

Ultrasonography: An Unchartered Modality in the Current Pandemic – A Study among Patients Admitted in the COVID-19 Intensive Care Unit

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Abstract

Background: The objectives were to perform an analysis of lung ultrasonography (LUS) findings in severely ill patients with novel coronavirus disease-2019 (COVID-19) and to compare the accuracy with high-resolution computed tomography (HRCT) of the thorax. **Methods:** Sixty-two intensive care unit (ICU) patients with COVID-19 were evaluated during their hospital stay. LUS was performed with convex and linear transducers using a designated ultrasonography machine placed in the COVID-19 ICU. The thorax was scanned in 12 areas. Initial LUS was performed on admission and follow-up LUS was done in 7 (mean) days. At the time of the initial LUS, HRCT was performed in 28/62 patients and a chest radiography in 19/62 patients. **Results:** On admission, LUS detected pleural line thickening (>6 lung areas) in 49/62, confluent B-lines in 38/62, and separate B-lines in 34/62, consolidation in 12/62, C prime profile in 19/62, and pleural and cardiac effusions in 4/62 and 1/62, respectively. The single beam “torchlight” artifact was seen in 16/62, which may possibly be a variation of the B-line which has not been described earlier. Follow-up LUS detected significantly lower rates ($P < 0.05$) of abnormalities. **Conclusion:** Ultrasound demonstrated B-lines, variable consolidations, and pleural line irregularities. This study also sheds light on the appearance of the C prime pattern and “torchlight” B-lines which were not described in COVID-19 earlier. LUS findings were significantly reduced by the time of the follow-up scan, insinuating at a rather slow but consistent reduction in some COVID-19 lung lesions. However, the lung ultrasound poorly correlated with HRCT as a diagnostic modality in COVID-19 patients.

Keywords: Acute respiratory failure, chest computed tomography, COVID-19 pneumonia, point-of-care lung ultrasound

INTRODUCTION

Novel coronavirus disease-2019 (COVID-19) has a protean clinical presentation ranging from asymptomatic cases, seasonal flu-like symptoms to cases of full-blown pneumonia with possible evolution into severe respiratory failure.^[1,2] Although high-resolution computed tomography (HRCT) has been widely used as the imaging modality of choice in the current pandemic, studies in lung ultrasonography (LUS) have been increasing over the past 20 years, with emphasis on the use of ultrasound in a standardized fashion to identify lung disease in COVID-19 era.^[3] Its use in the intensive care unit (ICU) to diagnose lung pathologies in the critically ill and immobile patients is well known. Since most lung parenchymal

lesions in COVID-19 are distributed peripherally, these lesions should theoretically be detected by LUS.^[4-11]

MATERIALS AND METHODS

Study design

The study was conducted in 62 confirmed cases who were admitted to a dedicated COVID-19 ICU (Odisha COVID hospital). Inclusion criteria were ICU admission and confirmed COVID-19 pneumonia. Coronavirus infection was determined by reverse transcription–polymerase chain reaction (RT-PCR)

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assays on throat swab samples using a TRUPCR SARS-CoV-2 RT quantitative PCR Kit (in DNA Life Sciences Pvt., Ltd.). Exclusion criteria were those who did not undergo both the initial and the follow-up LUS scan. Informed consent was taken from all 72 patients who had at least one LUS examination. The study was approved by the institutional ethics review board (KIMS-IRB-551).

Lung ultrasonography examination

LUS was performed with a convex (2–6 MHz) transducer set at depth of 6.8 cm and linear transducer (10–15 MHz) set at depth of 11.6 cm. Transducers were connected to the portable US machine assigned exclusively for the COVID-19 hospital. The LUS examination was performed by two radiology residents who were posted in the COVID wards during the study period. The intraclass correlation coefficient (ICC) was determined and an almost perfect agreement for the lung ultrasound scoring (LUSS) scores by the two residents was found (ICC 0.82, 95% confidence interval [CI]: 0.57–0.95).

