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RESEARCH

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Lung ultrasound is cost-effective for early diagnosis of COVID-19 pneumonia in primary care

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Abstract

Chest X-rays and lung ultrasounds are extensively utilized in primary care to diagnose pneumonia, a primary clinical manifestation of COVID-19. Employing chest X-rays for the diagnostic management of suspected COVID-19 pneumonia is significantly more costly than utilizing lung ultrasound. Since the pandemic swiftly overwhelmed healthcare systems globally, identifying the most cost-effective diagnostic tools is essential to optimize resource allocation.

Keywords General practice, Lung ultrasonography, Chest X-ray, COVID-19, Cost analysis

Background

The pandemic caused by COVID-19 started in December 2019 in China, quickly spreading and severely impacting the health systems globally [1]. With increasing numbers of affected people in Spain and other European countries [2], the World Health Organization declared the outbreak of COVID-19 a pandemic on March 11, 2020 [3]. While extraordinary measures to curb contagion were implemented throughout 2020, countries affected by the pandemic suffered substantial drops in GDP. At the same time, the need for equipment, material and personnel increased health spending [4, 5]. In February 2021, the aggregate economic impact of the pandemic in Spain was estimated at 2,342 million euro [6], with the largest drop in GDP of Europe [7].

Initially, the diversity of symptoms and limited availability of RT-PCR tests complicated the diagnosis of COVID-19 [8, 9]. Additionally, 54% of infected patients presented negative RT-PCR results, which further complicated treatment and isolation measures [10, 11]. Early diagnosis is particularly relevant to promptly treat the most severe sequela of the infection: interstitial lung disease [12]. In March 2020, the Spanish Society of Medical Radiology published guidelines [13] for the use of imaging techniques to diagnose lung disease caused by SARS-CoV-2 infection.

These guidelines point at the use of chest X-ray (CXR) and lung ultrasound (LU) in primary health care (PHC). CXRs can be difficult to evaluate and unspecific [14, 15],

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and expose the patient to radiation [16]. On the other hand, LU has high sensitivity and specificity, and it is easy to use [17]. Evidence [18, 19] suggests similar sensitivity and specificity for these two methods. In 2021, Martínez-Redondo et al. [20] concluded that LU is more accurate for early diagnosis of COVID-19 pneumonia. This is especially relevant for small and rural health centres that do not have X-ray equipment and need to refer patients to bigger health facilities. It is also relevant for the healthcare centres that are considering the acquisition of ultrasound equipment and the training of primary care professionals.

In PHC, the circuit to perform an ultrasound is not only shorter than for an X-ray, but also cheaper [21]. When limited resources are available, it is essential to undertake a cost-effectiveness analysis before a decision is made on which procedure to recommend.

According to a comprehensive analysis by Islam et al. 2021 and subsequently in 2022,, for CXR (17 studies, 8529 participants, 5303 [62%] cases), the sensitivity ranged from 44 to 94% and the specificity from 24 to 93%, with pooled sensitivity and specificity being 73.1% (95% CI: 64.1%−80.5%) and 73.3% (95% CI: 61.9%−82.2%), respectively. For LUS (15 studies, 2410 participants, 1158 [48%] cases), sensitivity ranged from 73 to 94% and specificity from 21 to 98%, with pooled sensitivity and specificity at 88.9% (95% CI: 84.9%−92.0%) and 72.2% (95% CI: 58.8%−82.5%), respectively. These findings indicate that LUS and CXR have similar specificities, while LUS has a higher sensitivity compared to CXR. Given these diagnostic accuracies, we argue that LUS, with its higher sensitivity and comparable specificity to CXR, offers a potentially more effective diagnostic tool in clinical practice [22, 23]. Thus, conducting a cost-effectiveness analysis between these methods is crucial for healthcare decision-making.

