Original Article

The Agreement Level of Colorimetric Indicator Paper and pH Meter Examination Compared to Urine Analyzer in Measuring Exudative Pleural Effusion Fluid pH

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Abstract

Background: Pleural effusion is an abnormal accumulation of fluid in the pleural space, commonly associated with pulmonary infections and malignancies. Measurement of pleural fluid pH is necessary for diagnosis, therapeutic decision-making, and prognostic evaluation. Multiple methods are used, including pH meters, indicator papers, and urine analyzers, but their concordance has not been widely studied in Indonesia. This study aimed to assess the agreement of pleural fluid pH results measured using pH meters, indicator papers, and urine analyzers to support the appropriate selection of diagnostic methods.

Methods: This observational analytic study with a cross-sectional design was conducted at dr. Moewardi General Hospital, Surakarta, from February to June 2025. The sample consisted of 55 patients with exudative pleural effusion who met the inclusion criteria. Pleural fluid pH was measured using three methods: colorimetric indicator paper, a pH meter, and a urine analyzer. Data were analyzed using the Kappa coefficient and the Intraclass Correlation Coefficient (ICC) to assess the agreement between methods.

Results: The mean pH values of pleural fluid measured by the urine analyzer, pH meter, and colorimetric indicator paper were 8.18±0.47, 8.13±0.46, and 8.15±0.59, respectively. Agreement analysis showed a very strong and statistically significant correlation between the pH meter and urine analyzer (ICC=0.948; *P*<0.001), between the pH strip and urine analyzer (ICC=0.855; *P*<0.001), and between the pH meter and pH strip (ICC=0.916; *P*<0.001). A significant positive correlation was also observed between glucose levels and pH measured by both the urine analyzer and the pH meter.

Conclusion: There is good agreement among pH measurements obtained using colorimetric indicator paper, urine analyzer, and pH meter in exudative pleural effusion fluid.

Keywords: colorimetric urine analyzer, exudative pleural fluid pH, indicator paper, pH meter

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INTRODUCTION

Pleural effusion is an abnormal accumulation of fluid within the pleural cavity.[1] It is a common symptom in patients with pulmonary diseases, particularly those associated with high mortality, including malignancies and infections. Approximately 1.5 million people in the United States experience pleural effusion annually.[2]

Pleural effusion is classified based on Light's Criteria into transudative and exudative types.[1,2] Transudative effusion results from an imbalance between hydrostatic and oncotic pressures, commonly observed in heart failure and cirrhosis. Exudative pleural effusion, by contrast, is caused by inflammation leading to increased capillary leakage and impaired lymphatic drainage due to obstruction.[3]

Exudative pleural effusion causes can be investigated through microbiological examination; total pleural fluid volume; differential cell count of the pleural fluid; biochemical analysis, including total protein, lactate dehydrogenase (LDH), glucose, pH; and pleural fluid biomarkers, such as C-reactive protein (CRP), procalcitonin, Soluble Triggering Receptor Expressed on Myeloid Cells-1 (STREM-1).[4]

Pleural fluid analysis remains a cornerstone of the diagnostic approach that is conducted.[2] Normal pleural effusion fluid typically has a potential of hydrogen (pH) between 7.60 and 7.64, protein levels less than (<) 2 milligrams per deciliter (mg/dL), <100 white blood cells per cubic millimeter (mm^3), glucose content similar to plasma, and LDH levels less than

half of those found in plasma.[5]

Meanwhile, in the parapneumonic fibropurulent stage, pleural fluid pH decreases to below 7.20, glucose levels drop below 60 mg/dL, and LDH levels increase. Similar to malignant pleural effusion, which generally demonstrates a pH <7.30, LDH levels >1000 units per liter (U/L), decreased pleural fluid glucose concentration between 30 and 50 mg/dL, and lymphocyte counts >50% to 70%.[3,5] The difference is visible in tuberculosis pleural fluid analysis, which typically shows a pH <7.4, glucose levels >60 mg/dL similar to plasma, and increased protein concentration >4.0 g/dL.[3]