The thorax was scanned in 12 lung areas.^[12-14] The cardiopulmonary limited ultrasound examination (CLUE): COVID-19 Lung Ultrasound in Emergency protocol^[15] was used for the anatomical parameter and LUSS system. At each zone, LUSS points range from 0 to 3, with higher points allocated to severe lung changes. Based on the total score from 12 lung zones, the severity was classified as mild (score 1–5), moderate (>5–15), and severe (>15). A normal lung will have a total score of 0. Although the objective scoring system also incorporates the clinician's assessment in decision-making of the patient, this aspect was not in the purview of our study. Follow-up LUS examinations were performed in all patients after 7 (mean) days of the initial LUS examination. LUS images were electronically stored and analyzed.

At the time of the initial LUS, HRCT was done and data was available for 28 of the 62 patients, they were then compared to the imaging findings of the initial LUS. A follow-up LUS was performed at 7 (mean) days after initial LUS and the changes were evaluated. The HRCT images were assessed according to the computed tomography (CT) total severity score^[16] and classified according to the RSNA chest CT classification.^[17]

Statistical analysis

Continuous variables were expressed as means. The ICCs were used to assess the degree of agreement between LUS score and CT SS. An ICC <0.50 was considered poor, that from 0.50 to 0.75 moderate, that from 0.75 to 0.90 good, and that from 0.90 to 1 excellent. The mean values were reported along with 95% CIs. Statistical significance was set at $P < 0.05$ using McNemar's Chi-square test.

Cohen's kappa (κ) test was used to compare abnormal chest CT findings with abnormal LUS findings using the scoring systems as described observer agreement and kappa values were calculated with the same.

RESULTS

Patient population

Seventy-two patients were admitted in the COVID-19 ICU during the study period. Ten patients were excluded due to their demise before the follow-up LUS examination. All patients underwent LUS examinations on the day of admission to the ICU. The baseline parameters and outcome measures of the study population were evaluated during the hospital stay and were tabulated [Table 1].

Three patients were admitted to the ICU with the acute abdomen (appendicitis, intestinal obstruction, and intestinal perforation), all three also had concomitant COVID-19 pneumonia. All patients received prone positioning, lung recruitment, and empiric therapy for COVID-19 with anticoagulants, dexamethasone, azithromycin, antivirals, and in selected patients plasma therapy after cross-matching.

The mean duration of mechanical ventilation was 11 days, and the ICU length of stay was 12 days. Follow-up data on a negative conversion rate of SARS-CoV-2 RNA assayed by RT-PCR was not available.

Lung ultrasonography findings in patients with coronavirus disease-2019

Each LUS examination lasted approximately 21 min (mean). LUS findings are summarized in [Table 2].

The presence of B-lines [Figure 1] was the most common finding in 59/62 (95.16%) of the cases.

Confluent B-lines originating from regular pleural lines which were previously described as "waterfall" artifacts [Figure 2c and Video 3] and were supposed to represent an early stage of actively spreading COVID-19 pneumonia alternating with areas of normal lung parenchyma were observed in 38/62 (61.2%) of the cases; however, other studies which were not in the ICU setting reported a higher incidence of

Table 1: Baseline parameters and outcome measures of the study population (n=62)

Parameter	Value
Age (years), mean (SD)	53 (6.7)
COVID ward admission to ICU admission (days) mean (SD)	6 (2.4)
SpO ₂ on ward admission mean (SD)	94.6 (1.1)
SpO ₂ on ICU admission mean (SD)	82.2 (1.8)
Duration of mechanical ventilation (days), mean (SD)	9 (2.1)
ICU length of stay (days), mean (SD)	12 (3.3)
Male (%)	77
Intubated and mechanically ventilated (%)	89.2
Nonintubated and receiving HFNC (%)	14.9
Shifted from ICU to COVID ward (%)	72.1
Discharged from hospital (%)	14

ICU: Intensive care unit, SD: Standard deviation, COVID: Coronavirus disease, HFNC: High Flow Nasal Cannula

Table 2: Lung ultrasonography findings in intensive care unit patients with coronavirus disease-19 (n=62)