However, it is crucial to note that while X-ray is a widespread technique, lung ultrasound requires some training, which is easily attainable, and the interpretation of the signs depends on the observer. In the context of COVID-19, thoracic imaging tests, including chest CT (considered the gold standard), have been extensively evaluated for diagnostic accuracy. According to a recent Cochrane review by Ebrahimzadeh et al., thoracic imaging tests, including chest CT and chest X-ray, have been evaluated against RT-PCR for diagnosing COVID-19. The review highlights that chest CT has the highest sensitivity among imaging modalities, while chest X-ray and lung ultrasound offer alternative diagnostic value with the added benefits of lower cost and accessibility in primary care settings [23].

The objective of the study was to determine the cost-effectiveness of LU versus CXR in primary care centres (PCC).

Methods

A cost-effectiveness analysis (CEA) was carried out with the aim of calculating the relationship between costs and results of both imaging methods. The product of the analysis are the monetary units that must be invested to achieve a percentage increase in effectiveness. Before conducting this economic analysis, a retrospective observational descriptive study (Martínez-Redondo et al. (2021)) was carried out between March and September 2020 in the city of Balaguer (Lleida, Spain). Inclusion criteria were: ≥ 18 years old, compatible symptomatic presentation for COVID-19 (cough, fever, dyspnea, or anosmia), and consultation at Balaguer PCC during the study period. Exclusion criteria were: patients with incomplete medical records, those who did not undergo both imaging tests (LU and CXR), and patients with preexisting diagnosis of chronic lung disease that would complicate imaging interpretation. Demographic data (comorbidities, gender, age) were collected in order to ensure that the study population accurately represented the local COVID-19 patient population. All imaging tests were performed following a protocol standardised by the Institut Català de la Salut. The family physician who performed the tests had followed a certified training programme in clinical ultrasound and had more than 10 years of experience prior to the study. Both UB and CXR were performed sequentially within the same clinical episode to minimise variability. The results of this study determined that the accuracy of LU was higher than CXR imaging for the diagnosis of COVID-19 pneumonia. This study provided the data for calculating effectiveness, with PPV estimates derived from Martínez Redondo J et al. [20].

Both CXR and LU are highly sensitive and specific with regard to COVID-19 imaging signs, which is crucial to establish early treatment and improve prognosis. Specificity is also essential to detect and isolate infected patients and their contacts, especially in cases where COVID-19 is suspected, and considering that diagnostic imaging can complement the RT-PCR test. Specificity and sensitivity are useful when evaluating the power or precision of a technique, but insufficient when having to decide which test to perform in a population. For this we use the predictive value, which explains the probability that the test result reflects the reality. Specifically, in this study we use the positive predictive value (PPV), a measure of the effectiveness of each technique to ensure a diagnosis. In short, effectiveness corresponds to the probability that a patient with an imaging test reported as interstitial lung disease has a positive COVID-19 RT-PCR test.

The costs have been calculated for the primary care centre (PCC) of Balaguer, the same PCC providing effectiveness data. Since the radiation absorbed when an X-ray is performed can be quantified but together with other costs such as travel, its economic cost cannot be evaluated, we have only considered the economic costs that can be charged to the public health system of Catalonia in Spain. According to the economic structure by chapters of the Institut Català de la Salut (ICS), which is one of the systems for providing public health services in Spain, specifically in Catalonia, one of the communities of the Spanish public health system, the following economic imputable chapters have been chosen: s salary expenses (Chapter 1); Equipment and Maintenance expenses, PCC building maintenance and supplies, as well as garmentlike (gloves, masks, clothes, ultrasound gel and personal protective equipment (PPE)) (Chapter 2) [24].

In order to obtain the cost per unit. We used the salary expenses, the equipment and its manteinance per minute. As for the costs of PCC building maintenance and supplies they will be prorated per square metre and time. Finally, expenses of clothing, PPE, masks, gloves and ultrasound gel are already calculated per unit.