Differences in pleural fluid pH in each infection and malignant cases make an assessment of pleural fluid pH important for diagnosis. It facilitates rapid and accurate diagnosis, thereby minimizing delays in therapy that may exacerbate the patient's condition. In addition, it helps determine the indication for chest drainage in cases of pleural infection or empyema, and it assists in assessing the prognosis of patients with malignant pleural effusions, as a low pH is often associated with reduced survival rates. Furthermore, pleural fluid pH testing can reduce diagnostic and therapeutic errors, and when performed using appropriate methods, it serves as a reliable clinical tool.[6]

The assessment of pH value in the diagnosis of exudative effusion can be conducted with colorimetric, pH meters, and urine analyzers.[7] Using a pH meter is an electrochemical technique that employs electrical instruments such as electrodes and millivoltmeters.[4,7] Chandler et al reported that 68% of hospital laboratories in the southeastern United States measured pleural fluid pH using either pH indicator paper or a pH meter.[8] More recently, Cheng et al demonstrated that pH meters are superior to colorimetric methods, which showed an average pH value of 8.23±0.06.[9]

On the other hand, a urine analyzer is employed to detect pH, red blood cells, white blood cells, protein, glucose, urobilinogen, bilirubin, ketone bodies, leukocyte esterase, and nitrite in urine. Urine reagent strips have also been investigated as a means of predicting pleural fluid pH and may serve as an additional diagnostic tool in infectious exudative effusions. They represent a rapid, inexpensive, and user-friendly method for supporting the diagnosis of pleural effusions.

A study conducted by Cheng et al, which compared pleural fluid pH measurement using an arterial blood gas (ABG) analyzer, a pH meter, and colorimetric indicator paper or pH strips, found that the ABG analyzer was the most accurate method for determining pleural fluid pH in clinical decision-making. In contrast, pH meters and colorimetric indicator paper tended to produce higher values, rendering them less reliable and increasing the risk of misdiagnosis.[9] However, this study did not use the ABG analyzer due to institutional approval concerns regarding infection risk from pleural effusion samples, as well as calibration limitations. This is acknowledged as one of the study's limitations.

Therefore, this study evaluates the consistency of colorimetric indicator paper and pH meter tests compared with urinalysis in measuring the pH of exudative pleural fluid. The findings are expected to provide a more comprehensive understanding of pleural fluid pH for clinical applications in cases of exudative effusions suggestive of malignancy or chronic infection, because research on the suitability of methods for pleural fluid pH analysis has been limited and remains scarcely reported in Indonesia, although several studies have been published internationally. So, further investigation, particularly in Indonesia, is crucial.

METHODS

This observational analytical study employed a cross-sectional design. The study was conducted at Dr. Moewardi General Hospital, Surakarta, with ethical clearance number from the Health Research Ethics Committee dr. Moewardi General Hospital: 581/III/HREC/2025.

The study population included all patients diagnosed with exudative pleural effusion based on Light's criteria who were treated at Dr. Moewardi Regional General Hospital during the study period,

from February to June 2025. According to Light's criteria, exudative pleural effusion is defined by one or more of the following conditions: a pleural fluid/serum protein ratio >0.5, a pleural fluid/serum LDH ratio >0.6, or pleural fluid LDH >2/3 of the upper limit of normal serum LDH.

The study sample was determined using the sample size formula for estimating the mean on numeric (continuous) data, which estimated the mean of the population, with the formula $n = \frac{Z^2 x S^2}{d^2}$ where Z is the standard value for a certain level of confidence (95%, Z=1.96); S is the standard deviation of pleural fluid pH values based on previous studies (SD=0.18); and d is the tolerable error, which is 0,5. This formula results in n=49,787 (~50). Considering the 10% of incomplete data, the sample size was increased by 10% of 50, which is 5, making the minimal sample size 55. The sample of 55 was obtained from medical records that met the inclusion and exclusion criteria.

