstructive Pulmonary Disease (COPD)? The Role of Mobile Spirometry in COPD Screening and Diagnosis—A Systematic Review

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Highlights:

What are the main findings?

- Portable spirometers are only slightly less efficient in diagnosing COPD than traditional spirometers
- The highest COPD prevalence was demonstrated when well-selected high-risk patients were tested

What is the implication of the main finding?

- Portable spirometers are useful in the early diagnosis of COPD
- Portable spirometers enable bedside COPD diagnosis

Abstract: COPD is the third leading cause of death worldwide. Its diagnosis can be made with spirometry, which is underused due to its limited accessibility. Portable spirometry holds promise for enhancing the efficacy of COPD diagnoses. The study aimed to estimate COPD prevalence diagnosed with a portable spirometer in high-risk patients and compare it with COPD prevalence based on data from conventional, on-site spirometry. We also evaluated the strategy of a proactive approach to identify COPD in high-risk individuals. We conducted a systematic review of original studies on COPD targeted screening and diagnosis with portable and conventional spirometers selected from 8496 publications initially found in three databases: Cochrane, PubMed, and Embase. The inclusion criteria were met by 28 studies. COPD prevalence evaluated with the use of portable spirometers reached 20.27% and was lower compared to that estimated with the use of conventional spirometers (24.67%). In 11 included studies, postbronchodilator tests were performed with portable spirometers, which enabled a bedside COPD diagnosis. Portable spirometers can be successfully used in COPD targeted screening and diagnosis and thus enhance the detection of COPD at early stages.

Keywords: COPD; spirometry; portable spirometer

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1. Introduction

Chronic obstructive pulmonary disease (COPD) is highly prevalent; it is estimated that its affects around 7.6–10.3% of the worldwide population aged 30–79 years [1]. Although in early stages, the disease is mildly symptomatic [2] and approximately 80% of the affected subjects are unaware of its presence [3], COPD is a progressive and fatal disease. In 2019, COPD was the third leading cause of death worldwide [4].

A COPD diagnosis can be made in subjects with a significant exposure to risk factors (e.g., cigarette smoke) when fixed airway obstruction in spirometry is found [5]. Although spirometry is easy and inexpensive, it is largely underused [6]. This is probably due to the limited accessibility to office spirometry, lack of properly trained personnel, and physicians' fear of potential misinterpretation. Moreover, patients with COPD are a psychologically difficult population, reluctant to undergo appropriate diagnostics. This group is often

unwilling to seek medical assistance; difficulty in traveling to health care centers may also be a contributing factor [7]. On the other hand, the timely diagnosis and treatment of COPD are crucial in slowing down the progression of the disease, given that the decline in the forced expiratory volume in the first second (FEV_1) tends to be more significant in the initial stages of the condition. [8]. Exacerbations of COPD can also manifest in its early stages, potentially resulting in hospitalization and increasing the risk of mortality [9]. Consequently, identifying and managing individuals with COPD, particularly in its early phases, can result in enhancements to their overall health conditions [10].

There are many different spirometers, ranging from advanced conventional devices used in well-equipped pulmonary function test laboratories in tertiary hospitals, to small-size spirometers used in primary care settings (most often desktop spirometers). For several years, portable easy-to-use spirometers have been available on the market. Importantly, the accuracy of such devices has been proven to be comparable to that of spirometers used in pulmonary function testing laboratories [11].

Small spirometers that can be connected to a smartphone via Bluetooth seem to bring significant technological progress to modern pulmonology. Nowadays, portable spirometers are used at patients' homes to assess the control of asthma [12]. Portable spirometry can also be performed and supervised remotely in cystic fibrosis patients to monitor disease progression [13,14]. Other examples of the use of small spirometers also include spirometry at home to assess the efficacy of pirfenidone in patients with lung interstitial diseases [15] or the early detection of pulmonary complications in an allogeneic hematopoietic cell transplant recipients [16].

Portable spirometers can also be used in COPD diagnosis and follow-up. Previous articles that have examined the use of portable spirometers in patients with COPD focused mainly on the reliability of baseline spirometry and their use in population screening and targeted screening actions [17]. Some publications also assessed the possibility of using devices other than spirometers in COPD screening, e.g., the COPD-6 device [18] or a handheld expiratory flow meter [19].

Many past studies did not specify the tested populations, failing to differentiate among screening in asymptomatic patients at risk, true population health screening, and testing symptomatic individuals (diagnostic spirometry). In our work, we aimed to distinguish studies that focused on specific subpopulations of patients. Future publications concerning the effectiveness of portable spirometry should strive to distinguish the device's effectiveness in screening actions in the general population, as well as in diagnostic spirometry.

There is only scarce data on the true diagnostic capabilities of portable spirometers. Thus, the authors decided to conduct a systematic review of the available articles that concerned COPD diagnosis in patients at risk using various types of spirometers, including portable devices.

The specific objectives of this systematic review were:

1. To estimate COPD prevalence diagnosed with a portable spirometer in high-risk patients and compare it with the disease prevalence reported in the studies that used conventional spirometers;
2. To evaluate strategies of proactive approaches to identify COPD in high-risk individuals.

2. Materials and Methods

2.1. General Study Design

This was a systematic review of previously published original papers. The authors followed the recommendations of the PRISMA 2020 [20]. The protocol of this systematic review was registered in the PROSPERO registry (ID CRD42022337420).

2.2. Definitions

2.2.1. Types of Screening

In line with the recommendations of the U.S. Preventive Services Task Force, the routine screening of asymptomatic patients for COPD is not advised due to its ineffectiveness.

The diagnosis of COPD is instead recommended for individuals presenting respiratory symptoms, such as chronic cough, sputum production, difficulty breathing, or wheezing [21]. This type of COPD testing, focused on symptomatic individuals, is referred to as diagnostic spirometry.

Only a subset of the publications included in our systematic review met the criteria for diagnostic spirometry. However, we limited our focus to publications concerning individuals at an increased risk of COPD, with a minimum cumulative cigarette smoke exposure of 10 pack-years. Consequently, all included papers adhere to the definition of targeted screening as adopted by the UK National Screening Committee [22].

2.2.2. Types of Spirometers

Spirometers differ in size, ranging from compact devices that fit in a pocket and can be easily connected to a smartphone (hand-held spirometers), to slightly larger models suitable for placement on a desk (desktop spirometers), and and culminating in spirometers utilized within pulmonary function test laboratories (conventional spirometers). However, in our paperwork we decided to apply a purely practical approach, classifying spirometers into 2 groups:

1. Portable spirometers—small/pocket devices, easily moved from room to room (also desktop spirometers), often connected to a smartphone, which can measure basic spirometric parameters (at least FEV_1, FVC, and FEV_1/FVC).
2. Conventional spirometers: a certified spirometer used in the pulmonary test laboratory that cannot be moved easily, usually used in the same office.

We believe that this this categorization enables the assessment of the feasibility of spirometers that can be used in active COPD diagnosis even outside healthcare facilities, as part of various spirometry initiatives.

2.3. Search Strategy

A systematic search of the literature was carried out to identify relevant, English language studies, published between 1958 and 7 December 2021. Pubmed, the Cochrane Central Register of Controlled Trials, and Embase databases were used as the source of the data. The keywords for our search included a combination of terms related to COPD ("obstructive pulmonary disease" [tiab] OR "obstructive lung disease" [tiab] OR "obstructive airway disease" [tiab] OR "airway or airflow obstruction" [tiab] OR "chronic bronchitis and pulmonary emphysema"), spirometry and screening (diagnosis [tiab] OR "case finding" [tiab] OR prevalence [tiab] OR "early detection" [tiab]) (Table S1). The wide search, including terms related not only to portable spirometers but to all of its types (including conventional spirometers), was performed in order to not miss any important study concerning targeted screening actions performed to detect COPD.

The reference lists of the selected articles were subjected to a hand search to identify additional articles.

2.4. Selection Criteria

Studies were eligible for inclusion if they met the PICOS criteria, namely the following:

1. Population: subjects aged $\geq$ 35 years with a history of smoking ($\geq$10 pack-years).
2. Intervention: baseline spirometry performed with a portable device/conventional spirometer and a postbronchodilator test performed to confirm the COPD diagnosis (defined as $FEV_1/FVC < 0.7$ [5] or <LLN [23]).
3. Comparison: n/a.
4. Outcome: prevalence of irreversible airway obstruction (i.e., airflow limitation not reversible after inhaled bronchodilator).
5. Study design: cross-sectional/cohort studies.

We excluded studies published in languages other than English, as well as non-original papers.

2.5. Study Selection

Relevant articles to be included in this review were identified and assessed independently by K.M. and P.J. All studies from the databases were screened by title and abstract. Irrelevant or duplicate articles were excluded, and all remaining articles were subjected to full-text screening. Differences between the reviewers in the inclusion of articles were resolved through discussion and consensus between all authors. Using the Joanna Briggs Institute critical appraisal tools for conducting JBI systematic reviews, studies underwent an evaluation to assess their methodological quality [24] (Table S2). Each study was assigned a score of either present (1) or absent (0), which was then aggregated to determine a final value. A significant risk of bias was identified when the percentage of positive responses was 49% or less. A moderate risk of bias was indicated when the percentage ranged between 50% and 69%. Conversely, a low risk of bias was detected when the percentage of positive responses exceeded 70%. Both reviewers (K.M. and P.J.) achieved consensus on the quality assessment outcomes through discussion. Figure 1 depicts the process of screening and including articles and lists the reasons for excluding articles. In the case of articles including no information about the spirometer's type, an email was sent to the corresponding author with request to deliver the needed data. When no answer was received an article was excluded.

