UNIVERSITÀ DI TRENTO

ULTRa ULTRASOUND LAB TRENTO

ILUS2023

International Lung Ultrasound Symposium

10 -12 July, 2023

Trento, Italy

Programme

DAY	TIME	EVENT/SESSION
Monday July 10	9:00	Open ceremony
	9:15	Fetal LUS
	10:20	*Break*
	10:50	Quantitative LUS 1
	12:30	*Lunch Break*
	14:30	Covid-19
	16:10	*Break*
	16:40	AI for Covid-19
	18:00	Practical Session
	19:00	End of Day 1
Tuesday July 11	9:00	Therapeutic and Safety
	10:35	*Break*
	11:05	Quantitative LUS 2
	12:20	*Lunch Break*
	14:30	Educational
	16:00	*Break*
	16:30	AI for LUS analysis 1
	18:15	End of Day 2
	19:30	Social Hours
Wednesday July 12	9:00	Simulations and Phantoms
	10:25	*Break*
	10:55	Quantitative LUS 3
	12:05	*Lunch Break*
	14:05	Clinical LUS
	16:15	*Break*
	16:45	AI for LUS analysis 2
	18:30	Awards and Closing session
	19:30	End of Day 3

FETAL LUS

9:15

A Novel Paradigm for Quantitative Texture Analysis in Preterm and Term Fetal Lung Ultrasound Images (INVITED)

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Fetal ultrasound has been employed for years to help evaluate fetal growth and development, and to monitor pregnancy. Furthermore, fetal lung maturity has been assessed pre-natally by examination of the amniotic fluid, usually obtained by transabdominal amniocentesis, for lecithin, lecithin/sphingomyelin ratio, or 'P' factor (fluorescent polarization measurement for lipids.) Quantitative ultrasound texture analysis of fetal lung has been proposed in previous studies as a promising noninvasive method to predict fetal lung maturity, fetal lung hypoplasia, and neonatal respiratory morbidity. This technique utilizes standard fetal lung images (Figure 1), which are easily obtained by sonographers during routine ultrasound examinations. Additional information then can be extracted from these images by applying quantitative processing methods that characterize the tissue. This objective of this study is to differentiate preterm (<37 weeks of gestation) from term (≥37 weeks of gestation) fetal lungs by quantitative texture analysis of ultrasound images. This quantification is based on the extent of heterogeneity associated with lung maturity by employing a unique, novel noninvasive technique to determine the Heterogeneity Index (HI) in ultrasound images. The HI values are then compared in sonograms of immature lungs with mature lungs. Advances for the possibility of integrating this technology in handheld ultraportable systems for point-of-care are also suggested.

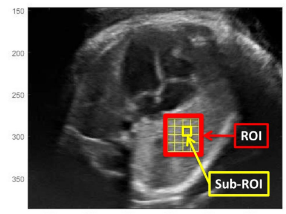

Figure 1: Four-chamber heart plane ultrasound fetal lung image with a user-defined region of interest (ROI).

9:40

Does the Colorization of Ultrasonic Fetal Lung Images Affect the Heterogeneity Index? (INVITED)

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Fetal ultrasound images have traditionally been displayed in grayscale. Ultrasound machines now provide image mapping options that can be used to create differences in image color and contrast. The ultrasound machines capture images in the Red Green Blue (RGB) color space. Some sonographers believe the colorization of fetal grayscale ultrasound images allows for a better interpretation of these images. In our ultrasound unit, most sonographers prefer to use color mapping over grayscale imaging when performing fetal ultrasound examinations. The two most frequently used color mapping choices made by our sonographers are Ice and Sepia. We have used ultrasound texture analysis by determining a heterogeneity index (HI) to differentiate preterm from term fetal lungs and to evaluate pregnancies at risk for lung hypoplasia using grayscale ultrasound images. The objective of this study was to compare HI between fetal lung images captured in grayscale and those same images after conversion to Ice and Sepia colorization (Figure 1). The null hypothesis was that there are no statistical differences in the fetal lung heterogeneity indices between grayscale images, Ice images and Sepia images. However, we observed that HI is affected by the application of color tones to ultrasound images of the fetal lung. Therefore, for each type of biological tissue and color tone, determination of distinct HI nomograms and cut off points is recommended.

Figure 1: Regions of interest on Grayscale (A), Sepia (B), and Ice (C) ultrasound fetal lung images.

10:00

Quantitative Medical Ultrasound for the study of fetal lung maturity

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Fetal lung immaturity is a public health problem in many countries. Because of this, it is necessary to explore the development of noninvasive techniques that can determine lung maturity during the gestational process. Quantitative ultrasound (QUS) has become a possible way to assess lung maturity. The main factors determining lung maturity are alveoli's number density, average size, and alveolar wall-lining thickness. From ultrasound measurements, we obtain the radiofrequency signals and calculate the attenuation and backscattering coefficients, from which estimate the effective size of the scatterers. Also, for low ultrasound frequencies, we determine the average speed of sound using an effective medium approximation. To test the idea we first use sponges with different pore sizes, determine the average size through the backscattering coefficient and compare the obtained results from a pore-size analysis using dark-field microscopy. As the second test, we compare our results with light-scattering techniques previously used to study lung tissue using light-scattering techniques (M.S. Durke, G. K. Fletcher, et al. Opt. Lett. Vol. 43, No. 20, 5001, 2018). Finally, we show the results presented using lungs from rabbits as well as the first samples of still-birth fetal lung tissue (Bioethical protocol National Institute of Perinatology INPER 2022-1-31) where the results of the quantitative ultrasound are compared with the results from pathology. [Partial Support from DGAPA-PAPIIT 107022.]

QUANTITATIVE LUS 1

10:50

Potential of open platforms for the development of dedicated lung ultrasound solutions (INVITED)

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Lung ultrasound (LUS) applications, where quantitative methods designed around the lung properties are needed, require special features to be implemented on the Ultrasound machines performing the analysis. In fact, differently from standard Ultrasound Imaging, LUS faces great challenges mainly due to the presence of air pockets which attenuate the echoes and produce high reverberating signals. Moreover, the presence of ribs creates additional artifacts when using standard Ultrasound instruments. In this scenario, the flexibility of the Ultrasound Instrument is of utmost importance, and the availability of so-called research platforms paves the way to novel imaging modalities implementations. Research platforms, also know as open scanners, have been fully developed in recent years. On one hand, open scanners allow the researchers to fully control all the parameters that are used for Ultrasound Imaging, on the other hand they can be used to acquire raw echo-data, so that it is possible to evaluate novel technologies that produces an image from the raw data, even if this is not yet implemented on the scanner. Starting from a basic imaging of the region of interest, an ideal open scanner should allow the researcher to program the requested sequence of transmission events, each one fully configurable, element by element, regarding the transmitted waveforms and the related focusing delays. On the receive side, apart from giving a standard beamforming, useful for the aforementioned basic imaging, the system should be equipped with large amount of storage memory. In fact, raw echo data can be massive in dimension, reaching data rate of tens of GB/s, rapidly saturating poorly equipped systems. Once the data are saved, the researcher will be able to develop innovative algorithms which, in the future, could be implemented on standard machines. In this talk, a complete picture on the features of open scanner and how they can be fruitfully used in LUS will be provided.