The inclusion criteria were patients diagnosed with exudative pleural effusion, patients aged 18 years or older, and patients who agreed to participate in the study by providing informed consent. Meanwhile, the exclusion criteria were patients diagnosed with transudative pleural effusion and those with pleural fluid contaminated by lidocaine, as lidocaine contamination can significantly decrease pH values.

Patients with exudative pleural effusion underwent thoracocentesis to aseptically collect pleural fluid samples. The samples were immediately placed in sterile tubes and stored at 4°C until analysis, which was performed within a maximum of 2 hours. Sample measured using three methods: colorimetric indicator paper, a pH meter, and a urine analyzer.

The colorimetric indicator paper method was carried out on approximately 0.5 mL of pleural fluid, which was placed on the indicator paper. The resulting color change was compared with the reference scale within 10 seconds. On the pH meter method, the instrument was calibrated using a buffer solution. The electrode was then immersed in approximately 1 mL of pleural fluid, and the pH value displayed on the screen was recorded. Whereas, on the urine analyzer method, approximately 1 mL of pleural fluid was placed into the designated container. The instrument was then operated according to the manufacturer's instructions, and the pH value was recorded. All measurement results from the three methods were recorded simultaneously for each patient to ensure data validity.

The results were processed using statistical software for comparative analysis and assessment of inter-method agreement. Area under the curve (AUC) was performed to evaluate the agreement between colorimetry, the pH meter, and the urine analyzer. Additional statistical tests were conducted to assess the level of agreement between pH measurements obtained by colorimetry, the pH meter, and the urine analyzer.

Data analysis was performed using IBM SPSS Statistics version 29. Numerical data are presented as mean±standard deviation, and comparative tests were conducted using the independent t-test or Mann–Whitney U test, depending on the normality and homogeneity of the data. Categorical data are presented as frequency distributions with percentages, and comparisons were performed using the chi-square test or Fisher's exact test. The normality of the data distribution was assessed using the Kolmogorov–Smirnov test. Agreement analysis was performed using the kappa coefficient.

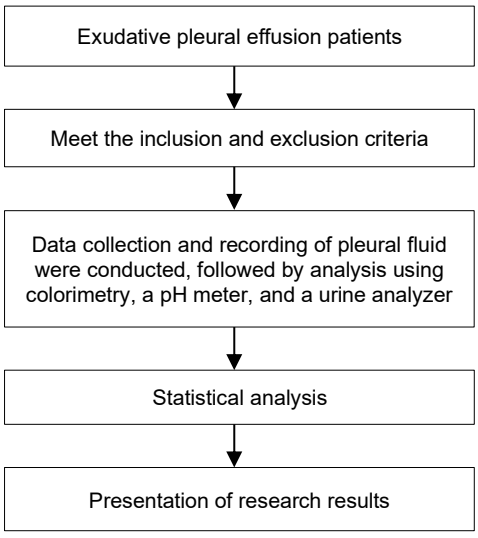

Figure 1. Research Flow

RESULTS

The baseline characteristics of the 55 study participants were obtained from data collection, including gender, age, effusion fluid clarity, the presence of clots, fluid color, and pH values measured using different modalities (urine analyzers, pH meters, and colorimetric indicator paper). In addition, other laboratory parameters were presented, including glucose levels, LDH, and cell counts, both mononuclear (MN) and polymorphonuclear (PMN) cells, illustrated in Table 1.

