



MESTRADO INTEGRADO EM MEDICINA

2020/2021

Henrique de Mesquita Guimarães e Ferreira Cardoso
Pulmonary Auscultation using Mobile Devices – Feasibility Study
in Respiratory Diseases

Março, 2021

FMUP

Henrique de Mesquita Guimarães e Ferreira Cardoso
Pulmonary Auscultation using Mobile Devices – Feasibility Study
in Respiratory Diseases

Mestrado Integrado em Medicina

Área: Pediatria

Tipologia: Dissertação

Trabalho efetuado sob a Orientação de:

Prof. Doutora Maria Inês Ferreira Águeda de Azevedo

E sob a Coorientação de:

Prof. Doutora Cristina Isabel Oliveira Jácome

Prof. Doutor João de Almeida Lopes da Fonseca

Trabalho organizado de acordo com as normas da revista: Sensors

Março, 2021

Eu, Henrique de Resende Guimarães e Ferreira Cardoso, abaixo assinado, nº mecanográfico 201603977, estudante do 6º ano do Ciclo de Estudos Integrado em Medicina, na Faculdade de Medicina da Universidade do Porto, declaro ter atuado com absoluta integridade na elaboração deste projeto de opção.

Neste sentido, confirmo que **NÃO** incorri em plágio (ato pelo qual um indivíduo, mesmo por omissão, assume a autoria de um determinado trabalho intelectual, ou partes dele). Mais declaro que todas as frases que retirei de trabalhos anteriores pertencentes a outros autores, foram referenciadas, ou redigidas com novas palavras, tendo colocado, neste caso, a citação da fonte bibliográfica.

Faculdade de Medicina da Universidade do Porto, 16/03/2027

Assinatura conforme cartão de identificação:

Henrique Cardoso

NOME

Henrique de Resquto Queimadas e Ferreira Cardoso

NÚMERO DE ESTUDANTE

201503777

E-MAIL

hmqfcardoso@gmail.com

DESIGNAÇÃO DA ÁREA DO PROJECTO

Pediatrics

TÍTULO DISSERTAÇÃO/MONOGRAFIA (riscar o que não interessa)

Pulmonary Auscultation using Mobile Devices – Feasibility Study in Respiratory Diseases

ORIENTADOR

Prof. Doutora Maria Inês Ferreira Aguiar de Aguiar

COORDENADOR (se aplicável)

Prof. Doutora Cristina Isabel Oliveira Gomes

ASSINALE APENAS UMA DAS OPÇÕES:

É AUTORIZADA A REPRODUÇÃO INTEGRAL DESTA TRABALHO APENAS PARA EFEITOS DE INVESTIGAÇÃO, MEDIANTE DECLARAÇÃO ESCRITA DO INTERESSADO, QUE A TAL SE COMPROMETE.	☒
É AUTORIZADA A REPRODUÇÃO PARCIAL DESTA TRABALHO (INDICAR, CASO TAL SEJA NECESSÁRIO, Nº MÁXIMO DE PÁGINAS, ILUSTRAÇÕES, GRÁFICOS, ETC.) APENAS PARA EFEITOS DE INVESTIGAÇÃO, MEDIANTE DECLARAÇÃO ESCRITA DO INTERESSADO, QUE A TAL SE COMPROMETE.	☐
DE ACORDO COM A LEGISLAÇÃO EM VIGOR, (INDICAR, CASO TAL SEJA NECESSÁRIO, Nº MÁXIMO DE PÁGINAS, ILUSTRAÇÕES, GRÁFICOS, ETC.) NÃO É PERMITIDA A REPRODUÇÃO DE QUALQUER PARTE DESTA TRABALHO.	☐

Faculdade de Medicina da Universidade do Porto, 16/03/2021

Assinatura conforme cartão de identificação:

Henrique Cardoso

Pulmonary Auscultation using Mobile Devices – Feasibility Study in Respiratory Diseases

Henrique Ferreira-Cardoso¹, Cristina Jácome^{2,3}, Sónia Silva⁴, Adelina Amorim^{1,5}, Margarida T Redondo⁵, José Fontoura-Matias⁴, Margarida Vicente-Ferreira⁴, José Valente⁶, Pedro Vieira-Marques³, João Almeida Fonseca^{2,3,6}, Inês Azevedo^{4,7,8,*}

¹ Faculty of Medicine, University of Porto, Porto, Portugal; hmgfcardoso@gmail.com; adelinamorim@gmail.com.

² MEDCIDS - Department of Community Medicine, Health Information and Decision, Faculty of Medicine, University of Porto, Porto, Portugal; cjacome@med.up.pt; fonseca.ja@gmail.com.

³ CINTESIS - Center for Health Technology and Services Research, Faculty of Medicine, University of Porto, Porto, Portugal.

⁴ Department of Pediatrics, Centro Hospitalar Universitário de São João, Porto, Portugal; sonia.luisa.silva@ch-sj.min-saude.pt; zpfmatias@gmail.com; margaridasvf@hotmail.com; iazevedo@med.up.pt*.

⁵ Department of Pulmonology, Centro Hospitalar Universitário de São João, Porto, Portugal; margarida.tredondo@gmail.com.

⁶ MEDIDA - Serviços em Medicina, Educação, Investigação, Desenvolvimento e Avaliação, LDA, Porto, Portugal; josecfvalente@gmail.com.

⁷ Department of Obstetrics, Gynecology and Pediatrics, Faculty of Medicine, University of Porto, Porto, Portugal.

⁸ EpiUnit, Institute of Public Health, University of Porto, Porto, Portugal.

Abstract: Conventional lung auscultation is essential in the management of respiratory diseases. However, detecting adventitious sounds outside medical facilities remains challenging. We assessed the feasibility of lung auscultation using the smartphone's embedded microphone in real-world clinical practice. Ninety-five patients (median[interquartile range] 16[11–24]y; 52% female; 42 cystic fibrosis, 24 asthma, 17 other respiratory diseases and 12 no respiratory diseases) were recruited at Pediatrics and Pulmonology departments of a tertiary hospital. Clinicians performed conventional auscultation at 4 locations (trachea, right anterior chest, right and left lung bases), documenting any adventitious sounds. Smartphone auscultation was recorded in the same locations. The recordings (n=738) were classified by two annotators and agreement calculated (%; Cohen's k (95%CI)). Recordings with quality were obtained in 88% of the participants and 69% of the recordings (91%; $k=0.80$ (95%CI 0.75–0.85)), with the quality proportion being higher at the trachea (79%) and lower in the asthma group (52%). Adventitious sounds were present in only 27% of the participants and 12% of the recordings (91%; $k=0.57$ (95%CI 0.46–0.68)), which may have contributed to the fair agreement between conventional and smartphone auscultation (86%; $k=0.25$ (95%CI 0.13–0.37)). Our results show that smartphone auscultation was feasible, but further investigation is required to improve its agreement with conventional auscultation.

Keywords: respiratory sounds; auscultation; smartphone; mobile applications; asthma; cystic fibrosis; crackles; wheezes.

1. Introduction

Respiratory diseases are a major public health problem, with a growing burden to healthcare systems and to the society[1–3]. Asthma affects about 339 million people and represents the most common chronic pediatric disease[1,4]. The overall direct and indirect cost of uncontrolled asthma is high[5], with patients having up to 4.6-fold greater

frequency of hospitalizations compared to healthy individuals[6]. Similarly, cystic fibrosis has an incidence of 70000 to 100000 people worldwide and affects more and more the adult population[7,8]. Its main impact and cause of death are mostly due to respiratory failure associated with chronic and recurrent infections[9], and its overall cost tends to grow as the disease progresses[10].

The progressive deterioration of these respiratory diseases depends mostly on the occurrence of exacerbations, causing frequent unscheduled medical visits, emergency department visits and hospitalizations. This leads to the need of a closer monitoring of patients' respiratory status[4,9,11]. Lung auscultation continues to be an essential part of physical examination, as it does not require any special resources beyond a stethoscope[12], which remains an indispensable tool for diagnosis and management of respiratory diseases[13,14]. The presence and frequency of wheezing is key for the diagnosis, classification and management of asthma and its exacerbations[15], whereas in cystic fibrosis exacerbations can be identifiable by the increase of crackles, associated with increased production of sputum, cough and dyspnea[11,16]. However, conventional lung auscultation has well documented limitations, namely its dependence on the skill and auditory capacity of the clinician[17,18]. Although telemedicine has become more and more relevant[19,20], promoting patient-centered care, and avoiding costly, risky and possibly unnecessary trips to the hospital[21–23], the absence of an alternative to conventional auscultation remains a considerable limitation to the remote monitoring of these patients. The COVID-19 pandemics has brought an even greater need for innovative technologies to assess lung sounds, given the quarantine-related limitations of going to the hospital[24], the social distancing measures, and the clinicians' vestments, often impeditive of conducting this physical exam[25,26].

Digital auscultation consists of recording patients' lung sounds with an electronic device and classifying/analyzing them automatically based on specific signal characteristics. Guidelines for research and clinical practice regarding computerized lung sounds have been published in 2000 by the CORSA project group[27–29], standardizing the instrumentation, ways of acquiring data, procedures and signal processing techniques and nomenclature[27–29]. Digital auscultation has since shown to be of interest for the diagnosis and management of respiratory diseases, such as obstructive sleep apnea[30], chronic obstructive pulmonary disease[31,32] and asthma[33–35]. Kevat et al. has shown that automated computerized recording and analysis of lung sounds could outperform conventional auscultation in patients with cystic fibrosis or patients presenting wheezes/crackles[36], even though the study included only 20 children. Digital auscultation, however, has not been sufficiently studied outside the medical context and facilities, for example during the patient's everyday life. The use of the smartphone's embedded microphone to perform digital auscultation could be of great interest to further develop and implement telemedicine services in the management of respiratory diseases.

To contribute to answer these research and clinical unmet needs, we have developed the AIRDOC mobile application (app), to support the remote monitoring of lung sounds in patients with chronic respiratory diseases[37] namely by enabling lung auscultation through the smartphone's built-in microphone[19,37]. To the best of our knowledge, solutions similar to the one henceforth described are not currently available, making it one of the first solutions based solely on software and on the use of smartphone embedded sensors, avoiding the use of additional equipment connected to mobile devices[37]. We believe this is a promising technology to boost the usefulness of lung auscultation and to support telemedicine, as well as improve self-management of patients with chronic respiratory diseases. The app takes advantage of the smartphones' ubiquity in everyday lives[14,37,38], as well as their portability, their recording, storing and computation features[38]. However, initial testing is still required to assess the feasibility of the lung auscultation through the app in clinical context.

We aimed to study the feasibility of lung auscultation in clinical context using the smartphone's built-in microphone, by assessing the quality of the recorded lung sounds

and the smartphone's capability of capturing adventitious sounds. Our secondary aims were to compare the findings of smartphone auscultation with those of conventional auscultation, to compare the quality of the recordings and the identification of adventitious sounds in different respiratory diseases and to create a lung sounds database that will support, in the future, the development and validation of sound processing methods.

2. Materials and Methods

Study design

An observational cross-sectional study was conducted with children and adults between September 2020 and March 2021. Patients were invited to participate during scheduled medical appointments by the clinicians, who then conducted the data collection. Prior to data collection, written informed consent was obtained from all the adult patients, as well as from the legal guardians of every child between 5 to 17 years old (Appendices A and B). In adolescents aged 14 to 17 years old, written informed assent was also obtained (Appendix C). Approval for this study was obtained from the ethics committee of Centro Hospitalar Universitário de São João (CHUSJ) – Faculty of Medicine of University of Porto (FMUP) (reference 316/20, September 18th, 2020; Annex A and Appendix D). The study reporting followed the strengthening the reporting of observational studies in epidemiology (STROBE) guidelines[39].

Patients

Patients were included if aged 5 or over and were under medical follow-up in the Pediatrics or Pulmonology departments of CHUSJ, a tertiary hospital. Exclusion criteria included refusal to participate and patients whose health status or condition prevented a harmless collection of their lung sounds. The included patients were grouped in 4 diagnostic groups, according to their previously established diagnosis: cystic fibrosis, asthma, other respiratory diseases or no respiratory diseases. The patients with no respiratory diseases were either patients with suspected respiratory diseases, which was not confirmed during the appointment, or patients from the adolescents' Attention Deficit Hyperactivity Disorder appointments from the Pediatrics department.

AIRDOC mobile application (app)

The AIRDOC mobile app aims to monitor and coach individuals with chronic respiratory diseases, using the smartphone and its integrated sensors. It enables the recording of sounds, from lung auscultation or forced expiratory maneuvers, as well as to complete validated questionnaires[37]. In this study, only the lung auscultation feature was used.

The app runs on iOS and on Android. Each investigator or recruiting clinician has created a profile in the app, in order to access the app's functionalities. Lung auscultation feature enables the recording of lung sounds in the 7 locations recommended by CORSA or others, with an adjustable duration. Each recording includes information of the location and duration, being also possible to write additional information in a note field. In this study, this field was used to register the patients' ID and any relevant occurrence during the recording. The AIRDOC app screens are depicted in Figure 1.

The app can be used offline (to facilitate its use in the clinical context) and whenever an internet connection is available, the mobile app automatically transfers the sound files to an online server at the FMUP, from which the recordings can be accessed.

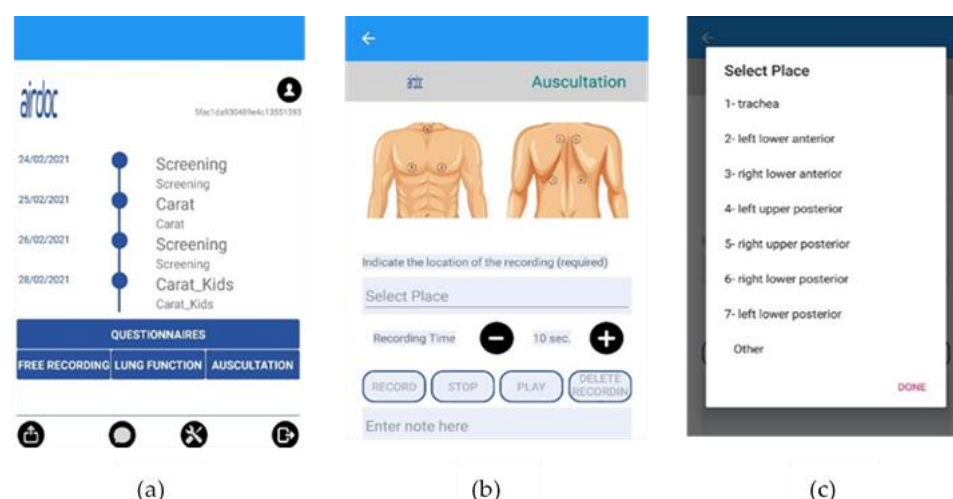


Figure 1. AIRDOC app screens: (a) main screen; (b) lung auscultation feature; (c) location selection.

Data collection

Patients' sex, age and height, as well as any previously diagnosed respiratory disease (no respiratory diseases, asthma, cystic fibrosis or other respiratory diseases), were initially documented in a case report form (Appendix E). Conventional lung auscultation with a stethoscope (Littman Classic III or Littman Cardiology IV, 3M™ Littman®, Maplewood, Minnesota, USA) was then performed by the recruiting clinicians (4 pediatricians, 2 pulmonologists and a final-year medical student), and any positive findings, namely the presence of adventitious sounds, were documented. Patients were in a seated upright position[28]. Adventitious sounds were defined as wheezes (adventitious, continuous sound having a musical character[29]) or crackles (adventitious, discontinuous, explosive sound occurring usually during inspiration[29]). The conventional auscultation was performed at 4 locations: the 3 locations described as the minimal recommended by CORSA – the trachea and the right and left posterior bases of the lungs[28] – and we chose to include additionally the right anterior chest, given the high prevalence of adventitious sounds in the right middle lobe[40]. The selected locations can be seen in Figure 2.

Lung auscultation was performed with each clinician's smartphone, in the same 4 locations, using the AIRDOC app. In total, 8 different smartphones were used for lung sound recordings, all covered with a sanitized plastic case: an iPhone 12 Pro (iOS 14.4), an iPhone XR (iOS 14.2), an iPhone 8 (iOS 14.0), an iPhone 7 (iOS 14.1), a Xiaomi M9 Pro (Android 10), an iPhone 6s (iOS 13.6.1), a Huawei p10 lite (EMUI 8) and a One Plus 7 Pro (Android 10). The auscultation process consisted of firmly pressing the smartphone's microphone to the patient's skin and keeping it stabilized, during which the patient was asked to breathe deeply with an open mouth[28]. Since data collection took place during the COVID-19 pandemics, the patients and the clinicians wore a mask during the procedures. Each auscultation location was recorded twice for 5 – 10s, allowing to include between 1 to 5 respiratory cycles, as recommended[13,27]. An example can be found in Figure 2.

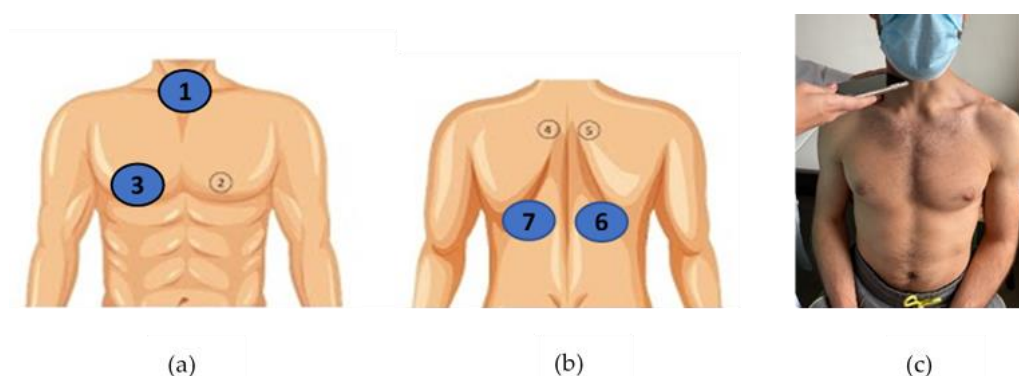


Figure 2. CORSA locations for lung sound recordings: (a) trachea (1) and right anterior chest (3); (b) right and left posterior bases (6 and 7); (c) example of a sound recording at the trachea during a medical appointment.

Data analysis

Descriptive statistics were used to characterize the sample regarding sex, age, height, and the previously diagnosed respiratory disease (or absence of it). Kolmogorov-Smirnov tests were used to assess the normality of the data. To explore the existence of differences across the 4 diagnostic groups, Chi-Square tests (sex, age group) and ANOVA tests (height, age) were used.

The lung sound recordings were listened to independently by two annotators (H.F.C., a final-year medical student and C.J., a physiotherapist/ lung sound expert) using Adobe Audition® CC 2020 version 13.0.11.38 (Adobe Inc®, San Jose, California, USA). Both annotators used high-quality headsets (Sennheiser® HD 380 pro, Wedemark, Germany, and Sony® WH-XB900N, Tokyo, Japan), while simultaneously viewing the sound spectrogram. The quality of each recording was evaluated, following the European Respiratory Society definition: a sound in which there is minimal artefact, respiratory phases are visible and a sound of interest can be demonstrated[41]. In this phase, disagreement between the two annotators was settled by consensus and only the lung sounds with quality were considered for further analysis. Both annotators then classified the lung sound recordings regarding the presence of identifiable adventitious sounds such as wheeze or crackles. When there was disagreement between the two annotators, a third annotator (I.A., a pediatric pulmonologist) was asked to independently classify the recordings in question, using a high-quality headset (Sennheiser® PXC 550, Wedemark, Germany) and the same audio software. The decision was then taken by majority rule.

Before settling the disagreement in both classifications (quality and the presence of adventitious sounds), the percentage of agreement between the two annotators and their inter-rater agreement were calculated, the latter by use of Cohen's Kappa (k) and its 95% Confidence Intervals (95%CI). This was done for the total sample of recordings and considering the recordings of each auscultation location, age group (children/adults) or diagnostic group. The Kappa values were interpreted as follows: 0–0.20 slight, 0.21–0.40 fair, 0.41–0.60 moderate, 0.61–0.80 substantial, and 0.81–1.0 almost perfect agreement[42].

The proportion of participants with at least one recording with quality and at least one recording with adventitious sounds (regardless of the auscultation location) were calculated for each age group and diagnostic group. The proportion of recordings with quality and the proportion of recordings with adventitious sounds were also calculated for each auscultation location, age group and diagnostic group. A Chi-Square test, with Bonferroni correction when needed, was used to explore any differences in the proportions between these groups.