Next, the minutes required to perform each step of the diagnosis will be multiplied by the unit cost to obtain the total prorated amount. Regarding the expenses of PPC building maintenance and supplies will be divided by the total square metres of the facilities and next multiplied by the area of the rooms where the procedures take place (CXR and consultation rooms). Next, this unit cost will also be multiplied by time. Once the calculations have been made for all chapters and its addition, the final result will be interpreted as the cost per intervention. All the information for the calculations has been obtained from the economic-financial and human resources departments of the ICS.

To compare the two diagnostic techniques, we will use the incremental cost-effectiveness ratio (ICER) [25, 26]. ICER is the quotient resulting from dividing the difference in costs between both methods. In CEA studies, a significant limitation is the lack of a homogeneous unit for expenses (monetary units) and effectiveness (clinical units). Therefore, in this type of study, we use a comparison in relative terms between two programmes, tools, processes etc. The formula to be used in this particular case is as follows [27]:

$$\frac{CostsLU - CostsCXR}{EffectivenessLU - EffectivenessCXR}$$

The result of the formula is the extra cost that each percentage point of PPV would have if using CXR instead of LU to diagnose pneumonia in this context.

Crucially, the diagnostic paths of the two options are different. In the case of CXR, the circuit is longer and more labour-intensive. In contrast, fewer professionals are needed for LU, with the added benefit of a shorter gap in time between the initial suspicion and the start of treatment.

Ethical approval

This study was approved by the Ethical Committee of Institut d'Investigació en Atenció Primària Jordi Gol i Gurina (Barcelona, Spain) (registration number p20/138).

Figure 1 below shows the care and diagnostic circuits for patients with a respiratory process and suspected pandemic covid-19 infection, those who underwent CXR, and those who underwent LU.

Results

A total of 212 patients were included in the study (Table 1), with an average age of 49.62 years; 58.49% were male. All participants (212) had a LU performed, and 187 LU plus CXR.

Table 2 shows costs per unit, obtained by prorating per year in of the salary expenses, PPC building maintenance equipment, and per year and square metre. These per unit costs have to be multiplied by the values in supplementary Table 2 to obtain the total cost of each step of the clinical diagnostic circuit for both imaging techniques.

In the case of the expenses of clothing, PPE, masks, gloves and ultrasound gel, since they are already divided by unit in Table 2, they only have to be multiplied by the amounts spent per procedure, shown in Supplementary Data.

Finally, Table 3 shows the costs calculation for each section of the diagnostic circuit grouped by type of cost. The cost per each CXR and LU in our context would amount to 102.42€ and 50.56 €, respectively.

$$\frac{102.42 - 50.56}{77.04 - 71.28} = 9€/PPV$$

The calculation of the ICER has produced a figure of €9/PPV, which equates the extra cost per increase of one percentage point of positive predictive value, our