11:15

Quantitative analysis of pleural line and B-lines in lung ultrasound images for severity assessment of COVID-19 pneumonia (INVITED)

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Background: Specific patterns of lung ultrasound (LUS) images have been utilized to assess the severity of COVID-19 pneumonia, including thickening of pleural line, confluence of B-lines and presence of lung consolidations. However, such assessment is mainly based on qualitative and subjective observations made by the clinicians. In this study, we propose a quantitative method to assess the severity of COVID-19 pneumonia by analyzing the LUS images and characterizing the patterns related to the pleural line and B-lines. Methods: 27 patients with COVID-19 pneumonia were enrolled in this study, including 13 common-type patients, 7 severe-type patients, and 7 critical-type patients. Biomarkers related to the pleural line, including the thickness (TPL) and roughness of the pleural line (RPL), and the mean (MPLI) and standard deviation (SDPLI) of the pleural line intensities were extracted from the LUS images. Biomarkers related to the B-lines, including the number

(NBL), accumulated width (AWBL), attenuation coefficient (ACBL), and accumulated intensity (AIBL) of B-lines were also extracted. The correlations between the biomarkers and the disease severity were determined using Spearman's correlation analysis. The performances in differentiating between the common-type and critically ill (including the severe- and critical-type) patients were assessed for each biomarker and support vector machine (SVM) classifiers with various combinations of the biomarkers as input by calculating sensitivity (SEN), specificity (SPC), and the area under the receiver operating characteristic curve (AUC). Results & Discussion: Fig. 1 shows the examples of LUS images from different types of patients. Several biomarkers, including the RPL ($r = 0.39$, $p < 0.05$), NBL ($r = 0.66$, $p < 0.001$), AWBL ($r = 0.70$, $p < 0.001$), and AIBL ($r = 0.39$, $p < 0.05$), show significant correlations with the disease severity (Table 1). The differentiating performance is optimal by employing the SVM classifier using all the biomarkers as input (AUC = 0.96, SEN = 0.93, SPC = 1) (Table 2). The proposed method may be a promising tool for automatic grading diagnosis and follow-up of patients with COVID-19 pneumonia.

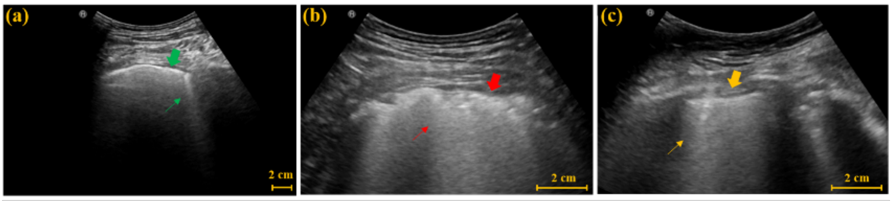

Fig. 1. Examples of LUS images from (a) a common-type patient, (b) a severe-type patient, and (c) a critical-type patient. The green thick arrow and thin arrow in (a) indicate a normal pleural line and a single B-line, respectively. The red thick arrow and thin arrow in (b) indicate the thickened and irregular pleural line, and the confluent B-lines, respectively. The yellow thick arrow and thin arrow in (c) indicate the interrupted pleural line and the confluent B-lines, respectively.

Table 1. Correlations of the proposed biomarkers with the severity of COVID-19 pneumonia

Biomarkers		*r*	*p* value
Pleural line	TPL	0.31	0.12
	RPL	0.39	<0.05*
	MPLI	-0.31	0.12
	SDPLI	0.21	0.30
B-lines	NBL	0.66	<0.001***
	AWBL	0.70	<0.001***
	ACBL	0.19	0.34
	AIBL	0.39	<0.05*

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$. *r*: Spearman's correlation coefficient.

Table 2. The classification results of each biomarker and the SVM classifiers using various combinations as input

Biomarkers		SEN	SPC	AUC [95% CI]
Pleural line	TPL	0.71	0.69	0.68 [0.47-0.88]
	RPL	**0.86**	**0.77**	**0.81 [0.64-0.99]**
	MPLI	0.43	0.92	0.69 [0.49-0.89]
	SDPLI	0.86	0.54	0.65 [0.43-0.88]
	SVM	0.86	0.93	0.87 [0.72-1.00]
B-lines	**NBL**	**0.86**	**0.92**	**0.91 [0.80-1.00]**
	AWBL	**0.86**	**0.92**	**0.91 [0.80-1.00]**
	ACBL	0.93	0.46	0.70 [0.49-0.90]
	AIBL	0.93	0.62	0.74 [0.54-0.94]
	SVM	0.93	0.86	0.94 [0.86-1.00]
SVM (PL+BL)		0.93	1.00	0.96 [0.88-1.00]

SEN = sensitivity, SPC =specificity, AUC = area under the receiver operating characteristics curve, CI = confidence level.

11:40

New sources of contrast for the quantitative assessment and monitoring of lung diseases (INVITED)

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The advent of ultra-portable ultrasound and wearable devices will boost lung ultrasound further as a true point-of-care modality. To take full advantage of these features, it will be necessary to develop quantitative ultrasound (QUS) markers of lung diseases, in order to objectively and unequivocally detect and quantify changes in lung tissue. This will avoid subjectivity of interpreting conventional ultrasound images, and the need for highly skilled and highly trained technicians, especially in remote areas and for underserved populations. To achieve this, we exploit new contrast mechanisms to detect and monitor lung diseases, by taking advantage of ultrasound scattering in lungs. Healthy lungs are expected to scatter ultrasound waves more than diseased lungs, due to the presence of healthy, air-filled alveoli. The spatial distribution of alveoli also impacts scattering patterns. We demonstrate that it is possible to use ultrasound scattering as a source of contrast to detect and assess the severity of pulmonary fibrosis and pulmonary edema. To ensure specificity, multiple ultrasound biomarkers are needed. Changes in lung microstructure such as changes in alveolar size, alveolar density or alveolar spacing will differently affect various QUS parameters Lung QUS has the potential to provides a very large parameter space that could be exploited for a more specific lung ultrasound assessment. We explore this parameter space by identifying five families of QUS parameters, and their potential to assess, follow up and discriminate diseases such as fibrosis, edema, and other lung diseases.

12:05

Quantitative Ultrasound in the Lung: Clinical Utility in Lung Diseases and Localizing Pulmonary Nodules (INVITED)

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Conventional ultrasound (US) of the lung does not produce an image, because of millions of alveoli that provide air-liquid interfaces, resulting in US multiple scattering (USMS). We used USMS in lung to learn about lung microarchitecture. USMS allows calculation of scattering mean free path (SMFP), the average distance an US wave travels in the lung. Using a programmable US scanner, we showed in 18 rats subjected to intervals of ischemia followed by reperfusion, edema occurred compared to lungs from 6 normal rats. Edema amount, assessed by wet:dry weight ratio and ex-vivo CT scan correlated with SMFP. We showed that 24 rat lungs rendered fibrotic (PF) by intra-tracheal bleomycin installation also had a longer SMFP than lungs from 6 normal rats. Severity of PF by histology and ex-vivo CT scan correlated with SMFP. We hypothesized that solid lesions like pulmonary nodules (PNs) would not cause USMS. We inserted 69 PNs into 2 canine and 13 porcine lungs, removed after death (12 Vaseline and 57 dental impression compound (DI)). With a programmable US scanner, we showed that PNs could be detected by mapping areas of single scattering and multiple scattering, rendering an image of the PN. 56 of 57 DI PNs were localized (98%). By switching to B-mode, the leading edge of a closed surgical stapler could be detected (but not the PN). By superimposing the rendered PN image with the B-mode stapler image, distance of the PN to the stapler could be determined. 6 PNs were resected with suitable margins. We plan to make an intra-thoracic steerable US probe to detect PNs and relationship to a stapler for faster and safer PN resection via minimally invasive thoracic surgery. This novel use of lung US may allow monitoring of patients with heart failure or PF, and localizing PNs for fast and safe minimally invasive resection.