Finally, the proportion of participants in which an adventitious sound was found in conventional auscultation was compared to the proportion of participants with at least one recording with adventitious sounds (percentage of agreement, k). This was done for

each age group and diagnostic group. The agreement between the two methods was also explored (percentage of agreement, k). This was done for each auscultation location, age group and diagnostic group.

The statistics software used was IBM® SPSS® Statistics (version 27.0.1.0, Chicago, Illinois, USA). The level of significance was set at 0.05.

3. Results

3.1. Participant's characteristics

A total of 103 participants were recruited, but 10 participants were only recorded in 7 locations, and one participant only in 5 locations, making a total of 811 recordings, as presented in Figure 3. However, due to technical issues concerning the app communication with the server, only 95 participants could be included in the analysis: 42 with cystic fibrosis, 24 with asthma, 17 with other respiratory diseases and 12 with no respiratory diseases. Of the 95 participants, 52% were female and 63% were children. The median [interquartile-IQR] age was 16 [11 – 24] years, whereas the median height was 1.59 [1.48 – 1.66] meters. The only statistically significant difference that was found among groups concerned age, with the participants in the asthma group (11 [9 – 16] years old) being significantly younger than those with cystic fibrosis (21 [13 – 32] years old) or those with other respiratory diseases (17 [13 – 50] years old). The participants' characteristics are presented in Table 1.

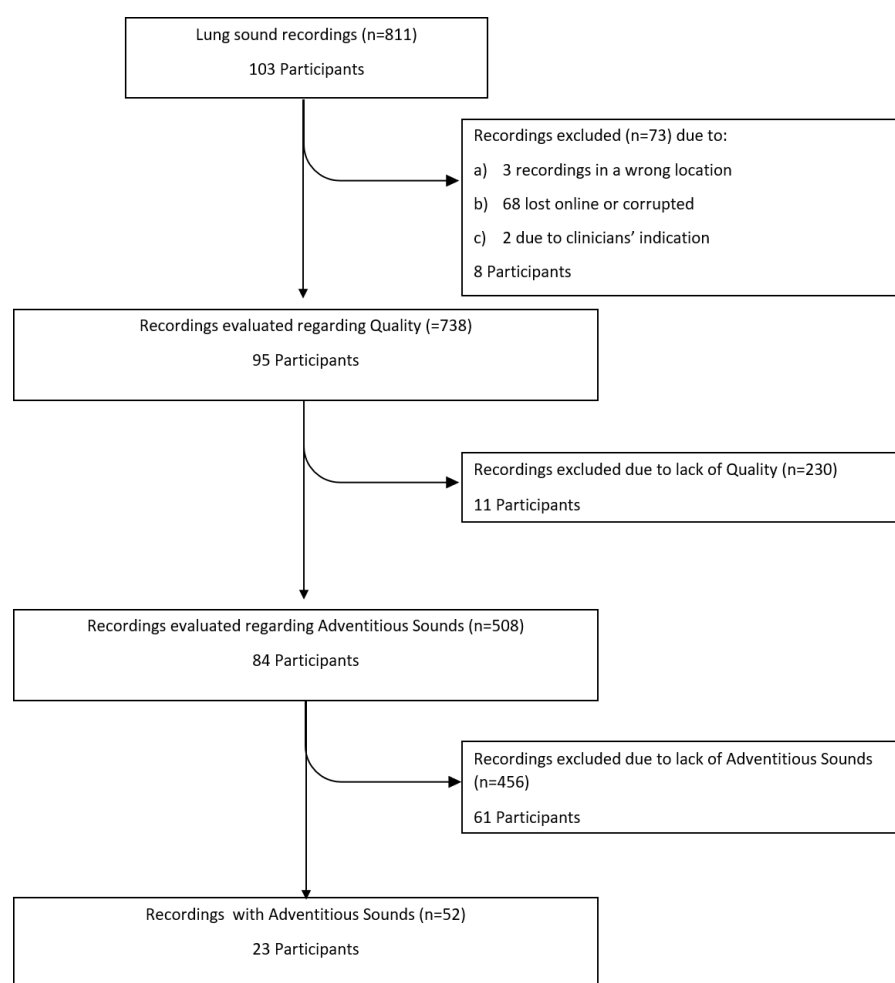


Figure 3. Flowchart with the number of recordings and participants throughout the study.

Table 1. Participants' characteristics (n=95).

239

Characteristics	Total	Cystic Fibrosis	Asthma	Other Respiratory Diseases	No Respiratory Diseases
Subjects, n	95	42	24	17	12
Children, %	63	36	92	63	65
Female, %	52	55	42	59	42
Age, median [Q1 – Q3] y	16 [11 – 24]	21 [13 – 32]	11 [9 – 16]	17 [13 – 50]	14 [10 – 16]
Height, median [Q1 – Q3] m	1.59 [1.48 – 1.66]	1.60 [1.53 – 1.68]	1.50 [1.38 – 1.60]	1.59 [1.48 – 1.63]	1.59 [1.46 – 1.65]

240

Q1 – Q3: interquartile range between the 25th and the 75th percentile.

241

3.2. Quality classification

242

As shown in Figure 3, 738 recordings were listened to and classified by both annotators. An agreement of 91% and a kappa of 0.80 were obtained. Regarding the auscultation location, the trachea and the right anterior chest had a percentage of agreement of 95% and 93%, respectively, and an almost perfect inter-rater agreement (both $k=0.85$). The posterior bases showed a slightly lower percentage of agreement (88%) and a substantial inter-rater agreement ($k=0.75$ in the right base and $k=0.76$ in the left base). The percentage of agreement was similar in both age groups (90% and 93%), with a slightly lower inter-rater agreement in the children's recordings ($k=0.77$ vs adults $k=0.85$). Regarding the diagnostic groups, the asthma group had the lowest percentage of agreement (83%) and inter-rater agreement ($k=0.66$), when compared to the other 3 groups, whose range of percentage of agreement was 92% – 97% and inter-rater agreement was 0.80 – 0.92. The inter-rater agreement between the two annotators can be found in Figure 4 and in Supplementary Table 1.

243

244

245

246

247

248

249

250

251

252

253

254

255

256

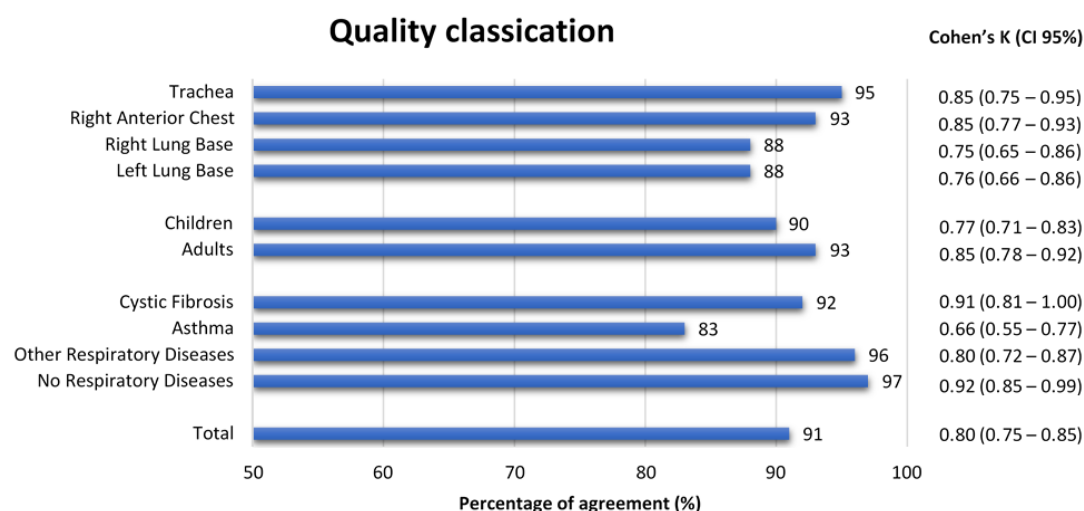


Figure 4. Percentage of agreement and inter-rater agreement on the quality classification of lung sound recordings.

3.3. Proportion of quality

The final classification on quality, showed that 84 (88%) participants had at least one lung sound recording with quality. No differences were found between age or diagnostic groups. These results can be found in Supplementary Tables 2 and 3.

Regarding the total number of recordings that were listened to, 508 were considered to have quality (69%). The proportion of quality sounds found in the trachea (79%) was significantly higher than the one found in the right and left posterior bases (60% and 66%, respectively). The asthma group was found to have a significantly lower proportion of quality recordings (52%) when compared to all other three groups. All other comparisons were not statistically significant. These results can be found in Table 2 and in Supplementary Table 4.

Table 2. Proportion of sounds with quality.

		With quality	No quality	Proportion (%)
Location	Trachea (n=187)	148	39	79
	Right Anterior Chest (n=182)	128	54	70
	Right Posterior Base (n=187)	112	75	60
	Left Posterior Base (n=182)	120	62	66
Age group	Children (n=458)	308	150	67
	Adults (n=280)	200	80	71
Diagnostic group	Cystic Fibrosis (n=338)	257	81	76
	Asthma (n=169)	88	81	52
	Other Respiratory Diseases (n=138)	93	45	67
	No Respiratory Diseases (n=93)	70	23	75
	Total (n=738)	508	230	69

3.4. Adventitious sounds classification

The 508 files that were considered to have quality were classified regarding the presence of adventitious sounds. A 91% agreement and an inter-rater agreement of $k=0.57$ was found between annotators. Concerning the auscultation location, the right and left bases showed a greater percentage of agreement (92% and 94%, respectively) and a greater inter-rater agreement ($k=0.65$ and $k=0.66$) than the other two auscultation locations, whose range percentage of agreement and inter-rater agreement were 86% – 91% and 0.47 – 0.56, respectively. Although the percentage of agreement for both age groups was similar (90% and 92%), the inter-rater agreement in the adults' group ($k=0.64$) was slightly higher than that of the children's group ($k=0.53$). Concerning the diagnostic groups, although the percentage of agreement ranged 89% – 95% in all 4 groups, the asthma and cystic fibrosis groups showed a considerably lower inter-rater agreement ($k=0.11$ and $k=0.38$, respectively) when compared to the other 2 groups, whose inter-rater agreement ranged 0.62 – 0.86%. The inter-rater agreement between the two annotators can be found in Figure 5. The results can also be found in Supplementary Table 1.

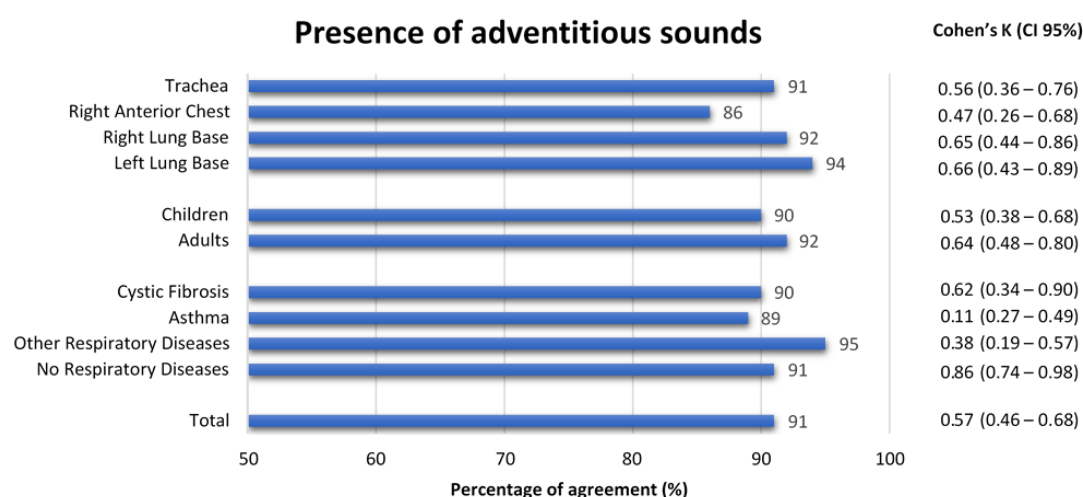


Figure 5. Percentage of agreement and inter-rater agreement on the presence of adventitious sounds in the lung sound recordings.

3.5. Proportion of adventitious sounds

The final classification on the presence of adventitious sounds (based on the majority rule), showed that 23 (27%) participants had at least one lung sound recording with adventitious sounds (Figure 3). No differences were found between age or diagnostic groups. These results can be found in Supplementary Tables 2 and 3.

Concerning the recordings, only 52 (12%) of the recordings with quality had adventitious sounds. The proportion of adventitious sounds detected across each auscultation location and each age group was not significantly different. However, the proportion of adventitious sounds in the group with other respiratory diseases was found to be significantly higher when compared to the asthma and the cystic fibrosis groups. The results can be found in Table 3 and Supplementary Table 4.

Table 3. Proportion of adventitious sounds.

308

	Adventitious Sounds	Present	Absent	Proportion (%)
Location	Trachea (n=148)	14	134	9
	Right Anterior Chest (n=128)	17	111	13
	Right Posterior Base (n=112)	12	100	11
	Left Posterior Base (n=120)	9	111	8
Age group	Children (n=308)	29	279	9
	Adults (n=200)	23	177	12
Diagnostic group	Cystic Fibrosis (n=257)	17	240	7
	Asthma (n=88)	4	84	5
	Other Respiratory Diseases (n=93)	23	70	25
	No Respiratory Diseases (n=70)	8	62	11
Total (n=508)		52	456	12

309

3.6. Conventional and smartphone auscultation

310

Conventional auscultation identified adventitious sounds in 21 (25%) participants. These were significantly less frequent in the asthma group, when compared to the cystic fibrosis group and the group with no respiratory diseases. These results can be found in Supplementary Tables 2 and 3. Regarding the smartphone auscultation, as mentioned above, 23 (27%) participants had at least one recording with adventitious sounds. A 69% agreement and a kappa of 0.20 [0.03 – 0.43] were found between the two methods. These results can be found in Supplementary Table 5.

311

312

313

314

315

316

317

Concerning the recordings, the comparison between conventional and smartphone auscultation evidenced a low value of kappa ($k=0.25$), despite having a high percentage of agreement (86%). Regarding the auscultation location, the percentage of agreement was similar across all 4 groups (81% – 89%), while the inter-rater agreement ranged 0.15 – 0.34, with the trachea having the lowest value of kappa ($k=0.15$). Concerning the age group, the children's group had a higher percentage of agreement (88%) and inter-rater agreement ($k=0.33$) when compared to the group with adults, whose percentage of agreement was 80% and inter-rater agreement was 0.17. Finally, in terms of diagnostic groups, the group with other respiratory diseases had a percentage of agreement of 88% and had the greatest inter-rater agreement ($k=0.53$), while the cystic fibrosis group, with a percentage of agreement of 82%, had a close-to-zero value of $k=0.095$. In the group with no respiratory diseases and in the asthma group (89% and 95% of agreement, respectively), the Cohen's Kappa could not be calculated because the stethoscope's classification had no positive findings. The results can be found in Figure 6. The results can also be found in Supplementary Table 5.

318

319

320

321

322

323

324

325

326

327

328

329

330

331

332

333

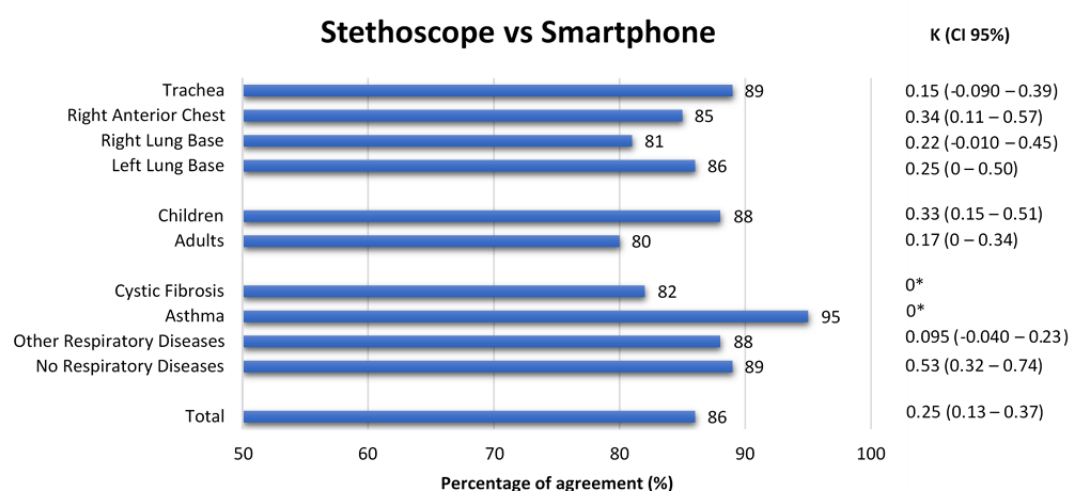


Figure 6. Percentage of agreement and inter-rater agreement between the stethoscopes' and the smartphones' classification regarding the presence of adventitious sounds in the recordings.

*Cohen's Kappa was not calculated because the stethoscope's classification was constant.

4. Discussion

To the best of our knowledge, this is the first study that assessed the feasibility of lung auscultation using only the smartphone's embedded microphone in real-world clinical practice. Our results, namely the high proportion of participants with at least one recording with quality (88%) and the 27% of participants with identified adventitious sounds, demonstrate that smartphone auscultation is feasible using a simple set-up applied during medical appointments. Both the conventional and smartphone auscultations were performed without the need of any person or instrument besides the clinician, a conventional stethoscope, and the clinicians' own smartphone – thus reinforcing the feasibility and practicality of using the AIRDOC app in the everyday clinical context. These results can, in the future, help to achieve a further clinical acceptance and utility of digital auscultation, as the sole use of a smartphone does not require any additional equipment[43] or extra cost, and can be used outside the medical context and facilities.

Regarding the quality of the sounds, the inter-rater agreement was found to be similar to previous studies using conventional or modified stethoscopes and objective acoustical analysis by experts[17,41]. This, adding to the high proportion of recordings with quality, which amounted to two thirds, shows that the smartphone's embedded microphone can be successful in recording lung sounds, and therefore that auscultation using a smartphone is feasible. Besides, the lack of quality in the excluded recordings was mostly attributable to outside noise or interference, misplacement of the smartphone or to poor respiratory pattern by the participants (e.g., low volume). The latter might be particularly true in the asthma group, which had a significantly lower proportion of sounds with quality, as the participants' physiological volumes[44] might, possibly, have diffculted the recording of lung sounds with enough intensity[45] to be classified as having quality. As for the higher proportion of sounds with quality that was found in the trachea, it has been previously reported that respiratory sounds acquired at the trachea are higher in intensity and easier to capture than sounds from the chest wall[46].

The inter-rater agreement concerning the presence of adventitious sounds was also similar to what has been reported in the literature, including studies performed in more controlled settings[17,41]. Although only 12% of the recordings had an identifiable adventitious sound, the percentage of participants with at least one recording with adventitious sounds (27%) was similar to the prevalence found in the Tromsø population (28%), even though the Tromsø study recorded the lung sounds with a microphone-coupled stethoscope[47]. It is, however, worth mentioning that both wheezes and crackles in-

crease with age[47–49], and that the Tromsø population's mean age (63.7 (± 10.5) years old) is considerably higher than our population's median age (16 [11 – 24] years old). For safety concerns related with the pandemics, patients were not observed in the outpatient department if they had acute exacerbations, but instead in the emergency room. This precluded inclusion of patients with worst respiratory health status in the present study, thus decreasing the probability of finding abnormal lung sounds. Moreover, similarly to the quality classification, the asthma and the cystic fibrosis groups' had significantly lower proportion of adventitious sounds, which might be explained by their decreased physiological volumes, possibly associated with fewer wheezes and crackles[50,51]. Another possible explanation is the fact that the COVID-19 pandemics has been linked to a decrease in the incidence of exacerbations in both asthma and cystic fibrosis[52,53], and therefore of identifiable adventitious sounds. Finally, although the presence of adventitious sounds in healthy individuals is well documented[54–56], our findings of 11% of the participants with no respiratory diseases presenting adventitious sounds might be attributable to the fact that some of these participants were being followed in the outpatient clinic due to a possible, but still undiagnosed respiratory disease.