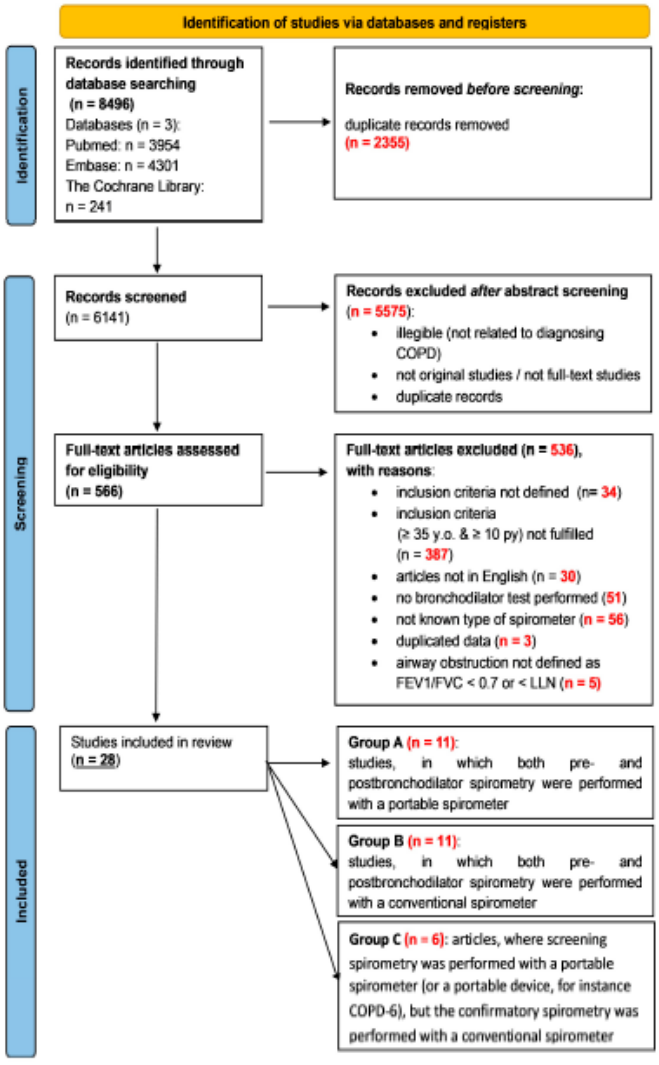

Figure 1. The process of screening and including articles for this systematic review; py—pack-years.

During the study selection, we observed that screening strategies could be categorized into three groups based on the type of spirometer employed (see: Data extraction). Studies included in the review, depending on the adopted strategy, are listed in Tables 1–3.

The whole process is pictured in the PRISMA flow diagram (Figure 1).

Table 1. Studies conducted with a portable spirometer.

	First Author, Year of Publication	Country/ Region	Spirometer (Manufacturer)	Participants: n (%F)	Population (Prevalence of Comorbidities: DM%; HTN%)	Inclusion Criteria: Age; PY	Age, Years (Mean: SD)	PY (Mean: SD)	Setting	FEV_1/FVC Cut off Value for Airway Obstruction	% Newly Diagnosed COPD
1	Kotz, 2008 [25]	The Netherlands	Vitalograph 2120 (Vitalograph)	676 (41.3)	GP (ND)	40–70; ≥10	52.3 (7.3)	40.4 (19.3)	ND	0.7	41.1 [1]
2	Kart, 2013 [26]	Turkey	MIR A23 (MIR)	648 (61.9)	GP (ND)	>40; ≥10	48.3 (9)	ND	HS	0.7	17
3	Al Omari, 2014 [27]	Jordan	FlowscreenCT (eResearch Technology GmbH)	512 (0)	GP (ND)	>35; >10	48.3 (10.2)	42.7 (10–200) [3]	PC	0.7	6.6
4	Cai, 2015 [28]	China	Portable	307 (8.8)	GP (ND)	>50; >20	61 (7)	37 (15)	HS	0.7	38.8 [4]
5	Frannsen, 2016 [29]	Europe	EasyOne (Medical Technologies)	2730 (14.1)	IHD (25.3; 89.1)	≥40; ≥10	ND	ND	OSC	0.7	21.2
6	Represas-Represas, 2016 [30]	Spain	Datospir 120 (Sibelmed)	362 (38.1)	GP (ND)	>40; ≥10	55.4 (9.9)	35 (19.8)	PC/ PHA/ HS	0.7	31.5 [1]
7	Al Lami, 2017 [31]	Iraq	Discovery 2 (Futuremed)	215 (ND)	GP (18.8; 37.8)	>35; >20	ND	ND	PC	0.7	16.7[1]
8	Mamary, 2018 [32]	USA	EasyOne (Medical Technologies)	8872 (45.6)	GP (ND)	45–80; ≥10	59.9 (9.1)	44.5 (25.1)	CSC	0.7	16.3
9	Mycroft, 2020 [33]	Poland	AioCare (HealthUp)	118 (33.1)	HO (22;92)	≥40; ≥10	66 (59–73) [2]	30 (20–40) [2]	HS	LLN	7.6
10	Tran, 2020 [34]	Australia	MicroLab	33 (42)	HO (21;58)	>40; >10	69.3 (6.8)	48.7 (24.2)	HS	0.7	27.2 [1]
11	Jaen-Moreno, 2021 [35]	Spain	DatoSpir Touch Easy D (Sibelmed)	113 (ND)	MENT (13.4; 8.5)	40–70; ≥10	49.4 (6)	36.6 (18.1)	HS	0.7	23.9

CSC: clinical study center; DM: diabetes mellitus; GP: general population; HO: hospitalized; HS: hospital; HTN: hypertension; IHD: patients with ischemic heart disease; MENT: patients with severe mental illness; ND: no data available; OSC: outpatient specialty clinic; PC: primary care; PHA: pharmacy; PY: pack-years. [1] Studies in which respiratory symptoms were one of the subject's inclusion criteria; [2] data are presented as the median (interquartile range) or [3] range; [4] not known if patients with previously diagnosed COPD were excluded.

Table 2. COPD diagnostic studies performed with conventional spirometers.

	First Author, Year of Publication	Country/ Region	Spirometer (Manufacturer)	Participants: n (%F)	Population (Prevalence of Comorbidities: DM%; HTN%)	Inclusion Criteria: Age; PY	Age, Years (Mean: SD)	PY (Mean: (SD)	Setting	FEV_1/FVC Cut off Value for Airway Obstruction	% Newly Diagnosed COPD
1	Stav, 2007 [36]	Israel	Jaeger, CareFusion	1058 (25)	GP (ND)	45–75; ≥20	ND	ND	ND	0.7	17.2
2	Yawn, 2009 [37]	USA	Biomedical Systems Corporation	1201 (ND)	GP (ND;41%)	>40; ≥10	ND	ND	PC	≤0.7	26 [1]
3	Makinson, 2014 [38]	France	laboratory spirometers	338 (17)	HIV (ND)	≥40; ≥20	50 (46–53) [2]	30 (25–38) [2]	HS	0.7	18.9
4	Lee, 2015 [39]	Canada	Winspiro (MIR)	11 (ND)	GP (22.9;51.2)	≥75; ≥20	ND	ND	PC	0.7	36.4 [1]
5	Sansores, 2015 [40]	Mexico	Sensormedics	2324 (50.1)	GP (ND)	>40; ≥10	51.9 (10.5)	19.50 (10–33) [2]	PC	LLN	11.4 [1]
6	Sansores, 2015 [40]	Mexico	Sensormedics	637 (52)	GP (ND)	>40; ≥10	49.63 (11.3)	17.00 (8–28) [2]	PC	LLN	5.7
7	Labor, 2016 [41]	Croatia	Jaeger, CareFusion	227 (50.6)	GP (ND)	40–65; ≥20	52.5 (6.8)	37.9 (17.4)	PC	0.7	18.9
8	Su, 2019 [42]	Taiwan	Spiro Medics system 2130 (SensorMedics)	301 (4.7)	PULMO (ND)	≥40; ≥20	70.7 (13.2)	45.4 (25.0)	HS	0.7	47.9 [1]
9	Tran, 2020 [34]	Australia	HypAir Compact+ (Medisoft)	33 (42.4)	HO (21;58)	>40; >10	69.3 (6.8)	48.7 (24.2)	HS	0.7	27.2 [1]
10	Hwang, 2021 [43]	South Korea	conventional spirometer	290 (ND)	GP (ND)	>40; >10	63.1 (11.0)	31.6 (20.0)	HS	0.7	47.9 [1]
11	Yangui, 2021 [44]	Tunisia	COSMED Quark Series	122 (1.7)	IHD (55.7;46.7)	>40; ≥10	59.3 (9.5)	52.3 (28.3)	HS	0.7	13.9

DM: diabetes mellitus; GP: general population; HIV: HIV-infected patients; HS: hospital; HTN: hypertension; IHD: patients with ischemic heart disease; LLN, lower limit of normal; ND: no data available; PC: primary care; PULMO, patients from pulmonary outpatient clinics; PY, pack-years. [1] Studies in which respiratory symptoms were one of the subject's inclusion criteria; [2] data are presented as the median (interquartile range).

Table 3. COPD diagnostic studies: baseline spirometry performed with a portable spirometer or COPD-6 device; confirmatory with a conventional spirometer.

	First Author, Year of Publication	Country/ Region	Device (Manufacturer) [3]	Participants: n (%F)	Population (Prevalence of Comorbidities: DM%; HTN%)	Inclusion Criteria: Age, PY	PY (Mean: (SD)	Setting	FEV_1/FVC Cut off Value for Airway Obstruction	% Newly Diagnosed COPD
1	Thorn, 2012 [45]	Sweden	COPD-6	305 (56.7)	GP (ND)	45–85; ≥15	30.3 (11.5)	PC	0.7	25.2 [2]
2	Ching, 2014 [46]	Malaysia	COPD-6	416 (0.2)	GP (ND; 46.2)	≥40; ≥10	20.4 (18)	PC	0.75/0/7 [4]	1.9
3	Kim, 2016 [47]	South Korea	COPD-6	190 (ND)	GP (17.8; 40)	>40; >10	28.5 (14.6)	PC	0.77/0.7 [4]	23.7 [1]
4	Korczyński, 2017 [48]	Poland	MicroLab 3500, CareFusion	178 (36.5)	GP (ND; 67)	>40; >10	28	RS	0.7	2.8
5	Liang, 2018 [49]	Australia	COPD-6	1045 (ND)	GP (ND)	≥40; ≥10	ND	PC	0.75/0.7 [4]	17.6
6	Lin, 2021 [50]	Taiwan	Spirobank Smart	370 (5.7)	GP (ND)	≥40; ≥10	42.6 (28.3)	PC	0.7	27.8 [1]

DM: diabetes mellitus; GP: general population; HTN: hypertension; ND: no data available; PC: primary care; PY: pack-years; RS: railway station. [1] Studies in which respiratory symptoms were one of the subject's inclusion criteria; [2] not known if patients with previously diagnosed COPD were excluded; [3] postbronchodilator spirometry was performed with a conventional spirometer; [4] the first value shows the FEV_1/FEV_6 cut-off value for airway obstruction for the COPD-6 device, and the second value shows the FEV_1/FVC cut-off value for airway obstruction for the conventional spirometer.

2.6. Data Extraction

The following information was extracted from the included studies by two authors: (1) authors and year of publication; (2) country/region where the study was conducted; (3) spirometer type (portable or conventional); (4) number of participants; (5) inclusion criteria (6) baseline participants' characteristics; (7) results, % of newly detected COPD cases (Tables 1–3).