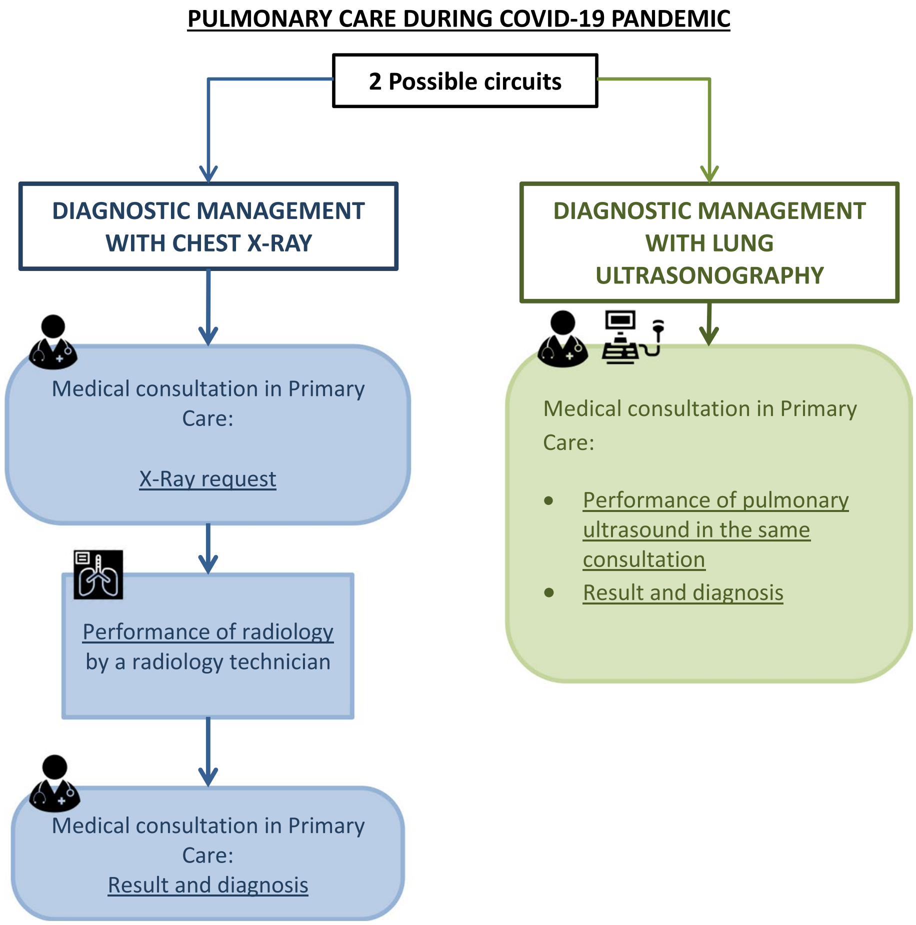

Fig. 1 Diagnostic circuits of LU and CXR in Primary Care during de COVID-19 Pandemic

Table 1 Description of the sample (Martínez-Redondo et al. (2021)) [20]

Demographic characteristics of participants	
Characteristics	
Age, in years (mean ± SD)	49.62 ± 21.22
Sex (men)	124 (58.49)
Total population	45,172
Ultrasound	212 (100.00%)
X-ray	187 (88.21%)

measure of effectiveness, if CXR is performed as the method of choice instead of LU.

In case a sensitivity analysis is performed according to the Departament de Salut official prices per visit [28] a value of −0.37€/PPV, meaning a saving in the CXR (Table 4).

$$\frac{124,26 - 122.48}{71,28 - 77,\ 04} = -0.37€/PPV$$

Discussion and limitations

The objective of this study was to determine the cost-effectiveness of LU and CXR for the diagnosis of COVID-19 pneumonia. Our study demonstrated that the diagnostic management using CXR for patients with suspected COVID-19 was significantly more expensive compared to LU. The analysis revealed that the overall cost of CXR was considerably higher than that of LU. We examined several cost components in our analysis: wages for medical professionals, costs associated with diagnostic equipment and its maintenance, the upkeep of healthcare facilities, and the expenses for disposable medical supplies. It was found that the cost of disposable supplies constituted a substantial portion of the total expenses for both diagnostic methods. However, the costs associated

Table 2 Costs of CXR and LU per unit

Chest X-ray	
Salary expenses	
Yearly salary of GP	0.077€/minute
Yearly salary of radiology technician	0.044€/minute
Yearly salary of administrative officer	0.038€/minute
Equipment and maintenance	
Cost of an X-ray device	0.012€/minute
Cost of insulating X-ray room using lead	0.010€/minute
Cost of device maintenance	0.004€/minute
Cost of digitizer maintenance	0.008€/minute
PPC building maintenance and equipment expenses	
Electricity, water and gas consumption	0.202€/minute
Cleaning of premises	0.409€/minute
Maintenance of building and climatisation	0.234€/minute
Clothing, PPE, masks, gloves	
Clothes of health workers	15€/change of clothes
PPE	6.1€/unit
FFP2 face masks	0.8€/unit
Gloves	0.0572/pair
Lung ultrasound	
Salary expenses	
Yearly salary of GP	0.077€/minute
Equipment and maintenance	
Cost of ultrasound device	0.004€/minute
PPC building maintenance and equipment expenses	
Electricity, water and gas consumption	0.202€/minute
Cleaning of premises	0.409€/minute
Maintenance of building and climatisation	0.234€/anual
Clothing, PPE, gloves, ultrasound gel, masks	
Clothes of health workers	15€/change of clothes
Gloves	0.0572/pair
Ultrasound gel	2€ per litre
PPE	6.1€/unit
FFP2 face mask	0.8€/unit