USG finding	On ICU admission (n=62), n (%)	Follow-up USG at 7 (mean) days (n=62), n (%)
Pleural line thickening (>6 lung areas)	49 (79.03)	22 (35.4)
Confluent B-lines	38 (61.2)	5 (8)**
Separate B-lines (>3 in a single intercostal space)	34 (54.8)	6 (9.6)*
C prime profile	19 (30.6)	8 (12.9)
Single light beam“torchlight”	16 (25.8)	4 (6.4)
Pleural effusion	4 (6.4)	7 (11.2)
Pericardial effusion	1 (1.6)	0
B-lines	59 (95.16)	25 (40.32)*
Right lung	49 (79.03)	19 (30.64)*
Anterior–superior	46 (74.19)	19 (30.64)
Anterior–inferior	49 (79.03)	20 (32.25)
Lateral–superior	47 (75.8)	19 (30.64)
Lateral–inferior	48 (77.4)	19 (30.64)
Posterior–superior	52 (83.8)	22 (35.48)*
Posterior–inferior	53 (85.4)	22 (35.48)*
Left lung	48 (77.4)	18 (29.03)
Anterior–superior	45 (72.5)	17 (27.41)
Anterior–inferior	47 (75.8)	17 (27.41)
Lateral–superior	49 (79.03)	19 (30.64)
Lateral–inferior	49 (79.03)	18 (29.03)*
Posterior–superior	52 (83.8)	21 (33.87)*
Posterior–inferior	53 (85.4)	22 (35.48)*
Consolidations	12 (19.3)	7 (11.29)
Right lung		
Anterior–superior	9 (14.51)	3 (4.83)
Anterior–inferior	8 (12.90)	3 (4.83)
Lateral–superior	9 (14.51)	3 (4.83)
Lateral–inferior	10 (16.12)	4 (6.45)
Posterior–superior	9 (14.51)	3 (4.83)
Posterior–inferior	12 (19.35)	5 (8.06)
Left lung		
Anterior–superior	8 (12.90)	3 (4.83)
Anterior–inferior	8 (12.90)	3 (4.83)
Lateral–superior	8 (12.90)	4 (6.45)
Lateral–inferior	10 (16.12)	5 (8.06)
Posterior–superior	9 (14.51)	4 (6.45)
Posterior–inferior	10 (16.12)	4 (6.45)
Vascularity of consolidations	2 (3.22)	7 (11.2)

* $P < 0.005$, ** $P < 0.001$ by Fisher’s exact test. ICU: Intensive care unit, USG: Ultrasonography

confluent B-lines.^[13,14,18] There is an overlap between the shining band-like artifact cascading down from a large portion of a normal pleural line, often appearing and disappearing with an on/off effect in the context of a normal A-lines lung pattern [Figure 2] visible on the background often referred to as the “waterfall” sign and “light beam” sign by some.

It has not been fully characterized well and confirmed if they mean one and the same. An interesting finding also encountered in this study was the narrow and bright B-line originating from the thickened pleura which was brighter and narrower than the regular separate B-lines and did not tend to fan out till the end of the screen. We are uncertain if this is a variety of the already described “waterfall” and “light beam sign”

which originate from a larger portion of the regular pleural line. We felt this was similar to a “torchlight” [Figure 1c and Video 2], a “single light beam” being flashed in a sense that it was extremely bright undoubtedly brighter than the Z-line and B-line, which was erased by A-lines and almost always was from a thickened pleura. These “torchlight” B-Lines were observed in 16 (25.8%) of the patients and were seen more in the anterior superior and anterior–inferior areas of bilateral lungs typically in clinically severe cases. All the 10 cases who did not survive for the follow-up LUS had these lines. Of the 16 patients with the “torchlight” B-line, 12 of them were diabetics. This needs to be further studied if it can be an indicator of severe COVID pneumonia.

In contrast, separate B-lines [Figure 1b and Video 1] (>3 in a single intercostal space) coming off from irregular pleural lines were evident in most cases (34/62, 54.8%) of the cases. Multifocal B lines which also corresponded to the ground glass opacities in HRCT [Figure 4a and b] was observed. Variable consolidations 16/62 (25.8%) predominantly seen in the posterior lung areas were noted. Both subpleural [Figure 3b] and “starry sky” patterns of consolidation (bright infiltrates and Video 4) were encountered; however, the subpleural kind was more common than the latter. Only a single case of extensive consolidation in the form of complete hepatization of the lung was encountered [Figure 4c]. This was a deviation from the previous studies which reported a higher incidence of the “starry sky” pattern usually involving more of the lung parenchyma.^[6,18] Pleural line thickening [Figure 3a and c] in >6 lung areas was seen in 49/62 (79.03%),

involving the right lung in 50/62(80.5%), and the left lung in 48/62 (78.7%).