COVID-19

14:30

Lung Ultrasound in diagnosing SARS-CoV-2 infection during the very first Italian phase of pandemic in the Emergency Department of "Santa Maria del Carmine" hospital of Rovereto

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Background: the very first phase of SARS-CoV-2 pandemic in Italy (winter season 2019-2020) was characterized by a great difficulty in diagnosing the presence of the disease with a clinically acceptable accuracy. The diagnostic gold standard is still now the amplification of some specific genes of the coronavirus through an RT-PCR (reverse transcriptase-polymerase chain reaction) on nasopharyngeal swab or other biologic specimen. RT-PCR exhibits a high number of false negative results – almost 30%. This level of sensibility was insufficient to ensure the security of the clinical management of the patient both in-hospital and out-of-hospital. We should remember that in the early phase of the pandemic spread there weren't specific therapies and the only reliable method for controlling the disease was isolation of positive patients. RT-PCR and lung HRCT (High Resolution Computed Tomography) availability was scarce, these exams were expensive and the results needed long time to be ready with consequent prolonged patient stay within the emergency department. A study showed that HRCT has a highest sensibility in identifying SARS-CoV-2 infection than RT-PCR on nasopharyngeal swab alone. Lung ultrasound has a close to 100% sensibility in the identification of acute interstitial syndrome (AIS) and we know the features that distinguish AIS caused by acute pulmonary edema and acute respiratory distress syndrome (ARDS) and we also know that SARS-CoV-2 shares a lot of specific features of an ARDS. When considering acute respiratory syndromes, it was established a strong correlation between imaging findings from HRTC and lung ultrasound, and the latter overwhelms traditional lung radiography in terms of diagnostic power. Emergency departments needed to find rapid and reliable diagnostic tools, and since the beginning of the pandemic lung ultrasound has been used in the initial diagnostic work-up – through the identification of specific ultrasonographic patterns of SARS-Cov-2, and in the follow-up phase of the patients, especially those who underwent mechanical ventilation. The wide availability of ultrasound scanners helped the implementation of lung ultrasound in the clinical decision pathways of SARS-CoV-2. Aim: verifying the validity and applicability in real life of a protocol for the management of patients with suspected or confirmed SARS-CoV-2 based on the ultrasonographic scan of the lung within the emergency department, from the triage to the final destination (home discharge or hospital admission). Methods: we included all consecutive patients with a clinical suspicion of SARS-CoV-2 based on symptoms admitted to the Accident&Emergency of the hospital "Santa Maria del Carmine" in Rovereto (TN) from day 10th March 2020 (date of the first confirmed case of

SARS-CoV-2 in our department) to day 9th April 2020. All patients were evaluated according to a flowchart. Results: we evaluated 208 consecutive patient admitted to the Accident&Emergency of the hospital "Santa Maria del Carmine" in Rovereto (TN). Of these, 199 patients (95.7%) underwent a nasopharingeal swab for SARS-CoV-2. Those who didn't present clinical features of suspicion for SARS-CoV-2 according to our protocol, didn't undergo nasopharyngeal swab. The most common symptoms at the presentation were fever (72.1%) and cough (67.3%), followed by dyspnea (30.8%). Fever, anosmia e ageusia correlated significantly with the positive result of nasopharyngeal swab for SARS-CoV-2. 164 (78.8%) patients underwent lung ultrasound, 78 (37.5%) underwent chest radiography and 113 (54.3%) underwent HRTC of the lungs. 156 patients underwent both lung ultrasound and nasopharyngeal swab. 93 (60%) patients showed ultrasonographic findings which suggested SARS-CoV-2 and of these66 (70.9%) had a positive RT-PCR on nasopharyngeal swab and 27 (29%) had a negative result of the swab. Concordance between lung ultrasound and RT-PCR was 77%. Among the patients with a positive RT-PCR on nasopharyngeal swab who underwent both lung ultrasound and HRTC of the lungs, these two imaging methods showed a high level of concordance between each other. Conclusions: since most patients underwent lung ultrasound, HRTC of the lungs and RT-PCT on nasopharingeal swab, we could compare the diagnostic power of these three methods . During the very first part the pandemic – with a high pre-test probability of having a SARS-CoV-2 infection – these data seem to confirm a highest sensibility of the imaging techniques compared to RT-PCR on nasopharyngeal swab. Furthermore, this study confirms the validity of lung ultrasound in the diagnostic work up of SARS-CoV-2, thanks to its low cost, easy availability and absence of contraindications.

14:50

Prediction of CT-scan Severity Score from lung ultrasound score in COVID-19 pneumonia

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Background and aim: CT-scan Severity Score (CT-SS) is the gold standard for the quantification of COVID-19 pneumonia, however CT-scan is not always available. Objectives are to determine whether it is possible to predict CTSS from the lung ultrasound (LU) score, and whether the change in LU score associates with a change in CT-SS during hospitalization. Methods: This is a retrospective observational study. Hospitalized patients with severe to critical COVID-19 pneumonia who performed LU within six hours from CT-scan were included. Two LU scores were calculated: the LU-Mean, by diving the sum of scores of all explored chest areas for the total number of areas, and the LU-Sum, by summing chest areas with a score ≥ 2. CT-SS was predicted using linear regression models and the agreement between fitted values and CT-SS was assessed using Bland-Altman plot. The correlation between the change in CT-SS and LU scores was reported using the Pearson correlation index. Results: The median CT-SS was 11 (IQR:6). LU-Mean and LU-Sum were linearly correlated with CT-SS ($r_{LU\text{-}Mean}$=0.78 and $r_{LU\text{-}Sum}$=0.79), with a Beta of 7.34 (P-value<0.001) and 0.94 (P-value<0.001), respectively. Two predictive models, based on LU scores and type of respiratory support, were developed, with an adjusted R-squared of 0.64 and 0.67, respectively. The correlation between the change of CT-SS and LU scores was 0.86 (P-value<0.001) for LU-Mean and 0.87 (P-value<0.001) for LU-Sum. Conclusions: Linear equations can be used to predict the CT-SS from the LU-Mean and LU-Sum scores, and the change of LU score during hospitalization linearly correlates with that of CT-SS. LU score can be used to predict CTSS in those settings where CT-scan is not available or to reduce the exposure to ionizing radiations.

15:10

Relevance of lung ultrasonography and 6-minute walking test in predicting abnormal pulmonary function in Covid-19 survivors

Nicola Compagnone,[1*] Patrizia Rovere-Querini,[1,2] Rebecca De Lorenzo,[1] Cecilia Bussolari,[1] Elena Cinel,[1] Elisabetta Falbo,[1] Giacomo Pacioni,[1] Jacopo Castellani,[1] Marica Ferrante,[1] Marta Cilla,[1] Giordano Vitali,[2] Sarah Damanti,[3] George Cremona[4]; [1]Vita-Salute San Raffaele University, Milan, Italy, [2]Division of Immunology, Transplantation and Infectious Diseases, IRCCS San Raffaele Hospital, Milan, [3]Unit of General Medicine and Advanced Care, IRCCS San Raffaele Scientific Institute, Milan, [4]Unit of Respiratory Medicine, IRCCS San Raffaele Scientific Institute, Milan; [*]dott.nicolacompagnone@gmail.com