The comparisons between the stethoscopes' and the smartphones' findings, despite having identified adventitious sounds in a similar percentage of participants (25% and 27%, respectively), have shown only some range of agreement. One possible factor that might have contributed to different classifications is the fact that conventional auscultation in the clinical context is often only performed during 1 respiratory cycle per location and that, unlike the lung sound recordings, conventional auscultation cannot be re-heard or played back. Besides, in our study, the respiratory cycles which were heard with the stethoscope were never the same respiratory cycles that were recorded with the smartphone, as these two procedures were done separately[57,58]. This might account for some of the disagreement between the two auscultation methods' findings too. To overcome this limitation, in future investigations, it would be interesting to record the lung sounds and perform the conventional auscultation simultaneously, so that the same respiratory cycles were listened to and classified. Other studies which have compared conventional auscultation with lung sound recordings (with digital stethoscopes and not with a smartphone) have documented percentages of agreement ranging from 75% to 100%[36,59], which are similar to the 69% and the 86% percentages of agreement found in our study (regarding the participants and the recordings, respectively). Our study's inter-rater agreement ($k=0.20$ and $k=0.25$), however, was lower than these studies' (ranging from 0.44 to 0.55[36,59]), which can be attributable to the fact that our study was conducted in a real-world clinical context. Besides, our kappa values may be hampered by the low proportion of adventitious sounds that were found, as the Cohen's Kappa calculus is prevalence-dependent[60].

Our study has some limitations that need to be acknowledged. Our population is relatively small-sized, but considering the short recruitment period and the COVID-19 pandemics scenario in Portugal, which has replaced most presential medical appointments by remote appointments, we consider it positive that so many participants and clinicians could be involved – once again reinforcing the feasibility and practicality of this technology. Due to this small-sized population, and as this is an initial study, our inferential analysis focused more on the recordings than in the participants. In future studies, with a larger population, it would be interesting to focus the scope of the inferential analysis in the participants. Another limitation is related with the different smartphones used for the recordings, whose specifications could not be thoroughly described and were therefore not studied as variables in this investigation - a factor that merits to be explored in future studies. Besides, the use of face masks, due to the pandemic, made it difficult for the clinicians to explain and correct the respiratory pattern during recordings, which may have possibly influenced the understanding and compliance with the respiratory pattern required. However, this study has collected a great number of lung sound recordings, which will allow further studies and the development of new methods

of automatic lung sound analysis, as well as the improvement of the already existent, which were developed to deal with digital stethoscope's recordings, and not with smartphones' recordings.

We believe this to be a promising technology, both for the clinical context and for the future implementation of telemedicine and remote appointments, as the smartphone can enable the clinician, and even the patient him/herself, with a ubiquitous, wireless, and practical instrument to assess and monitor his/her respiratory status and health.

5. Conclusions

The main findings suggest that lung auscultation with the different smartphones' embedded microphones is feasible in the clinical context, as it can record lung sounds with quality and can successfully record adventitious sounds. Further investigation is required to further develop this and improve the agreement between this technology and conventional auscultation.

Author Contributions: Conceptualization, H.F.C., C.J., J.A.F., I.A.; Methodology, H.F.C., C.J., J.A.F., I.A.; development of the AIRDOC application, J.A.F., C.J.; data collection, H.F.C., I.A., S.S., A.M., M.R., J.F.M., M.F.; data analysis, H.F.C., C.J.; original draft preparation, H.F.C.; writing—review and editing, H.F.C., C.J. I.A., J.A.F., S.S., A.M., M.R., J.F.M., M.F.. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee Centro Hospitalar Universitário de São João (CHUSJ) - Faculty of Medicine of University of Porto (FMUP) (reference 316/20, September 18th, 2020).

Informed Consent Statement: Written informed consent was obtained from all subjects involved in the study.

Acknowledgments: We thank all the participants for who were enrolled in this study.

Conflicts of Interest: The authors declare no conflict of interest.

References

- European Respiratory Society, 2017 Forum of International Respiratory Societies The Global Impact of Respiratory Disease. 2017, 1–43. Available online: https://www.who.int/gard/publications/The_Global_Impact_of_Respiratory_Disease.pdf (accessed on Mar 1, 2021).
- Gibson, G.J.; Loddenkemper, R.; Lundbäck, B.; Sibille, Y. Respiratory health and disease in Europe: The new European Lung White Book. *Eur. Respir. J.* 2013, 42, 559–563, doi:10.1183/09031936.00105513.
- Soriano, J.B.; Kendrick, P.J.; Paulson, K.R.; Gupta, V.; Abrams, E.M.; Adedoyin, R.A.; Adhikari, T.B.; Advani, S.M.; Agrawal, A.; Ahmadian, E.; et al. Prevalence and attributable health burden of chronic respiratory diseases, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet Respir. Med.* 2020, 8, 585–596, doi:10.1016/S2213-2600(20)30105-3.
- WHO Global Asthma Network The Global Asthma Report; 2018; ISBN 9780473465230. Available online: <http://globalasthmareport.org/> (accessed on Mar 1, 2021).
- Ferreira de Magalhães, M.; Amaral, R.; Pereira, A.M.; Sá-Sousa, A.; Azevedo, I.; Azevedo, L.F.; Fonseca, J.A. Cost of asthma in children: A nationwide, population-based, cost-of-illness study. *Pediatr. Allergy Immunol.* 2017, 28, 683–691, doi:10.1111/pai.12772.

6. Nunes, C.; Pereira, A.M.; Morais-Almeida, M. Asthma costs and social impact. *Asthma Res. Pract.* 2017, 3, 1, doi:10.1186/s40733-016-0029-3. 471
472
7. Scotet, V.; L'hostis, C.; Férec, C. The changing epidemiology of cystic fibrosis: Incidence, survival and impact of the CFTRGene discovery. *Genes (Basel)*. 2020, 11, doi: 10.3390/genes11060589. 473
474
8. Kelly, J. Environmental scan of cystic fibrosis research worldwide. *J. Cyst. Fibros.* 2017, 16, 367–370, doi:10.1016/j.jcf.2016.11.002. 475
476
9. Schwarz, C.; Staab, D. Zystische Fibrose und ihre Komplikationen. *Internist* 2015, 56, 263–274, doi:10.1007/s00108-014-3646-z. 477
478
10. Van Gool, K.; Norman, R.; Delatycki, M.B.; Hall, J.; Massie, J. Understanding the costs of care for cystic fibrosis: An analysis by age and health state. *Value Heal.* 2013, 16, 345–355, doi:10.1016/j.jval.2012.12.003. 479
480
11. Bilton, D.; Canny, G.; Conway, S.; Dumcius, S.; Hjelte, L.; Proesmans, M.; Tümmler, B.; Vavrova, V.; De Boeck, K. Pulmonary exacerbation: Towards a definition for use in clinical trials. Report from the EuroCareCF Working Group on outcome parameters in clinical trials. *J. Cyst. Fibros.* 2011, 10, doi:10.1016/S1569-1993(11)60012-X. 481
482
483
12. Bohadana, A.; Izbicki, G.; Kraman, S.S. Fundamentals of lung auscultation. *N. Engl. J. Med.* 2014, 370, 744–751, doi:10.1056/NEJMra1302901. 484
485
13. Sarkar, M.; Madabhavi, I.; Niranjana, N.; Dogra, M. Auscultation of the respiratory system. *Ann. Thorac. Med.* 2015, 10, 158–168, doi: 10.4103/1817-1737.160831. 486
487
14. Tabatabaei, S.A.H.; Fischer, P.; Schneider, H.; Koehler, U.; Gross, V.; Sohrabi, K. Methods for Adventitious Respiratory Sound Analyzing Applications Based on Smartphones: A Survey. *IEEE Rev. Biomed. Eng.* 2020, 1–1, doi:10.1109/RBME.2020.3002970. 488
489
490
15. Global Initiative for Asthma Global Strategy for Asthma Management and Prevention Updated 2020 Available online: www.ginasthma.org (accessed on Mar 1, 2021). 491
492
16. Regelman, W.E.; Schechter, M.S.; Wagener, J.S.; Morgan, W.J.; Pasta, D.J.; Elkin, E.P.; Konstan, M.W. Pulmonary exacerbations in cystic fibrosis: Young children with characteristic signs and symptoms. *Pediatr. Pulmonol.* 2013, 48, 649–657, doi:10.1002/ppul.22658. 493
494
495
17. Brooks, D.; Thomas, J. Interrater reliability of auscultation of breath sounds among physical therapists. *Phys. Ther.* 1995, 75, 1082–1088, doi:10.1093/ptj/75.12.1082. 496
497
18. Piirila, P.; Sovijarvi, A.R.A. Crackles: Recording, analysis and clinical significance. *Eur. Respir. J.* 1995, 8, 2139–2148, doi: 10.1183/09031936.95.08122139. 498
499
19. Waller, M.; Stotler, C. Telemedicine: a Primer. *Curr. Allergy Asthma Rep.* 2018, 18, 54, doi: 10.1007/s11882-018-0808-4. 500
20. Mann, D.M.; Chen, J.; Chunara, R.; Testa, P.A.; Nov, O. COVID-19 transforms health care through telemedicine: Evidence from the field. *J. Am. Med. Inform. Assoc.* 2020, 27, 1132–1135, doi:10.1093/jamia/ocaa072. 501
502
21. Markwick, L.; McConnochie, K.; Wood, N. Expanding telemedicine to include primary care for the urban adult. *J. Health Care Poor Underserved* 2015, 26, 771–776, doi:10.1353/hpu.2015.0078. 503
504
22. McConnochie, K.M.; Wood, N.E.; Herendeen, N.E.; Ng, P.K.; Noyes, K.; Wang, H.; Roghmann, K.J. Acute illness care patterns change with use of telemedicine. *Pediatrics* 2009, 123, doi:10.1542/peds.2008-2698. 505
506
23. Gupta, G. Are medical apps the future of medicine? *Med. J. Armed Forces India* 2013, 69, 105–106, doi: 10.1016/j.mjafi.2013.02.013. 507
508
24. Ramos-Lacuey, B.; Herranz Aguirre, M.; Calderón Gallego, C.; Ilundain López de Munain, A.; Gembero Esarte, E.; Moreno-Galarraga, L. ECIEN-2020 study: the effect of COVID-19 on admissions for non-COVID-19 diseases. *World J. Pediatr.* 2021, 17, doi:10.1007/s12519-020-00406-9. 509
510
511
25. Faezipour, M.; Abuzneid, A. Smartphone-based self-testing of COVID-19 using breathing sounds. *Telemed. e-Health* 2020, 512

- 26, 1202–1205, doi:10.1089/tmj.2020.0114. 513
26. Beaney, T.; Salman, D.; Samee, T.; Mak, V. Assessment and management of adults with asthma during the covid-19 pandemic. *BMJ* 2020, 369, doi:10.1136/bmj.m2092. 514
27. Charbonneau, G.; Ademovic, E.; Cheetham, B.M.G.; Malmberg, L.P.; Vanderschoot, J.; Sovijärvi, A.R.A. Basic techniques for respiratory sound analysis. *Eur. Respir. Rev.* 2000, 10, 625–635. 515
28. M. Rossi, A.R.A. Sovijärvi, P. Piirilä, L. Vannuccini, F. Dalmaso, J.V. Environmental and subject conditions and breathing manoeuvres for respiratory sound recordings. *Eur. Respir. Rev.* 2000, 10, 611–615. 516
29. Sovijärvi, A.R.A.; Dalmaso, F.; Vanderschoot, J.; Malmberg, L.P.; Righini, G.; Stoneman, S.A.T. Definition of terms for applications of respiratory sounds. *Eur. Respir. Rev.* 2000, 10, 597–610. 517
30. Fino, E.; Mazzetti, M. Monitoring healthy and disturbed sleep through smartphone applications: a review of experimental evidence. *Sleep Breath.* 2019, 23, 13–24, doi: 10.1007/s11325-018-1661-3. 518
31. Sánchez Morillo, D.; Astorga Moreno, S.; Fernández Granero, M.Á.; León Jiménez, A. Computerized analysis of respiratory sounds during COPD exacerbations. *Comput. Biol. Med.* 2013, 43, 914–921, doi:10.1016/j.compbiomed.2013.03.011. 519
32. Jácome, C.; Oliveira, A.; Marques, A. Computerized respiratory sounds: a comparison between patients with stable and exacerbated COPD. *Clin. Respir. J.* 2017, 11, 612–620, doi:10.1111/crj.12392. 520
33. Shimoda, T.; Obase, Y.; Nagasaka, Y.; Nakano, H.; Kishikawa, R.; Iwanaga, T. Lung Sound Analysis and Airway Inflammation in Bronchial Asthma. *J. Allergy Clin. Immunol. Pract.* 2016, 4, 505–511, doi:10.1016/j.jaip.2016.02.001. 521
34. Shimoda, T.; Obase, Y.; Nagasaka, Y.; Nakano, H.; Ishimatsu, A.; Kishikawa, R.; Iwanaga, T. Lung sound analysis helps localize airway inflammation in patients with bronchial asthma. *J. Asthma Allergy* 2017, 10, 99–108, doi:10.2147/JAA.S125938. 522
35. Shimoda, T.; Obase, Y.; Nagasaka, Y.; Nakano, H.; Kishikawa, R.; Iwanaga, T. Lung sound analysis can be an index of the control of bronchial asthma. *Allergol. Int.* 2017, 66, 64–69, doi:10.1016/j.alit.2016.05.002. 523
36. Kevat, A.C.; Kalirajah, A.; Roseby, R. Digital stethoscopes compared to standard auscultation for detecting abnormal paediatric breath sounds. *Eur. J. Pediatr.* 2017, 176, 989–992, doi:10.1007/s00431-017-2929-5. 524
37. Almeida, R.; Jácome, C.; Martinho, D.; Vieira-Marques, P.; Jacinto, T.; Ferreira, A.; Almeida, A.; Martins, C.; Pereira, M.; Pereira, A.; et al. AIRDOC: Smart mobile application for individualized support and monitoring of respiratory function and sounds of patients with chronic obstructive disease. In Proceedings of the Proceedings of the 12th IADIS International Conference e-Health 2020, EH 2020 - Part of the 14th Multi Conference on Computer Science and Information Systems, MCCSIS 2020; 2020; pp. 78–88. 525
38. Reyes, B.A.; Reljin, N.; Chon, K.H. Tracheal sounds acquisition using smartphones. *Sensors (Switzerland)* 2014, 14, 13830–13850, doi:10.3390/s140813830. 526
39. Von Elm, E.; Altman, D.G.; Egger, M.; Pocock, S.J.; Gøtzsche, P.C.; Vandenbroucke, J.P. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: Guidelines for reporting observational studies. *UroToday Int. J.* 2009, 2, doi:10.4038/jccpsl.v13i2.2965. 527
40. Adachi, S.; Nakano, H.; Odajima, H.; Motomura, C.; Yoshioka, Y. Lung sounds in children before and after respiratory physical therapy for right middle lobe atelectasis. In Proceedings of the PLoS ONE; Public Library of Science, 2016; Vol. 11, doi: 10.1371/journal.pone.016253. 528
41. Pasterkamp, H.; Brand, P.L.P.; Everard, M.; Garcia-Marcos, L.; Melbye, H.; Priftis, K.N. Towards the standardisation of lung sound nomenclature. *Eur. Respir. J.* 2016, 47, 724–732, doi:10.1183/13993003.01132-2015. 529
42. Landis, J.R.; Koch, G.G. The Measurement of Observer Agreement for Categorical Data. *Biometrics* 1977, 33, 159, doi:10.2307/2529310. 530
43. Pramono, R.X.A.; Bowyer, S.; Rodriguez-Villegas, E. Automatic adventitious respiratory sound analysis: A systematic 531

- review. PLoS One 2017, 12, doi:10.1371/journal.pone.0177926. 555
44. Kerr, A.A. Dead space ventilation in normal children and children with obstructive airways disease. *Thorax* 1976, 31, 63–69, doi:10.1136/thx.31.1.63. 556
 45. Jácome, C.; Aviles-Solis, J.C.; Uhre, Å.M.; Pasterkamp, H.; Melbye, H. Adventitious and normal lung sounds in the general population: Comparison of standardized and spontaneous breathing. *Respir. Care* 2018, 63, 1379–1387, doi:10.4187/respcare.06121. 557
 46. Earis, J.E.; Cheetham, B.M.G. Future perspectives for respiratory sound research. *Eur. Respir. Rev.* 2000, 10, 641–646. 558
 47. Aviles-Solis, J.C.; Jácome, C.; Davidsen, A.; Einarsen, R.; Vanbelle, S.; Pasterkamp, H.; Melbye, H. Prevalence and clinical associations of wheezes and crackles in the general population: The Tromsø study. *BMC Pulm. Med.* 2019, 19, doi:10.1186/s12890-019-0928-1. 559
 48. Kataoka, H.; Matsuno, O. Age-related pulmonary crackles (rales) in asymptomatic cardiovascular patients. *Ann. Fam. Med.* 2008, 6, 239–245, doi:10.1370/afm.834. 560
 49. Janssens, J.P.; Pache, J.C.; Nicod, L.P. Physiological changes in respiratory function associated with ageing. *Eur. Respir. J.* 1999, 13, 197–205, doi: 10.1034/j.1399-3003.1999.13a36.x. 561
 50. Ploysongsang, Y.; Baughman, R.P.; Loudon, R.G.; Rashkin, M.C. Factors influencing the production of wheezes during expiratory maneuvers in normal subjects. *Respiration* 1988, 54, 50–60, doi:10.1159/000195501. 562
 51. Nath, A.R.; Capel, L.H. Inspiratory crackles and mechanical events of breathing. *Thorax* 1974, 29, 695–698, doi:10.1136/thx.29.6.695. 563
 52. Fainardi, V.; Longo, F.; Chetta, A.; Esposito, S.; Pisi, G. SARS-CoV-2 infection in patients with cystic fibrosis. An overview. *Acta Biomed.* 2020, 91, 1–5, doi: 10.23750/abm.v91i3.10391. 564
 53. Taquechel, K.; Diwadkar, A.R.; Sayed, S.; Dudley, J.W.; Grundmeier, R.W.; Kenyon, C.C.; Henrickson, S.E.; Himes, B.E.; Hill, D.A. Pediatric Asthma Health Care Utilization, Viral Testing, and Air Pollution Changes During the COVID-19 Pandemic. *J. Allergy Clin. Immunol. Pract.* 2020, 8, 3378–3387.e11, doi:10.1016/j.jaip.2020.07.057. 565
 54. Murphy, R.L.H.; Vyshedskiy, A.; Power-Charnitsky, V.A.; Bana, D.S.; Marinelli, P.M.; Wong-Tse, A.; Paciej, R. Automated lung sound analysis in patients with pneumonia. *Respir. Care* 2004, 49, 1490–1497, doi:10.1378/chest.124.4_meetingabstracts.190s-b. 566
 55. Murphy, R.L.H. In defense of the stethoscope. *Respir. Care* 2008, 53, 355–369, doi: 10.1136/adc.2003.046458. 567
 56. Bettencourt, P.E.; Del Bono, E.A.; Spiegelman, D.; Hertzmark, E.; Murphy, R.L.H. Clinical utility of chest auscultation in common pulmonary diseases. *Am. J. Respir. Crit. Care Med.* 1994, 150, 1291–1297, doi:10.1164/ajrccm.150.5.7952555. 568
 57. Spiteri, M.A.; Cook, D.G.; Clarke, S.W. Reliability of eliciting physical signs in examination of the chest. *Lancet* 1988, 331, 873–875, doi:10.1016/S0140-6736(88)91613-3. 569
 58. Holleman, D.R.; Simel, D.L.; Goldberg, J.S. Diagnosis of obstructive airways disease from the clinical examination. *J. Gen. Intern. Med.* 1993, 8, 63–68, doi:10.1007/BF02599985. 570
 59. Proadhan, P.; Dela Rosa, R.S.; Shubina, M.; Haver, K.E.; Matthews, B.D.; Buck, S.; Kacmarek, R.M.; Noviski, N.N. Wheeze detection in the pediatric intensive care unit: Comparison among physician, nurses, respiratory therapists, and a computerized respiratory sound monitor. *Respir. Care* 2008, 53, 1304–1309. 571
 60. Guggenmoos-Holzmann, I. The meaning of kappa: Probabilistic concepts of reliability and validity revisited. *J. Clin. Epidemiol.* 1996, 49, 775–782, doi:10.1016/0895-4356(96)00011-X. 572

Supplementary Table 1. Inter-rater agreement regarding the quality classification and the presence of adventitious sounds.