Table 3 Results of the calculation of costs per imaging test

Chest x-Ray	
Salary expenses	3,710 €
Equipment and maintenance	0.732 €
PPC equipment maintenance and supplies expenses	46,475 €
Clothing, PPE, gloves, ultrasound gel, masks	51.5 €
Total	102.42€
Lung ultrasound	
Salary expenses	2,310 €
Equipment and maintenance	0.120 €
PPC equipment maintenance and supplies expenses	25,350 €
Clothing, PPE, gloves, ultrasound gel, masks	22.78 €
Total	50.56 €

Table 4 CXR and LU expenses accordint to the Departament de Salut data

CXR	
Health Center non urgent Primary Care (ICS) (× 2)	53,25 € (× 2)
Postero-anterior standard CXR projection (Departament de Salut)	15,98€
Total	122,48€
LU	
Health Center non urgent Primary Care (ICS)	53,25€
Transthorac cardiac ultrasound (ICS)	71,35€
Total	124,26€

with wages, equipment, and facilities made up a relatively smaller proportion of the total expenditure.

In terms of diagnostic effectiveness, our study found that while CXR had a somewhat higher PPV compared to LU, the incremental ICER revealed that LU is a more cost-effective diagnostic tool for COVID-19 pneumonia. This suggests that, despite CXR's slightly higher diagnostic accuracy, LU offers a more economically efficient approach for diagnosing COVID-19 pneumonia due to its lower cost per unit increase in PPV.

As point-of-care ultrasound becomes more prevalent, driven by advancements in technology and increased professional training, LU is expected to offer substantial benefits from both a cost and clinical perspective. Our study supports the view that LU not only represents a cost-effective alternative to CXR but also aligns with broader trends in healthcare toward more efficient and accessible diagnostic practices.

For instance, prior research has demonstrated that similar diagnostic strategies can lead to significant cost savings and effectiveness improvements in various healthcare contexts [28]. Our results echo these findings, emphasizing that as LU technology continues to evolve and expand, it is likely to provide both economic and clinical advantages for diagnosing COVID-19 pneumonia and other comparable respiratory conditions.

The current CEA was performed using data from concrete place and time, therefore the extrapolation of other surroundings should be performed taking in account this issue [20]. There is literature focused in other particular contexts or for other pathologies were a result was found aligned with what has been already explained regarding the use of LU to perform this kind of diagnosis relating other diagnosis techniques by images and its expenses [29].

Extrapolation of these results need to take into account that this CEA was carried out using data from a specific time period and location. Nonetheless, studies conducted for different diseases and settings show similar results regarding the usefulness and cost-effectiveness of ultrasound compared to other diagnostic imaging techniques [30].

We should underline the importance of cost-effectiveness analyses in the health sector to assist in determining the option that maximises results in a climate of budget restrictions. Use of CEA is widely extended in countries that have pioneered economic evaluation of health programs such as the United Kingdom, Australia and Canada [27, 31].