Table 1. Baseline Characteristics of the Study Subjects

Characteristics	n (%)	Mean±SD (range)
Age, years	----	56.96±15.80 (18.00-83.00)
Sex		
Male	21 (38.2%)	----
Female	34 (61.8%)	----
Clarity		
Clear	8 (14.5%)	----
Slightly turbid	13 (23.6%)	----
Turbid	30 (54.5%)	----
Highly turbid	4 (7.3%)	----
Clot		
Present	7 (12.7%)	----
Absent	48 (87.3%)	----
Color		
Brown	2 (3.6%)	----
Black	1 (1.8%)	----
Reddish	2 (3.6%)	----
Yellow	26 (47.3%)	----
Yellowish-red	5 (9.1%)	----
Red-yellow	1 (1.8%)	----
Light-yellow	2 (3.6%)	----
Dark-yellow	2 (3.6%)	----
Red	13 (23.6%)	----
Reddish-brown	1 (1.8%)	----
pH (Urine Analyzer)	----	8.18±0.47 (7.00-8.50)
pH (pH Meter)	----	8.13±0.46 (7.00-8.87)
pH (Colorimetric Indicator Paper)	----	8.15±0.59 (7.00-9.00)
Protein (gr/dl)	----	3.55±1.41 (0.50-7.20)
Glucose (mg/dl)	----	114.11±77.37(2.00-399.00)
LDH (U/L)	----	2168.00±6132.46 (184.00-42726.00)
Cell count (/ul)	----	18408.09±80585.76 (5.00-485654.00)
MN (%)	----	72.25±25.96 (14.00-99.00)
PMN (%)	----	27.78±25.97 (1.00-86.00)

Note: LDH=lactate dehydrogenase; PMN=polymorphonuclear; MN=mononuclear

The mean patient age was 56.96±15.80 years, ranging from 18 to 83 years. Most patients were female (61.8%). Effusion fluid examination revealed that most samples were cloudy (54.5%), with a smaller proportion containing clots (12.7%). The predominant color of the effusion fluid was yellow (47.3%), followed by red (23.6%). Laboratory examination results showed that the mean pH value measured using a urine analyzer was 8.18±0.47 (range: 7.0–8.5), while the pH meter results obtained a mean of 8.13±0.46 (range: 7.0–8.87), and the colorimetric indicator paper (pH strip) produced a mean of 8.15±0.59 (range: 7.0–9.0).

The mean protein level was 3.55±1.41 g/dL, ranging from 0.50 to 7.20 g/dL. The mean glucose level was 114.11±77.37 mg/dL (range: 2.00–399.00). The mean LDH level was 2168±6132.46 U/L, with values ranging from 184 to 42,726. The mean cell count was 18,408.09±80,585.76 cells/μL (range: 5–485,654). The mean MN cell percentage was 72.25±25.96% (range: 14–99), while the mean PMN cell percentage was 27.78±25.97% (range: 1–86).

Normality testing using the Kolmogorov–Smirnov test showed that the variables age, urine pH, pH meter, colorimetric indicator paper (pH strip), glucose, LDH, cell count, MN, and PMN did not meet the assumption of normality (P<0.05). In contrast, the protein variable was normally distributed (P>0.05). Correlation analysis between laboratory examination results of pleural effusion samples and pleural effusion pH in this study was performed using the Spearman rank test, as the data were not normally distributed. The correlation analysis between laboratory parameters and pleural effusion pH is presented in Table 2.

Age, protein, LDH, cell count, MN, and PMN were not significantly associated with pH as measured by the urine analyzer, pH meter, or colorimetric indicator paper (pH strip) (P>0.05). Glucose showed a positive and significant correlation with urine analyzer pH (r=0.314; P=0.020) and with pH meter measurements (r=0.329; P=0.014). This indicates that an increase in glucose levels was significantly associated with an increase in pH values measured by the urine analyzer and pH meter. In contrast, glucose was not significantly correlated with pH strip values (r=0.196; P=0.153).

Table 2. Correlation Analysis of Laboratory Examination Results with Pleural Effusion pH (n=55)

Characteristics	pH Urine		pH Meter		pH Strip	
	r	*P*	r	*P*	r	*P*
Age ≥18 years	-0.034	0.805	-0.089	0.520	-0.029	0.836
Protein	0.221	0.104	0.189	0.166	-0.032	0.815
Glucose	0.314	0.020*	0.329	0.014*	0.196	0.153
LDH	-0.010	0.939	0.095	0.489	0.041	0.765
Cell count	-0.049	0.720	-0.069	0.617	-0.087	0.527
MN	0.044	0.752	0.019	0.893	-0.099	0.472
PMN	-0.047	0.733	-0.022	0.876	0.097	0.480