599

			Agreement %	Cohens' k	95% CI	p
Quality	Location	Trachea (n=187)	95	0.85	0.75 – 0.95	<0.001
		Right Anterior Chest (n=182)	93	0.85	0.77 – 0.93	<0.001
		Right Posterior Base (n=187)	88	0.75	0.65 – 0.85	<0.001
		Left Posterior Base (n=182)	88	0.76	0.66 – 0.86	<0.001
	Age group	Children (n=458)	90	0.77	0.71 – 0.83	<0.001
		Adults (n=280)	93	0.85	0.78 – 0.92	<0.001
	Diagnostic group	Cystic Fibrosis (n=338)	92	0.80	0.72 – 0.87	<0.001
		Asthma (n=169)	83	0.66	0.55 – 0.77	<0.001
		Other Respiratory Diseases (n=138)	96	0.92	0.85 – 0.99	<0.001
		No Respiratory Diseases (n=93)	97	0.91	0.81 – 1.00	<0.001
	Total (n=738)		91	0.80	0.75 – 0.85	<0.001
Presence of adventitious sounds	Location	Trachea (n=148)	91	0.56	0.36 – 0.76	<0.001
		Right Anterior Chest (n=128)	86	0.47	0.26 – 0.68	<0.001
		Right Posterior Base (n=112)	92	0.65	0.44 – 0.86	<0.001
		Left Posterior Base (n=120)	94	0.66	0.43 – 0.89	<0.001
	Age group	Children (n=308)	90	0.53	0.38 – 0.68	<0.001
		Adults (n=200)	92	0.64	0.48 – 0.80	<0.001
	Diagnostic group	Cystic Fibrosis (n=257)	90	0.38	0.19 – 0.57	<0.001
		Asthma (n=88)	89	0.11	-0.27 – 0.49	0.321
		Other Respiratory Diseases (n=93)	95	0.86	0.74 – 0.98	<0.001
		No Respiratory Diseases (n=70)	91	0.62	0.34 – 0.90	<0.001
	Total (n=508)		91	0.57	0.46 – 0.68	<0.001

600

601

602

Supplementary Table 2. Proportions of participants with recordings with quality, recordings with adventitious sounds, and stethoscope identified adventitious sounds.

			With quality or adventitious sounds	No quality or no adventitious sounds	Proportion (%)
Recordings with quality	Age group	Children (n=60)	53	7	88
		Adults (n=35)	31	4	89
	Diagnostic group	Cystic Fibrosis (n=42)	37	5	88
		Asthma (n=24)	19	5	79
		Other Respiratory Diseases (n=17)	13	4	76
		No Respiratory Diseases (n=12)	11	1	91
	Total (n=95)		84	11	88
Recordings with adventitious sounds	Age group	Children (n=53)	12	41	23
		Adults (n=31)	11	21	35
	Diagnostic group	Cystic Fibrosis (n=37)	9	28	24
		Asthma (n=19)	3	16	16
		Other Respiratory Diseases (n=17)	8	9	47
		No Respiratory Diseases (n=11)	3	8	27
	Total (n=84)		23	61	27
Stethoscope identified adventitious sounds	Age group	Children (n=53)	7	46	13
		Adults (n=31)	14	17	45
	Diagnostic group	Cystic Fibrosis (n=37)	14	23	38
		Asthma (n=19)	0	19	0
		Other Respiratory Diseases (n=17)	7	10	64
		No Respiratory Diseases (n=11)	0	11	0
	Total (n=84)		21	63	25

Supplementary Table 3. Comparison of the proportions of participants with recordings with quality, recordings with adventitious sounds, and stethoscope identified adventitious sounds between age group or diagnostic group.

Comparison				Chi-Square
Recordings with quality	Age group	Children	Adults	0.234
	Diagnostic group	Diagnostic group overall comparison		<0.001*
Recordings with adventitious sounds	Age group	Children	Adults	0.203
	Diagnostic group	Diagnostic group overall comparison		0.190
Stethoscope identified adventitious sounds	Age group	Children	Adults	0.165
	Diagnostic group	Diagnostic group overall comparison		0.001*
		Cystic Fibrosis	Asthma	0.002*
		Cystic Fibrosis	Other Respiratory Diseases	0.815
		Cystic Fibrosis	No Respiratory Diseases	0.15
		Asthma	Other Respiratory Diseases	0.002*
		Asthma	No Respiratory Diseases	†
		Other Respiratory Diseases	No Respiratory Diseases	0.14

* A statistically significant difference was found.

† Chi-Square could not be calculated because the stethoscope's findings were constant in both groups (no adventitious sounds were found).

Supplementary Table 4. Comparison of the proportions of recordings with quality with adventitious sounds between auscultation location, age group or diagnostic group.

		Comparison	Chi-Square
Quality	Location	Auscultation location overall comparison	<0.001*
		Trachea Right Anterior Chest	0.051
		Trachea Right Posterior Base	<0.001*
		Trachea Left Posterior Base	0.004*
		Right Anterior Chest Right Posterior Base	0.036
		Right Anterior Chest Left Posterior Base	0.368
		Right Posterior Base Left Posterior Base	0.230
	Age group	Children Adults	0.234
	Diagnostic group	Diagnostic group overall comparison	<0.001*
		Cystic Fibrosis Asthma	<0.001*
		Cystic Fibrosis Other Respiratory Diseases	0.052
		Cystic Fibrosis No Respiratory Diseases	0.878
		Asthma Other Respiratory Diseases	0.007*
		Asthma No Respiratory Diseases	<0.001*
		Other Respiratory Diseases No Respiratory Diseases	0.198
Presence of adventitious sounds	Location	Auscultation location overall comparison	0.495
	Age group	Children Adults	0.449
	Diagnostic group	Diagnostic group overall comparison	<0.001*
		Cystic Fibrosis Asthma	0.483
		Cystic Fibrosis Other Respiratory Diseases	<0.001*
		Cystic Fibrosis No Respiratory Diseases	0.179
		Asthma Other Respiratory Diseases	<0.001*
		Asthma No Respiratory Diseases	0.105
		Other Respiratory Diseases No Respiratory Diseases	0.032

614

615

616

617

618

Supplementary Table 5. Comparison between the findings of conventional auscultation and smartphone auscultation regarding the participants and the recordings.

			Agreement %	Cohens' k	95% CI	p
Participants	Age group	Children (n=53)	70	0.179	-0.12 – 0.48	0.170
		Adults (n=31)	58	0.137	-0.21 – 0.48	0.436
	Diagnostic group	Cystic Fibrosis (n=37)	59	0.073	-0.24 – 0.37	0.639
		Asthma (n=19)	84	0 ⁺		
		Other Respiratory Diseases (n=17)	71	0.406	-0.03 – 0.84	0.092
		No Respiratory Diseases (n=11)	72	0 ⁺		
	Total (n=84)		69	0.20	-0.03 – 0.43	0.066
Recordings	Location	Trachea (n=148)	89	0.15	-0.09 – 0.39	0.041
		Right Anterior Chest (n=128)	85	0.34	0.11 – 0.57	<0.001
		Right Posterior Base (n=112)	81	0.22	-0.01 – 0.45	0.016
		Left Posterior Base (n=120)	86	0.25	0 – 0.50	0.004
	Age group	Children (n=308)	88	0.33	0.15 – 0.51	<0.001
		Adults (n=200)	80	0.17	0 – 0.34	<0.016
	Diagnostic group	Cystic Fibrosis (n=257)	82	0.095	-0.04 – 0.23	0.090
		Asthma (n=88)	95	0 ⁺		
		Other Respiratory Diseases (n=93)	88	0.53	0.32 – 0.74	<0.001
		No Respiratory Diseases (n=70)	89	0 ⁺		
	Total (n=508)		86	0.25	0.13 – 0.37	<0.001

Agradecimentos

À minha orientadora, Prof. Doutora Inês Azevedo, pela paixão com que exerce e ensina Medicina.

À minha coorientadora, Prof. Doutora Cristina Jácome, cuja inesgotável paciência e apoio me permitiram concluir mais uma etapa do meu curso.

Ao meu coorientador, Prof. Doutor João Fonseca, pela oportunidade de integrar a equipa competente e profissional que permitiu o desenvolvimento deste trabalho.

À Prof. Doutora Isaura Tavares, pela dedicação incansável – e desconfio que inabalável – aos seus alunos e à Faculdade de Medicina. Levo de todas as partilhas uma inspiração para o profissional que desejo ser.

À minha família, a quem devo tudo o que sou e tudo que fiz. Aos meus pais, pelo exemplo e valores com que me muniram para o futuro. Aos meus irmãos Pedro, Luísa e Margarida, por serem sempre a minha pedra angular.

À Margarida, pelo apoio incondicional, pelo carinho e pelo projecto que dá sentido a tudo o resto. Sem ti nada seria possível.

À Mariana, ao Miguel, à Rita, à Ana e à Ritinha, pelo caminho que fizemos juntos e pela amizade sempre presente, leal e honesta.

À Missão País e à AEFMUP, por me porem ao serviço do outro.

Num último agradecimento muito especial, à minha Turma, a quem devo o completar dos 6 anos de Medicina. Estou certo de que sem a vossa amizade (e paciência) não estaria aqui.

*“O segredo de uma vida
feliz está em gostar - e aprender
a gostar - de fazer aquilo que se
deve e que é a nossa missão”*

ANEXO A

Parecer da Comissão de Ética do Centro Hospitalar
Universitário de S.João – Faculdade de Medicina
da Universidade do Porto (CHUSJ – FMUP)

Parecer da Comissão de Ética do

Centro Hospitalar de São João

Centro Hospitalar Universitário de São João / Faculdade de Medicina da Universidade do Porto

Assunto: Pulmonary auscultation using mobile devices - Feasibility study in respiratory diseases

Projeto de investigação científica submetido à apreciação da Comissão de Ética do

Título do Projeto: Pulmonary auscultation using mobile devices - Feasibility study in respiratory diseases

Nome do Investigador Principal: Henrique Ferreira Cardoso, estudo do MIM da FMUP

Onde decorre o Estudo: No Serviço de Pediatria e Pneumologia. Apresentou declarações da Dra. Eunice Trindade e do Prof. Doutor Venceslau Hespanhol.

Objectivos, conceção e pertinência do Estudo:

Avaliar a exequibilidade de uma aplicação móvel, com uma componente de aquisição de sons respiratórios, desenhada para melhorar a auto-monitorização e auto-gestão das doenças respiratórias obstrutivas crónicas.

Mais especificamente, pretende testar a aquisição dos sons respiratórios com microfone de dispositivos móveis e sua gravação em aplicação móvel, anotando as observações identificadas na auscultação convencional pelo médico usando um estetoscópio; constituir uma base de dados de sons respiratórios úteis para o desenvolvimento e validação de algoritmos de processamento do som para dispositivos móveis.

Estudo realizado no âmbito do MIM da FMUP, sob orientação da Prof.^a Doutora Maria Inês Ferreira Águeda Azevedo, e coorientação do Prof. Doutor João Fonseca e da Prof.^a Doutora Cristina Jácome.

Benefício/risco: Não desproporcional

Confidencialidade dos dados:

A anonimização é garantida por dois processos sequenciais detalhados no protocolo do estudo. Não são colhidos dados que permitam identificar os participantes.

Apresentou um pedido de reutilização de registos clínicos para Investigação e Desenvolvimento ao RAI.

Respeito pela liberdade e autonomia do sujeito de ensaio:

Será solicitado consentimento informado aos participantes e/ou representantes legais mediante documento institucional e com informação escrita adequada

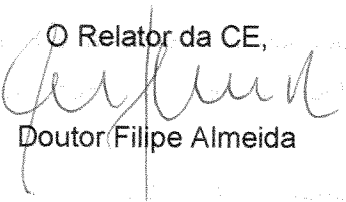
Curriculum do investigador: Adequado à investigação.

Data previsível da conclusão do estudo: março 2021

Conclusão: Proponho um parecer favorável à realização deste projeto de investigação.

Porto, 18 de setembro de 2020

O Relator da CE,


Doutor Filipe Almeida

Exmo. Sr. Presidente da Comissão de Ética do Centro Hospitalar Universitário de São João,
Senhor Prof. Doutor Filipe Almeida,

Assunto: Aditamento à aprovação do Projeto de Investigação n.º 316/20 "Pulmonary auscultation using mobile devices - Feasibility study in respiratory diseases"

Venho por este meio propôr um aditamento ao Projeto de Investigação n.º 316/20 "Pulmonary auscultation using mobile devices - Feasibility study in respiratory diseases", nomeadamente no que toca aos seus critérios de inclusão e exclusão. No protocolo submetido e aceite, definimos 3 grupos de participantes (doentes com asma, doentes com fibrose quística e pessoas sem patologia respiratória). Com este aditamento, pretendemos incluir um quarto grupo (doentes com outras patologias respiratórias), visando mitigar as dificuldades que adivinhamos no recrutamento de participantes. Esta seria uma forma de responder aos objetivos do estudo mantendo as recolhas restritas aos serviços de Pediatria e de Pneumologia, mantendo-se todos os procedimentos inalterados.

Com esta alteração, será corrigido o Protocolo submetido, na linha 6 da página 4, ficando então da seguinte forma os critérios de elegibilidade deste projeto de investigação:

Critérios de inclusão:

1. Indivíduos de qualquer idade superior a 5 anos, em tratamento em Pediatria ou Pneumologia no CHUSJ;
2. Diagnóstico de asma (grupo A), fibrose quística (grupo B), sem doença respiratória (grupo C) ou com outras doenças respiratórias (Grupo D).

Serão excluídos do recrutamento os indivíduos:

1. Cujo estado de saúde não permita a recolha sem riscos para o participante (contraindicações para a recolha de sons respiratórios);
2. Recusa em participar no estudo.

Mais informo que nenhuma outra alteração foi realizada no Protocolo.

Agradeço a consideração desta proposta de aditamento, despedindo-me com os melhores cumprimentos,

Henrique Cardoso

Estudante do MIMD-FMUP

Parecer da Comissão de Ética do
Centro Hospitalar Universitário de São João / Faculdade de Medicina da Universidade do Porto

Parecer

Título do Projeto: Pulmonary auscultation using mobile devices - Feasibility study in respiratory diseases - **ADENDA**

Nome do Investigador Principal: Henrique Ferreira Cardoso, estudante do MIM da FMUP

Onde decorre o Estudo: No Serviço de Pediatria e Pneumologia. Apresentou declarações da Dra. Eunice Trindade e do Prof. Doutor Venceslau Hespanhol.

Objectivos, conceção e pertinência da Adenda ao Estudo:

Com este aditamento, pretende-se incluir um quarto grupo de investigação “doentes com outras patologias respiratórias”, para além dos três grupos iniciais (“doentes com asma”, “doentes com fibrose quística” e “doentes sem doença respiratória”), na tentativa de mitigar as dificuldades de recrutamento em função da pandemia vigente.

Benefício/risco: NA

Confidencialidade dos dados: NA

Respeito pela liberdade e autonomia do sujeito de ensaio: NA

Curriculum do investigador: NA.

Data previsível da conclusão do estudo: NA

Conclusão: Proponho um parecer favorável à implementação desta Adenda ao projecto de investigação.

Porto, 18 de dezembro de 2020

*levar nota formalmente
aos membros da CE, por
via electrónica
20.12.18
Filipe Almeida*

O Relator da CE,

Prof. Doutor Filipe Almeida


Prof. Doutor Filipe Almeida
Presidente da Comissão de Ética

ANEXO B

Normas de publicação da revista *Sensors*

Manuscript Submission Overview



Types of Publications

Sensors has no restrictions on the length of manuscripts, provided that the text is concise and comprehensive. Full experimental details must be provided so that the results can be reproduced. *Sensors* requires that authors publish all experimental controls and make full datasets available where possible (see the guidelines on **Supplementary Materials** and references to unpublished data).

Manuscripts submitted to *Sensors* should neither be published previously nor be under consideration for publication in another journal. The main article types are as follows:

- ◆ **Articles:** The journal considers all original research manuscripts, provided that the work reports scientifically sound experiments and provides a substantial amount of new information. Authors should not unnecessarily divide their work into several related manuscripts, although short *Communications* of preliminary but significant results will be considered. The quality and impact of the study will be considered during peer review. The recommended length of an Article is more than 16 journal pages.
- ◆ **Reviews:** These provide concise and precise updates on the latest progress made in a given area of research. Systematic reviews should follow the **PRISMA guidelines**. The recommended length of a Review is more than 20 journal pages.
- ◆ **Perspectives:** Perspectives are personal points of view on the state-of-the-art of a specific area of knowledge and its future prospects. Links to areas of intense current research focus can also be made. The emphasis should be on a personal assessment rather than a comprehensive, critical review; however, comments should be put into the context of the existing literature. Perspectives are invited by the Editor-in-Chief and will be subject to peer review. Authors with potential topics for Perspectives may contact the Editor-in-Chief for an invitation. The recommended length of a *Perspectives* is more than 6 journal pages.
- ◆ **Communication:** A Communication is a brief disclosure of a significant new sensing concept or application and will be considered on an accelerated schedule. The recommended length of a Communication is more than 10 journal pages.

Submission Process

Manuscripts for *Sensors* should be submitted online at **susy.mdpi.com**. The submitting author, who is generally the corresponding author, is responsible for the manuscript during the submission and peer-review process. The submitting author must ensure that all eligible co-authors have been included in the author list (read the **criteria to qualify for authorship**) and that they have all read and approved the submitted version of the manuscript. To submit your manuscript, register and log in to the **submission website**. Once you have registered, **click here to go to the submission form for Sensors**. All co-authors can see the manuscript details in the submission system, if they register and log in using the e-mail address provided during manuscript submission.

Accepted File Formats

Authors must use the **Microsoft Word template** or **LaTeX template** to prepare their manuscript. Using the template file will substantially shorten the time to complete copy-editing and publication of accepted manuscripts. The total amount of data for all files must not exceed 120 MB. If this is a problem, please contact the Editorial Office **sensors@mdpi.com**. Accepted file formats are:

- ◆ **Microsoft Word:** Manuscripts prepared in Microsoft Word must be converted into a single file before submission. When preparing manuscripts in Microsoft Word, the **Sensors Microsoft Word template file** must be used. Please insert your graphics (schemes, figures, etc.) in the main text after the paragraph of its first citation.
- ◆ **LaTeX:** Manuscripts prepared in LaTeX must be collated into one ZIP folder (including all source files and images, so that the Editorial Office can recompile the submitted PDF). When preparing manuscripts in LaTeX, please use the **Sensors LaTeX template files**. You can now also use the online application **writeLaTeX** to submit articles directly to *Sensors*. The MDPI LaTeX template file should be selected from the **writeLaTeX template gallery**.
- ◆ **Supplementary files:** May be any format, but it is recommended that you use common, non-proprietary formats where possible (see **below** for further details).

Disclaimer: Usage of these templates is exclusively intended for submission to the journal for peer-review, and strictly limited to this purpose and it cannot be used for posting online on preprint servers or other websites.

Free Format Submission

Sensors now accepts free format submission:

- ◆ We do not have strict formatting requirements, but all manuscripts must contain the required sections: Author Information, Abstract, Keywords, Introduction, Materials & Methods, Results, Conclusions, Figures and Tables with Captions, Funding Information, Author Contributions, Conflict of Interest and other Ethics Statements. Check the Journal ***Instructions for Authors*** for more details.
- ◆ Your references may be in any style, provided that you use the consistent formatting throughout. It is essential to include author(s) name(s), journal or book title, article or chapter title (where required), year of publication, volume and issue (where appropriate) and pagination. DOI numbers (Digital Object Identifier) are not mandatory but highly encouraged. The bibliography software package *EndNote*, **Zotero**, *Mendeley*, *Reference Manager* are recommended.
- ◆ When your manuscript reaches the revision stage, you will be requested to format the manuscript according to the journal guidelines.

Cover Letter

A cover letter must be included with each manuscript submission. It should be concise and explain why the content of the paper is significant, placing the findings in the context of existing work and why it fits the scope of the journal. Confirm that neither the manuscript nor any parts of its content are currently under consideration or published in another journal. Any prior submissions of the manuscript to MDPI journals must be acknowledged. The names of proposed and excluded reviewers should be provided in the submission system, not in the cover letter.

Author Biography

Authors are encouraged to add a biography (maximum 150 words) to the submission and publish it. This should be a single paragraph and should contain the following points:

1. Authors' full names followed by current positions;
2. Education background including institution information and year of graduation (type and level of degree received);
3. Work experience;
4. Current and previous research interests;
5. Memberships of professional societies and awards received.

Note for Authors Funded by the National Institutes of Health (NIH)

This journal automatically deposits papers to PubMed Central after publication of an issue. Authors do not need to separately submit their papers through the NIH Manuscript Submission System (NIHMS, <http://nihms.nih.gov/>).