The C prime profile which was seen as thickened pleural lines where there was small subpleural hypoechoic lung parenchyma of different measurements all below 0.6 cm in depth was seen in 19/62 (30.6%) and pleural and pericardial effusions in 4/62 (6.4%) and 1/62 (1.6%), respectively.

With effusion coming across solely in patients with preexisting renal disease, pneumothorax, pneumomediastinum, and subcutaneous emphysema were all noted in a single patient, possibly due to barotrauma and could not be certainly attributed to the COVID-19 pneumonia. On follow-up, LUS lung abnormalities were still present [Table 2]; however, it was significantly lower ($P < 0.05$) compared to findings on the initial scan.

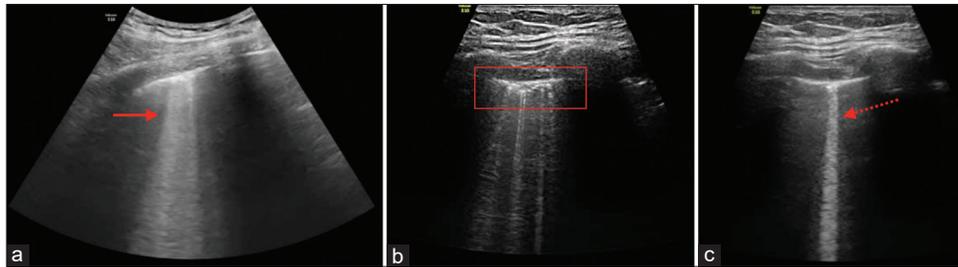


Figure 1: B-Lines in the study population. Confluent B-lines (arrow) in the inferior–posterior area of the right lung scanned by a curvilinear (3 MHz) transducer (a). Thickened pleural line with multiple hypoechoic subpleural areas’ consolidation-shredded lung pattern representing multiple shred sign or C-profile (red box) with B-lines below. Scanned by a liner high-frequency (15 MHz) transducer in the anterior–superior area of the right lung (b). Torchlight sign (dashed arrow) variant of the B-lines in the posterior superior area of the left lung scanned by a liner high-frequency (15 MHz) transducer (c)

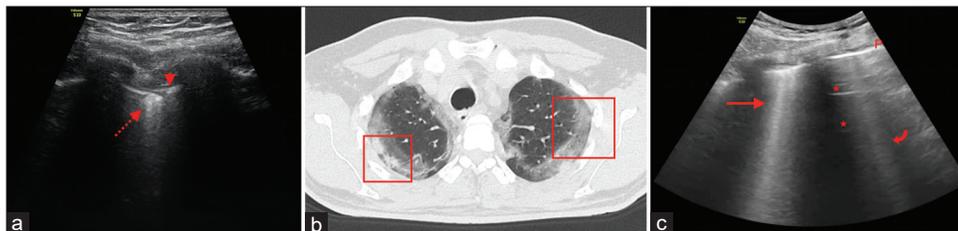


Figure 2: Same patient. Pleural-based consolidation (dashed arrow) with thickening and pleural irregularities (arrowhead) depicted by a linear high-frequency transducer in the superior lateral area of the right lung (a). Classic Waterfall sign (arrow) next intercostal space showing the normal pleural line P, normal A-lines (asterisk) and normal Z-line (curved arrow) (c). High-resolution computed tomography of the same patient box on the right lung showing the area of consolidation corresponding to A, Box on the left lung showing the area of ground-glass opacities corresponding to coalescent B-lines-Waterfall sign on c (b)



Figure 3: Consolidations in the study population. Small subcentimetric consolidation (arrow) with associated pleural thickening depicted by a linear high-frequency transducer in the inferior–lateral area of the left lung (a). Larger area of hyperechoic starry sky consolidation (dashed arrow) with mild pleural effusion (arrowhead) using a curvilinear transducer in the inferior lateral area of the right lung above the liver (L) (b). Evolving consolidation with pleural irregularity (curved arrow) and pleural thickening (thin arrow) (c)