In total, 28 studies were taken into consideration. The selected articles were classified into 3 categories depending on the type of the spirometer used to screen for and to diagnose COPD (Figure 2):

1. Studies in which both pre- and post-bronchodilator spirometry were performed with a portable spirometer (Group A, Table 1);
2. Studies in which both pre- and post-bronchodilator spirometry were performed with a conventional spirometer (Group B, Table 2);
3. Articles in which baseline spirometry was performed with a portable spirometer (or a portable device, for instance COPD-6), but the confirmatory spirometry was performed with a conventional spirometer (Group C, Table 3).

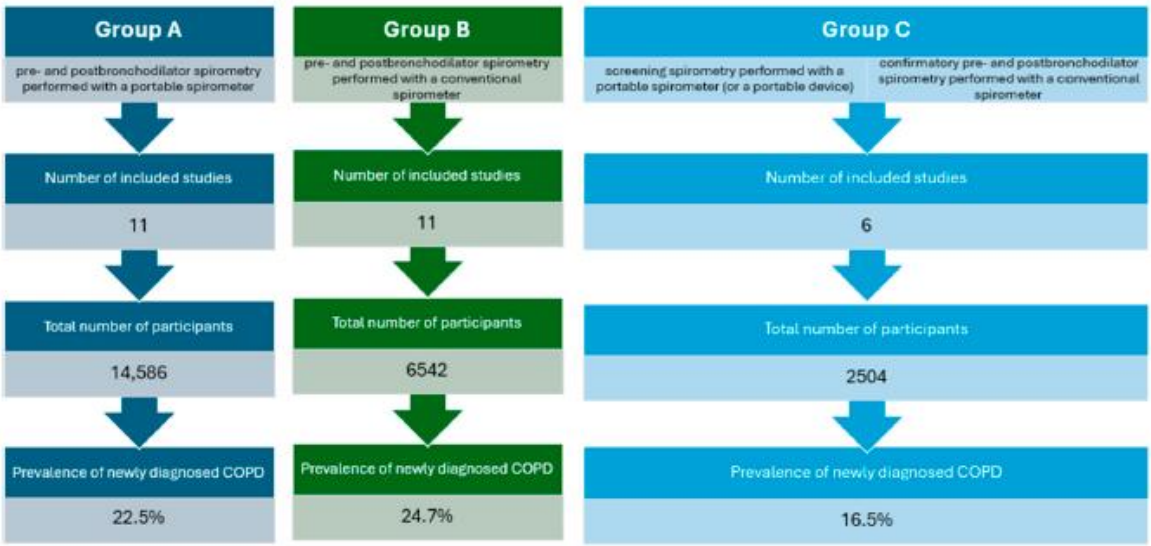

Figure 2. Comparison of distinguished publication groups.

In one study [34], both portable and conventional spirometers were used to screen for COPD, and hence, we included the data from this study in two groups: A and B. In another paper [40], two different subgroups of patients were included (with and without respiratory symptoms), so we analyzed these subgroups separately.

2.7. Statistical Analysis

Statistical analysis was performed using MedCalc® Statistical Software version 20.218 (MedCalc Software Ltd., Ostend, Belgium; https://www.medcalc.org; 5 Januray 2024). A p-value of <0.05 was considered statistically significant. The primary outcome was the diagnostic yield with the 95% confidence interval (CI), which was calculated by dividing the number of successful diagnoses by the percentage of newly diagnosed COPD cases. Study heterogeneity was assessed using the Cochran Q test (χ^2 test) and quantified based on the I^2 index [51]. Statistical heterogeneity was indicated in cases of $p < 0.01$ with a χ^2 test, and an I^2 index value of >50% was considered significant heterogeneity [52]. Random-effect models with the inverse variance method were applied to reflect the variability of effect sizes among included studies with diversity in adjunctive modalities [53]. Publication bias was evaluated using funnel plot asymmetry based on both the Egger's and Begg tests.

3. Results

3.1. Overview of Included Publications

The 28 publications included in our systematic review exhibited significant heterogeneity (Tables 1–3). Beyond the three categories highlighted according to the type of spirometer used, the included publications differed in terms of patients' symptoms and the setting where the spirometry was performed.

3.1.1. Risk of Bias

The majority of publications demonstrated a low risk of bias, indicating a high percentage of positive responses to the questions in the JBI tool (Table S2). In 6 out of 28 included studies, the risk of bias was evaluated as moderate. The risk of bias reached 50% in only one of the included papers [36], where the study subjects and the setting were not described in detail, and the outcomes were not measured in a valid manner.

3.1.2. Symptomatic Patients

Out of the 28 selected publications, 12 studies focused on the diagnostic testing of COPD (Table S3). In these studies, patients with at least one respiratory symptom were eligible for spirometry. In the group of publications where respiratory symptoms were one of the inclusion criteria, there were four studies that used portable spirometers [25,30,31,34], six studies that used conventional spirometers [34,37,39,40,42,43], and two studies where the initial spirometry was performed using a portable spirometer or COPD-device and confirmed using a conventional spirometer [47,50].

In most publications, participants completed the COPD Assessment Test (CAT), the Modified Medical Research Council Dyspnea Scale (mMRC), or custom questionnaires, including, age, sex, smoking status, and the presence of respiratory symptoms, such as cough, phlegm, wheezing, and shortness of breath. In most cases, an individual was considered symptomatic if they exhibited at least one of the aforementioned symptoms. In some publications, the criterion regarding symptoms was more precise, as in the case of the paper by Yawn [37], in which patients were recruited for the study based on self-reported symptoms of chronic bronchitis, defined as the presence of a productive cough for at least three consecutive months in each of two successive years.

3.1.3. Setting

The heterogeneity of the publications included in our systematic review is also evident in the setting where COPD targeted screening was conducted. In the majority of the studies, spirometry was performed in primary care settings. For some publications, volunteers

were invited to undergo pulmonary function testing at a hospital. One described study was partially conducted at a railway station [48]. Two of the studies included by us were conducted on hospitalized patients [33,34].

3.2. Portable Spirometers

Eleven studies using portable spirometers in the COPD-targeted -screening process met the predefined criteria (Group A, Table 1) [25–35]. In all selected articles, a portable spirometer was used both for the baseline spirometry and in the postbronchodilator testing. The included studies differed in the study population's size, airway obstruction criteria, and setting. The percentage of newly found COPD cases among studies using portable spirometers ranged from 6.6% to 41%, with the proportion (random effects) of 21.5% (95% CI 16.4–27.2) (Figure 3A). There was substantial heterogeneity across studies with I2 97.3% (95%CI 96.6–98.1), $p < 0.0001$. Egger's and Begg's tests excluded publication bias with $p = 0.34$ and $p = 0.81$, respectively. Importantly, some of the selected articles included only subjects with respiratory symptoms [25,30,34]. In those studies, average COPD detection was higher (29.08%) than in the remaining studies (15.43).

The largest smoker populations were analyzed in two studies [29,32] that used the portable spirometer EasyOne (NDD Medical Technologies). The Canadian study by Mamary et al. [32] was conducted on the general smoker population ($n = 8872$) in the primary care setting and reported an incidence of newly diagnosed COPD of 16.3%; 20% of the previously undetected COPD patients had been already diagnosed with asthma. A higher COPD incidence (21.2%) was reached in the European study by Frannsen and colleagues. In this study, a pulmonary function test was performed on patients ($n = 2730$) burdened with ischemic heart disease (IHD) attending cardiology outpatient clinics. Only patients with an established IHD diagnosis were included, irrespective of their reported pulmonary symptoms.

The efficacy of spirometry perfomed with a portable device in COPD targeted screening was also confirmed in a study conducted in patients with severe mental disorders, such as schizophrenia or bipolar disease [35]. Only patients without a prior lung disease diagnosis were included. COPD was detected in almost one of four patients studied, with the vast majority (78%) presenting with moderate or severe disease stages (GOLD II and III). According to the study results, in most cases (85%), COPD was clinically indolent.

In two of the included studies, baseline spirometry was performed for hospitalized smokers at bedside [33,34]. The complete COPD diagnostic process (both pre- and postbronchodilator spirometry) proved successful without the need to transport the patients to a pulmonary test laboratory. Small spirometers (MicroLab and AioCare) were used with a COPD detection rate of 27% (patients hospitalized due to productive cough and dyspnea [25]) and 7.6% (inpatients of pulmonary and cardiology departments meeting the criteria for age and smoking history [33]). Hospitalized smokers from these studies were the oldest population tested with the use of a portable spirometer among studies included in our review, with the average patient age above 65 years.

The other spirometry targeted screening action performed in the hospital setting (however not among inpatients) was performed in Turkey [26]. Volunteers aged above 40 years with a smoking history of more than 10 pack-years who visited the hospital for any reason had spirometry performed in the hospital's garden with the use of a portable spirometer; 17% of the participants were newly diagnosed with COPD.

The highest incidence (>30% of patients) of newly diagnosed COPD was achieved in studies conducted in the primary care setting [25,28,30]. The studies by Kotz and colleagues [25] and Represas-Represas [30] enrolled only smokers with respiratory symptoms. In the study performed in China [27], older (>50 years of age) smokers with increased exposure to tobacco smoke (>20 py) were recruited, which could possibly result in a higher positive COPD prevalence (38.8%). It is also not clear whether patients with previously detected and treated COPD were excluded from the analysis.