Manuscript Preparation

General Considerations

- ◆ **Research manuscripts** should comprise:
 - ◆ **Front matter:** Title, Author list, Affiliations, Abstract, Keywords
 - ◆ **Research manuscript sections:** Introduction, Materials and Methods, Results, Discussion, Conclusions (optional).
 - ◆ **Back matter:** Supplementary Materials, Acknowledgments, Author Contributions, Conflicts of Interest, **References**.
- ◆ **Review manuscripts** should comprise the **front matter**, literature review sections and the **back matter**. The template file can also be used to prepare the front and back matter of your review manuscript. It is not necessary to follow the remaining structure. Structured reviews and meta-analyses should use the same structure as research articles and ensure they conform to the **PRISMA** guidelines.

◆ **Graphical Abstract:**

A graphical abstract (GA) is an image that appears alongside the text abstract in the Table of Contents. In addition to summarizing content, it should represent the topic of the article in an attention-grabbing way.

The GA should be a high-quality illustration or diagram in any of the following formats: PNG, JPEG, EPS, SVG, PSD or AI. Written text in a GA should be clear and easy to read, using one of the following fonts: Times, Arial, Courier, Helvetica, Ubuntu or Calibri.

- ◆ The minimum required size for the GA is 560 × 1100 pixels (height × width). When submitting larger images, please make sure to keep to the same ratio.
- ◆ **Abbreviations** should be defined in parentheses the first time they appear in the abstract, main text, and in figure or table captions and used consistently thereafter.
- ◆ **SI Units** (International System of Units) should be used. Imperial, US customary and other units should be converted to SI units whenever possible.
- ◆ **Accession numbers** of RNA, DNA and protein sequences used in the manuscript should be provided in the Materials and Methods section. Also see the section on **Deposition of Sequences and of Expression Data**.
- ◆ **Equations:** If you are using Word, please use either the Microsoft Equation Editor or the MathType add-on. Equations should be editable by the editorial office and not appear in a picture format.
- ◆ **Research Data and supplementary materials:** Note that publication of your manuscript implies that you must make all materials, data, and protocols associated with the publication available to readers. Disclose at the submission stage any restrictions on the availability of materials or information. Read the information about **Supplementary Materials** and Data Deposit for additional guidelines.
- ◆ **Preregistration:** Where authors have preregistered studies or analysis plans, links to the preregistration must be provided in the manuscript.
- ◆ **Guidelines and standards:** MDPI follows standards and guidelines for certain types of research. See https://www.mdpi.com/editorial_process for further information.

Front Matter

These sections should appear in all manuscript types

- ◆ **Title:** The title of your manuscript should be concise, specific and relevant. It should identify if the study reports (human or animal) trial data, or is a systematic review, meta-analysis or replication study. When gene or protein names are included, the abbreviated name rather than full name should be used.
- ◆ **Author List and Affiliations:** Authors' full first and last names must be provided. The initials of any middle names can be added. The PubMed/MEDLINE standard format is used for affiliations: complete address information including city, zip code, state/province, and country. At least one author should be designated as corresponding author, and his or her email address and other details should be included at the end of the affiliation section. Please read the **criteria to qualify for authorship**.
- ◆ **Abstract:** The abstract should be a total of about 200 words maximum. The abstract should be a single paragraph and should follow the style of structured abstracts, but without headings: 1) Background: Place the question addressed in a broad context and highlight the purpose of the study; 2) Methods: Describe briefly the main methods or treatments applied. Include any relevant preregistration numbers, and species and strains of any animals used. 3) Results: Summarize the article's main findings; and 4) Conclusion: Indicate the main conclusions or interpretations. The abstract should be an objective representation of the article: it must not contain results which are not presented and substantiated in the main text and should not exaggerate the main conclusions.
- ◆ **Keywords:** Three to ten pertinent keywords need to be added after the abstract. We recommend that the keywords are specific to the article, yet reasonably common within the subject discipline.

Research Manuscript Sections

- ◆ **Introduction:** The introduction should briefly place the study in a broad context and highlight why it is important. It should define the purpose of the work and its significance, including specific hypotheses being tested. The current state of the research field should be reviewed carefully and key publications cited. Please highlight controversial and diverging hypotheses when necessary. Finally, briefly mention the main aim of the work and highlight the main conclusions. Keep the introduction comprehensible to scientists working outside the topic of the paper.

- ◆ **Materials and Methods:** They should be described with sufficient detail to allow others to replicate and build on published results. New methods and protocols should be described in detail while well-established methods can be briefly described and appropriately cited. Give the name and version of any software used and make clear whether computer code used is available. Include any pre-registration codes.
- ◆ **Results:** Provide a concise and precise description of the experimental results, their interpretation as well as the experimental conclusions that can be drawn.
- ◆ **Discussion:** Authors should discuss the results and how they can be interpreted in perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible and limitations of the work highlighted. Future research directions may also be mentioned. This section may be combined with Results.
- ◆ **Conclusions:** This section is not mandatory, but can be added to the manuscript if the discussion is unusually long or complex.
- ◆ **Patents:** This section is not mandatory, but may be added if there are patents resulting from the work reported in this manuscript.

Back Matter

- ◆ **Supplementary Materials:** Describe any supplementary material published online alongside the manuscript (figure, tables, video, spreadsheets, etc.). Please indicate the name and title of each element as follows Figure S1: title, Table S1: title, etc.
- ◆ **Funding:** All sources of funding of the study should be disclosed. Clearly indicate grants that you have received in support of your research work and if you received funds to cover publication costs. Note that some funders will not refund article processing charges (APC) if the funder and grant number are not clearly and correctly identified in the paper. Funding information can be entered separately into the submission system by the authors during submission of their manuscript. Such funding information, if available, will be deposited to FundRef if the manuscript is finally published. Please add: "This research received no external funding" or "This research was funded by [name of funder] grant number [xxx]" and "The APC was funded by [XXX]" in this section. Check carefully that the details given are accurate and use the standard spelling of funding agency names at <https://search.crossref.org/funding>, any errors may affect your future funding.
- ◆ **Acknowledgments:** In this section you can acknowledge any support given which is not covered by the author contribution or funding sections. This may include administrative and technical support, or donations in kind (e.g., materials used for experiments).
- ◆ **Author Contributions:** Each author is expected to have made substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data; or the creation of new software used in the work; or have drafted the work or substantively revised it; AND has approved the submitted version (and version substantially edited by journal staff that involves the author's contribution to the study); AND agrees to be personally accountable for the author's own contributions and for ensuring that questions related to the accuracy or integrity of any part of the work, even ones in which the author was not personally involved, are appropriately investigated, resolved, and documented in the literature. For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "Conceptualization, X.X. and Y.Y.; Methodology, X.X.; Software, X.X.; Validation, X.X., Y.Y. and Z.Z.; Formal Analysis, X.X.; Investigation, X.X.; Resources, X.X.; Data Curation, X.X.; Writing – Original Draft Preparation, X.X.; Writing – Review & Editing, X.X.; Visualization, X.X.; Supervision, X.X.; Project Administration, X.X.; Funding Acquisition, Y.Y.", please turn to the **CRedit taxonomy** for the term explanation. For more background on CRediT, see [here](#). **"Authorship must include and be limited to those who have contributed substantially to the work. Please read the section concerning the criteria to qualify for authorship carefully".**
- ◆ **Institutional Review Board Statement:** In this section, please add the Institutional Review Board Statement and approval number for studies involving humans or animals. Please note that the Editorial Office might ask you for further information. Please add "The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of NAME OF INSTITUTE (protocol code XXX and date of approval)." OR "Ethical review and approval were waived for this study, due to REASON (please provide a detailed justification)." OR "Not applicable" for studies not involving humans or animals. You might also choose to exclude this statement if the study did not involve humans or animals.
- ◆ **Informed Consent Statement:** Any research article describing a study involving humans should contain this statement. Please add "Informed consent was obtained from all subjects involved in the study." OR "Patient consent was waived due to REASON (please provide a detailed justification)." OR "Not applicable" for studies not involving humans. You might also choose to exclude this statement if the study did not involve humans. Written informed consent for publication must be obtained from participating patients who can be identified (including by the patients themselves). Please state "Written informed consent has been obtained from the patient(s) to publish this paper" if applicable.

- ◆ **Data Availability Statement:** In this section, please provide details regarding where data supporting reported results can be found, including links to publicly archived datasets analyzed or generated during the study. Please refer to suggested Data Availability Statements in section “**MDPI Research Data Policies**”. You might choose to exclude this statement if the study did not report any data.
- ◆ **Conflicts of Interest:** Authors must identify and declare any personal circumstances or interest that may be perceived as influencing the representation or interpretation of reported research results. If there is no conflict of interest, please state “The authors declare no conflict of interest.” Any role of the funding sponsors in the choice of research project; design of the study; in the collection, analyses or interpretation of data; in the writing of the manuscript; or in the decision to publish the results must be declared in this section. *Sensors* does not publish studies funded by the tobacco industry. Any projects funded by industry must pay special attention to the full declaration of funder involvement. If there is no role, please state “The sponsors had no role in the design, execution, interpretation, or writing of the study”. For more details please see **Conflict of Interest**.
- ◆ **References:** References must be numbered in order of appearance in the text (including table captions and figure legends) and listed individually at the end of the manuscript. We recommend preparing the references with a bibliography software package, such as **EndNote**, **ReferenceManager** or **Zotero** to avoid typing mistakes and duplicated references. We encourage citations to data, computer code and other citable research material. If available online, you may use reference style 9. below.
- ◆ Citations and References in Supplementary files are permitted provided that they also appear in the main text and in the reference list.

In the text, reference numbers should be placed in square brackets [], and placed before the punctuation; for example [1], [1–3] or [1,3]. For embedded citations in the text with pagination, use both parentheses and brackets to indicate the reference number and page numbers; for example [5] (p. 10). or [6] (pp. 101–105).

The reference list should include the full title, as recommended by the ACS style guide. Style files for **Endnote** and **Zotero** are available.

References should be described as follows, depending on the type of work:

- ◆ **Journal Articles:**
 1. Author 1, A.B.; Author 2, C.D. Title of the article. *Abbreviated Journal Name* **Year**, *Volume*, page range.
- ◆ **Books and Book Chapters:**
 2. Author 1, A.; Author 2, B. *Book Title*, 3rd ed.; Publisher: Publisher Location, Country, Year; pp. 154–196.
 3. Author 1, A.; Author 2, B. Title of the chapter. In *Book Title*, 2nd ed.; Editor 1, A., Editor 2, B., Eds.; Publisher: Publisher Location, Country, Year; Volume 3, pp. 154–196.
- ◆ **Unpublished work, submitted work, personal communication:**
 4. Author 1, A.B.; Author 2, C. Title of Unpublished Work. status (unpublished; manuscript in preparation).
 5. Author 1, A.B.; Author 2, C. Title of Unpublished Work. *Abbreviated Journal Name* stage of publication (under review; accepted; in press).
 6. Author 1, A.B. (University, City, State, Country); Author 2, C. (Institute, City, State, Country). Personal communication, Year.
- ◆ **Conference Proceedings:**
 7. Author 1, A.B.; Author 2, C.D.; Author 3, E.F. Title of Presentation. In *Title of the Collected Work* (if available), Proceedings of the Name of the Conference, Location of Conference, Country, Date of Conference; Editor 1, Editor 2, Eds. (if available); Publisher: City, Country, Year (if available); Abstract Number (optional), Pagination (optional).
- ◆ **Thesis:**
 8. Author 1, A.B. Title of Thesis. Level of Thesis, Degree-Granting University, Location of University, Date of Completion.
- ◆ **Websites:**
 9. Title of Site. Available online: URL (accessed on Day Month Year).
Unlike published works, websites may change over time or disappear, so we encourage you create an archive of the cited website using a service such as **WebCite**. Archived websites should be cited using the link provided as follows:
 10. Title of Site. URL (archived on Day Month Year).
See the **Reference List and Citations Guide** for more detailed information.

Preparing Figures, Schemes and Tables

- ◆ File for Figures and Schemes must be provided during submission in a single zip archive and at a sufficiently high resolution (minimum 1000 pixels width/height, or a resolution of 300 dpi or higher). Common formats are accepted, however, TIFF, JPEG, EPS and PDF are preferred.
- ◆ *Sensors* can publish multimedia files in articles or as supplementary materials. Please contact the editorial office for further information.
- ◆ All Figures, Schemes and Tables should be inserted into the main text close to their first citation and must be numbered following their number of appearance (Figure 1, Scheme I, Figure 2, Scheme II, Table 1, *etc.*).
- ◆ All Figures, Schemes and Tables should have a short explanatory title and caption.
- ◆ All table columns should have an explanatory heading. To facilitate the copy-editing of larger tables, smaller fonts may be used, but no less than 8 pt. in size. Authors should use the Table option of Microsoft Word to create tables.
- ◆ Authors are encouraged to prepare figures and schemes in color (RGB at 8-bit per channel). There is no additional cost for publishing full color graphics.

Supplementary Materials, Data Deposit and Software Source Code

MDPI Research Data Policies

MDPI is committed to supporting open scientific exchange and enabling our authors to achieve best practices in sharing and archiving research data. We encourage all authors of articles published in MDPI journals to share their research data. Individual journal guidelines can be found at the journal 'Instructions for Authors' page. Data sharing policies concern the minimal dataset that supports the central findings of a published study. Generated data should be publicly available and cited in accordance with journal guidelines.

MDPI data policies are informed by **TOP Guidelines**.

Where ethical, legal or privacy issues are present, data should not be shared. The authors should make any limitations clear in the Data Availability Statement upon submission. Authors should ensure that data shared are in accordance with consent provided by participants on the use of confidential data.

Data Availability Statements provide details regarding where data supporting reported results can be found, including links to publicly archived datasets analyzed or generated during the study.

Below are suggested Data Availability Statements:

- ◆ Data available in a publicly accessible repository
The data presented in this study are openly available in [repository name e.g., FigShare] at [doi], reference number [reference number].
- ◆ Data available in a publicly accessible repository that does not issue DOIs
Publicly available datasets were analyzed in this study. This data can be found here: [link/accession number]
- ◆ Data available on request due to restrictions eg privacy or ethical
The data presented in this study are available on request from the corresponding author. The data are not publicly available due to [insert reason here]
- ◆ 3rd Party Data
Restrictions apply to the availability of these data. Data was obtained from [third party] and are available [from the authors / at URL] with the permission of [third party].
- ◆ Data sharing not applicable
No new data were created or analyzed in this study. Data sharing is not applicable to this article.
- ◆ Data is contained within the article or supplementary material
The data presented in this study are available in [insert article or supplementary material here]
- ◆ Data citation:
- ◆ [dataset] Authors. Year. Dataset title; Data repository or archive; Version (if any); Persistent identifier (e.g., DOI).
- ◆ *Computer Code and Software*

For work where novel computer code was developed, authors should release the code either by depositing in a recognized, public repository such as **GitHub** or uploading as supplementary information to the publication. The name, version, corporation and location information for all software used should be clearly indicated. Please include all the parameters used to run software/programs analyses.

Supplementary Material

Additional data and files can be uploaded as "Supplementary Files" during the manuscript submission process. The supplementary files will also be available to the referees as part of the peer-review process. Any file format is acceptable; however, we recommend that common, non-proprietary formats are used where possible.

References in Supplementary Files

Citations and References in Supplementary files are permitted provided that they also appear in the reference list of the main text.

Unpublished Data

Restrictions on data availability should be noted during submission and in the manuscript. "Data not shown" should be avoided: authors are encouraged to publish all observations related to the submitted manuscript as Supplementary Material. "Unpublished data" intended for publication in a manuscript that is either planned, "in preparation" or "submitted" but not yet accepted, should be cited in the text and a reference should be added in the References section. "Personal Communication" should also be cited in the text and reference added in the References section. (see also the MDPI reference list and citations style guide).

Remote Hosting and Large Data Sets

Data may be deposited with specialized service providers or institutional/subject repositories, preferably those that use the DataCite mechanism. Large data sets and files greater than 60 MB must be deposited in this way. For a list of other repositories specialized in scientific and experimental data, please consult **databib.org** or **re3data.org**. The data repository name, link to the data set (URL) and accession number, doi or handle number of the data set must be provided in the paper. The journal **Data** also accepts submissions of data set papers.

Deposition of Sequences and of Expression Data

New sequence information must be deposited to the appropriate database prior to submission of the manuscript. Accession numbers provided by the database should be included in the submitted manuscript. Manuscripts will not be published until the accession number is provided.

- ◆ *New nucleic acid sequences* must be deposited in one of the following databases: **GenBank**, **EMBL**, or **DDBJ**. Sequences should be submitted to only one database.
- ◆ *New high throughput sequencing (HTS) datasets* (RNA-seq, ChIP-Seq, degradome analysis, ...) must be deposited either in the **GEO database** or in the NCBI's **Sequence Read Archive (SRA)**.
- ◆ *New microarray data* must be deposited either in the **GEO** or the **ArrayExpress** databases. The "Minimal Information About a Microarray Experiment" (MIAME) guidelines published by the Microarray Gene Expression Data Society must be followed.
- ◆ *New protein sequences* obtained by protein sequencing must be submitted to UniProt (submission tool **SPIN**). Annotated protein structure and its reference sequence must be submitted to **RCSB of Protein Data Bank**.

All sequence names and the accession numbers provided by the databases must be provided in the Materials and Methods section of the article.

Deposition of Proteomics Data

Methods used to generate the proteomics data should be described in detail and we encourage authors to adhere to the "**Minimum Information About a Proteomics Experiment**". All generated mass spectrometry raw data must be deposited in the appropriate public database such as **ProteomeXchange**, **PRIDE** or **jPOST**. At the time of submission, please include all relevant information in the materials and methods section, such as repository where the data was submitted and link, data set identifier, username and password needed to access the data.

Research and Publication Ethics

Research Ethics

Research Involving Human Subjects

When reporting on research that involves human subjects, human material, human tissues, or human data, authors must declare that the investigations were carried out following the rules of the Declaration of Helsinki of 1975 (<https://www.wma.net/what-we-do/medical-ethics/declaration-of-helsinki/>), revised in 2013. According to point 23 of this declaration, an approval from an ethics committee should have been obtained before undertaking the research. At a minimum, a statement including the project identification code, date of approval, and name of the ethics committee or institutional review board should be stated in Section 'Institutional Review Board Statement' of the article. Data relating to individual participants must be described in detail, but private information identifying participants need not be included unless the identifiable materials are of relevance to the research (for example, photographs of participants' faces that show a particular symptom). Editors reserve the right to reject any submission that does not meet these requirements.

Example of an ethical statement: "All subjects gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of XXX (Project identification code)."

A written informed consent for publication must be obtained from participating patients who can be identified (including by the patients themselves). Patients' initials or other personal identifiers must not appear in any images. For manuscripts that include any case details, personal information, and/or images of patients, authors must obtain signed informed consent from patients (or their relatives/guardians) before submitting to an MDPI journal. Patient details must be anonymized as far as possible, e.g., do not mention specific age, ethnicity, or occupation where they are not relevant to the conclusions. A **template permission form** is available to download. A blank version of the form used to obtain permission (without the patient names or signature) must be uploaded with your submission.

You may refer to our sample form and provide an appropriate form after consulting with your affiliated institution. Alternatively, you may provide a detailed justification of why informed consent is not necessary. For the purposes of publishing in MDPI journals, a consent, permission, or release form should include unlimited permission for publication in all formats (including print, electronic, and online), in sublicensed and reprinted versions (including translations and derived works), and in other works and products under open access license. To respect patients' and any other individual's privacy, please do not send signed forms. The journal reserves the right to ask authors to provide signed forms if necessary.

Research Involving Cell Lines

Methods sections for submissions reporting on research with cell lines should state the origin of any cell lines. For established cell lines the provenance should be stated and references must also be given to either a published paper or to a commercial source. If previously unpublished *de novo* cell lines were used, including those gifted from another laboratory, details of institutional review board or ethics committee approval must be given, and confirmation of written informed consent must be provided if the line is of human origin.

An example of Ethical Statements:

The HCT116 cell line was obtained from XXXX. The MLH1⁺ cell line was provided by XXXXX, Ltd. The DLD-1 cell line was obtained from Dr. XXXX. The DR-GFP and SA-GFP reporter plasmids were obtained from Dr. XXX and the Rad51K133A expression vector was obtained from Dr. XXXX.

Clinical Trials Registration

Registration

MDPI follows the International Committee of Medical Journal Editors (ICMJE) **guidelines** which require and recommend registration of clinical trials in a public trials registry at or before the time of first patient enrollment as a condition of consideration for publication.