Note: LDH=lactate dehydrogenase; PMN=polymorphonuclear; MN=mononuclear; *significant at *P*<0.05, with Spearman rank correlation test

Agreement analysis between examination modalities was performed using the Intraclass Correlation Coefficient (ICC), as the data from the pH meter, colorimetric indicator paper (pH strip), and urine analyzer were ratio-scale numerical data. The results of the agreement analysis between the pH meter, colorimetric indicator paper (pH strip), and urine analyzer are presented in Tables 3, 4, and 5.

Table 3 shows the conformity test results, where the mean pH value measured by the urine analyzer was 8.18±0.47, while the mean value measured by the pH meter was 8.13 ± 0.46. The F-test yielded F=2.789 and *P*=0.101, indicating that there was no statistically significant difference between the pH values measured by the urine analyzer and the pH meter. The ICC test showed ICC=0.948 and *P*<0.001, indicating a very strong and statistically significant correlation between the urine analyzer and the pH meter measurements, where higher urine pH values were consistently accompanied by higher pH meter readings. Thus, the findings demonstrate that there is a strong concordance between the pH meter and urine analyzer measurements.

Table 3. Agreement Analysis Between pH Meter and Urine pH (Urine Analyzer)

Urine pH	pH Meter	F	*P*	ICC	*P*
8.18±0.47	8.13±0.46	2.789	0.101	0.948	<0.001*

Note: ICC (Intraclass Correlation Coefficient) test; *significant at *P*<0.05

Based on Table 4, the urine analyzer showed a mean pH of 8.18±0.47, while the pH Strip showed a mean of 8.15±0.59. The F-test indicated no significant difference between the two measurements (F=0.495; *P*=0.485). However, the ICC demonstrated a very strong and statistically significant correlation (ICC=0.855; *P*<0.001), confirming concordance between the urine analyzer and the pH Strip.

Table 4. Analysis of the Agreement Between pH Strip and Urine pH (Urine Analyzer)

Urine pH	pH Strip	F	*P*	ICC	*P*
8.18±0.47	8.15±0.59	0.495	0.485	0.855	<0.001*

Note: ICC (Intraclass Correlation Coefficient) test; *significant at *P*<0.05

Table 5 shows no significant difference between pH values measured by the pH meter (8.13±0.46) and the pH Strip (8.15±0.59) with F=0.056 and *P*=0.814. However, the ICC indicated a very strong and statistically significant correlation (ICC=0.916; *P*<0.001), confirming strong agreement between the two methods.

Table 5. Agreement Analysis Between the pH Meter and the pH Strip

pH Meter	pH Strip	F	*P*	ICC	*P*
8.13±0.46	8.15±0.59	0.056	0.814	0.916	<0.001*

Note: ICC (Intraclass Correlation Coefficient) test; *significant at *P*<0.05

DISCUSSIONS

Pleural effusion is a prominent manifestation of various diseases. The categorization of pleural effusion as either transudate or exudate reflects the underlying pathophysiological process, where Light's criteria are used, which can achieve very high sensitivity (98%) for identifying exudates, as this type of effusion generally requires further diagnostic evaluation. However, a Light's criteria had a limitation, are the potential for misclassification in approximately 20–30% of effusion cases associated with liver or heart failure.[9,10]

Therefore, measurement of pleural fluid pH is often performed to improve diagnostic accuracy. Ng et al surveyed 161 healthcare professionals in New Zealand and reported that 48% of pleural fluid pH measurements in healthcare facilities were performed using blood gas analyzers (manufactured by Radiometer, Siemens, and Werfen), all of which are considered to provide the most accurate results. In addition, pH measurements were performed using pH strips (11%) and pH meters (5%), both regarded as less accurate. The remaining 36% of respondents

were unaware of the specific instruments used in their laboratories for pleural fluid pH measurement.[11]