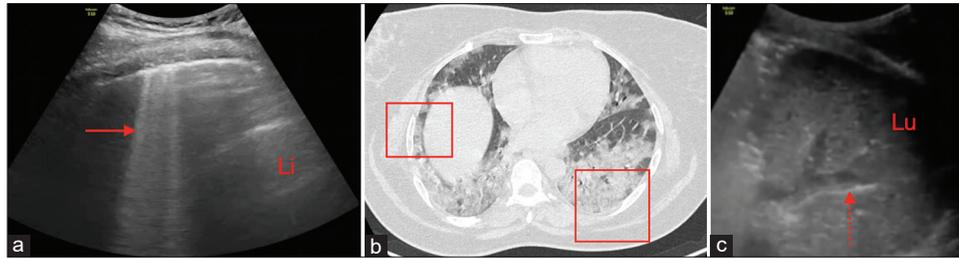


Figure 4: Multifocal B-lines (arrow) coming off from the pleura above the Liver (Li) using a curvilinear transducer in the lateral inferior area of the right lung (a). Near-complete hepatization (consolidation) of the lung (Lu), air (dashed arrow) within the air bronchogram is appreciated and moves to and fro during scan in the posterior inferior area of the left lung (c). HRCT of the same patient box on the right lung showing the area of ground-glass opacities corresponding to (a), Box on the left lung showing the area of consolidation with air bronchogram corresponding to lung hepatization on c (b). HRCT: High-resolution computed tomography

High-resolution computed tomography in patients with coronavirus disease-2019

HRCT data for only 28 of the 62 patients were available. The HRCT was evaluated and given a CT total severity score^[16] and classified according to the RSNA chest CT classification^[17] [Table 3].

Correlating the modalities

The degree of agreement between LUS score and CT severity score was calculated using ICC. We calculated an ICC value of 0.72 (moderate agreement); however, this was highly possible due to the small sample size of our study which underwent HRCT. This was also the first study in our knowledge which had utilized the CLUE: COVID-19 Lung Ultrasound in Emergency protocol^[15] for a comparison study with HRCT [Table 4]. The CLUE was initially developed for scanning bedside patients with cardiopulmonary pathologies. It is a simple, quick to learn, and easily reproducible method of scanning the chest. Other studies show a higher and better correlation of LUS with HRCT. Imaging findings indicative of or highly compatible with COVID-19 were present in patients (92.58%) on both HRCT and LUS examination. An attempt to draw a parallel between the findings [Table 5] of the two modalities was made.

An observer agreement was found to be 39.3% and kappa of 0.1136 ($P = 0.3362$) was calculated which correlated the two investigations poorly. The statistical agreement between Chest X-ray and CT scan was poor ($k = 0.122$, $P = 0.15$). LUS results were weakly correlated with chest X-ray findings ($k = 0.243$, $P = 0.039$).

DISCUSSION

Owing to the abrupt nature of the COVID-19 pandemic and its extreme effects on the health-care services, articles on LUS are still in progress. We found that LUS effectively detected lung abnormalities such as B-lines, pleural line abnormalities, variable consolidations, and pleural effusions.

In our study, LUS performed on ICU admission revealed bilateral lung abnormalities predominantly in the posterior parts of the lungs. Our patient group showed a considerable amount of lung parenchymal involvement in LUS examinations on ICU admission.

Table 3: Imaging modality findings of the patient population with coronavirus disease-2019 assessed by both lung ultrasonography and high-resolution computed tomography

Imaging modality	Number of patients (n=28)
HRCT	28
COVID-19 suggestive	26
Ground-glass opacity	
Rounded	
Central	22
Peripheral	10
Nonrounded	1
Interlobular septal thickening (crazy paving)	13
Pneumonic consolidation	11
Subpleural consolidation	6
Traction bronchiectasis	4
Pleural effusion	1
Mediastinal lymphadenopathy	5
Fibrobronchiectatic changes	2
RSNA chest CT classification	
Typical appearance	20
Indeterminate appearance	4
Atypical appearance	3
Negative for pneumonia	1
CT TSS group	
Normal	3
Mild	4
Moderate	14
Severe	7
COVID-19 ultrasound CLUE protocol	
Normal (LUSS 0)	2
Mild (LUSS 1-5)	8
Moderate (LUSS >5-15)	11
Severe (LUSS >15)	7