Purely observational studies do not require registration. A clinical trial not only refers to studies that take place in a hospital or involve pharmaceuticals, but also refer to all studies which involve participant randomization and group classification in the context of the intervention under assessment.

Authors are strongly encouraged to pre-register clinical trials with an international clinical trials register and cite a reference to the registration in the abstract and Methods section. Suitable databases include **clinicaltrials.gov**, **the EU Clinical Trials Register** and those listed by the World Health Organisation **International Clinical Trials Registry Platform**.

Approval to conduct a study from an independent local, regional, or national review body is not equivalent to prospective clinical trial registration. MDPI reserves the right to decline any paper without trial registration for further peer-review. However, if the study protocol has been published before the enrolment, the registration can be waived with correct citation of the published protocol.

CONSORT Statement

MDPI requires a completed CONSORT 2010 **checklist** and **flow diagram** as a condition of submission when reporting the results of a randomized trial. Templates for these can be found here or on the CONSORT website (<http://www.consort-statement.org>) which also describes several CONSORT checklist extensions for different designs and types of data beyond two group parallel trials. At minimum, your article should report the content addressed by each item of the checklist.

Borders and Territories

Potential disputes over borders and territories may have particular relevance for authors in describing their research or in an author or editor correspondence address, and should be respected. Content decisions are an editorial matter and where there is a potential or perceived dispute or complaint, the editorial team will attempt to find a resolution that satisfies parties involved.

MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Publication Ethics Statement

Sensors is a member of the Committee on Publication Ethics (COPE). We fully adhere to its **Code of Conduct** and to its **Best Practice Guidelines**.

The editors of this journal enforce a rigorous peer-review process together with strict ethical policies and standards to ensure to add high quality scientific works to the field of scholarly publication. Unfortunately, cases of plagiarism, data falsification, image manipulation, inappropriate authorship credit, and the like, do arise. The editors of *Sensors* take such publishing ethics issues very seriously and are trained to proceed in such cases with a zero tolerance policy.

Authors wishing to publish their papers in *Sensors* must abide to the following:

- ◆ Any facts that might be perceived as a possible conflict of interest of the author(s) must be disclosed in the paper prior to submission.
- ◆ Authors should accurately present their research findings and include an objective discussion of the significance of their findings.
- ◆ Data and methods used in the research need to be presented in sufficient detail in the paper, so that other researchers can replicate the work.
- ◆ Raw data should preferably be publicly deposited by the authors before submission of their manuscript. Authors need to at least have the raw data readily available for presentation to the referees and the editors of the journal, if requested. Authors need to ensure appropriate measures are taken so that raw data is retained in full for a reasonable time after publication.
- ◆ Simultaneous submission of manuscripts to more than one journal is not tolerated.
- ◆ Republishing content that is not novel is not tolerated (for example, an English translation of a paper that is already published in another language will not be accepted).
- ◆ If errors and inaccuracies are found by the authors after publication of their paper, they need to be promptly communicated to the editors of this journal so that appropriate actions can be taken. Please refer to our **policy regarding Updating Published Papers**.
- ◆ Your manuscript should not contain any information that has already been published. If you include already published figures or images, please obtain the necessary permission from the copyright holder to publish under the CC-BY license. For further information, see the **Rights and Permissions** page.
- ◆ Plagiarism, data fabrication and image manipulation are not tolerated.

- ◆ **Plagiarism is not acceptable** in *Sensors* submissions.

Plagiarism includes copying text, ideas, images, or data from another source, even from your own publications, without giving any credit to the original source.

Reuse of text that is copied from another source must be between quotes and the original source must be cited. If a study's design or the manuscript's structure or language has been inspired by previous works, these works must be explicitly cited.

If plagiarism is detected during the peer review process, the manuscript may be rejected. If plagiarism is detected after publication, we may publish a correction or retract the paper.

- ◆ **Image files must not be manipulated or adjusted in any way** that could lead to misinterpretation of the information provided by the original image.

Irregular manipulation includes: 1) introduction, enhancement, moving, or removing features from the original image; 2) grouping of images that should obviously be presented separately (e.g., from different parts of the same gel, or from different gels); or 3) modifying the contrast, brightness or color balance to obscure, eliminate or enhance some information.

If irregular image manipulation is identified and confirmed during the peer review process, we may reject the manuscript. If irregular image manipulation is identified and confirmed after publication, we may correct or retract the paper.

Our in-house editors will investigate any allegations of publication misconduct and may contact the authors' institutions or funders if necessary. If evidence of misconduct is found, appropriate action will be taken to correct or retract the publication. Authors are expected to comply with the best ethical publication practices when publishing with MDPI.

Citation Policy

Authors should ensure that where material is taken from other sources (including their own published writing) the source is clearly cited and that where appropriate permission is obtained.

Authors should not engage in excessive self-citation of their own work.

Authors should not copy references from other publications if they have not read the cited work.

Authors should not preferentially cite their own or their friends', peers', or institution's publications.

Authors should not cite advertisements or advertorial material.

In accordance with COPE guidelines, we expect that "original wording taken directly from publications by other researchers should appear in quotation marks with the appropriate citations." This condition also applies to an author's own work. COPE have produced a discussion document on **citation manipulation** with recommendations for best practice.

Reviewer Suggestions

During the submission process, please suggest three potential reviewers with the appropriate expertise to review the manuscript. The editors will not necessarily approach these referees. Please provide detailed contact information (address, homepage, phone, e-mail address). The proposed referees should neither be current collaborators of the co-authors nor have published with any of the co-authors of the manuscript within the last five years. Proposed reviewers should be from different institutions to the authors. You may identify appropriate Editorial Board members of the journal as potential reviewers. You may suggest reviewers from among the authors that you frequently cite in your paper.

English Corrections

To facilitate proper peer-reviewing of your manuscript, it is essential that it is submitted in grammatically correct English. Advice on some specific language points can be found [here](#).

If you are not a native English speaker, we recommend that you have your manuscript professionally edited before submission or read by a native English-speaking colleague. This can be carried out by MDPI's **English editing service**. Professional editing will enable reviewers and future readers to more easily read and assess the content of submitted manuscripts. All accepted manuscripts undergo language editing, however **an additional fee will be charged** to authors if very extensive English corrections must be made by the Editorial Office: pricing is according to the service [here](#).

Preprints and Conference Papers

Sensors accepts submissions that have previously been made available as preprints provided that they have not undergone peer review. A preprint is a draft version of a paper made available online before submission to a journal.

MDPI operates **Preprints**, a preprint server to which submitted papers can be uploaded directly after completing journal submission. Note that *Preprints* operates independently of the journal and posting a preprint does not affect the peer review process. Check the *Preprints* **instructions for authors** for further information.

Expanded and high-quality conference papers can be considered as articles if they fulfill the following requirements: (1) the paper should be expanded to the size of a research article; (2) the conference paper should be cited and noted on the first page of the paper; (3) if the authors do not hold the copyright of the published conference paper, authors should seek the appropriate permission from the copyright holder; (4) authors are asked to disclose that it is conference paper in their cover

letter and include a statement on what has been changed compared to the original conference paper. *Sensors* does not publish pilot studies or studies with inadequate statistical power.

Unpublished conference papers that do not meet the above conditions are recommended to be submitted to the Proceedings series of journals:

Proceedings: <https://www.mdpi.com/journal/proceedings>

Chemistry Proceedings: <https://www.mdpi.com/journal/chemproc>

Engineering Proceedings: <https://www.mdpi.com/journal/engproc>

Materials Proceedings: <https://www.mdpi.com/journal/materproc>

Environmental Sciences Proceedings: <https://www.mdpi.com/journal/environsciproc>

Authorship

MDPI follows the International Committee of Medical Journal Editors (**ICMJE**) guidelines which state that, in order to qualify for authorship of a manuscript, the following criteria should be observed:

- ◆ Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; AND
- ◆ Drafting the work or revising it critically for important intellectual content; AND
- ◆ Final approval of the version to be published; AND
- ◆ Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Those who contributed to the work but do not qualify for authorship should be listed in the acknowledgments. More detailed guidance on authorship is given by the **International Council of Medical Journal Editors (ICMJE)**.

Any change to the author list should be approved by all authors including any who have been removed from the list. The corresponding author should act as a point of contact between the editor and the other authors and should keep co-authors informed and involve them in major decisions about the publication. We reserve the right to request confirmation that all authors meet the authorship conditions.

Reviewers Recommendation

Authors can recommend potential reviewers. Journal editors will check to make sure there are no conflicts of interest before contacting those reviewers, and will not consider those with competing interests. Reviewers are asked to declare any conflicts of interest. Authors can also enter the names of potential peer reviewers they wish to exclude from consideration in the peer review of their manuscript, during the initial submission progress. The editorial team will respect these requests so long as this does not interfere with the objective and thorough assessment of the submission.

Editorial Independence

Lack of Interference With Editorial Decisions

Editorial independence is of utmost importance and MDPI does not interfere with editorial decisions. All articles published by MDPI are peer reviewed and assessed by our independent editorial boards, and MDPI staff are not involved in decisions to accept manuscripts. When making an editorial decision, we expect the academic editor to make their decision based only upon:

- ◆ The suitability of selected reviewers;
- ◆ Adequacy of reviewer comments and author response;
- ◆ Overall scientific quality of the paper.

In all of our journals, in every aspect of operation, MDPI policies are informed by the mission to make science and research findings open and accessible as widely and rapidly as possible.

Editors and Editorial Staff as Authors

Editorial staff or editors shall not be involved in processing their own academic work. Submissions authored by editorial staff/editors will be assigned to at least two independent outside reviewers. Decisions will be made by other Editorial Board Members who do not have a conflict of interest with the author. Journal staff are not involved in the processing of their own work submitted to any MDPI journals.

Conflict of Interests

According to The International Committee of Medical Journal Editors, “Authors should avoid entering into agreements with study sponsors, both for-profit and non-profit, that interfere with authors’ access to all of the study’s data or that interfere with their ability to analyze and interpret the data and to prepare and publish manuscripts independently when and where they choose.”

All authors must disclose all relationships or interests that could inappropriately influence or bias their work. Examples of potential conflicts of interest include but are not limited to financial interests (such as membership, employment, consultancies, stocks/shares ownership, honoraria, grants or other funding, paid expert testimonies and patent-licensing arrangements) and non-financial interests (such as personal or professional relationships, affiliations, personal beliefs).

Authors can disclose potential conflicts of interest via the online submission system during the submission process. Declarations regarding conflicts of interest can also be collected via the **MDPI disclosure form**. The corresponding author must include a summary statement in the manuscript in a separate section “Conflicts of Interest” placed just before the reference list. The statement should reflect all the collected potential conflict of interest disclosures in the form.

See below for examples of disclosures:

Conflicts of Interest: Author A has received research grants from Company A. Author B has received a speaker honorarium from Company X and owns stocks in Company Y. Author C has been involved as a consultant and expert witness in Company Z. Author D is the inventor of patent X.

If no conflicts exist, the authors should state:

Conflicts of Interest: The authors declare no conflicts of interest.

Editorial Procedures and Peer-Review

Initial Checks

All submitted manuscripts received by the Editorial Office will be checked by a professional in-house *Managing Editor* to determine whether they are properly prepared and whether they follow the ethical policies of the journal, including those for human and animal experimentation. Manuscripts that do not fit the journal's ethics policy or do not meet the standards of the journal will be rejected before peer-review. Manuscripts that are not properly prepared will be returned to the authors for revision and resubmission. After these checks, the *Managing Editor* will consult the journals’ *Editor-in-Chief* or *Associate Editors* to determine whether the manuscript fits the scope of the journal and whether it is scientifically sound. No judgment on the potential impact of the work will be made at this stage. Reject decisions at this stage will be verified by the *Editor-in-Chief*.

Peer-Review

Once a manuscript passes the initial checks, it will be assigned to at least two independent experts for peer-review. A single-blind review is applied, where authors’ identities are known to reviewers. Peer review comments are confidential and will only be disclosed with the express agreement of the reviewer.

In the case of regular submissions, in-house assistant editors will invite experts, including recommendations by an academic editor. These experts may also include *Editorial Board Members* and Guest Editors of the journal. Potential reviewers suggested by the authors may also be considered. Reviewers should not have published with any of the co-authors during the past five years and should not currently work or collaborate with any of the institutions of the co-authors of the submitted manuscript.

Optional Open Peer-Review

The journal operates optional open peer-review: *Authors are given the option for all review reports and editorial decisions to be published alongside their manuscript. In addition, reviewers can sign their review, i.e., identify themselves in the published review reports.* Authors can alter their choice for open review at any time before publication, but once the paper has been published changes will only be made at the discretion of the *Publisher* and *Editor-in-Chief*. We encourage authors to take advantage of this opportunity as proof of the rigorous process employed in publishing their research. To guarantee impartial refereeing, the names of referees will be revealed only if the referees agree to do so, and after a paper has been accepted for publication.

Editorial Decision and Revision

All the articles, reviews and communications published in MDPI journals go through the peer-review process and receive at least two reviews. The in-house editor will communicate the decision of the academic editor, which will be one of the following:

- ◆ *Accept after Minor Revisions:*

The paper is in principle accepted after revision based on the reviewer’s comments. Authors are given five days for minor revisions.

- ◆ *Reconsider after Major Revisions:*
The acceptance of the manuscript would depend on the revisions. The author needs to provide a point by point response or provide a rebuttal if some of the reviewer's comments cannot be revised. Usually, only one round of major revisions is allowed. Authors will be asked to resubmit the revised paper within a suitable time frame, and the revised version will be returned to the reviewer for further comments.
- ◆ *Reject and Encourage Resubmission:*
If additional experiments are needed to support the conclusions, the manuscript will be rejected and the authors will be encouraged to re-submit the paper once further experiments have been conducted.
- ◆ *Reject:*
The article has serious flaws, and/or makes no original significant contribution. No offer of resubmission to the journal is provided.

All reviewer comments should be responded to in a point-by-point fashion. Where the authors disagree with a reviewer, they must provide a clear response.

Author Appeals

Authors may appeal a rejection by sending an e-mail to the Editorial Office of the journal. The appeal must provide a detailed justification, including point-by-point responses to the reviewers' and/or Editor's comments. The *Managing Editor* of the journal will forward the manuscript and related information (including the identities of the referees) to the Editor-in-Chief, Associate Editor, or Editorial Board member. The academic Editor being consulted will be asked to give an advisory recommendation on the manuscript and may recommend acceptance, further peer-review, or uphold the original rejection decision. A reject decision at this stage is final and cannot be reversed.

In the case of a special issue, the *Managing Editor* of the journal will forward the manuscript and related information (including the identities of the referees) to the *Editor-in-Chief* who will be asked to give an advisory recommendation on the manuscript and may recommend acceptance, further peer-review, or uphold the original rejection decision. A reject decision at this stage will be final and cannot be reversed.

Production and Publication

Once accepted, the manuscript will undergo professional copy-editing, English editing, proofreading by the authors, final corrections, pagination, and, publication on the **www.mdpi.com** website.

Promoting Equity, Diversity and Inclusiveness Within MDPI Journals

Our Managing Editors encourage the Editors-in-Chief and Associate Editors to appoint diverse expert Editorial Boards. This is also reflective in our multi-national and inclusive workplace. We are proud to create equal opportunities without regard to gender, ethnicity, sexual orientation, age, religion, or socio-economic status. There is no place for discrimination in our workplace and editors of MDPI journals are to uphold these principles in high regard.

ANEXO C

Strengthening the Reporting of
Observational studies in Epidemiology
(STROBE) guidelines

STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

	Item No	Recommendation	Page No
Title and abstract	1	(a) Indicate the study’s design with a commonly used term in the title or the abstract	
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	1
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	2
Objectives	3	State specific objectives, including any prespecified hypotheses	2
Methods			
Study design	4	Present key elements of study design early in the paper	3
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	3
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants	3
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	3
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	5
Bias	9	Describe any efforts to address potential sources of bias	5
Study size	10	Explain how the study size was arrived at	6
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	5
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	5
		(b) Describe any methods used to examine subgroups and interactions	5
		(c) Explain how missing data were addressed	
		(d) If applicable, describe analytical methods taking account of sampling strategy	
		(e) Describe any sensitivity analyses	
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	6
		(b) Give reasons for non-participation at each stage	5
		(c) Consider use of a flow diagram	6
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	7
		(b) Indicate number of participants with missing data for each variable of interest	8, 9
Outcome data	15*	Report numbers of outcome events or summary measures	
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	7

		(b) Report category boundaries when continuous variables were categorized	
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	5
Discussion			
Key results	18	Summarise key results with reference to study objectives	11
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	12
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	13
Generalisability	21	Discuss the generalisability (external validity) of the study results	
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	13

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at www.strobe-statement.org.

STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

Item No:

1. “Ninety-five patients (...) were recruited at Pediatrics and Pulmonology departments of a tertiary hospital. Clinicians performed conventional auscultation at 4 locations (trachea, right anterior chest, right and left lung bases), documenting any adventitious sounds. Smartphone auscultation was recorded in the same locations. The recordings (n=738) were classified by two annotators and agreement calculated (%; Cohen’s κ (95%CI)). (...) Our results show that smartphone auscultation was feasible”
2. “Guidelines for research and clinical practice in the field of respiratory sounds have been published in 2000 by the CORSA project group. (...) This technology, however, faces a significant challenge before achieving clinical acceptance”
3. “We aimed to study the feasibility of lung auscultation in clinical context using the smartphone’s built-in microphone, by assessing the quality of the recorded lung sounds and the smartphone’s capability of capturing adventitious sounds. (...)”
4. “An observational cross-sectional study was conducted with children and adults between September 2020 and March 2021. (...) Patients were included if aged 5 or over and were under medical follow-up in the Pediatrics or Pulmonology departments of CHUSJ, a tertiary hospital.”
5. “An observational cross-sectional study was conducted with children and adults between September 2020 and March 2021. (...) Patients were included if aged 5 or over and were under medical follow-up in the Pediatrics or Pulmonology departments of CHUSJ, a tertiary hospital. (...) The included patients were grouped in 4 diagnostic groups, according to their previously established diagnosis: cystic fibrosis, asthma, other respiratory diseases or no respiratory diseases.”
6. “Patients were included if aged 5 or over and were under medical follow-up in the Pediatrics or Pulmonology departments of CHUSJ, a tertiary hospital. Exclusion criteria included refusal to participate and patients whose health status or condition prevented a harmless collection of their lung sounds.”
7. “(...) lung auscultation was performed with each clinician’s smartphone (...)”
8. “To explore the existence of differences across the 4 diagnostic groups, Chi-Square tests (sex, age group) and ANOVA tests (height, age) were used.”
9. “The lung sound recordings were listened to independently by two annotators (...)”
10. “A total of 103 participants were recruited, but 10 participants were only recorded in 7 locations, and one participant only in 5 locations, making a total of 811 recordings, as presented in Figure 3. However, due to technical issues concerning the app communication with the server, only 95 participants could be included in the analysis: 42 with cystic fibrosis, 24 with asthma, 17 with other respiratory diseases and 12 with no respiratory diseases.”
11. “(...) and ANOVA tests (height, age) were used”
12. (a) “To explore the existence of differences across the 4 diagnostic groups, Chi-Square tests (sex, age group) and ANOVA tests (height, age) were used.”; (b) “A Chi-Square test, with Bonferroni correction when needed, was used to explore any differences in the proportions between these groups”
13. (a) Described in the flowchart; (b) “only the lung sounds with quality were considered for further analysis”; (c) A flowchart was used.
14. “The participants characteristics are presented in Table 1.”
15. “Regarding the total number of recordings that were listened to, 508 were considered to have quality (69%). (...) Concerning the recordings, only 52 (12%) of the recordings with quality had adventitious sounds”
16. The 95% Confidence interval for the kappa values calculated in this study can be found in Supplementary Tables 1 and 5.
17. “A Chi-Square test, with Bonferroni correction when needed, was used to explore any differences in the proportions between these groups”

18. “Our results, namely the high proportion of participants with at least one recording with quality (88%) and the 27% of participants with identified adventitious sounds, demonstrate that smartphone auscultation is feasible using a simple set-up applied during medical appointments.”
19. “Our study has some limitations that need to be acknowledged.”
20. “The main findings suggest that lung auscultation with the different smartphones’ embedded microphones is feasible in the clinical context (...) Further investigation is required (...)”
22. “This research received no external funding.”

APÊNDICE A

Consentimento Informado - Participantes

FOLHA DE INFORMAÇÃO AO PARTICIPANTE

Título do estudo: Auscultação Pulmonar com recurso a Dispositivos Móveis – Estudo de Viabilidade em Doenças Respiratórias.