Based on the patient characteristics presented in Table 1, the mean age of patients with exudative pleural effusion was 56.96±15.80 years (range 18–83 years). This finding is slightly higher than that reported by Li et al, who found a mean age of 56.41±15.3 years (range 25–88 years).[12] Further, Hutagalung et al also reported that pleural effusion was most frequently observed in the 40–59 year age group (56 out of 96 samples).[13] The results of this study are consistent with the findings of Dewi and Fairuz at Raden Mattaher General Hospital and H. Abdul Manap General Hospital, Jambi, during the period 2017–2018.[14]

Pleural effusion tends to occur more often in individuals of productive age due to declining lung function, exposure to pollution or carcinogenic substances, and underlying diseases.[15] At this age, inactivation of the methylenetetrahydrofolate reductase (MTHFR) gene may occur. A mutation of this gene is a genetic risk factor for venous thromboembolism, which has been associated with pleural effusion.[16]

The predominance of females (61.8%) among patients with exudative pleural effusion in this study is in line with previous findings from Hasan Sadikin General Hospital, Bandung, where 58.97% of cases were female. Most of these cases were associated with malignancies, particularly breast cancer in women and lung cancer in men.[17] Conversely, a study conducted at dr. Soetomo General Hospital, Surabaya, has reported a more balanced distribution.[18]

These variations suggest that sex differences in pleural effusion may depend on the underlying etiology. The higher proportion of male patients reported in several studies is often linked to predisposing factors, including occupational exposure, smoking habits, and alcohol consumption, which are more common among men. However, the absence of large-scale epidemiological data in Indonesia limits definitive conclusions regarding sex-related predisposition to exudative pleural effusion.[13]

The pleural effusion analysis in this study showed that most samples were cloudy (54.5%), with a smaller proportion containing clots (12.7%), and the predominant effusion colors were yellow (47.3%) and red (23.6%). These findings are consistent with a study conducted at the Borneo Anatomical Pathology Laboratory, which reported that among 16 pleural effusion samples, the majority were yellow and cloudy (12 cases; 75%). In addition, one case each (6%) presented as reddish-cloudy and whitish-cloudy, while brownish-cloudy fluid was observed in two samples (13%). Microscopically, thick smears were used in 14 cases (88%), whereas thin smears were prepared in only 2 cases (13%).[19]

The pleural fluid pH analysis of exudative pleural effusion using different modalities showed an alkaline mean value: the urine analyzer was 8.18, the pH meter was 8.13, and the pH strip was 8.15. This finding may be attributed to the heterogeneity in both the stage and etiology of exudative pleural effusion included in this study. The pH values in exudative pleural effusion may vary, where in uncomplicated exudative pleural effusion, pH typically tends to be alkaline, above 7.20. However, when the condition progresses to complicated exudative pleural effusion, the pH generally shifts to acidic, which is below 7.20, which may indicate the need for drainage.[20]

Budnick et al analyzed 83 pleural fluid samples from patients with neutropenia and reported results consistent with the present study. They found that 37.3% of cases were infectious exudative pleural effusions, 25.3% were malignant, and 25.3% were caused by other etiologies. Across these groups, the pH characteristics were similar, that is, alkaline values with a mean pH above 7.[21]

Conversely, Lin et al reported variable results depending on the etiology. The mean pH values of pleural effusion were 7.5 in tuberculosis, approximately 7 in malignancy, around 7 in parapneumonic complicated cases, 7.5 in uncomplicated cases, and 7.55 in connective tissue diseases.[22] Similarly, Kho et al examined 150 patients and reported mean pleural fluid pH values of 7.21 in parapneumonic effusion, 7.48 in pneumonic

effusion, and 7.49 in tuberculous effusion.[23]

Another factor influencing the pH is the testing delay. Delayed analysis has been shown to increase pleural fluid alkalinity and variability, with an average shift of 0.039 pH units.[24] Nevertheless, in this study, the standard operating procedures for examination were strictly followed, including ensuring that the examination was conducted in less than two hours, as delayed testing could affect the results.