COVID-19: Coronavirus disease-2019, LUS: Lung ultrasonography, RSNA: Radiological Society of North America, CLUE protocol: COVID-19 Lung Ultrasound in Emergency protocol, LUSS: Lung ultrasound scoring system, TSS: Total severity score, CT: Computed tomography, CLUE: Cardiopulmonary limited ultrasound examination, HRCT: High-resolution computed tomography

HRCT has many limitations, such as radiation exposure, low availability, and contraindication to its use in unstable

Table 4: Disease severity in the patient population using lung ultrasonography and high-resolution computed tomography scoring systems

HRCT scoring system	LUS scoring system				Total
	Normal	Mild	Moderate	Severe	
Normal	1	1	0	0	3
Mild	1	2	2	0	4
Moderate	0	5	5	4	14
Severe	0	0	4	3	7
Total	2	8	11	7	28

LUS: Lung ultrasonography, HRCT: High-resolution computed tomography

Table 5: Drawing a parallel on the imaging findings in patients who underwent both ultrasonography and high-resolution computed tomography

HRCT	Lung ultrasound
Pleural thickening	Pleural line thickening
Pleural irregularity with small subpleural consolidations	C prime profile
Ground-glass opacities	Confluent B-lines
Lobar consolidation	Lung hepatization
Pleural effusion uncommon	Pleural effusion uncommon
Atelectatic bands are an indicator of recovery	Reappearance of A-lines is an indicator of recovery

HRCT: High-resolution computed tomography

patients. Bedside LUS avoids transport of the patient with suspected COVID-19 to the radiology department (exposing other patients or health care providers); however, this is variable such as our hospital where a designated COVID CT machine solves this problem. LUS is a bedside tool that can potentially reduce the risk of cross-infection related to the transport of COVID-19 patients.

New LUS observations with respect to COVID 19 pneumonia made in our study:

- The “torchlight” B-lines [Figure 1c] which was seen predominantly in the anterior areas typically in clinically severe cases, this was unlike the confluent B-lines which was seen more in the posterior regions
- C prime profile in the subpleural areas with a shredded lung appearance
- Revascularization of the consolidations was usually associated with a better clinical prognosis
- Pleural effusion was seen in the follow-up LUS scan in patients who did not have it in the initial LUS evaluation, probably an indication that it was a late-appearing LUS feature even in the ICU setting.

Strengths

To the best of our knowledge, this is one of the few studies correlating LUS with HRCT. In conclusion, this study illustrated that LUS may be an alternative imaging modality in the diagnosis and monitoring of only critically ill patients with COVID-19. LUS successfully identified B-lines, pleural

line irregularities, and variable consolidations which are the imaging features of COVID-19 pneumonia.

Limitations

There are definitely some limitations present in this study that need to be addressed. The number of patients was small; hence, no statistically significant subgroup analysis could be performed. We could not correlate the LUS findings with HRCT scans in all studied cases in the first LUS examination; however, the follow-up LUS examination did help clear any discrepancies.

The main limitation with LUS is the poor specificity; its findings overlap with those for other pneumonia etiologies. Thus, the results from this study provide an opportunity to further investigate the use of ultrasound in various settings and clinical scenarios when the prevalence and incidence of COVID-19 infection decreases.

CONCLUSIONS

LUS is a safe, nonradioactive, reproducible, low-cost, and short-term examination method for COVID-19. LUS can be used to quickly diagnose lung diseases, such as pneumothorax, alveolar interstitial syndrome, pulmonary consolidation, and pleural effusion, and for sequential examinations to evaluate evolving pathological changes. However, LUS identifies only peripheral lesions in the lung, and central lesions must still be evaluated by CT. Contrast LUS may also be looked into a subject to its availability.

Nonetheless given the ICU setting, LUS is definitely something that can be carried out with ease and also has the capacity to determine the requirement of interventions like intubation. In the pandemic, as paucity of resources and workforce encompass a threat to our health-care systems, LUS will have to be used as a modality to diagnose as well as monitor the lung findings in patients with COVID-19 pneumonia and its complications. This study has opened doors to many new findings that may be studied in the COVID pneumonia provided they are backed by more research data.

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Conflicts of interest

There are no conflicts of interest.

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