Finalidade: Este estudo pretende avaliar a possibilidade de usar uma aplicação móvel para a auscultação pulmonar nas doenças respiratórias crónicas, em crianças e adultos. O estudo decorrerá nos Serviços de Pediatria e de Pneumologia do Centro Hospitalar Universitário de São João.

Participação: Se decidir participar, será realizada uma auscultação pulmonar de duas formas diferentes: o seu médico auscultará o seu peito em 4 locais primeiro com um estetoscópio e de seguida repetirá o procedimento com um telemóvel, encostando o telemóvel à sua pele, de modo a gravar os seus sons respiratórios.

Benefícios: A sua participação poderá ajudar, no futuro, a utilizar esta aplicação num contexto de telemedicina, isto é, poderá permitir a realização de auscultações pulmonares à distância.

Riscos e inconvenientes: Não é esperado nenhum efeito secundário, desvantagem ou risco. O possível desconforto é o associado ao curto período de tempo necessário para a realização das duas auscultações pulmonares. A sua participação é totalmente voluntária, podendo desistir a qualquer momento sem dar nenhuma explicação e sem que por isso venha a ser prejudicado nos cuidados de saúde que lhe são prestados.

Receber informações acerca do estudo: Se desejar e fornecer o seu e-mail, poderá receber informações acerca dos resultados deste e outros estudos de avaliação e desenvolvimento de aplicações móveis para a gestão de doenças respiratórias.

Tratamento de dados: Toda a informação recolhida, neste estudo, será estritamente confidencial e a sua identidade nunca será revelada, em qualquer relatório ou publicação. O material recolhido será utilizado somente para fins de investigação e desenvolvimento, de acordo com o Regime Geral de Proteção de Dados, Lei nº58/2019, de 08 de agosto. Caso o permita, os sons respiratórios gravados poderão ser adicionados totalmente anonimizados a um repositório público de sinais sonoros para investigação. De acordo com a legislação, poderá solicitar, a qualquer momento, o acesso às informações que forem recolhidas sobre si. Pode também solicitar a alteração, correção ou eliminação das informações pessoais. Pode ainda optar por não receber futuras comunicações acerca do estudo. Caso o pretenda, por favor contacte-nos através dos contactos abaixo.

Contacto para mais informações

Investigador responsável: Maria Inês Ferreira Águeda de Azevedo

Assistente Hospitalar Graduada no Centro Hospitalar Universitário de São João (CHUSJ)

E-mail: iazevedo@med.up.pt

Contacto telefónico: 934 552 654

CONSENTIMENTO INFORMADO, LIVRE E ESCLARECIDO

Título do estudo: Auscultação Pulmonar com recurso a Dispositivos Móveis – Estudo de Viabilidade em Doenças Respiratórias.

Ao participante

Por favor, leia com atenção a folha de informação. Verifique se compreende todas as informações dadas e esclareça todas as suas dúvidas. Se concordar, assine o consentimento em duplicado e fique com um dos exemplares.

Por favor, para cada uma das seguintes afirmações assinale com um

(X) a caixa que melhor expressa a sua vontade:

Sim Não

- Confirmo que li e entendi a informação relativa a este estudo, tive oportunidade de fazer perguntas e recebi respostas satisfatórias, e tive tempo suficiente para tomar a minha decisão.

☐
☐

- Confirmo que a minha participação neste estudo é voluntária e que me foi explicado que não haverá qualquer prejuízo nos cuidados de saúde que me são prestados se eu, em algum momento, recusar participar.

☐
☐

- Autorizo que os elementos da equipa de investigação acedam aos meus dados exclusivamente no âmbito deste estudo.

☐
☐

Autorizo que os meus dados sejam conservados por um período de 5 anos.

☐
☐

Sim Não

Adicionalmente (opcional), autorizo ser contactado para o seguinte email (PF preencher) _____ no âmbito de outras investigações e futuros estudos de avaliação e desenvolvimento de aplicações móveis para a gestão de doenças respiratórias.

☐
☐

Adicionalmente (opcional), autorizo que os sons respiratórios gravados no âmbito deste estudo sejam incluídos totalmente anonimizados num repositório público de sinais sonoros para investigação.

☐
☐

Adicionalmente (opcional), autorizo que os dados colhidos no âmbito deste estudo sejam conservados totalmente anonimizados para outras investigações e futuros estudos.

☐
☐

Nome legível do participante: _____

Data ____/____/____ Assinatura _____

O Investigador

Confirmo que expliquei ao participante os procedimentos necessários para participar no estudo. Respondi a todas as questões que me foram colocadas e assegurei-me de que houve um período de reflexão suficiente para a tomada de decisão. Também garanti que, em caso de recusa, serão assegurados os melhores cuidados possíveis nesse contexto, no respeito pelos seus direitos.

Nome legível do investigador: _____

Data ____/____/____ Assinatura _____

Nota: Este documento é feito em duplicado: uma via para o/a investigador /a, outra para a pessoa que consente.

APÊNDICE B

Consentimento Informado – Representante Legal

FOLHA DE INFORMAÇÃO AO REPRESENTANTE LEGAL

Título do estudo: Auscultação Pulmonar com recurso a Dispositivos Móveis – Estudo de Viabilidade em Doenças Respiratórias.

Finalidade: Este estudo pretende avaliar a possibilidade de usar uma aplicação móvel para a auscultação pulmonar nas doenças respiratórias crónicas, em crianças e adultos. O estudo decorrerá nos Serviços de Pediatria e de Pneumologia do Centro Hospitalar Universitário de São João.

Participação: Se consentir a participação do seu filho/a, será realizada uma auscultação pulmonar de duas formas diferentes: o seu médico auscultará o peito do seu filho/a em 4 locais primeiro com um estetoscópio e de seguida repetirá o procedimento com um telemóvel, encostando o telemóvel à sua pele, de modo a gravar os seus sons respiratórios.

Benefícios: A participação do seu filho/a poderá ajudar, no futuro, a utilizar esta aplicação num contexto de telemedicina, isto é, poderá permitir a realização de auscultações pulmonares à distância.

Riscos e inconvenientes: Não é esperado nenhum efeito secundário, desvantagem ou risco. O possível desconforto é o associado ao curto período de tempo necessário para a realização das duas auscultações pulmonares. A sua participação do seu filho/a é totalmente voluntária, podendo desistir a qualquer momento sem dar qualquer explicação e sem que por isso venha a ser prejudicado nos cuidados de saúde que lhe são prestados.

Receber informações acerca do estudo: Se desejar e fornecer o seu e-mail, poderá receber informações acerca dos resultados deste e outros estudos de avaliação e desenvolvimento de aplicações móveis para a gestão de doenças respiratórias.

Tratamento de dados: Toda a informação recolhida, neste estudo, será estritamente confidencial e a identidade do seu filho/a nunca será revelada, em qualquer relatório ou publicação. O material recolhido será utilizado somente para fins de investigação e desenvolvimento, de acordo com o Regime Geral de Proteção de Dados, Lei nº58/2019, de 08 de agosto. Caso o permita, os sons respiratórios gravados poderão ser adicionados totalmente anonimizados a um repositório público de sinais sonoros para investigação. De acordo com a legislação, poderá solicitar, a qualquer momento, o acesso às informações que forem recolhidas. Pode também solicitar a alteração, correção ou eliminação das informações pessoais. Pode ainda optar por não receber futuras comunicações acerca do estudo. Caso o pretenda, por favor contacte-nos através dos contactos abaixo.

Contacto para mais informações

Investigador responsável: Maria Inês Ferreira Águeda de Azevedo

Assistente Hospitalar Graduada no Centro Hospitalar Universitário de São João (CHUSJ)

E-mail: iazevedo@med.up.pt

Contacto telefónico: 934 552 654

CONSENTIMENTO INFORMADO, LIVRE E ESCLARECIDO

Título do estudo: Auscultação Pulmonar com recurso a Dispositivos Móveis – Estudo de Viabilidade em Doenças Respiratórias.

Ao representante legal

Por favor, leia com atenção a folha de informação. Verifique se compreende todas as informações dadas e esclareça todas as suas dúvidas. Se concordar, assine o consentimento em duplicado e fique com um dos exemplares.

Por favor, para cada uma das seguintes afirmações assinale com um

(X) a caixa que melhor expressa a sua vontade:

Sim Não

- Confirmo que li e entendi a informação relativa a este estudo, tive oportunidade de fazer perguntas e recebi respostas satisfatórias, e tive tempo suficiente para tomar a minha decisão.

☐ ☐

- Confirmo que a participação do meu filho/a neste estudo é voluntária e que me foi explicado que não haverá qualquer prejuízo nos cuidados de saúde que lhe são prestados se eu, em algum momento, recusar a sua participação.

☐ ☐

- Autorizo que os elementos da equipa de investigação acedam aos dados do meu filho/a exclusivamente no âmbito deste estudo.

☐ ☐

Autorizo que os dados do meu filho/a sejam conservados por um período de 5 anos.

☐ ☐

Sim Não

Adicionalmente (opcional), autorizo ser contactado para o seguinte email (PF preencher)

☐ ☐

_____ no âmbito de outras investigações e futuros estudos de avaliação e desenvolvimento de aplicações móveis para a gestão de doenças respiratórias.

Adicionalmente (opcional), autorizo que os sons respiratórios gravados no âmbito deste estudo sejam incluídos totalmente anonimizados num repositório público de sinais sonoros para investigação.

☐ ☐

Adicionalmente (opcional), autorizo que os dados colhidos no âmbito deste estudo sejam conservados totalmente anonimizados para outras investigações e futuros estudos.

☐ ☐

Nome legível do representante legal: _____

Data ____/____/____ Assinatura _____

O Investigador

Confirmo que expliquei ao representante legal os procedimentos necessários para participar no estudo. Respondi a todas as questões que me foram colocadas e assegurei-me de que houve um período de reflexão suficiente para a tomada de decisão. Também garanti que, em caso de recusa, serão assegurados os melhores cuidados possíveis nesse contexto, no respeito pelos seus direitos.

Nome legível do investigador: _____

Data ____/____/____ Assinatura _____

Nota: Este documento é feito em duplicado: uma via para o/a investigador /a, outra para a pessoa que consente.

APÊNDICE C

Assentimento Informado

FOLHA DE INFORMAÇÃO AO PARTICIPANTE

Título do estudo: Auscultação Pulmonar com recurso a Dispositivos Móveis – Estudo de Viabilidade em Doenças Respiratórias.

Finalidade: Este estudo pretende avaliar a possibilidade de usar uma aplicação móvel para a auscultação pulmonar nas doenças respiratórias crónicas, em crianças e adultos. O estudo decorrerá nos Serviços de Pediatria e de Pneumologia do Centro Hospitalar Universitário de São João.

Participação: Se decidir participar, será realizada uma auscultação pulmonar de duas formas diferentes: o seu médico auscultará o seu peito em 4 locais primeiro com um estetoscópio e de seguida repetirá o procedimento com um telemóvel, encostando o telemóvel à sua pele, de modo a gravar os seus sons respiratórios.

Benefícios: A sua participação poderá ajudar, no futuro, a utilizar esta aplicação num contexto de telemedicina, isto é, poderá permitir a realização de auscultações pulmonares à distância.

Riscos e inconvenientes: Não é esperado nenhum efeito secundário, desvantagem ou risco. O possível desconforto é o associado ao curto período de tempo necessário para a realização das duas auscultações pulmonares. A sua participação é totalmente voluntária, podendo desistir a qualquer momento sem dar nenhuma explicação e sem que por isso venha a ser prejudicado nos cuidados de saúde que lhe são prestados.

Receber informações acerca do estudo: Se desejar e fornecer o seu e-mail, poderá receber informações acerca dos resultados deste e outros estudos de avaliação e desenvolvimento de aplicações móveis para a gestão de doenças respiratórias.

Tratamento de dados: Toda a informação recolhida, neste estudo, será estritamente confidencial e a sua identidade nunca será revelada, em qualquer relatório ou publicação. O material recolhido será utilizado somente para fins de investigação e desenvolvimento, de acordo com o Regime Geral de Proteção de Dados, Lei nº58/2019, de 08 de agosto. Caso o permita, os sons respiratórios gravados poderão ser adicionados totalmente anonimizados a um repositório público de sinais sonoros para investigação. De acordo com a legislação, poderá solicitar, a qualquer momento, o acesso às informações que forem recolhidas sobre si. Pode também solicitar a alteração, correção ou eliminação das informações pessoais. Pode ainda optar por não receber futuras comunicações acerca do estudo. Caso o pretenda, por favor contacte-nos através dos contactos abaixo.

Contacto para mais informações

Investigador responsável: Maria Inês Ferreira Águeda de Azevedo

Assistente Hospitalar Graduada no Centro Hospitalar Universitário de São João (CHUSJ)

E-mail: iazevedo@med.up.pt

Contacto telefónico: 934 552 654

ASSENTIMENTO INFORMADO, LIVRE E ESCLARECIDO

Título do estudo: Auscultação Pulmonar com recurso a Dispositivos Móveis – Estudo de Viabilidade em Doenças Respiratórias.

Ao participante

Por favor, leia com atenção a folha de informação. Verifique se compreende todas as informações dadas e esclareça todas as suas dúvidas. Se concordar, assine o consentimento em duplicado e fique com um dos exemplares.

Por favor, para cada uma das seguintes afirmações assinale com um

(X) a caixa que melhor expressa a sua vontade:

Sim Não

- Confirmando que li e entendi a informação relativa a este estudo, tive oportunidade de fazer perguntas e recebi respostas satisfatórias, e tive tempo suficiente para tomar a minha decisão.

☐ ☐

- Confirmando que a minha participação neste estudo é voluntária e que me foi explicado que não haverá qualquer prejuízo nos cuidados de saúde que me são prestados se eu, em algum momento, recusar participar.

☐ ☐

- Autorizo que os elementos da equipa de investigação acedam aos meus dados exclusivamente no âmbito deste estudo.

☐ ☐

Autorizo que os meus dados sejam conservados por um período de 5 anos.

☐ ☐

Sim Não

Adicionalmente (opcional), autorizo ser contactado para o seguinte email (PF preencher) _____ no âmbito de outras investigações e futuros estudos de avaliação e desenvolvimento de aplicações móveis para a gestão de doenças respiratórias.

☐ ☐

Adicionalmente (opcional), autorizo que os sons respiratórios gravados no âmbito deste estudo sejam incluídos totalmente anonimizados num repositório público de sinais sonoros para investigação.

☐ ☐

Adicionalmente (opcional), autorizo que os dados colhidos no âmbito deste estudo sejam conservados totalmente anonimizados para outras investigações e futuros estudos.

☐ ☐

Nome legível do participante: _____

Data ____/____/____ Assinatura _____

O Investigador

Confirmando que expliquei ao participante os procedimentos necessários para participar no estudo. Respondi a todas as questões que me foram colocadas e assegurei-me de que houve um período de reflexão suficiente para a tomada de decisão. Também garanti que, em caso de recusa, serão assegurados os melhores cuidados possíveis nesse contexto, no respeito pelos seus direitos.

Nome legível do investigador: _____

Data ____/____/____ Assinatura _____

Nota: Este documento é feito em duplicado: uma via para o/a investigador /a, outra para a pessoa que consente.

APÊNDICE D

Protocolo do Projeto de Investigação

Dissertação/Projeto
Mestrado Integrado em Medicina
Ano Letivo 2020/2021

PROTOCOLO

“Pulmonary Auscultation using Mobile Devices – Feasibility Study in Respiratory Diseases”

ESTUDANTE

Henrique de Mesquita Guimarães e Ferreira Cardoso

Nº Estudante: 201503177

Contacto Telefónico: 914444602

Correio Eletrónico: hmgfcardoso@gmail.com

ORIENTADORA

Maria Inês Ferreira Águeda de Azevedo

Professora Doutorada pela Faculdade de Medicina da Universidade do Porto

Assistente Hospitalar Graduada no Centro Hospitalar Universitário de São João (CHUSJ)

CO-ORIENTADORES

João de Almeida Lopes da Fonseca

Professor Associado da Faculdade de Medicina da Universidade do Porto

Departamento Medicina da Comunidade, Informação e Decisão em Saúde

Cristina Isabel Oliveira Jácome

Professora Doutorada Equiparada a Investigadora Auxiliar pela Faculdade de Medicina da
Universidade do Porto

Departamento Medicina da Comunidade, Informação e Decisão em Saúde

1. Introdução

Mais de mil milhões de pessoas sofrem de doenças respiratórias crónicas em todo o mundo . A asma, concretamente, atinge cerca de 339 milhões de pessoas e representa a doença crónica mais comum na infância, estando presente em mais de 14% das crianças globalmente. Anualmente, esta constitui um motivo frequente de hospitalizações nos países desenvolvidos^{1,2}. A fibrose quística, por sua vez, apresenta uma prevalência de 1/4500 na Europa Ocidental, afetando cada vez mais a população adulta, dado que a esperança média de vida está próxima dos 50 anos e a proporção de doentes adultos é já superior a 50%³. O principal impacto e causa de morte na fibrose quística prende-se com a insuficiência respiratória, associada a infeções recorrentes e crónicas⁴.

Estas doenças respiratórias constituem um problema de saúde pública com crescente sobrecarga para os sistemas de saúde, a economia e a sociedade. A sua deterioração progressiva depende primariamente da ocorrência de agudizações, necessitando os doentes de consultas médicas regulares e monitorização frequente do seu estado de saúde. Tradicionalmente, os cuidados de saúde são fornecidos através de intervenções presenciais entre o doente e o profissional de saúde mas, cada vez mais, as consultas em telemedicina têm adquirido maior relevância. A interação à distância promove os cuidados centrados nos doentes, ao evitar deslocações onerosas, desnecessárias ou de risco, dos doentes ao hospital. Todavia, embora a entrevista clínica, a observação de meios complementares de diagnóstico e a prescrição médica possam ser efetuadas facilmente por meios eletrónicos, a principal limitação é a incapacidade de observação completa do doente. Em doenças respiratórias, essa limitação é particularmente notória na componente de auscultação pulmonar. Durante a pandemia COVID-19, a impossibilidade de auscultar os doentes suspeitos de infeção pelo vírus SARS-CoV-2, devido ao uso de equipamento de proteção individual, tornou também premente a necessidade de se desenvolverem novas formas de avaliar sons respiratórios.

A auscultação pulmonar é uma parte importante do exame físico, fornecendo informação relevante sobre o estado do sistema respiratório e auxiliando o diagnóstico de várias patologias respiratórias⁵. Na asma, a observação de um aumento da frequência e da intensidade dos sons respiratórios poderá ter mais sensibilidade do que a presença de sibilos, embora estes sejam mais frequentes e mais facilmente identificáveis⁶. Na fibrose quística, entre os sinais e sintomas independentemente associados à classificação de um evento como “exacerbação” destaca-se a presença de crepitações, aliada ao aumento da produção de expectoração e tosse, em crianças com menos de 6 anos, uma redução de 45% no percentil do peso corporal⁷. Assim, a auscultação pulmonar revela-se de extrema importância no diagnóstico e seguimento dos doentes com estas patologias. Dessa forma, a potenciação de um maior acesso a ferramentas simples de auscultação e comunicação com o profissional de saúde, por parte do doente, poderá contribuir para um melhor controlo destas patologias, resultando numa diminuição do número de hospitalizações e de consultas não programadas.

Na procura de respostas a este problema, desenvolvemos uma aplicação móvel com vista à monitorização das doenças respiratórias crónicas, nomeadamente no que toca à auscultação pulmonar usando apenas o *smartphone* e os seus sensores integrados. Com esta aplicação móvel, para além da melhorar e facilitar a auto-gestão das doenças respiratórias crónicas, pretendemos aproveitar as capacidades dos *smartphones*, nomeadamente a portabilidade, a capacidade de processamento e armazenamento, os sensores não invasivos e a capacidade de comunicação sem fios, com o método de Análise de Sons Respiratórios Computarizada (CORSa – Computerized Respiratory Sound Analysis)⁸.

Foi demonstrado que a gravação e análise computarizada de sons respiratórios supera a auscultação convencional na pneumologia pediátrica⁹, mas não sabemos se utilizando o *smartphone* o mesmo se verifica. É necessário, assim, investigar a exequibilidade da auscultação pulmonar com um *smartphone* em contexto clínico, bem como comparar a qualidade e os achados (sons adventícios) das gravações obtidas com a auscultação com estetoscópio convencional.

2. Objetivos

O objetivo geral deste estudo é avaliar a exequibilidade de uma aplicação móvel, com uma componente de aquisição de sons respiratórios, desenhada para melhorar a auto-monitorização e auto-gestão das doenças respiratórias obstrutivas crónicas.