Abnormal pulmonary function tests (PFTs) are frequently reported in COVID-19 survivors, but their correlation with radiological abnormalities is still unclear. Since the beginning of pandemic, Lung Ultrasonography (LUS) has been widely used for diagnosis and risk stratification of COVID-19, but data about LUS at follow-up evaluation are still lacking. We evaluated 154 adult patients obtaining pulmonary function tests at median 130 (91 – 207) days from hospital discharge. Results of LUS score (LUSS) and 6-Minute Walking Test (6MWT) at 1, 3 and 6-months were also collected from a prior evaluation at COVID-19. Of the entire cohort, 58 patients had a moderate-severity disease requiring oxygen support, 46 patients had severe disease requiring non-invasive mechanical ventilation (NIV) and 50 patients had a critical disease requiring mechanical ventilation. The interpretation of PFT showed a total amount of 16 obstructive patterns (10%), 49 restrictive pattern (32%) and 93 DLCO

impairment (60%). A higher number of obstructive abnormalities was observed in moderate disease in comparison to severe disease (12 vs 1, p=0.004). Conversely, restrictive pattern was mostly represented in critical disease compared to moderate disease (25 vs 11, p=0.002). Median LUSS at 1-month evaluation was 4 (1 - 8), and was significantly higher in severe compared to moderate disease (6 vs 2, p=0.001). No difference was observed in LUSS at 3 and 6-months evaluation. The average of LUSS at 1, 3 and 6-months evaluation was 3 (0 - 6), and appeared significantly higher in severe and critical disease in comparison to moderate disease (3 vs 1, p=0.01). Average LUS score presented a negative correlation with TLC% (Pearson's correlation coefficient, PCC = -0.412, p<0.001) and DLCO% (PCC = -0.689, p<0.001). In the multiple regression model, age, PaO2/FiO2 ratio at hospital admission, average LUSS and pathologic 6MWT were associated with abnormal PFTs (respectively p = 0.001, p = 0.038, p=0.007, p=0.028). These data confirm that LUS offer to the physician a valid alternative to traditional imaging technique. A follow-up schedule comprehensive of LUS and 6MWT could help physicians to identify residual lung sequelae in patients who need to be addressed to a respiratory specialistic evaluation.

15:30

Chest imaging by LUS and CT in CoViD-19 pneumonia

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Background: The Lung Ultrasound Score (LUS) is a semiquantitative measure of lung aeration loss, and represents the sum of the scores of various pulmonary regions. LUS has been employed in the evaluation of patients with CoronaVirus Disease 2019 (CoViD-19). Chest high- resolution computed tomography (HRCT) is the gold standard method to evaluate the severity of lung involvement from CoViD-19. Few studies have investigated the clinical significance of LUS and HRCT score in patient with CoViD-19. Indirect comparisons among chest CT and ultrasound gave similar good sensitivity, and both have a fair specificity. These data were confirmed by a direct comparison in a multicentric study. Purposes of this study were 1) to compare LUS with HRCT data in acute phase of CoViD 19 pneumonia, in order to evaluate LUS usefulness in a routine clinical setting as a real life study, and then 2) to evaluate eventual LUS changes at six month follow-up. Methods: In the study, retrospective data from 40 patients admitted in 2020 in a High Intensity Internal Medicine Unit having both chest HRCT and LUS within 36 hours from admission, were considered. all subjects underwent complete clinical and laboratory examinations, and they should. LUS was performed with a ultrasound scanner (MyLab™X6, Esaote, Genova, Italy) equipped with a 3.5 MHz convex probe, dividing each hemithorax into six regions: two anteriors, two laterals and two posteriors, according to the anatomical landmarks set by the anterior and posterior axillary lines. Each region is in turn divided in two halves: upper and lower. For each explored region, the worst finding is reported according with the following ratings. Score 0: the pleural line is continuous and regular. Horizontal artifacts are present. These artifacts are generally referred to as A lines. Score 1: the pleural line is indented. Below the indent, vertical areas of white are visible. These artifacts are generally referred to as B lines. Score 2: the pleural line is broken. Below the breaking point, small to large consolidated areas (darker areas) appear with associated areas of white below the consolidated area (white lung). Score 3: the scanned area shows dense and largely extended white lung with or without larger consolidations. A LUS ranging between 0 and 36 was calculated as the sum of all regions. For HRCT image data acquisition, all chest scans were performed using a GE Revolution Evo CT scanner (GE Medical System, Boston, Massachusetts, USA). They were analysed three parameters: lesions distribution, CT abnormalities, and other findings. In the evaluation of distribution, the focus was to observe whether lesions were unilateral or bilateral, single or multifocal, involving one or several lung lobes, with upper, middle or lower predilection, peripheral or central location, cranio-caudal and antero-posterior as a predominance. The degree of extention was calculated dividing the lungs in six segments and calculating for each segment the percentage of involvement. Results: The population was mainly composed by middle-aged men (86% males, mean age 63±11,8 years). LUS was directely associated with HRCT lung score (r=0.51, p=0.004). Mean LUS values at baseline were 22.6±10.0 points, and they were reduced at 16.02±6.0 points at follow up (p=0.0001). Conclusion In the present study performed in a common clinical setting (real life study) of a High Intensity Internal Medicine Unit, lung ultrasound measures were compared and found associated with chest CT findings in patients with CoViD-19, confirming LUS as a low-cost, fast, safe, noninvasive alternative to HRCT for the lung first-line evaluation of CoViD-19 patients.

15:50

Diagnostic role of Lung Ultrasound in COVID-19 patients with respiratory sequelae

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From the beginning of COVID-19 pandemic, a great effort was required to the scientific community to determinate the most appropriate approach to the acute SARS-CoV-2 infection and the consequent follow-up. For this purpose, lung ultrasound (LUS) may represent an effective diagnostic and prognostic evaluation tool since it is rapid, portable, repeatable, and non-ionizing. The main aim of our study was to determinate the correlation of the severity of LUS patterns with the radiological pulmonary parenchymal changes investigated by chest HRCT. We also examined every case of discordance and the potential correlation between the severity of LUS score and altered pulmonary gas exchanges. From November 2020 to June 2021, 15 patients, negative to RT-PCR test for SARS-CoV-2 after an initial positive result and hospitalized for persistent respiratory symptoms after COVID-19 pneumonia, were enrolled and evaluated using a LUS scoring system ranging from 0 to 3 and a HRCT score ranging from 0 (normal lung) to 4. We collected 210 ultrasound and HRCT landmarks, respectively. LUS pattern 0 is surprisingly indicative of minimal lung peripheral parenchyma involvement in 100% of cases. LUS pattern 1 was associated in 20 of 49 cases to HRCT grade 1 and no case showed a HRCT grade ≥ 3. LUS pattern 2 was reported in 50 of 75 cases to HRCT grade 2. Lastly, LUS pattern 3 was reported in 37 of 37 scans to HRCT grade 3, with 96% agreement. In conclusion, LUS has gained a significant role in the management of COVID-19 patients with respiratory sequelae, representing a rapid bed-side evaluation tool in case of both minimal lung peripheral parenchyma involvement and larger and irreversible injury. Further research is needed to support these preliminary findings and to understand the potential application of lung ultrasound in other types of respiratory diseases.