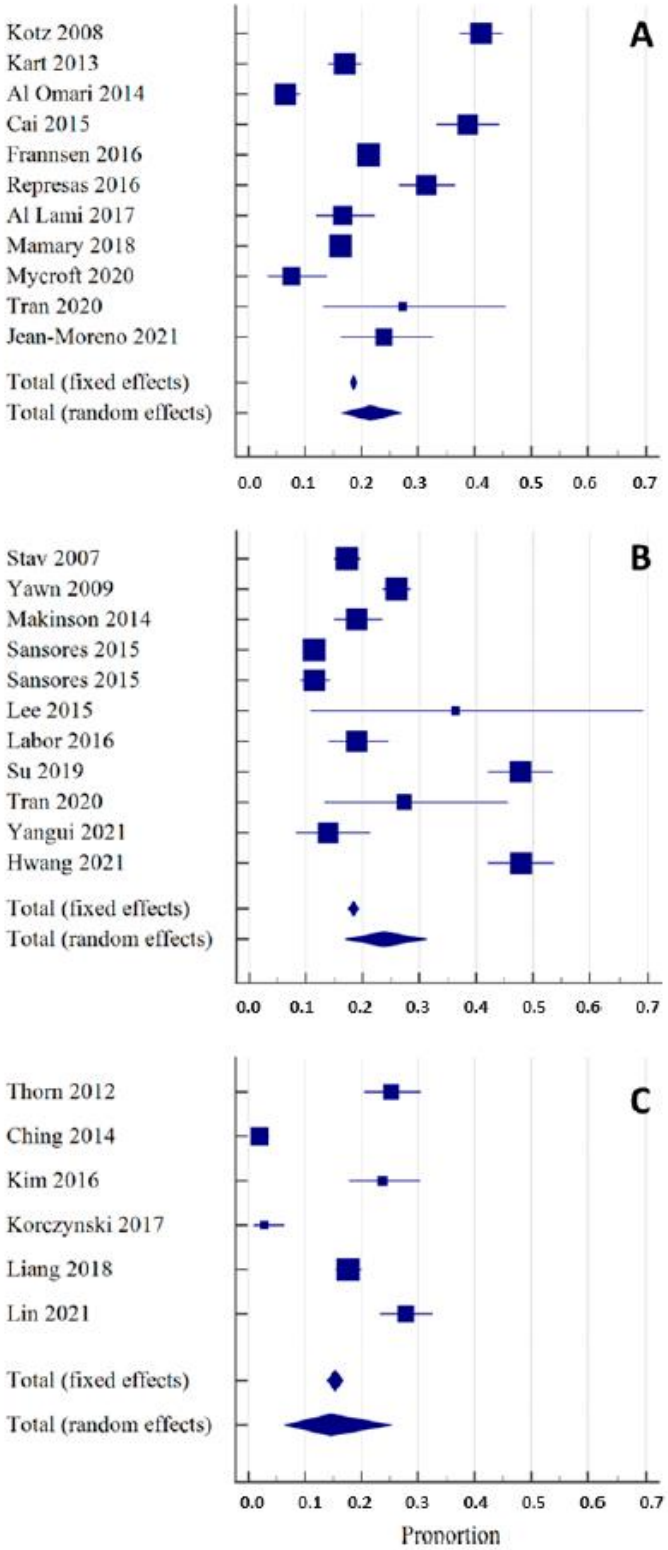

Figure 3. Overall diagnostic yield of spirometers in the detection of new COPD cases shown as the weighted summary proportion (expressed as a percentage), with their 95% CIs, found in the individual studies included in the systematic review [25–50]. The size of the square corresponds to the size of the studied population. Section (**A**): publications that used portable spirometers. Section (**B**): publications that used conventional spirometers. Section (**C**): publications that used a double-step strategy, using a portable spirometer or a COPD-6 device for baseline spirometry and a conventional spirometer for the postbronchodilator test.

The youngest smokers (of at least 35 years of age) were invited to the COPD targeted screening programs in two studies performed in Middle East countries [27,31]. Both studies were conducted in the primary care setting with the use of handheld spirometers (Discovery 2 and FlowscreenCT). In the study by Al Lami et al., spirometry was performed only among smokers with respiratory symptoms, which can explain the higher prevalence of newly diagnosed COPD compared with the second above-mentioned study (16.7% vs. 6.6%).

3.3. Conventional Spirometers

We identified 11 studies that utilized conventional spirometers for conducting COPD targeted screening actions (Group B, Table 2) [34,36,40–44].

The detection of new COPD cases among studies using conventional spirometers ranged from 11.4% to 47.8%, with the proportion (random effects) of 23.7% (95% CI 16.8–31.4) (Figure 3B). There was substantial heterogeneity with I2 97.5% (95% CI 96.7–98.2), $p < 0.0001$. Egger's and Begg's test excluded publication bias with $p = 0.17$ and $p = 0.31$, respectively.

As anticipated, the highest incidence of newly diagnosed COPD was achieved in studies that included only subjects presenting with respiratory symptoms [37,39,42,43]. In two of the above studies [42,43], nearly half of the patients (47.9%) were newly diagnosed with COPD. Both studies were performed at hospitals. The study by Su et al. [42] was conducted in Taiwan on patients referred to hospitals from pulmonary outpatient clinics. Relevantly, the investigated group consisted of well-selected patients with a history of a minimum of 20 pack-years and the average age of above 70 years. In the study conducted by Hwang et al. [43], COPD targeted screening was performed in the South Korean tertiary hospitals on patients presenting with respiratory symptoms, such as dyspnea or a productive cough.

A high rate of newly detected COPD cases (36.4%) was also achieved in the study by Lee [39], in which a very small population of elderly patients (>75 yrs.) with a history of a minimum of 20 pack-years was recruited. This study was performed in the primary care setting.

Two of 11 studies, which used laboratory spirometers for COPD targeted screening action, were conducted on a specific group of smokers—infected with HIV [38] and with ischemic heart disease [44]. The higher incidence of newly recognized COPD cases was achieved in the study with an inclusion criterion of a more relevant smoking history (min. 20 pack-years in the study by Makinson et al. [38] vs. 10 pack-years in the study by Yangui et al. [44]).

In our analysis of COPD targeted screening actions utilizing conventional spirometers, we treated the article by Sansores et al. [40] as comprising two independent studies. This approach was applied because the study examined two distinct patient subpopulations: individuals with respiratory symptoms and those without. By implementing more precise inclusion criteria, the study revealed a significant increase in the incidence of newly detected COPD cases (11.4% vs. 5.7%).

3.4. Baseline Testing with a Portable/COPD-6 Device, Confirmatory Spirometry with a Conventional Spirometer

We found six studies in which a COPD diagnostics were performed in two steps with the use of two different spirometer types (Table 3) [45–50]. In all of these studies, the first step the baseline spirometry was either performed with a portable spirometer [48,50] or with the use of a COPD-6 device [45–47,49]. Confirmatory spirometry leading to a COPD diagnosis was performed with a conventional spirometer.

The detection of new COPD cases among studies using both types of spirometers ranged from 1.9% to 27.8%, with the proportion (random effects) of 14.6% (95% CI 6.4–25.3) (Figure 3C). There was substantial heterogeneity across studies with I2 97.7% (95% CI 96.5–98.5), $p < 0.0001$ Egger's and Begg's test excluded publication bias with $p = 0.82$ and $p = 0.85$, respectively.

As in the previously described groups, the highest incidence of newly detected COPD was found in the studies, which recruited patients with at least one respiratory symptom

(27.8%) [50]. In this study, performed in the primary care setting, all eligible participants underwent the targeted screening spirometry with the hand-held spirometer Spirobank Smart and, regardless of its results, the confirmatory postbronchodilator spirometry with the diagnostic spirometer.

A similar approach was applied in the study by Kim et al. [47]. Only subjects complaining of respiratory symptoms were enrolled. Regardless of the result of FEV_1/FEV_6 measured with the COPD-6 device in the primary care setting, all study participants were then reffered for laboratory spirometry conducted in tertiary hospitals. The COPD detection rate was 23.7%.

Also in the study by Thorn et al. [45], irrespective of the results of the initial test performed using the COPD-6 device, all participants underwent confirmatory spirometry with a COPD detection rate of 25.2%.

Other targeted screening methods were applied in the studies performed in Poland [48] and in Malaysia [46]. The first study was conducted in an unusual setting. Medical students recruited smoking passengers (min. 10 pack-years) at a railway station. A baseline spirometry was performed with the use of a portable spirometer MicroLab 3500 (Care Fusion). Among all participants, only those with airway obstruction were encouraged to undergo stationary spirometry in a pulmonary department. The low incidence of newly detected COPD patients (2.8%) was probably due to the very low response rate—only 15 out of 37 participants with airflow obstruction came forward for confirmatory spirometry.

In the study conducted in a primary care setting in Malaysia [46], an initial test was performed with a COPD-6 device. Only subjects with the suspicion of airflow limitation ($FEV_1/FEV_6 < 0.75$) were asked to return for formal spirometry testing. Similarly to the study by Korczyński et al. [48], only a few participants attended a confirmatory test, resulting in a low incidence of newly detected COPD (1.9%).

A higher rate of successful COPD targeted screening was achieved in the study by Liang et al. [49] (17.6%), where confirmatory spirometry was performed at the same place (general practice clinics in Australia) directly succeeding the baseline test (conducted with a COPD-6 device).

3.5. Incidence of COPD

The incidence of newly detected COPD cases with the use of different spirometer types is shown in Figure 4. In all groups (A–C), the incidence of newly diagnosed COPD cases was higher in studies in which only subjects presenting with respiratory symptoms were included.

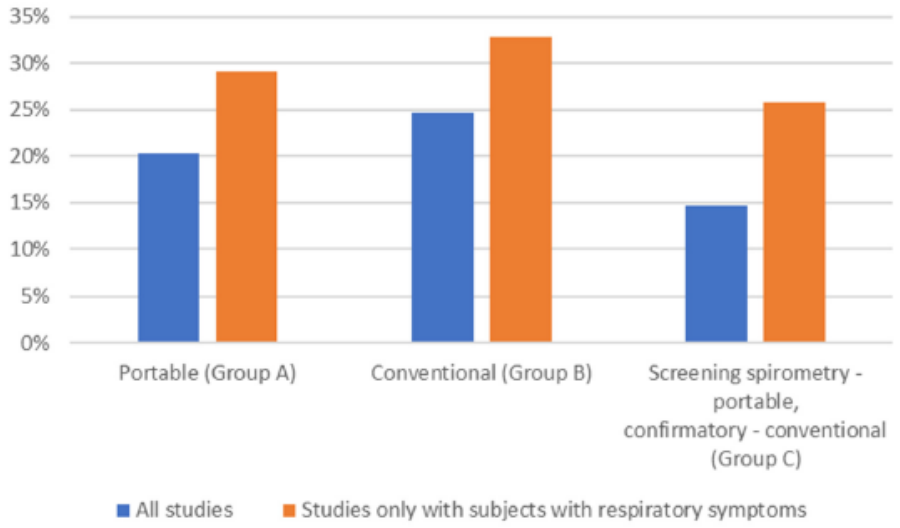

Figure 4. Incidence of newly detected COPD cases with the use of different spirometer types (average; %). All studies: blue; studies that included only subjects with respiratory symptoms: orange.

4. Discussion

4.1. Principal Findings

To our knowledge, this is the first systematic review to assess the feasibility of using small, handheld, or pocket-sized spirometers for COPD targeted screening and detection, in addition to comparing the results of portable and conventional spirometry targeted screening actions.