Mais especificamente, este estudo pretende:

1. Testar a aquisição dos sons respiratórios com microfone de dispositivos móveis e sua gravação em aplicação móvel, anotando as observações identificadas na auscultação convencional pelo médico usando um estetoscópio;
2. Constituir uma base de dados de sons respiratórios úteis para o desenvolvimento e validação de algoritmos de processamento do som para dispositivos móveis.

3. Desenho do estudo

Este é um estudo observacional transversal que prevê a inclusão de 120 indivíduos, com diagnóstico de asma, fibrose quística ou sem patologia respiratória. O estudo inclui uma visita única por parte dos investigadores aquando da deslocação do doente ao hospital para uma consulta programada ou não programada, ou internamento, pelo que o participante não terá de se deslocar ao Centro Hospitalar Universitário de São João propositadamente para a realização do estudo. A investigação será conduzida nos serviços de Pediatria e de Pneumologia do Centro Hospitalar Universitário de São João (CHUSJ).

É expectável que o período de recrutamento decorra de setembro de 2020 a janeiro de 2021.

4. Participantes

Critérios de inclusão:

1. Indivíduos de qualquer idade superior a 5 anos, em tratamento em Pediatria ou Pneumologia no CHUSJ;
2. Diagnóstico de asma (grupo A), fibrose quística (grupo B), sem doença respiratória (grupo C) ou com outras doenças respiratórias (Grupo D).

Serão excluídos do recrutamento os indivíduos:

1. Cujo estado de saúde não permita a recolha sem riscos para o participante (contraindicações para a recolha de sons respiratórios);
2. Recusa em participar no estudo.

5. Aplicação AIRDOC

O objetivo da aplicação AIRDOC é ser uma ferramenta útil na monitorização das doenças respiratórias, nomeadamente na monitorização da auscultação pulmonar usando apenas o *smartphone* e os seus sensores integrados.

5.1. Recolha de som de auscultação pulmonar

Esta componente da aplicação tem como objetivo a recolha de som de auscultação sem recurso a dispositivos externos ao *smartphone* (Figura 1). A localização da auscultação é selecionável entre uma das predefinidas ou descrita em campo aberto. A duração do registo é definida num primeiro passo após o qual se inicia o registo manualmente. O dispositivo móvel deve ser colocado com o microfone ligeiramente pressionado sobre a pele no ponto de auscultação escolhido. O som é gravado durante o período de tempo predefinido. No final do registo é possível reproduzir o mesmo e adicionar uma nota. Todos os dados são identificados por um *id* interno e armazenados localmente, podendo, mediante autenticação e autorização por parte do participante ou do seu representante legal no estudo, ser enviados, por este, para um servidor protegido segundo as normas de segurança e privacidade em conformidade com o Regime Geral de Proteção de Dados (RGPD), regidas pela Universidade do Porto (Ver Secção 8).

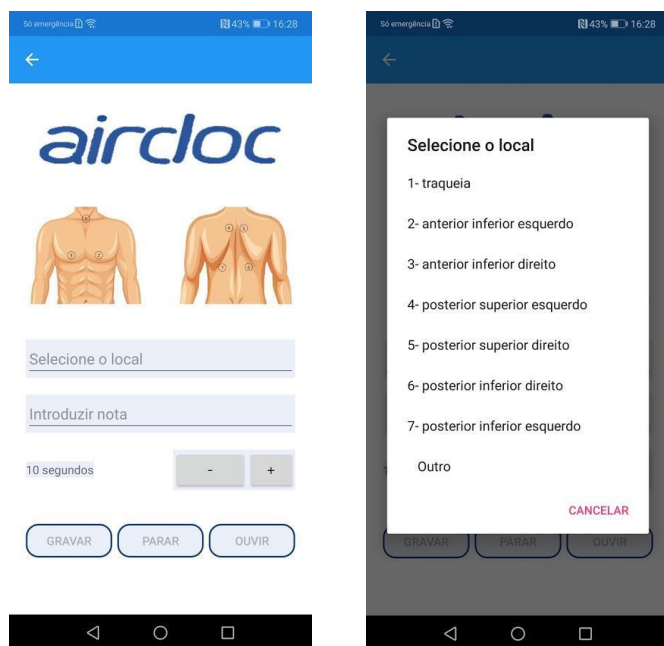


Figura 1 Recolha de auscultação pulmonar.

6. Recolha de dados

Todos os dados serão recolhidos presencialmente durante uma única visita por parte dos investigadores, aquando de consulta programada ou não programada, ou internamento. Alguns dados serão registados numa CRF em papel, pelo médico ou pelos investigadores, e outros registados diretamente na própria aplicação. Para além da auscultação pulmonar, serão recolhidas informações sobre a idade, o sexo, a altura, a patologia de cada participante e as observações do médico relativas à auscultação realizada.

Com a pandemia de COVID-19, é necessário garantir a segurança do participante e do investigador. Assim, será realizada a higienização das mãos, com solução de base alcoólica e segundo as recomendações da Organização Mundial de Saúde, entre cada participante. A desinfecção dos equipamentos e o equipamento de proteção individual serão feitas segundo as normas em vigor no CHUSJ. Estes procedimentos serão seguidos durante todas as atividades propostas neste protocolo do estudo.

O dispositivo móvel, já com a aplicação AIRDOC instalada, será usado em cada participante numa saqueta de plástico e toda a manipulação do dispositivo irá acontecer com esta proteção. A saqueta apresentará apenas uma pequena abertura no local do microfone, de forma a não comprometer a gravação dos sons. As saquetas de plástico serão trocadas entre participantes.

Para além disso, com a inclusão de doentes com fibrose quística, pelo risco infeccioso inerente a esta patologia, serão garantidos todos os cuidados de higiene e desinfecção entre cada paciente¹⁰, nomeadamente:

1. Utilização de máscara, luvas e todo o material de proteção individual exigido;
2. Higienização das mãos e do *smartphone*;
3. Desinfecção do estetoscópio, recorrendo a álcool ou toalhetes desinfectantes de base alcoólica, entre cada doente. O investigador deverá colocar solução desinfectante nas duas mãos, manuseando o diafragma entre estas de modo a higienizá-lo¹¹.

6.1 Recolha da auscultação pulmonar

A auscultação pulmonar será realizada por um profissional de saúde, com recurso a um estetoscópio convencional, nas localizações 1, 3, 6 e 7, representadas nas figuras 2 e 3, respeitantes às localizações indicadas nas *guidelines* do CORSA. Notas acerca da auscultação convencional serão registadas na CRF. O investigador irá também adquirir os sons respiratórios, recorrendo ao *smartphone*, nas mesmas localizações, efetuando os seguintes procedimentos:

1. É iniciado o módulo de gravação de som a utilizar e explicado o mesmo ao participante;
2. É selecionado o tempo de gravação de 10 segundos;
3. A auscultação pulmonar deve ser realizada com o participante sentado, com as costas direitas e, nos adultos, com os pés bem assentes no chão;
4. É selecionada e inserida na aplicação a localização da auscultação a efetuar;
5. O doente (adultos e crianças colaborantes) deve ser instruído a respirar pela boca, mais profundamente do que o normal, antes e durante a aquisição do som;
6. O investigador deve posicionar o dispositivo móvel, pressionando ligeiramente (contacto firme) a face onde se encontra o microfone contra o tórax na localização selecionada, e iniciar o registo com o módulo da aplicação, registando o som pulmonar durante o tempo definido;
7. O procedimento deverá ser repetido desde o passo 4, para cada localização de registo prevista;
8. Deverão ser realizadas 2 recolhas em cada localização.

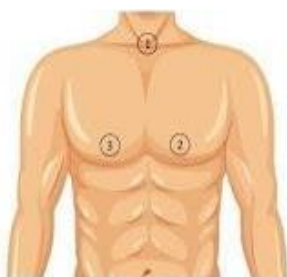


Figura 2 - Representação das localizações para auscultação (traqueia, quadrante anterior inferior direito, quadrante anterior inferior esquerdo).

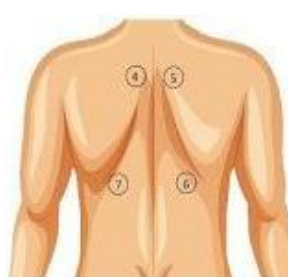


Figura 3 - Representação das localizações para auscultação (quadrante posterior superior direito e esquerdo, quadrante posterior inferior direito e esquerdo).

7. Análise dos dados

Os sons gravados aquando da auscultação pulmonar com *smartphone* serão ouvidos, posteriormente à sua recolha, e analisados quanto à qualidade da gravação e à presença de sons adventícios. Esta avaliação será comparada com os dados registados pelo profissional de saúde aquando da auscultação com estetoscópio convencional.

Todas as análises estatísticas serão realizadas usando a base de dados anonimizada. Técnicas de estatística descritiva serão usadas para caracterizar as variáveis recolhidas. A normalidade de cada variável será avaliada com o teste de Shapiro-Wilk e por análise visual da sua distribuição. As frequências relativas e absolutas serão usadas para caracterizar as variáveis categóricas e a média, mediana, desvio-padrão, máximo, mínimo e intervalo interquartil, selecionadas de acordo com a distribuição dos dados, para caracterizar as variáveis contínuas.

Recorrer-se-á também à estatística inferencial de acordo com a distribuição da normalidade. Correlações entre parâmetros adquiridos com *smartphone* e através de testes padrão serão exploradas com os coeficientes de Pearson ou de Spearman.

Os sons respiratórios recolhidos serão objeto de análise através de técnicas de pré-processamento e processamento desenvolvidas pela equipa. As gravações serão analisadas com algoritmos de caracterização do som respiratório - intensidade e frequência - e de deteção de sons respiratórios adventícios. Caso o doente o permita, os sons respiratórios gravados poderão ser adicionados totalmente anonimizados a um repositório público de sinais sonoros para investigação.

8. Considerações éticas

O descrito no RGPD será atendido e cumprido pela Lei nº 58/2019, de 08 de agosto. Este protocolo surge integrado num projeto maior, o projeto AIRDOC, que tem já estabelecida uma estratégia sólida para garantir a segurança e privacidade dos dados pessoais e sensíveis que estão a ser recolhidos. Serão adotadas medidas de pseudo-anonimização com dois níveis de separação. Isto é, será feita uma primeira pseudoanonimização à base de dados extraída do repositório de dados do projeto AIRDOC, apenas com os dados necessários a serem usados no estudo (e.g., minimização). Esta pseudoanonimização será feita pelo investigador responsável da atividade de privacidade e segurança (A4) do projeto (IRPS). Será depois seguida de uma segunda pseudoanonimização à base de dados gerada na primeira pseudoanonimização, para melhor garantir a distância entre os códigos que correspondem aos dados originais e os códigos duplamente pseudoanonimizados, estes últimos, os que vão ser usados realmente no estudo em questão. A primeira base de dados pseudoanonimizada será guardada numa *pen* protegida por palavra-passe, apenas conhecida pelo Investigador Responsável (IR). Esta *pen* será mantida numa gaveta fechada à chave no escritório do IR, num espaço físico separado do servidor com

a base de dados original. Neste primeiro passo, a chave usada para a codificação (e.g., a pseudoanonimização) será cifrada e guardada em local físico protegido separado dos dados identificativos, pelo IR. O segundo processo de pseudoanonimização será a repetição do primeiro, tendo como a única diferença o fato da base de dados gerada pela segunda pseudoanonimização ser partilhada com um grupo muito limitado de profissionais, obrigados a confidencialidade, que terão acesso a esses dados duplamente pseudo-anonimizados para efeitos de investigação no âmbito deste estudo em concreto, e nunca tendo acesso, desta forma, aos dados originais. Uma vez mais, a chave usada para a codificação (diferente da primeira pseudoanonimização) será também cifrada e guardada em local físico protegido separado dos dados identificativos, pelo IR. Os investigadores irão explicar aos participantes ou aos seus representantes legais o objetivo do estudo e questionar acerca da vontade em participar. Sendo dado o acordo de participação, o estudo será descrito em maior detalhe, nomeadamente os seus procedimentos e o tipo de dados recolhidos. Para assegurar que os participantes ou representantes legais compreendem o objetivo e requisitos para a participação, ser-lhes-á pedido para verbalizar a sua compreensão do estudo. De seguida, o consentimento informado escrito de acordo com a declaração de Helsínquia, com informação detalhada do objetivo e procedimentos do estudo, será entregue ao participante ou seu representante legal, que o irá ler, ou será lido pelo investigador. O consentimento informado escrito será obtido previamente a qualquer recolha de dados.

O armazenamento dos dados identificativos dos participantes será gerido com as mesmas medidas de segurança que estão desenvolvidas para os utilizadores do projecto AIRDOC. Existe um plano de gestão de segurança para conformidade com o RGPD. Este plano inclui uma avaliação de impacto de risco de todos os dados pessoais usados no projecto AIRDOC, e todas as medidas e requisitos de segurança que estão a ser implementados para proteger, em conformidade com o RGPD, os dados referidos. Para além disso, em termos de arquitetura, os dados pessoais são armazenados numa base de dados centralizada, protegida com níveis de acesso, usando a autenticação baseada em *tokens* segundo os protocolos de autenticação (OAuth2) e autorização (openID) que, atualmente, são os mais robustos, testados e atualizados, e permitem um uso reduzido das credenciais de acesso dos utilizadores, diminuindo assim a sua exposição a ataques. Para além disso, os dados são estruturados usando o *standard FHIR*, que permite não só uma melhor organização, gestão e separação dos dados, mas também uma manutenção de registos mais segura visto que pode também reunir informações sobre o contexto em que os dados foram obtidos, para efeitos de auditoria e monitorização, também requisito do RGPD. Esta base de dados é armazenada num servidor protegido segundo as normas de segurança e privacidade em conformidade com o RGPD, regidas pela Universidade do Porto, onde o mesmo se localiza.

Devemos salientar, no entanto, que este pedido feito à Comissão de Ética refere-se apenas ao estudo de exequibilidade descrito neste protocolo e estudo específico, que salvaguarda a proteção de dados dos participantes com a dupla pseudoanonimização, anteriormente descrita.

9. Razão risco benefício favorável

Uma vez que não irá ocorrer qualquer alteração ao tratamento das doenças respiratórias decorrentes do estudo, nem qualquer intervenção, não são antecipados quaisquer riscos para os doentes com a participação neste estudo. A participação é totalmente voluntária e a desistência poderá acontecer a qualquer momento sem necessidade de explicação pelo participante e sem prejuízo nos cuidados de saúde que lhe são prestados.

10. Recursos e/ou financiamento

Este estudo não tem financiamento. Contudo, está integrado no projeto AIRDOC (NORTE-01-0247-FEDER-033275), que é um estudo de caso de um projeto consórcio internacional ITEA 3 designado de PHE - Personal Health Empowerment (referência 16040, sem financiamento), que contempla 2 estudos de caso (doenças respiratórias obstrutivas crónicas e locais de trabalho saudáveis). Assim, o equipamento necessário e as técnicas de análise dos sons respiratórios serão providenciados pelo projeto em curso.

Os participantes e as instituições de saúde não terão qualquer encargo com este estudo.

11. Conclusão

A patologia respiratória crónica apresenta uma grande prevalência na população e constitui um grande sobrecarga económica para os doentes e para os sistemas de saúde. O acesso a novas ferramentas de controlo e monitorização da auscultação pulmonar poderão auxiliar a mitigar o impacto de patologias como a asma ou a fibrose quística. Esta aplicação poderá, no futuro, ajudar os doentes, cuidadores e profissionais de saúde a detetar precocemente períodos de agudização. Para além disso, esta aplicação poderá facilitar a gestão e transmissão de dados entre o doente e o clínico/serviços de saúde e promover uma gestão mais informada e participada da doença crónica. Mais ainda, a análise dos sons respiratórios poderá servir de indicador sobre a adesão à terapêutica por parte do doente, assim como da localização da inflamação na via respiratória^{12,13}.

Assim, a investigação e desenvolvimento desta aplicação poder-se-á revelar deveras útil para a aquisição de conhecimentos e para a inovação da telemedicina, promovendo uma melhor gestão da patologia respiratória crónica.

12. Referências

1. European Respiratory Society 2017. Forum of International Respiratory Societies The Global Impact of Respiratory Disease. Published online 2017:1-43.
2. OMS TGAN. *Global Asthma Network The Global Asthma Report.*; 2018. Accessed September 5, 2020. www.globalasthmanetwork.org
3. Scotet V, L'hostis C, Férec C. The changing epidemiology of cystic fibrosis: Incidence, survival and impact of the CFTRGene discovery. *Genes (Basel)*. 2020;11(6). doi:10.3390/genes11060589
4. Schwarz C, Staab D. Zystische Fibrose und ihre Komplikationen. *Internist*. 2015;56(3):263-274. doi:10.1007/s00108-014-3646-z
5. Sarkar M, Madabhavi I, Niranjana N, Dogra M. Auscultation of the respiratory system. *Ann Thorac Med*. 2015;10(3):158-168. doi:10.4103/1817-1737.160831
6. Nagasaka Y. Lung sounds in bronchial asthma. *Allergol Int*. 2012;61(3):353-363. doi:10.2332/allergolint.12-RAI-0449
7. Regelman WE, Schechter MS, Wagener JS, et al. Pulmonary exacerbations in cystic fibrosis: Young children with characteristic signs and symptoms. *Pediatr Pulmonol*. 2013;48(7):649-657. doi:10.1002/ppul.22658
8. Reyes BA, Reljin N, Chon KH. Tracheal sounds acquisition using smartphones. *Sensors (Switzerland)*. 2014;14(8):13830-13850. doi:10.3390/s140813830
9. Prodhon P, Dela Rosa RS, Shubina M, et al. Wheeze detection in the pediatric intensive care unit: Comparison among physician, nurses, respiratory therapists, and a computerized respiratory sound monitor. *Respir Care*. 2008;53(10):1304-1309.
10. Rutala WA, Weber DJ. *Guideline for Disinfection and Sterilization in Healthcare Facilities*, 2008.
11. Napolitani M, Bezzini D, Moirano F, Bedogni C, Messina G. Methods of disinfecting stethoscopes: Systematic review. *Int J Environ Res Public Health*. 2020;17(6). doi:10.3390/ijerph17061856
12. Shimoda T, Obase Y, Nagasaka Y, Nakano H, Kishikawa R, Iwanaga T. Lung sound analysis can be an index of the control of bronchial asthma. *Allergol Int*. 2017;66(1):64-69. doi:10.1016/j.alit.2016.05.002
13. Shimoda T, Obase Y, Nagasaka Y, et al. Lung sound analysis helps localize airway inflammation in patients with bronchial asthma. *J Asthma Allergy*. 2017;10:99-108. doi:10.2147/JAA.S125938

APÊNDICE E

Case Report Form (CRF)

CRF I. RECOLHA DE SONS RESPIRATÓRIOS
(questões a responder exclusivamente pelo médico)

1. Dados do participante

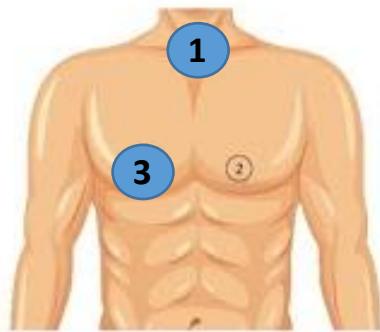
- a. Sexo M ☐₁ F ☐₂
b. Idade (anos) _____
c. Altura (m) _____

2. Patologia respiratória

- a. Asma ☐₁
b. Fibrose Quística ☐₂
c. Sem patologia respiratória ☐₃
d. Outra patologia respiratória ☐₄

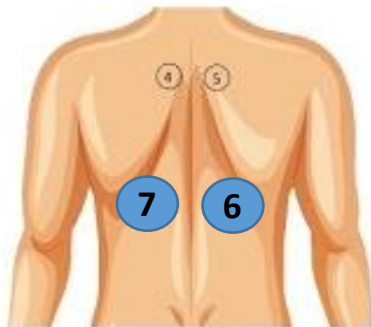
Se d, especifique: _____

3. Dados da auscultação pulmonar convencional (registar em cada local os achados significativos)



1 Traqueia _____

3 Lobo médio (dto) _____



6 Base pulmonar dta _____

7 Base pulmonar esq _____

4. Auscultação com smartphone – NÃO ESQUECER adicionar o ID do doente em todas as gravações, no campo “Notas”

5. Notas adicionais (ex. Notas relativas às gravações)