AI FOR COVID-19

16:40

A Novel Statistical-based Aggregation Technique for Automatic Covid-19 LUS Data Scoring

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As a result of the COVID-19 outbreak, numerous researchers are focused on developing a system for identifying and monitoring patients who are infected with SARS-CoV 2. The use of lung ultrasound (LUS) in the evaluation of patients with COVID-19 is rapidly spreading because of its fundamental characteristics: low cost, radiation-free, easily sanitized equipment that allows structural evaluation of SARS-CoV-2 lung damage. Given that the output required by doctors for clinical evaluation is generally provided at the video-level, our main objective is to develop an aggregation technique that enables us to move from frame-level to video-level analysis. To this end, we perform frame level scoring by a pre-trained deep neural network (DNN), followed by suggesting an innovative aggregation strategy utilizing cross-correlation coefficients. The rationale behind using cross-correlation is first linked to the intrinsic subjectivity connected to the semi-quantitative nature of the analysis, which is limited to neighboring scores. Secondly, based on the similarity between the score's variables (at frame level), the cross-correlation should be informative as to how to discriminate at video level. The next step in our suggested technique is to use a decision tree (DT) for final video level scoring. To evaluate the proposed technique, we applied it to LUS data of 100 confirmed COVID-19 positive patients consisted of 283, 231, and 1313 LUS videos from Lodi General, Gemelli, and San Matteo Hospital, respectively. Results show that a 59.51%, 63.29%, and 84.90% agreement with clinical specialists is achieved at the video, exam and prognostic level, respectively.

17:00

A Weighted Majority Voting Ensemble Framework for LUS Pattern Classification in COVID-19 induced Pneumonia Patients

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Towards automating semi-quantitative analysis of lung ultrasound (LUS) data, various deep learning-based (DL) classification models have been developed to stratify the LUS patterns among pneumonia patients. These models showed promising results, however, did struggle to obtain satisfactory performance in classifying few of those patterns correctly. A possible explanation to this can be due to handling of imbalanced data and blurred decision boundaries between the data labels. Ensemble learning

aims to integrate data modeling into a unified framework. It utilizes different models and fuses the informative knowledge to achieve better predictive performance via voting schemes. In this study, a weighted majority voting ensemble framework is proposed. Multiple classification models are evaluated in the ensemble and their contributions to the final prediction are adjusted based on a weighing mechanism. In this regard, weights are assigned based on the overall performance of the model along with the confidence level for each prediction. As a proof of concept, we employed three different classification models (EfficientNetB7, RegNetX, and ResNet18) in the ensemble framework. The models were trained and tested over ICLUS-DB v1 comprising of 35 patients. When comparing individual performances of these models with the ensemble approach, significant improvement in overall classification was found resulting in an F1-Score of 0.7026. Moreover, pattern-wise classification performance was also enhanced in the proposed approach. On comparison with the existing state-of-the-art techniques (reported 0.688 as the highest F1-Score), our proposed ensemble approach outperforms them in classifying LUS patterns due to COVID-19 induced pneumonia.

17:20

ULTRACOV Project: Computer aided diagnosis of pneumonia in COVID-19

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The motivation of this work was to democratize the access to lung echography by contributing to simplifying the lung echography exam. Our approach was to develop an intelligent ultrasound scanner, able to guide the physician during the examination and to provide an automated diagnosis of pneumonia. This could hopefully reduce the learning curve of the technique, making it accessible to more physicians and medical services and, therefore, to more patients. A fully functional scanner was developed, and a first clinical trial with 28 patients with COVID-19 was performed in two hospitals in Madrid. The objectives were to evaluate the performance of the algorithms and to test the usability of the equipment in the field. In a second study, the inter-operator variability was studied, giving the same sub-set of acquired videos to 33 physicians for evaluation, and their observations were compared. Results: From the clinical study, the coincidence between the automated diagnosis algorithm and the expert physician was 88.0 % for B-Lines and 93.4% for consolidations, the two principal artifacts associated with pneumonia. When analyzing the global lung score, the standard deviation of the difference between the expert and the algorithm was ±2 points over 36. With regard to the scanning time, the average with the developed scanner was 5.3 minutes per patient, while with a conventional scanner without aided diagnosis tools, it was 12.6 minutes. From the inter-operator variability study, a substantial IRR was found in the cases of normal LUS (= 0.74), with only a fair IRR for the presence of individual B-lines (= 0.36) and for confluent B-lines occupying < 50% (= 0.26) and a moderate IRR in consolidations and B-lines > 50% (= 0.50). No statistically significant differences between the longitudinal and transverse scans were found. Conclusions: The principal conclusion is that developing an automated algorithm for detection and quantification of pneumonia by ultrasound is feasible. The clinical trial revealed that the concordance between the algorithm and an expert is high, in particular with regard to the lung score. Furthermore, the scanning time was reduced less than half when compared with a conventional scanner, which could have a positive impact on high demand services as emergency or primary care. The conclusion from the inter-operator variability study is that the most reliable LUS findings with COVID-19 were the presence of B-lines and determining whether a scan is normal. We did not observe statistically significant differences between the longitudinal and transverse scans.

17:40

Real-time implementation of artificial intelligence algorithms for assisted diagnosis in COVID-19

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Background, motivation and objectives: Lung ultrasound has emerged as a promising technique for diagnosing and monitoring pneumonia, a critical complication of SARS-COV-2 infection. However, the lack of trained personnel in this field continues to limit its use. This work aims to extend the use of lung ultrasound by reducing the learning curve of junior technicians through computer-aided diagnosis. Real-time algorithms based on Artificial Intelligence (AI) have been implemented to guide the operator during exploration and suggest possible diagnoses based on lung artefacts found. Methods: To facilitate lung exploration and detect the presence of pneumonia, a real-time algorithm has been developed. It combines AI models implemented with Keras and Tensorflow 2 and signal processing algorithms using the Python language. The algorithm helps technicians obtain the best image conditions by guiding them through several coloured labels on the screen based on the region explored, movement and probe orientation, and similarity with previously labelled pulmonary images. The AI models first evaluate the acquired image to determine if it is suitable for processing. Once marked as valid, another AI model is used to detect the pleura, which is crucial to detecting typical lung patterns such as A-lines, pleura irregularity and B-lines through signal processing, and consolidations, the diagnosis of which is one of the main points of disagreement in the interpretation of lung ultrasound by physicians. Multiple parallel processes using an i7 octa-core CPU were necessary to achieve a continuous image refresh rate due to the computational cost of the AI algorithms. Results and conclusions: The algorithm achieved a processing rate of 16 frames per second without any delay, capable of detecting typical pneumonia artefacts in real-time. This is a sufficient image rate for the human eye to track fluently. In conclusion, real-time AI-based algorithms for pneumonia detection are possible using a CPU. Future work involves computational improvements to accelerate processing, such as using graphical processor units (GPUs) and novel Adaptive Compute Acceleration Platform (ACAP) devices.

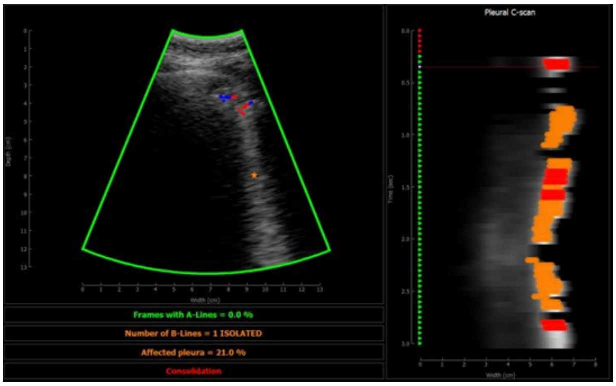

Figure 1. Real-time pleura, consolidation and B-line detection sample screen with pleura C-Scan image.