Our study shows that portable spirometric tools are slightly less efective in the COPD targeted screening actions as traditional, laboratory spirometers. This type of spirometer is not only useful for pre-bronchodilator testing, but can be considered a reliable tool when performing postbronchodilator spirometry and thus in confirming an irreversible airflow limitation, which in smokers, is equivalent to a COPD diagnosis. In a few studies analyzed in our systematic review, a handheld, mobile-phone linked spirometer proved advantageous for COPD targeted screening at the bedside of hospitalized patients not capable of being transported to a pulmonary function testing laboratory.

According to this systematic review, diagnostic COPD spirometry is more effective than screening asymptomatic individuals. A higher rate of COPD diagnoses was achieved in studies that included older participants with respiratory symptoms and a history of many pack-years.

Moreover, if a targeted screening action is to be successful, the postbronchodilator test has to be performed on site, directly succeeding the baseline test. Among over 500 excluded studies, the lack of a postbronchodilator test was the third cause of exclusion after not meeting the age criterion and the lack of information about the type of spirometer.

4.2. Methodology

A precise methodology has to be established to obtain a good-quality study and reliable evidence. Our aim was to find as many studies in which portable spirometry was used in a COPD targeted screening action as possible. Our general approach was to search only for studies that ended in a disease diagnosis. We are convinced that we achieved this goal. Secondly, we aimed to make our study clear and easy to read. To achieve this, we used a PRISMA 2020 flow diagram added as a methodology figure. Furthermore, we rejected a significant number of studies (over 8450). It is well-known that a proper review needs to be double-checked. Therefore, two of the authors performed the rejection process twice separately to be sure that none of the appealing studies had been missed.

4.3. Strong Points of the Study

To our knowledge, the current study is the first systematic review to examine the feasibility of spirometry perfomed with portable spirometers in COPD targeted screening. It has to be emphasized that all studies included in our review led not only to the detection of airflow limitation, but directly to a COPD diagnosis, as in all found studies a post-bronchodilator test was performed. Beyond the scientific value, the findings of our research have clinical importance, as we proved that with the help of a portable spirometer, a proper COPD diagnosis can be made and an appropriate treatment can be launched. It is widely known that treating patients with COPD, especially in the early stages, can lead to an improvement in their health status [10].

An additional advantage of our work is the fact that we have applied very strict inclusion criteria. Only publications confirming persistent obstruction were considered as indicating COPD, with the exclusion of studies where individuals with asthma were part of the study population.

Another advantage of this systematic review is that studies from all over the world have been selected (Figure 5). According to the results of the study, the countries of North America and the Far East have the greatest effectiveness in diagnosing COPD in spirometry actions.

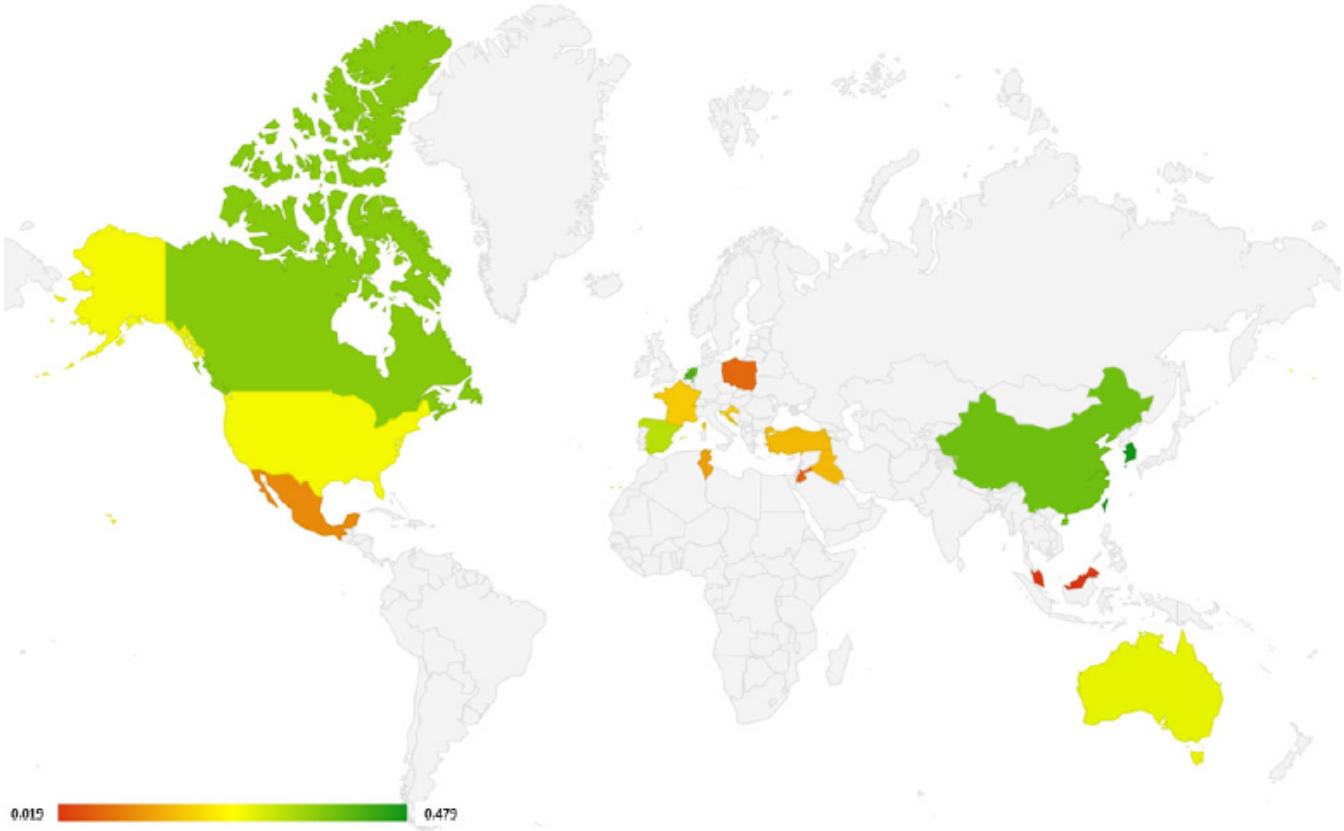

Figure 5. World map with countries, where studies included in this systematic review were performed (all types of spirometers). Different colors depict the % of newly diagnosed COPD (green color: high rate of newly detected COPD cases; red color: low rate). If in one country more than one study was performed, the study with the highest rate of newly detected COPD cases was selected.

4.4. Potential Confounding Aspects and Limitations of the Study

This systematic review has some limitations. Although the number of records identified through the database search was considerable, the rigorous inclusion criteria to select papers evaluating the use of a portable spirometer for the diagnosis of COPD resulted in relatively few matching papers ultimately being included in this systematic review remaining. Firstly, we excluded studies in which a postbronchodilator test was not performed. We also excluded papers in which it was not clear what type of spirometer was used for the COPD targeted screening action and the corresponding author of the paper did not provide a response to our inquiry. Secondly, in two included studies from two different groups (A and C) [28,45], it was not known if patients with previously diagnosed COPD were excluded from the studied population. In this case, it may have led to an overstatement of newly detected COPD cases and the effectiveness of COPD targeted screening actions.

Thirdly, despite our initial exclusion criteria of publications where individuals with previously diagnosed asthma were part of the study population, it is possible that some smokers with persistent obstruction were actually suffering from this condition. It is clear that in distinguishing between COPD and asthma, clinical symptoms are important, not just the results of additional tests, such as spirometry. Unfortunately, clinical symptoms were not reported in all included publications, which could result in an overestimation of COPD prevalence.

Another limitation of our study was the fact that we decided to include studies that were not conducted with the help of a portable spirometer, but a COPD-6 device. This tool is not capable of measuring the FEV1/FVC, but can measure an alternative FEV1/FEV6. However, in studies included in group C, a confirmatory spirometry leading to COPD detection was

always conducted with a confirmatory spirometer. Lastly, the included studies exhibited significant heterogeneity. Selected publications differed, among other factors, in the criteria used for patient selection (e.g., various questionnaires assessing patients' symptoms). Only a few analyzed studies assessed the quality of spirometry tests performed. Furthermore, included studies employed different spirometry criteria for diagnosing COPD. The most commonly used criterion was the one recommended by GOLD (FEV1/FVC < 0.70 in the postbronchodilator test) [5], followed by <LLN [24]. The included papers also varied in terms of the adopted technical standards for conducting spirometry tests and spirometry reference values. Although we are aware that reference values likely varied as well, partly due to the time span and geographic scope of the analyzed publications (2007–2021), almost none of the cited publications provided information on this topic.

Unfortunately, not all included papers provided data on the coexistence of other chronic diseases, such as diabetes or arterial hypertension. Only in isolated cases did the included publications contain data on the coexistence of congestive heart failure, which undoubtedly could have affected the results of spirometry.

The analyzed studies also do not include data on the time and quality of training of individuals performing spirometry, both for portable spirometers, as well as conventional ones, which could have influenced the results. According to the results of the Chinese meta-analysis [14], the effectiveness of portable spirometers in diagnosing airway obstruction, among other factors, depended on the proper technical execution of spirometry. As demonstrated in previous publications [54]; the percentage of correctly performed spirometry tests leading to the diagnosis of airway obstruction using a portable spirometer increased with the experience of the person conducting the test and the duration of training. Future analyses comparing the effectiveness of using portable and conventional spirometers in diagnosing COPD should be designed in such a way that the individuals conducting the tests are properly and uniformly trained. This will result in the achievement of reproducible tests and likely in a higher prevalence of COPD.

4.5. Comparison with Other Studies

Our review provides the first comprehensive summary of up-to-date evidence on the feasibility of portable spirometers for the targeted screening and, simultaneously, the diagnosis of COPD. This systematic review included 28 articles, of which 11 concerned COPD targeted screening with the use of portable spirometers. To compare, in their meta-analysis, Zhou et al. [14] identified 31 studies that systematically evaluated the diagnostic value of portable spirometers for detecting COPD. However, a different aim of this study was chosen and a different approach was applied, as in included articles, portable devices were used to determine airway obstruction, not necessarily a COPD diagnosis. Only in one study [25], which was also included in our systematic review, was a post-bronchodilator test conducted using a portable spirometer (Datospir 120, Sibelmed), which led to confirmed COPD diagnoses in over 31% of cases. The same study [30] was also found in the systematic review published in 2021 [55]. Also in this review, it was the only included study in which a portable spirometer was used to perform a post-BD spirometry. The other 12 identified articles measured the sensitivity and specificity of the portable devices (mainly COPD-6) in diagnosing airway obstruction, which were not used to conduct the post-BD test.