Laboratory results show that the mean glucose level in this study was found to be 114.11 mmol/L. This result is slightly higher than that reported by Darooei et al, who found that the mean glucose level in exudative pleural effusion fluid with malignant etiology was 112.85 mg/dL, whereas that with tuberculosis etiology was 92.21 mg/dL.[25] Similarly, the present finding is also slightly higher than that reported by Makwana et al, although still within a comparable range (>60 mg/dL). Their study reported mean glucose levels of 88 mg/dL in malignant exudative pleural effusion, 78 mg/dL in tuberculous pleural effusion, and 79.63 mg/dL in parapneumonic pleural effusion.[26]

The mean LDH level in exudative pleural effusion fluid samples in this study was 2.168 U/L^{-1}. This result is markedly higher than that reported by Allama et al, who analyzed blood samples from 90 patients with exudative pleural effusion and found mean serum LDH levels of 226 U/L^{-1} in benign cases and 220 U/L^{-1} in malignant cases.[27] Verma et al analyzed 163 exudative pleural effusion fluid samples and reported variable mean LDH levels: 834.5 U/L^{-1} in malignant cases, 1.037 U/L^{-1} in tuberculous cases, and 3,800 U/L in parapneumonic cases.[28]

Similarly, Zhao et al analyzed 618 exudative pleural effusion fluid samples and also observed wide variations: 449 U/L^{-1} in tuberculous cases, 2.542 U/L^{-1} in parapneumonic cases, and 357 U/L^{-1} in malignant cases.[29] These findings demonstrate substantial variability in LDH levels across different etiologies of exudative pleural effusion. The high mean LDH level observed in the present study suggests that most cases were likely due to parapneumonic effusion.

The mean of MN cell count in this study was 72.25 cells/mm^3, while the mean PMN cell count was 27.78 cells/mm^3. A previous study involving 256 cases of exudative pleural effusion reported that the mean levels of both MN and PMN cells were significantly higher in exudative pleural effusion compared to transudates (P<0.05). Among patients with exudative pleural effusion, the mean MN count, primarily lymphocytes, was 1.3 cells/mm^3, whereas the mean PMN count, primarily neutrophils, was 6.9 cells/mm^3.[30]

Correlation analysis results show that age, protein, LDH, total cell count, MN, and PMN were not significantly associated with pH measured by urine analyzer, pH meter, or pH strip. In contrast, glucose showed a significant positive correlation with pH measured by both the urine analyzer and pH meter, indicating that higher glucose levels were associated with increased pH values.

A large-scale study conducted across hospitals in Spain, the UK, and Australia involving a total of 2,971 patients examined the relationship between pleural fluid pH and blood glucose levels. The study found a strong non-linear association between pleural fluid pH and glucose. However, in most cases, the level of one parameter could not reliably predict the level of the other. The concordance rate was relatively high, and in many cases, measurement of either one was sufficient.[31]

Most samples (91.9%) showed concordant results when using cut-off values of 7.20 for pH and 3.30 mmol/L for glucose, respectively. Using pH alone, without glucose, may identified 95.0% of infection-related effusions when either pH or glucose was below the threshold, whereas glucose alone identified 91.7%.[31]

The concordance test in this study demonstrated a very strong and statistically significant correlation among the three methods of measuring pleural effusion pH in exudative cases. The mean pH values obtained were 8.18±0.47 with the urine analyzer, 8.13±0.46 with the pH meter, and 8.15±0.59 with the pH strip, where the ICC analysis showed high statistical agreement among the three measurement methods. The ICC values between the

urine analyzer and pH meter were 0.948 (P<0.001), between the urine analyzer and pH strip were 0.855 (P<0.001), and between the pH meter and pH strip were 0.916 (P<0.001).

Based on the ICC results, the highest concordance was observed between the urine analyzer and the pH meter (ICC=0.948; P<0.001), which falls into the "excellent" category and indicates that the measurements were highly consistent and comparable. Although all devices demonstrated high concordance without significant differences in pH measurements, the urine analyzer exhibited the most optimal performance, as its results were highly comparable to the pH meter while being more practical and efficient for routine use. Therefore, the urine analyzer may be considered the most suitable tool for pH measurement based on concordance analysis.