THERAPEUTIC AND SAFETY

9:00

Significance of Intraoperative Thoracic and Lung Ultrasound (INVITED)

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Over the past 15 years, intraoperative chest and lung ultrasound (ioTLUS) has been routinely used during video-assisted thoraoscopy (VAT) and thoracotomy (ThT). The aim was to evaluate the benefits of ioTLUS in relation to the detection of lung and mediastinal tumors and the assessment of resectability in locally advanced lung cancer. Lung lesions can be detected on ultrasound during VAT. Sonographic detection of mediastinal tumors and their relationship to vessels makes VAT resection safer. Thoracoscopic ultrasound improves the assessment of resectability in locally advanced lung cancer. A prospective study showed that the resection rate after sonographic examination could be increased by 33% compared to CT examination alone. The ioTLUS enables optimal access to the tumor in order to protect the vessels. Thus, preservation of the lung parenchyma is possible. In summery, the ioTLUS is very helpful in tumor localization, assessing resectability and defining the surgical strategy to make the surgery safer.

9:25

Therapeutic Applications of Ultrasound on Lung: Mechanism of Action, pre-clinical Research and future Potential

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Lung Sonography is clinically well established as a diagnostic tool for pulmonary diseases. Additionally, it is widely used for guiding of interventions such as puncture of pleural effusions, biopsy sampling of peripheral / endobronchial nodules or as guidance for RF Ablation. Despite these interventions, attempts have been made inducing therapeutic effects with direct ultrasound exposure in lung. The lung-tissue interface, as total reflector of acoustic waves, provides atypical conditions which increases heat induction and cavitation. Such effects could seal pulmonary leaks. Furthermore, the composition of isolated lung parts can be changed by inducing atelectasis or controlled liquid filling such as with perfluorocarbon or saline. The liquid phase generates acoustic access to central lung areas which can enable indirect heating of lung by ultrasound such as for hyperthermia or direct heating for thermal ablation. This work reflects the special acoustic conditions in lung. Based on those the attempts in clinical and mostly pre-clinical research inducing therapeutic effects in lung and therefore enabling therapeutic interventions will be presented.

9:45

Thoracic Ultrasound-Guided Procedures (INVITED)

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Thoracic ultrasound can be used to guide thoracentesis, chest tube positioning, transthoracic biopsies and biopsies of thoracic wall lesions. Probes and ultrasound settings should be chosen to optimize image quality by allowing needles to be visualized constantly during the procedure while preventing artefacts that can pose a hazard, including slice thickness or lateral displacement artefacts. Furthermore, sterile ultrasound gel, the sterile probe sheath/cover, elastic bands, and specific needle passes must be used to minimize the risk of complications. Thoracentesis indications include diagnosis and treatment of pleural effusion, while relative contraindications include increased bleeding risk, skin lesions at the insertion site, and morbid obesity. The incidence of pneumothorax, the most common complication, is much lower when the procedure is guided with ultrasound. Ultrasound also improves the successful placement of the chest tube, especially in located pockets of fluid. Indications for diagnostics ultrasound-guided percutaneous needle biopsy of the thorax include peripheral pulmonary nodules or masses and lesions of the pleura or chest wall. The most common complication is pneumothorax, followed by hemoptysis. Thoracic ultrasonography is safe, relatively inexpensive, and portable. It is superior to chest radiographs and CT scans for real-time procedure guidance and examination of the pleura and peripheral lung masses. Training has become a part of medical programs in many universities worldwide. Hopefully, the new generation of doctors will have a much broader and more consistent exposure to thoracic ultrasound to elevate their pleural and thoracic procedural skills.

10:10

Ultrasound interaction at the air-tissue interface: related bioeffects on lung tissue and current safety concerns and recommendation for the safe use of Lung Sonography (INVITED)

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Lung tissue is very sensitive to mechanical stress and in exposure of acoustic pressure the lung tends to break down the alveolar capillary air tissue interface. Animal studies showed induction of pulmonary capillary hemorrhage (PCH) in lung in the diagnostic regime at intensities below thermal or cavitation damage appearing in solid tissue. The pulsed ultrasound-induced bioeffect of pulmonary capillary hemorrhage (PCH) was discovered over 30 y ago but only recently has engendered concern over clinical risk as the use of LUS has grown. In research, PCH is only seen above a threshold value of the Mechanical Index (MI) of exposure (displayed on diagnostic US machines with a guideline upper limit of 1.9). Areas of PCH rapidly increase for increasing MI above the threshold, and increase with time of exposure. Such PCH is asymptomatic but can falsify the diagnostic outcome due to induction of pathological LUS sign of B lines. The causes remain still unknown but is not related to cavitation or thermal effects. The PCH threshold depends on the ultrasound frequency and mode. Other important ultrasound factors are pulse duration, pulse echo repetition period, and the video frames per second. The patient's factors of intravenous infusion, positive pressure ventilation and hemorrhagic shock increase the threshold, while oxygen supplementation, anesthetics and sedatives may increase PCH risk for some procedures. A key factor for clinical translation of safety information is that human chest wall attenuation of ultrasonic pulses is greater than the attenuation used for the displayed MI. This provides a safety margin for the displayed MI for thick chest walls and high ultrasonic frequencies: high BMI adults likely have minimal risk of LUS PCH. Conversely, the PCH safety issue is imperative for neonatal LUS owing to the thin chest walls. Threshold for rat LUS have been reported at MI=0.34-0.39 for 12 MHz ultrasound and 5 mm chest walls (similar to human neonates). Observational studies on humans have not confirm the findings as investigated on pathological level on animal models. Therefore, this subject remains controversial. This work summarizes the underlying mechanism of ultrasound interaction at the alveolar epithelium-gas interface, gives a comprehensive overview of studies investigating PCH under different sonographic exposure conditions. The overall safety picture is complex, but minimum threshold MI of about 0.3-0.4 has been noted in safety assessments. Finally, recent recommendations for output limitations given by AIUM, BMUS and EFSUMB will be presented and a workshop provided for hand on setting of correct LUS parameter.

QUANTITATIVE LUS 2

11:05

Quantitative lung ultrasound spectroscopy for improved lung ultrasound specificity (INVITED)

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Lung ultrasound (LUS) is widely used to assess the state of the lung surface. However, the anatomical investigation of this organ is essentially not possible as standard ultrasound imaging assumptions are unmet in the lung due to the presence of air. Indeed, LUS is mainly based on the analysis of imaging artifacts, i.e., the horizontal and vertical ones. The analysis of vertical artifacts is particularly relevant, as these artifacts correlate with different pathologies. Of particular interest is their dependence on frequency, which carries important diagnostic information able to improve LUS specificity. In this study, raw radiofrequency (RF) data were acquired from 101 patients affected by different pathologies (e.g., cardiogenic pulmonary edema and pneumonia). The data were collected by exploiting a multifrequency approach implemented with an ULA-OP research platform. This multifrequency approach is based on transmitting orthogonal sub-bands (each having a 1-MHz bandwidth) centered at different center frequencies. Specifically, the center frequencies of the data acquired with the linear probe are 3, 4, 5, and 6 MHz, whereas, the center frequencies for the convex probe are 2, 3, and 4 MHz. About 12,000 and 3,600 multifrequency frames were acquired with convex and linear probes, respectively. The vertical artifacts observed in these frames were manually segmented, and their frequency content and intensity analyzed. Specifically, the potential of three features extracted from vertical artifacts (i.e., center frequency, bandwidth, and total intensity) in discriminating different pathologies was assessed. Moreover, we compared the obtained results with the ones obtained in a previous study (conducted in another clinical center, but with the same acquisition strategy), in which patients affected by pulmonary fibrosis were present. The presented strategy could potentially represent an important step towards the improvement of LUS specificity.