4.6. Benefits of Portable Spirometers

According to the results of our systematic review, the diagnostic value of portable spirometers for COPD targeted screening is slightly lower than that of conventional spirometers. As indicated above, this could be attributed to various factors, including significant heterogeneity among the included publications. However, the numerous advantages of the portable spirometer make its use in COPD testing worthy of further investigation, preferably with consideration given to the appropriate design of the study. Important advantages of portable spirometers include, among others, the ability to examine patients at their hospital bedside, as well as cost-effectiveness. Studies have shown that

portable-spirometer-targeted screening is cost-saving in primary care patients presenting with respiratory symptoms compared with questionnaire screening and no screening [56].

4.7. Minimal Standards of Portable Spirometers

A portable spirometer should meet basic standards. Although it has been demonstrated that the FEV1/FEV6 can be regarded as a viable surrogate indicator for diagnosing COPD [14], a portable spirometer, according to its definition, must be able to measure at least FEV1, FVC, and FEV1/FVC. Portable spirometry also needs to be performed under strict quality control. To achieve consistent results, it is important to emphasize proper training for individuals conducting spirometry using portable devices. Spirometry performed using these devices should adhere to applicable technical standards and current reference norms.

5. Conclusions

Present studies suggest that portable spirometers are only slightly less efficient in diagnosing COPD compared to traditional spirometers. Future spirometry targeted screening for the diagnosis of COPD, in order to increase its effectiveness, should be considered in selected symptomatic subjects.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/arm92020018/s1, Table S1: Search strategy for PubMed; Table S2: JBI assessment results of studies; Table S3: Publications addressing the diagnostic screening of COPD along with the characterization of patient inclusion criteria.

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9. Podsumowanie wyników

W badaniach, które stanowią podstawę publikacji składających się na niniejszą rozprawę doktorską wykazano skuteczność przenośnego spirometru jako narzędzia diagnostycznego u chorych znajdujących się w grupie ryzyka POChP.

W badaniu, w którym stosowano PS do wykrywania obturacji dróg oddechowych w miejscu publicznym (dworzec kolejowy) wykazano niewielką gotowość osób z czynnikami ryzyka rozwoju POChP (wywiady nikotynizmu >10 paczkolat) do uczestnictwa w publicznej akcji spirometrycznej. Jedynie 19,6% spośród wszystkich zaproszonych osób, które spełniały kryteria włączenia do badania, zgodziło się wziąć w nim udział. Nawet w przypadku wykrycia obturacji oskrzeli lub wyniku na dolnej granicy normy w pierwotnym badaniu spirometrycznym wykonanym na dworcu kolejowym, jedynie 25,4% pacjentów zgłosiło się na wizytę kontrolną do stacjonarnej pracowni spirometrycznej w celu potwierdzenia wyniku. Jednocześnie wykazano użyteczność wykorzystania przenośnego spirometru do przeprowadzenia badania przesiewowego zorganizowanego w miejscu publicznym (dworzec kolejowy), w czasie której można było wykryć *de novo* obturację u 10,7% uczestników badania.

Inne badanie potwierdziło, że zastosowanie przenośnego spirometru umożliwia skuteczne przeprowadzenie pełnej diagnostyki POChP bezpośrednio przy łóżku chorego u pacjentów z czynnikami ryzyka hospitalizowanych na oddziałach kardiologii i pulmonologii. Mobilne urządzenie pozwoliło nie tylko na wykonanie początkowego badania spirometrycznego, ale również na przeprowadzenie próby rozkurczowej bez potrzeby transportowania chorego do pracowni spirometrycznej. W grupie chorych z rozpoznaniem POChP 28% pacjentów miało rozpoznaną chorobę po raz pierwszy. Większość nowych przypadków charakteryzowała się łagodnym lub umiarkowanym ograniczeniem przepływu powietrza. Wyniki badania sugerują, że taka strategia wykonywania badań spirometrycznych może znacząco zwiększyć wykrywalność POChP w środowisku szpitalnym, szczególnie w grupie byłych palaczy z łagodnymi objawami choroby.

Duże, ogólnopolskie badanie wykazało, że przenośny spirometr z możliwością automatycznej kontroli jakości badań może być wykorzystany na skalą krajową w warunkach podstawowej opieki zdrowotnej. Spośród wszystkich 10 936 przeprowadzonych badań spirometrycznych, 49% spełniało kryteria akceptowalności i powtarzalności według wytycznych ATS/ERS. Najczęstszymi błędami stwierdzanymi podczas badań były kolejno: nieuzyskanie plateau w końcowej fazie wydechu (17,7%), przekroczenie dopuszczalnej objętości wstecznie ektrapolowanej (ang. BEV, *back extrapolated volume*) (16.5%) oraz zbyt krótki czas natężonego wydechu (ang. FET, *forced expiratory time*) (14.3%). Częstość występowania obturacji była częstsza u mieszkańców miast z mniej niż 40 000 mieszkańców

niż w dużych miastach (27,1% vs. 17,3%, $p < 0.01$). W publikacji przeanalizowano dane z wcześniejszych badań dotyczących oceny błędów spirometrycznych w warunkach podstawowej opieki zdrowotnej. Wykazano, że kluczowe dla zapewnienia wysokiej jakości badań spirometrycznych są takie czynniki, jak czas trwania szkolenia z zakresu spirometrii, regularne szkolenia uzupełniające oraz doświadczenie instruktora. Wyniki badania sugerują, że przenośne spirometry mogą być skutecznie wykorzystywane w podstawowej opiece zdrowotnej. W celu poprawy jakości badań konieczne jest wprowadzenie intensywniejszych i regularnych szkoleń dla personelu medycznego.

Przeprowadzony systematyczny przegląd piśmiennictwa pozwolił na dokonanie rzetelnej oceny częstości występowania POChP zdiagnozowanego przy użyciu przenośnych spirometrów u pacjentów z grupy wysokiego ryzyka. Ponadto, wyniki dla PS porównano z danymi uzyskanymi za pomocą konwencjonalnych spirometrów. Spośród 8496 ocenianych publikacji ostatecznie uwzględniono 28 artykułów, które spełniały przyjęte kryteria włączenia. Publikacje uwzględnione w przeglądzie wykazywały znaczną heterogeniczność. Średnia częstość występowania POChP przy zastosowaniu przenośnych spirometrów wynosiła 20,27%, co było nieco niższym wynikiem w porównaniu z tradycyjnymi spirometrami (24,67%). Wyniki przeglądu systematycznego wskazują, że przenośne spirometry charakteryzują się jedynie nieznacznie niższą skutecznością w przesiewowym wykrywaniu POChP w porównaniu z spirometrami tradycyjnymi. Tego typu urządzenia mogą stanowić wiarygodne narzędzie diagnostyczne, umożliwiające przeprowadzenie próby rozkurczowej i potwierdzenie nieodwracalnego ograniczenia przepływu powietrza, które u osób palących jest podstawą rozpoznania POChP.

10. Wnioski

W oparciu o wyniki publikacji składających się na niniejszą rozprawę doktorską można sformułować następujące wnioski:

1. przenośne spirometry mogą być skutecznie wykorzystywane w proaktywnych strategiach diagnostycznych, ukierunkowanych na wykrywanie POChP u osób z grupy wysokiego ryzyka;

2. przenośne spirometry mogą być z powodzeniem stosowane w diagnostyce POChP w różnych warunkach klinicznych, w tym w podstawowej opiece zdrowotnej, u pacjentów hospitalizowanych oraz w ramach badań przesiewowych prowadzonych poza placówkami medycznymi;

3. częstość występowania POChP, zdiagnozowanego za pomocą przenośnego spirometru u pacjentów z czynnikami ryzyka wynosi około 20% i jest jedynie nieznacznie niższa niż odsetek rozpoznań uzyskiwanych przy użyciu konwencjonalnych spirometrów;

4. analiza najczęściej popełnianych błędów w badaniach spirometrycznych wykazała, że kluczowym czynnikiem wpływającym na jakość wyników jest odpowiednie przygotowanie techniczne oraz doświadczenie personelu medycznego. W celu poprawy precyzji pomiarów konieczne jest wprowadzenie regularnych szkoleń oraz procedur kontrolnych.

11. Opinia Komisji Bioetycznej

Komisja Bioetyczna
przy Warszawskim Uniwersytecie Medycznym

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Fax: 022/ 57 - 20 -165

ul. Żwirki i Wigury nr 61
02-091 Warszawa

e-mail: komisja.bioetyczna@wum.edu.pl
www.komisja-bioetyczna.wum.edu.pl

AWBE/140/15

Warszawa, dn. 01 grudnia 2015r.

Dr n. med. Piotr Korczyński,
Katedra i Klinika Chorób Wewnętrznych
Pneumonologii i Alergologii ,
ul. Banacha 1a,
02-007 Warszawa

OŚWIADCZENIE

Niniejszym oświadczam, że Komisja Bioetyczna przy Warszawskim Uniwersytecie Medycznym w dniu 01 grudnia 2015 przyjęła do wiadomości informację na temat badania pt. „ Możliwości rozpoznania POChP przez studentów medycyny w ramach edukacyjnych i spirometrycznych akcji ulicznych." oraz nie zgłasza zastrzeżeń.