Over 70% of COVID-19 pneumonias diagnosed by ultrasound can be followed up in an outpatient setting [32]. This illustrates the relevance of this cost-effectiveness study for primary care services, involving: 1. health policies that increase ultrasound equipment and training of professionals; 2. improvement of quality care and follow up of patients, since portable ultrasound devices reach places where conventional radiology cannot operate, such as nursing homes.As the use of point-of-care ultrasound becomes more widespread with greater equipment and training of professionals, the diagnosis of COVID 19 pneumonia and other processes with similar behavior will be beneficial from a cost point of view. Cost-effectiveness as shown in our study for health systems, in addition diagnoses will be earlier and accuracy [20] and the displacement of patients will be avoided.

Limitations of this study included lack of patient reported outcome/experience measures and the use an intermediate measure to estimate efficacy. Secondary analyses: No sensitivity analysis was possible with this type of study Before concluding this point, we thought to cross-check our numbers against other sources but these could only be had for inpatient care spending and so were not totally comparable. Additionally, there were no non-active comparator data to examine not only safety but also efficacy. The imaging approach to ARI has included radiographs, though lung ultrasound scan is sensitive and specific but depends on operator skill. Nonetheless, this did not influence the results of our study since all lung US examinations were performed by one expert in clinical ultrasound. Furthermore, given the absence of very early availability to widespread RT-PCR testing a clinical diagnosis based on symptoms had to be employed. It is also important to recognize that the diagnostic criteria for pneumonia were not standardized and that confirmatory tests were not available for all patients as testing was not available at the beginning of the pandemic. Finally, the economic results of this publication are mainly valid in the context of the specific health system in which the study was conducted. Moreover, we recognize that the external validity of our findings is limited, as the study was conducted in a single primary care center, within one healthcare system, and during a specific period of the COVID-19 pandemic. Patient characteristics, resource availability, and diagnostic pathways may differ in other regions or countries. Therefore, caution should be exercised when generalizing these results to other settings. Future multicenter studies with diverse populations and healthcare environments are necessary.

Conclusions

Our findings reveal that using CXR for the diagnostic management of suspected COVID-19 pneumonia is considerably more expensive than using LU. Specifically, the costs associated with CXR are significantly higher compared to those for LU.

In terms of diagnostic effectiveness, CXR demonstrated a PPV that was slightly higher than that of LU. However, the ICER indicates that LU provides a more cost-effective approach per unit of diagnostic effectiveness compared to CXR.

These results suggest that LU, while slightly less effective in terms of PPV, is a more economical choice for diagnosing COVID-19 pneumonia. As point-of-care ultrasound technology becomes increasingly accessible and professionals receive more training, LU is likely to become an even more valuable tool for early diagnosis and cost-effective management of COVID-19 pneumonia and similar conditions. Thus, integrating LU into routine clinical practice could enhance diagnostic efficiency, reduce healthcare costs, and minimize the need for patient referrals to secondary care facilities. Moreover, in a pandemic context a shorter diagnostic circuit reduces travel and the chain of contagion by helping early diagnosis at the point of care and isolation of patients. It also optimizes the workload of health professionals. In areas of geographically scattered locations and/or low-income, ultrasound devices can operate with batteries [33], avoiding the need for a continuous electricity supply.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12890-025-03753-3.

Additional file 1.

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Authors' contributions

JMR, MCP, CGS, JPS, MCC, MOB and JMPP conceived the study design and oversaw the project. JMR, MCP, CGS, JPS were responsible for data acquisition. AC and MCC performed the statistical analyses.

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Data availability
The datasets generated and/or analysed during the current study are not publicly available due to institutional policies, but are available from the corresponding author on reasonable request. Informed consent was obtained from all subjects involved in the study.

Declarations

Ethics approval and consent to participate
The study protocol and study methodology was approved by ethic committees by the Clinical Research Ethics Committee (CEIC) of the Primary Care Research Institute (IDIAP Jordi Gol). Registration CEIC 20/138-PCV. Once the project information sheet has been explained and delivered, written consent will be requested for participation in the study.
The database will be in the hands of the IP and the research team in an Excel format and with password access. An anonymized database will be used for the analysis.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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