11:30

Quantitative ultrasound assessment of lungs by separation of single and multiple scattering contributions (INVITED)

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Quantitative ultrasound (QUS) methods have been applied successfully in numerous organ systems for several preclinical and clinical applications. Lung ultrasound studies have demonstrated the subjective nature of the interpretation of conventional ultrasound images of lungs as well as their dependence on scanner settings. Therefore, QUS could pave the way towards a routine tool to assess lung diseases quantitatively in a system- and user-independent fashion. However, adoption of QUS methods to quantitatively assess lung ultrasound data is complicated by the presence of multiple scattering (MS). Therefore, the impact of scattering regime on QUS assessment of lung diseases was explored by applying QUS to lung ultrasound data where the single scattering (SS) and MS components were separated. The methods are illustrated on data acquired by a Verasonics Vantage ultrasound scanner from rat models of edema and fibrosis and associated healthy controls. SS and MS components of the raw ultrasound data were separated by a random matrix theory approach using a singular value decomposition. Spectral QUS and envelope statistical parameters were then estimated from the SS and MS data separately. Initial results were obtained using the healthy and pulmonary edema data, where the extracted QUS parameters were correlated to the wet-to-dry (W/D) weight ratio, a gold standard measurement of edema. Several QUS parameters were significantly correlated to W/D ratio for both the SS and MS data. This study demonstrates the utility of QUS for assessing lung disease and provide further insight on the effects of SS and MS on spectral QUS and envelope statistical parameters.

11:55

Surface wave elastography application to lung diseases (INVITED)

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Ultrasonography is not typically used clinically to assess lung disease. As the lungs are normally filled with air, the difference in acoustic impedance between air and lung parenchyma is large. Most of the energy of the ultrasound wave is reflected from the lung surface. Ultrasonography evaluation of the thorax is limited to evaluating structures outside of the lung such as pleural fluid or superficial thoracic lesions. We have developed a noninvasive lung ultrasound surface wave elastography (LUSWE) technique for measuring superficial lung tissue stiffness. In LUSWE, a local, 0.1 second harmonic vibration is generated on the chest wall of a subject using a handheld vibrator. An ultrasound probe is positioned in the same intercostal space as the indenter of the vibrator to measure the generated surface wave propagation on the lung. We have applied LUSWE for assessing patients with interstitial lung disease (ILD). ILD consists of multiple serious lung disorders associated with lung fibrosis and stiffened lung parenchyma. CT is the clinical standard for assessing lung fibrosis but is expensive and uses radiation. Many ILDs are typically distributed in the lung's peripheral and subpleural regions. Our results suggest that LUSWE may be useful for screening early stage ILD patients and assessing disease progression. While the superficial distribution of lung fibrosis is especially suited for LUSWE, LUSWE may be used to assess other lung diseases, such as pulmonary edema.

EDUCATIONAL

14:30

Expert-Level Medical Data Labeling at Scale via a Gamified Crowdsourcing Mobile Application (INVITED)

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IMPORTANCE: Artificial intelligence/machine learning models can yield fast and more accurate medical diagnoses, however developing artificial intelligence/machine learning models is limited by a lack of high-quality labeled training data. Crowdsourced labeling is a potential solution but can be constrained by concerns about label quality. OBJECTIVE: We

examined whether a gamified crowdsourcing platform with continuous performance assessment, user feedback, and performance-based incentives could produce expert-quality labels on lung point-of-care ultrasound data. DESIGN, SETTING, AND PARTICIPANTS: This was a diagnostic comparison study using a dataset of 2,384 lung ultrasound clips retrospectively collected from 203 emergency department patients. Labels classifying B-line categories on 393 clips were sourced from six experts and used to construct gold-standard labels. Crowd opinions were sourced from DiagnosUs iOS application users. EXPOSURES: Crowdsourced opinions were collected from unique users over eight days, filtered based on past performance, aggregated using majority rule, and analyzed for accuracy and level of agreement compared to a hold-out test set of expert-labeled clips. MAIN OUTCOMES AND MEASURES: We compared the accuracy of a gamified approach to crowd opinion collection to trained experts in classifying B-lines on lung ultrasound clips. We also determined the number of crowd opinions required per clip to achieve maximal accuracy. RESULTS: Our dataset included patients with a mean [standard deviation] age, 60.0 [19.0] years; 105 (51.7%) were female; 114 (56.1%) were White. Over 8 days 99,238 total opinions were collected from 426 unique users. On a test set of 198 clips, the mean accuracy of individual experts relative to the expert-majority gold-standard was 85.0% +/- 2.0 (standard error of mean), and the accuracy of crowdsourced labels was 87.9% (p = 0.15). When individual expert accuracies were computed against a set of consensus labels where each individual experts' response was excluded in evaluating their own performance, the mean expert accuracy was 80.8% +/- 1.6 compared to the crowd accuracy of 87.4% (p<0.001). CONCLUSIONS AND RELEVANCE: Crowdsourced labels for B-line classification on lung ultrasound clips via a gamified approach achieved expert-level accuracy. This suggests a strategic role for gamified crowdsourcing in efficiently generating labeled image datasets for training artificial intelligence/machine learning systems.

14:55

Educational Protocols and Essential Requirements in Lung Ultrasound Training (INVITED)

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Lung ultrasound (LUS) is increasingly being integrated into patient care in many specialties, such as pulmonary, emergency, and critical care medicine, anesthesiology, and internal medicine. Furthermore, LUS requires complex skills, involving image acquisition, image interpretation, and clinical integration of findings at the bedside in heterogeneous clinical contexts. All ultrasound examinations are dependent on the skill of the operator. Recommendations for LUS training differ among countries. Most recommendations set a fixed number of examinations that the operator must perform to be competent, based on limited evidence. However, some operators learn the ultrasound examination technique faster than others. Thus, performing a fixed number of examinations could be insufficient to evaluate LUS competence. To support competency-based education, training programs need to provide standards of knowledge-assessment and to establish a programmatic approach to assessments. Mastery-based learning is associated with improved clinical outcomes. Achievement of minimum passing scores set by an expert panel is associated with superior skills and patient outcomes. While expert panel cut scores are commonly used for standards setting, the use of traditional standards-setting methods could result in learners being able to miss a fixed percentage of assessment items, without attention to which items were being missed, resulting in patient safety concerns. Recurrent workplace-based observations are essential to help trainees achieve competence and to support decision-making and judgments regarding their competence. Objective structured assessments of technical skills have been developed for ultrasound imaging. This review summarizes the literature on medical education and highlights open questions.

15:20

The Integration of Virtual Reality and Simulation to Augment Thoracotomy Training

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The loss of interface between the visceral and parental pleural in the chest cavity is what defines a pneumothorax, colloquially known as a "collapsed lung". Large untreated pneumothoraces may result in significant hypoxia, obstructive shock due to tension pneumothorax, and/or death. Part of combat and trauma training includes the acute management of pneumothoraces through thoracostomy placement. Aside from hands-on supervised procedural training, simulation and animal models may also be used for this low frequency, high stress procedure. Virtual reality offers an untapped alternative solution to traditional hands-on training, by mimicking in-person training. In collaboration with a virtual reality company, 360-degree view training content has been filmed in a real hospital environment. During the module, participants can visualize the hands-on experience of inserting a chest tube from a first-person, virtual encounter. Created by skilled faculty, this technology offers trainees and practicing physicians the opportunity to interact with their surroundings and experience authentic chest tube placement with simulated visualization and haptic feedback in a safe and simulated environment. Virtual reality and just-in-time training provides opportunities for combat and on-the-job training for rare and uncommon procedures that require a level of consistent competency. As asynchronous and simulation-based learning continues to be an integral part of trauma training, virtual reality will become more affordable and ubiquitous for continued medical education. The implications of this virtual reality content can be expanded upon for several other applications of pulmonary intervention including needle thoracostomy, finger thoracostomy, pleurodesis, thoracentesis and others.