The diagnostic results of pleural effusion fluid pH measurement using a pH meter and urine analyzer showed an ICC value of 0.948 (P<0.05), indicating a strong and statistically significant level of concordance between the two methods. No previous studies were identified regarding the comparison of pH meters and urine analyzers used in pleural effusion fluid. However, some studies have evaluated the application of these instruments in other biological samples, which may provide relevant insights.

Coninck et al assessed the accuracy of urinary pH measurement methods by comparing them with a laboratory pH meter as the gold standard. A total of 77 urine samples from healthy volunteers were analyzed using pH strips, a urine analyzer, and a portable pH meter. The findings demonstrated that the portable pH meter had the highest accuracy. Moreover, the portable pH meter exhibited the highest correlation and the narrowest limits of agreement in the Bland–Altman analysis. Consequently, the study concluded that the portable pH meter is the most accurate and reliable tool for measuring pH.[32]

The diagnostic results of pleural effusion fluid pH measurement using pH strips and a urine analyzer showed an ICC value of 0.855 (P<0.05), indicating a strong and statistically significant concordance between the two methods. Cheng et al tested 50 pleural effusion fluid samples using pH strips and a blood gas analyzer, and got the mean pH measured by the blood gas analyzer (7.42±0.01) was significantly lower compared with both the pH meter (7.58±0.02) and the pH strip (8.23±0.06).

Further analysis of seven additional samples demonstrated that when the blood gas analyzer was calibrated at 25°C, the pH values measured were nearly identical, with readings of 7.54±0.02 for the blood gas analyzer and 7.53±0.01 for the pH meter.[32] In addition, Siu et al evaluated reconstituted fluid samples to compare the performance of pH strips and a urine analyzer and showed that the urine analyzer performed comparably to the pH strip, and it was considered capable of accurately measuring pH values within the range of 5.0 to 8.0.[33]

The measurement of pleural effusion pH using a pH meter and pH strip yielded an ICC of 0.916 (P<0.05), representing a robust and statistically significant concordance between the two methods. Cho et al also compared the analytical performance of pH strips with the advanced testing device i-STAT G3+ (Abbott), which served as the reference standard for pH measurement. The within-device coefficient of variation for pH measurements in 86 pleural effusion samples was reported to be less than 0.1%, demonstrating an exceptionally high level of precision.[33]

Another study evaluated the accuracy of pH strips in a different biological sample, which may still provide relevant insights. Phukpattanachai et al compared the accuracy of pH measurements in gastric fluid using pH strips against a standard pH meter across 113 gastric samples from 27 critically ill patients. The findings indicated that the pH strip demonstrated a very strong correlation with the reference method ($Y = 0.95X + 0.56$; rho = 0.91; P<0.001). The study concluded that the pH strip is a reasonably reliable method for measuring gastric pH in critically ill patients.[34]

LIMITATIONS

As it is a single-centre study conducted in one hospital with a relatively small sample size, this study may limit the generalizability of the findings to the

broader population of patients with exudative pleural effusion. A multicentre study design would have a broader impact and ensure that the results are more representative and generalizable.

CONCLUSION

There is a high degree of consensus among the results obtained using pH strips, a urine analyser, and a pH meter in measuring pleural fluid pH in patients with exudative pleural effusion. The high level of agreement between pleural fluid pH measurements using colorimetric indicator paper or a pH meter and those obtained with a urine analyzer indicates that these alternative methods can be clinically applied as more practical and cost-effective tools, particularly in healthcare facilities with limited equipment or resources. In certain situations, such as suspected empyema or severe pleural infection, rapid and accurate pleural fluid pH measurement is crucial for guiding clinical decision-making, including the need for drainage or surgical intervention.

CONFLICT OF INTEREST

The authors declare no conflict of interest in this research.

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