Zastępca Przewodniczącej
Komisji Bioetycznej
Barbara Gajkowska
/Prof. dr hab. Barbara Gajkowska/

Komisja Bioetyczna
przy Warszawskim Uniwersytecie Medycznym

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KB/.232...../2018

Komisja Bioetyczna przy Warszawskim Uniwersytecie Medycznym
w dniu 10 grudnia 2018 r. po zapoznaniu się z wnioskiem:

Dr hab. n. med. Katarzyna Górska
Katedra i Klinika Chorób Wewnętrznych, Pneumonologii i Alergologii
ul. Banacha 1a, 02-097 Warszawa

dotyczącym: wyrażenia opinii w sprawie badania pt :„Zastosowanie przenośnego spirometru w diagnostyce przewlekłej obturacyjnej choroby płuc u pacjentów hospitalizowanych na oddziałach internistycznych"

wyraża następującą
o p i n i ę

- stwierdza, że jest ono dopuszczalne i zgodne z zasadami naukowo-etycznymi*.
- ~~stwierdza, że jest ono niedopuszczalne i niezgodne z zasadami naukowo-etycznymi.*~~

Uwagi Komisji – *verte*

Komisja działa na podstawie art.29 ustawy z dnia 5.12.1996r. o zawodzie lekarza /Dz.U.nr 28/97 poz.152 wraz z późn.zm./, zarządzenia MZiOS z dn.11.05.1999r. w sprawie szczegółowych zasad powoływania i finansowania oraz trybu działania komisji bioetycznych /Dz.U.nr 47 poz.480/, Ustawy prawo farmaceutyczne z dnia 6 września 2001r. (Dz.U.Nr 126, poz. 1381 z późn. zm.) oraz Zarządzenie nr 56/2007 z dnia 15 października 2007r. w sprawie działania Komisji Bioetycznej przy Warszawskim Uniwersytecie Medycznym /Regulamin Komisji Bioetycznej przy Warszawskim Uniwersytecie Medycznym/.
Komisja działa zgodnie z zasadami GCP .
W załączeniu: skład komisji oraz lista obecności

Przewodnicząca Komisji Bioetycznej

Prof. dr hab. n. med. Magdalena Kuźma-Kozakiewicz

*niepotrzebne skreślić

Komisja wyraża pozytywną opinię w sprawie przeprowadzenia wnioskowanych badań- na warunkach określonych we wniosku oraz dodatkowo zastrzegając:
1/ obowiązek przedstawienia Komisji:

- wszystkich zmian w protokole mających wpływ na przebieg oraz ocenę badania,
- wszystkich przypadków zdarzeń niepożądanych,
- zawiadomienia o przyczynach przedwczesnego zakończenia badania,
- sprawozdania w toku przeprowadzonych badań-za sześć miesięcy,
- raportu końcowego.

strona podpisowa do uchwały Komisji Bioetycznej przy Warszawskim Uniwersytecie Medycznym nr KB/.....232..... z dnia 10 grudnia 2018r.

1. Prof. dr hab. n.med. Magdalena Kuźma –Kozakiewicz .....
2. Dr hab. n. med. Tomasz Grzela .....
3. Dr hab. n. med. Andrea Horvath-Stolarczyk .....
4. Prof. dr hab. n. med. Paweł Piątkiewicz .....
5. Dr hab. n. med. Marek Postuła .....
6. Dr hab. n. med. Marcin Ufnal .....
7. Dr hab. n. med. Katarzyna Kosińska-Kaczyńska .....
8. Dr hab. n. farm. Sylwia Flis .....
9. Dr n. med. Agnieszka Serafin .....
10. Ks. Paweł Śmierzchalski .....
11. Prof. dr hab. Maria Boratyńska .....

Komisja Bioetyczna
przy Warszawskim Uniwersytecie Medycznym

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www.komisja-bioetyczna.wum.edu.pl

AKBE/ 159 / 2020

Warszawa, dnia 14 września 2020r.

Dr hab. n. med. Katarzyna Górska
Katedra i Klinika Chorób Wewnętrznych,
Pneumonologii i Alergologii,
ul. Banacha 1a,02-097 Warszawa

OŚWIADCZENIE

Niniejszym oświadczam, że Komisja Bioetyczna przy Warszawskim Uniwersytecie Medycznym w dniu 14 września 2020 r. przyjęła do wiadomości informację na temat badania pt.:"Ocena przydatności przenośnego spirometru oraz jakości badań spirometrycznych w warunkach podstawowej opieki zdrowotnej." Przedstawione badanie nie stanowi eksperymentu medycznego w rozumieniu art. 21 ust. 1 ustawy z dnia 5 grudnia 1996 r. o zawodach lekarza i lekarza dentysty(Dz.U. z 2018 r. poz. 617) i nie wymaga uzyskania opinii Komisji Bioetycznej przy Warszawskim Uniwersytecie Medycznym, o której mowa w art. 29 ust. 1 ww. ustawy.

Przewodnicząca Komisji Bioetycznej

Prof. dr hab. n. med. Magdalena Kuźma –Kozakiewicz

12. Oświadczenia współautorów publikacji

Warszawa, 09.03.2025 r.

Lek. Piotr Jankowski

OŚWIADCZENIE

Jako współautor pracy pt. ***Public spirometry campaign in chronic obstructive pulmonary disease screening - hope or hype? (doi:10.5603/ARM.2017.0024)*** oświadczam, że mój wkład merytoryczny w powstanie tej pracy obejmował opracowanie koncepcji badania, rekrutację pacjentów, interpretację wyników badań oraz pracę nad tekstem manuskryptu. Mój udział procentowy w przygotowanie publikacji wynosił 30%.

Jako współautor pracy pt. ***Active screening for COPD among hospitalized smokers - a feasibility study. (doi:10.1177/2040622320971111)*** oświadczam, że mój wkład merytoryczny w powstanie tej pracy obejmował opracowanie koncepcji badania, rekrutację pacjentów, analizę wyników badań oraz pracę nad tekstem manuskryptu. Mój udział procentowy w przygotowanie publikacji wynosił 20%.

Jako współautor pracy pt. ***The use of a mobile spirometry with a feedback quality assessment in primary care setting - A nationwide cross-sectional feasibility study. (doi:10.1016/j.rmed.2021.106472)*** oświadczam, że mój wkład merytoryczny w powstanie tej pracy obejmował opracowanie koncepcji badania, interpretację wyników badań oraz pracę nad tekstem manuskryptu. Mój udział procentowy w przygotowanie publikacji wynosił 50%.

Jako współautor pracy pt. ***How to enhance the diagnosis of early stages of chronic obstructive pulmonary disease (COPD)? The role of mobile spirometry in COPD screening and diagnosis - a systematic review. (doi:10.3390/arm92020018)*** oświadczam, że mój wkład merytoryczny w powstanie tej pracy obejmował opracowanie koncepcji badania, przegląd piśmiennictwa, selekcję badań zgodnie z ustalonymi kryteriami włączenia i wyłączenia, analizę zebranych danych oraz ich opracowanie graficzne, a także pracę nad tekstem manuskryptu. Mój udział procentowy w przygotowanie publikacji wynosił 60%.

Piotr Jankowski

.....

(podpis oświadczającego)

Warszawa, 21.02.2025 r.

Prof. dr hab. n. med. Rafał Krenke

OŚWIADCZENIE

Jako współautor pracy pt. ***Public spirometry campaign in chronic obstructive pulmonary disease screening - hope or hype? (doi:10.5603/ARM.2017.0024)*** oświadczam, że mój wkład merytoryczny w powstanie tej pracy obejmował pracę nad tekstem manuskryptu oraz merytoryczne poprawki. Mój udział procentowy w przygotowanie publikacji wynosił 5%.

Jako współautor pracy pt. ***Active screening for COPD among hospitalized smokers - a feasibility study. (doi:10.1177/2040622320971111)*** oświadczam, że mój wkład merytoryczny w powstanie tej pracy obejmował analizę wyników badań, pracę nad tekstem manuskryptu oraz merytoryczne poprawki. Mój udział procentowy w przygotowanie publikacji wynosił 6%.

Jako współautor pracy pt. ***The use of a mobile spirometry with a feedback quality assessment in primary care setting - A nationwide cross-sectional feasibility study. (doi:10.1016/j.rmed.2021.106472)*** oświadczam, że mój wkład merytoryczny w powstanie tej pracy obejmował interpretację wyników badań, pracę nad tekstem manuskryptu oraz merytoryczne poprawki. Mój udział procentowy w przygotowanie publikacji wynosił 10%.

Jako współautor pracy pt. ***How to enhance the diagnosis of early stages of chronic obstructive pulmonary disease (COPD)? The role of mobile spirometry in COPD screening and diagnosis - a systematic review. (doi:10.3390/arm92020018)*** oświadczam, że mój wkład merytoryczny w powstanie tej pracy obejmował opracowanie koncepcji badania, analizę zebranych danych, pracę nad tekstem manuskryptu oraz merytoryczne poprawki. Mój udział procentowy w przygotowanie publikacji wynosił 10%.

Jednocześnie wyrażam zgodę na wykorzystanie w/w prac jako części rozprawy doktorskiej lek. Piotra Jankowskiego.

.....

(podpis oświadczającego)

Warszawa, 21.02.2025 r.

Dr hab. n. med. Katarzyna Górska

OŚWIADCZENIE

Jako współautorka pracy pt. ***Public spirometry campaign in chronic obstructive pulmonary disease screening - hope or hype? (doi:10.5603/ARM.2017.0024)*** oświadczam, że mój wkład merytoryczny w powstanie tej pracy obejmował opracowanie koncepcji badania, interpretację wyników badań oraz pracę nad tekstem manuskryptu. Mój udział procentowy w przygotowanie publikacji wynosił 23%.

Jako współautorka pracy pt. ***Active screening for COPD among hospitalized smokers - a feasibility study. (doi:10.1177/2040622320971111)*** oświadczam, że mój wkład merytoryczny w powstanie tej pracy obejmował opracowanie koncepcji badania, analizę wyników badań, pracę nad tekstem manuskryptu oraz merytoryczne poprawki. Mój udział procentowy w przygotowanie publikacji wynosił 15%.

Jako współautorka pracy pt. ***The use of a mobile spirometry with a feedback quality assessment in primary care setting - A nationwide cross-sectional feasibility study. (doi:10.1016/j.rmed.2021.106472)*** oświadczam, że mój wkład merytoryczny w powstanie tej pracy obejmował opracowanie koncepcji badania, interpretację wyników badań, pracę nad tekstem manuskryptu oraz merytoryczne poprawki. Mój udział procentowy w przygotowanie publikacji wynosił 12,5%.

Jako współautorka pracy pt. ***How to enhance the diagnosis of early stages of chronic obstructive pulmonary disease (COPD)? The role of mobile spirometry in COPD screening and diagnosis - a systematic review. (doi:10.3390/arm92020018)*** oświadczam, że mój wkład merytoryczny w powstanie tej pracy obejmował opracowanie koncepcji badania, interpretację wyników badań oraz pracę nad tekstem manuskryptu. Mój udział procentowy w przygotowanie publikacji wynosił 15%.

Jednocześnie wyrażam zgodę na wykorzystanie w/w prac jako części rozprawy doktorskiej lek. Piotra Jankowskiego.

....Katarzyna Górska...
(podpis oświadczającego)

Warszawa, 21.02.2025 r.

Dr hab. n. med. Piotr Korczyński

OŚWIADCZENIE

Jako współautor pracy pt. ***Public spirometry campaign in chronic obstructive pulmonary disease screening - hope or hype? (doi:10.5603/ARM.2017.0024)*** oświadczam, że mój wkład merytoryczny w powstanie tej pracy obejmował opracowanie koncepcji badania, pracę nad tekstem manuskryptu oraz merytoryczne poprawki. Mój udział procentowy w przygotowanie publikacji wynosił 25%.

Jako współautor pracy pt. ***Active screening for COPD among hospitalized smokers - a feasibility study. (doi:10.1177/2040622320971111)*** oświadczam, że mój wkład merytoryczny w powstanie tej pracy obejmował opracowanie koncepcji badania, analizę wyników badań, pracę nad tekstem manuskryptu oraz merytoryczne poprawki. Mój udział procentowy w przygotowanie publikacji wynosił 10%.

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Jednocześnie wyrażam zgodę na wykorzystanie w/w prac jako części rozprawy doktorskiej lek. Piotra Jankowskiego.

.....

(podpis oświadczającego)

Warszawa, 21.02.2025 r.

Lek. Katarzyna Mycroft-Rzeszotarska

OŚWIADCZENIE

Jako współautorka pracy pt. ***Active screening for COPD among hospitalized smokers - a feasibility study. (doi:10.1177/2040622320971111)*** oświadczam, że mój wkład merytoryczny w powstanie tej pracy obejmował opracowanie koncepcji badania, rekrutację pacjentów, analizę wyników badań oraz pracę nad tekstem manuskryptu. Mój udział procentowy w przygotowanie publikacji wynosił 20%.

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Jednocześnie wyrażam zgodę na wykorzystanie w/w prac jako części rozprawy doktorskiej lek. Piotra Jankowskiego.

K. Mycroft-Rzeszotarska

(podpis oświadczającego)

Warszawa, 22.02.2025 r.

Prof. dr hab. n. med. Łukasz Kołtowski

OŚWIADCZENIE

Jako współautor pracy pt. ***Active screening for COPD among hospitalized smokers - a feasibility study. (doi:10.1177/2040622320971111)*** oświadczam, że mój wkład merytoryczny w powstanie tej pracy obejmował opracowanie koncepcji badania oraz merytoryczne poprawki. Mój udział procentowy w przygotowanie publikacji wynosił 5%.

Jako współautor pracy pt. ***The use of a mobile spirometry with a feedback quality assessment in primary care setting - A nationwide cross-sectional feasibility study. (doi:10.1016/j.rmed.2021.106472)*** oświadczam, że mój wkład merytoryczny w powstanie tej pracy obejmował opracowanie koncepcji badania. Mój udział procentowy w przygotowanie publikacji wynosił 3%.

Jednocześnie wyrażam zgodę na wykorzystanie w/w prac jako części rozprawy doktorskiej lek. Piotra Jankowskiego.

Digitally signed by Łukasz Nikodem Kołtowski
Date: 2025.02.22 11:37:26 CET

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(podpis oświadczającego)

Warszawa, 25.02.2025 r.

Dr nauk fizycznych inż. Mateusz Soliński

OŚWIADCZENIE

Jako współautor pracy pt. ***The use of a mobile spirometry with a feedback quality assessment in primary care setting - A nationwide cross-sectional feasibility study. (doi:10.1016/j.rmed.2021.106472)*** oświadczam, że mój wkład merytoryczny w powstanie tej pracy obejmował przeprowadzenie analizy statystycznej oraz opracowanie grafik ilustrujących wyniki badań. Mój udział procentowy w przygotowanie publikacji wynosił 7%.

Jednocześnie wyrażam zgodę na wykorzystanie w/w prac jako części rozprawy doktorskiej lek. Piotra Jankowskiego.

……
(podpis oświadczającego)

Warszawa, 16.02.2025 r.

Lek. Jakub Kosiński

OŚWIADCZENIE

Jako współautor pracy pt. ***Public spirometry campaign in chronic obstructive pulmonary disease screening - hope or hype? (doi:10.5603/ARM.2017.0024)*** oświadczam, że mój wkład merytoryczny w powstanie tej pracy obejmował rekrutację chorych oraz pracę nad tekstem manuskryptu. Mój udział procentowy w przygotowanie publikacji wynosił 5%.

Jednocześnie wyrażam zgodę na wykorzystanie w/w prac jako części rozprawy doktorskiej lek. Piotra Jankowskiego.

Jakub Kosiński

(podpis oświadczającego)

Warszawa, 16.02.2025 r.

Lek. Agata Kudas

OŚWIADCZENIE

Jako współautorka pracy pt. ***Public spirometry campaign in chronic obstructive pulmonary disease screening - hope or hype? (doi:10.5603/ARM.2017.0024)*** oświadczam, że mój wkład merytoryczny w powstanie tej pracy obejmował rekrutację chorych. Mój udział procentowy w przygotowanie publikacji wynosił 4%.

Jednocześnie wyrażam zgodę na wykorzystanie w/w prac jako części rozprawy doktorskiej lek. Piotra Jankowskiego.

Agata Kudas
.....
(podpis oświadczającego)

Warszawa, 28.02.2025 r.

Lek. Katarzyna Sułek

OŚWIADCZENIE

Jako współautorka pracy pt. ***Public spirometry campaign in chronic obstructive pulmonary disease screening - hope or hype? (doi:10.5603/ARM.2017.0024)*** oświadczam, że mój wkład merytoryczny w powstanie tej pracy obejmował rekrutację chorych. Mój udział procentowy w przygotowanie publikacji wynosił 3%.

Jednocześnie wyrażam zgodę na wykorzystanie w/w prac jako części rozprawy doktorskiej lek. Piotra Jankowskiego.

Katarzyna Sułek
(podpis oświadczającego)

Warszawa, 16.02.2025 r.

Lek. Maria Jankowska

OŚWIADCZENIE

Jako współautorka pracy pt. ***Public spirometry campaign in chronic obstructive pulmonary disease screening - hope or hype? (doi:10.5603/ARM.2017.0024)*** oświadczam, że mój wkład merytoryczny w powstanie tej pracy obejmował rekrutację chorych. Mój udział procentowy w przygotowanie publikacji wynosił 2%.

Jednocześnie wyrażam zgodę na wykorzystanie w/w prac jako części rozprawy doktorskiej lek. Piotra Jankowskiego.

.....

(podpis oświadczającego)

Warszawa, 16.02.2025 r.

Lek. Kaja Jaśkiewicz

OŚWIADCZENIE

Jako współautorka pracy pt. ***Public spirometry campaign in chronic obstructive pulmonary disease screening - hope or hype? (doi:10.5603/ARM.2017.0024)*** oświadczam, że mój wkład merytoryczny w powstanie tej pracy obejmował rekrutację chorych. Mój udział procentowy w przygotowanie publikacji wynosił 3%.

Jednocześnie wyrażam zgodę na wykorzystanie w/w prac jako części rozprawy doktorskiej lek. Piotra Jankowskiego.

Kaja Jaśkiewicz

…….

(podpis oświadczającego)

Warszawa, 21.02.2025 r.

Lek. Mikołaj Kutka

OŚWIADCZENIE

Jako współautor pracy pt. ***Active screening for COPD among hospitalized smokers - a feasibility study. (doi:10.1177/2040622320971111)*** oświadczam, że mój wkład merytoryczny w powstanie tej pracy obejmował opracowanie narzędzi umożliwiających zbieranie danych od pacjentów, w tym zaprojektowanie kwestionariuszy oraz przygotowanie platformy cyfrowej. Mój udział procentowy w przygotowanie publikacji wynosił 10%.

Jednocześnie wyrażam zgodę na wykorzystanie w/w prac jako części rozprawy doktorskiej lek. Piotra Jankowskiego.

Lek. Mikołaj Kutka

.....

(podpis oświadczającego)

Warszawa, 16.02.2025 r.

Lek. Olga Żelazna

OŚWIADCZENIE

Jako współautorka pracy pt. ***Active screening for COPD among hospitalized smokers - a feasibility study. (doi:10.1177/2040622320971111)*** oświadczam, że mój wkład merytoryczny w powstanie tej pracy obejmował rekrutację pacjentów. Mój udział procentowy w przygotowanie publikacji wynosił 3%.

Jednocześnie wyrażam zgodę na wykorzystanie w/w prac jako części rozprawy doktorskiej lek. Piotra Jankowskiego.

Olga Żelazna
.....
(podpis oświadczającego)

Warszawa, 16.02.2025 r.

Lek. Marcin Zagaja

OŚWIADCZENIE

Jako współautor pracy pt. ***Active screening for COPD among hospitalized smokers - a feasibility study. (doi:10.1177/2040622320971111)*** oświadczam, że mój wkład merytoryczny w powstanie tej pracy obejmował rekrutację pacjentów. Mój udział procentowy w przygotowanie publikacji wynosił 3%.

Jednocześnie wyrażam zgodę na wykorzystanie w/w prac jako części rozprawy doktorskiej lek. Piotra Jankowskiego.

M. Żagaja
.....
(podpis oświadczającego)

Warszawa, 16.02.2025 r.

Lek. Kornelia Woźniczko

OŚWIADCZENIE

Jako współautorka pracy pt. ***Active screening for COPD among hospitalized smokers - a feasibility study. (doi:10.1177/2040622320971111)*** oświadczam, że mój wkład merytoryczny w powstanie tej pracy obejmował rekrutację pacjentów. Mój udział procentowy w przygotowanie publikacji wynosił 3%.

Jednocześnie wyrażam zgodę na wykorzystanie w/w prac jako części rozprawy doktorskiej lek. Piotra Jankowskiego.

Kornelia Woźniczko

(podpis oświadczającego)

Warszawa, 16.02.2025 r.

Lek. Urszula Szafrańska

OŚWIADCZENIE

Jako współautorka pracy pt. ***Active screening for COPD among hospitalized smokers - a feasibility study. (doi:10.1177/2040622320971111)*** oświadczam, że mój wkład merytoryczny w powstanie tej pracy obejmował rekrutację pacjentów. Mój udział procentowy w przygotowanie publikacji wynosił 3%.

Jednocześnie wyrażam zgodę na wykorzystanie w/w prac jako części rozprawy doktorskiej lek. Piotra Jankowskiego.

Urszula Szafrańska

(podpis oświadczającego)

Warszawa, 21.02.2025 r.

Prof. dr hab. n. med. Grzegorz Opolski

OŚWIADCZENIE

Jako współautor pracy pt. ***Active screening for COPD among hospitalized smokers - a feasibility study. (doi:10.1177/2040622320971111)*** oświadczam, że mój wkład merytoryczny w powstanie tej pracy obejmował opracowanie koncepcji badania oraz merytoryczne poprawki. Mój udział procentowy w przygotowanie publikacji wynosił 2%.

Jednocześnie wyrażam zgodę na wykorzystanie w/w prac jako części rozprawy doktorskiej lek. Piotra Jankowskiego.

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(podpis oświadczającego)

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