15:40

Peer teaching in lung ultrasound - a new road to success?

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The SARS-CoV-2 pandemic has proven that lung ultrasound (LUS) is a valuable tool not only in the fight against COVID-19, but above all in everyday clinical practice. Since 2019, LUS has become an examination performed more and more often by clinicians, and the number of scientific reports on this subject is dynamically growing. In addition, there is an extremely wide range of commercial training courses that enable the acquisition of this valuable skill. In addition to continuous training of physicians, appropriate ultrasound training for students is crucial so that they can master this tool as soon as possible and gain practical experience from the first day of clinical work. The research conducted by the author concerns the increasingly popular concept of "peer teaching" - mutual teaching of students by students. The research group consisted of 20 students, trained in groups of 3-5 people, about 2-3 hours a day, for a total of 5-6 meetings. The group consisted of students of the first to third year of medical studies doing summer medical internships. The training program was original and included: the basics of ultrasound, the specificity of the LUS examination, the most popular pathologies and practical workshops conducted on oneself and then on patients. Each meeting ended with a short debriefing "what have I learned today" or "what is my take home message". The training ended with a practical and theoretical exam. The majority of students (80%) acquired basic theoretical and practical knowledge of LUS after the 3rd meeting. After the last meeting, all students were able to recognize the basic disease entities and perform a practical examination. Moreover, 95% of students considered LUS to be a tool they would like to use in the future in clinical practice. Based on the observations, the conducted form of the study was positively received by students, while the training process turned out to be extremely effective. In the future, there is a need to popularize peer teaching among students and to conduct observations examining the long-term results of this form of training. [Disclaimer: The author of the study is a student of the University of Opole, and at the time of the study he was a graduate of LUS courses at the basic to advanced levels with relevant practical experience.]

AI FOR LUS ANALYSIS 1

16:30

Comparison of Pulmonary Congestion severity using AI-assisted scoring vs. clinical experts: A Secondary Analysis of BLUSHED-AHF (INVITED)

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Background: Acute decompensated heart failure (ADHF) is the leading cause of cardiovascular hospitalizations in the United States. Detecting B-lines through lung ultrasound (LUS) can enhance clinicians' prognostic and diagnostic capabilities. Artificial Intelligence/Machine Learning (AI/ML)-based automated guidance systems may allow novice users to apply LUS to clinical care. Aim: We investigated whether an AI/ML automated LUS congestion score correlates with experts interpretations of B-line quantification from an external patient dataset. Methods: This was a secondary analysis from the BLUSHED-AHF study which investigated the effect of LUS-guided therapy on patients with ADHF. In BLUSHED-AHF, LUS was performed and B-lines were quantified by ultrasound operators. Two experts then separately quantified the number of B-lines per ultrasound video clip recorded. Here, an AI/ML-based lung congestion score (LCS) was calculated for all LUS clips from BLUSHED-AHF. Spearman correlation was computed between LCS and counts from each of the original three raters. Results: A total of 3,858 LUS clips were analyzed. The LCS demonstrated good agreement with the two experts' B-line quantification score ($r=0.894$, 0.882). Both experts' B-line quantification scores had significantly better agreement with the LCS than they did with the ultrasound operator's score ($p<0.005$, $p<0.001$). Conclusion: AI/ML-based LCS correlated with expert-level B-line quantification. Future studies are needed to determine whether automated tools may assist novice users in LUS interpretation, and perhaps determine which patients may be at risk for rehospitalization and/or death.

16:55

Automated lung ultrasound diagnosis of interstitial lung disease using a state-of-the-art transformer for video classification

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During the COVID-19 pandemic, lung ultrasound (LUS) has emerged as a viable method for point of care (POC) diagnostics and management of lung diseases. LUS is easily accessible, has no radiation-related risks and due to the portability of ultrasound machines, it does not require relocating the patient, which can aid in the prevention of further infection. This research aims to develop an efficient and automated method for interstitial syndrome diagnosis (Figure 1) from LUS clips using Artificial Intelligence (AI) to support clinicians in the diagnostic procedure. Herein, we use a binary classifier based on a state-of-the-art transformer (Swin Transformer) to discriminate between LUS clips of healthy patients and patients with interstitial lung disease (i.e., unhealthy patients). 22 LUS clips from 22 patients (including 10 healthy and 12 unhealthy patients) were selected from an existing dataset collected at the Royal Melbourne Hospital (Melbourne Health Human Research Ethics Committee approval HREC/18/MH/269). The algorithm was assessed with a 4-fold cross-validation on 20 patients, where each fold was trained on 17 patients (8 healthy and 9 unhealthy patients) and tested on 5 patients (2 healthy and 3 unhealthy patients), using the medical report of the corresponding LUS clips as ground-truth annotations. The algorithm could always distinguish correctly between healthy patients and patients with interstitial lung disease at test time (100% accuracy), despite the limited number of clips used for training. Besides showing the promising performance of transformers, the approach here presented does not require any additional annotations from clinicians. This work is thus the next step towards a time-efficient integration of AI into the clinical setting.

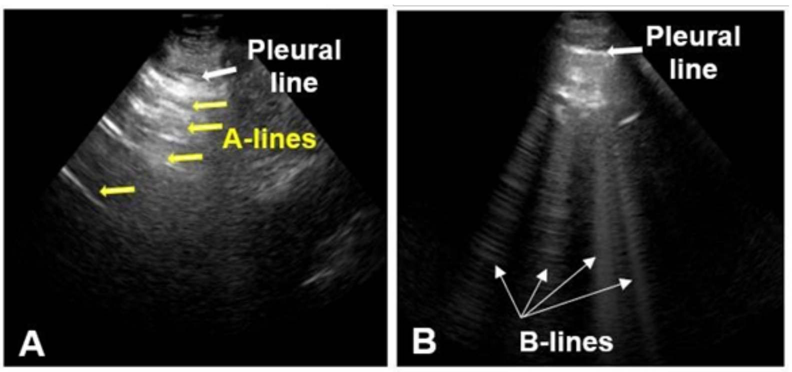

Figure 1: LUS image frames showing (A) a healthy lung with hyperechoic, horizontal lines (i.e., A lines) which represent reverberation artifacts and (B) an unhealthy lung affected by interstitial lung disease, with the appearance of discrete echogenic vertical lines (i.e, B-lines) extending from the pleural line.

17:15

Automated Lung Ultrasound Image Segmentation Using a Deep Learning Approach

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Point-of-care (POC) lung ultrasound (LUS) allows clinicians to diagnose pleural effusion (PE) by allowing for further investigation and treatment plans by allowing to scan patients in real-time. LUS requires trained experienced experts to provide

accurate image interpretation. This limitation is addressed from our previous study using a deep-learning model that is capable of detecting imaging patterns associated with PE on LUS images with an accuracy greater than 90\%, when compared to an experienced LUS operator. The follow-up study developed a deep-learning model to provide segmentations for PE in LUS. Twenty four patients diagnosed with PE were selected for this study. The segmented ground truth images used to train the algorithm were provided by two LUS experts using a twn-fold cross-validation. The trained algorithm performed segmentation of a separate subset of patient. These segmentations compared to the LUS experts demonstrated an average Dice Similarity Coefficient (DSC) of 0.70 on a per patient level. In contrast, the per patient average DSC observed between the experts was 0.61. Our automated approach achieved a comparable average DSC at PE segmentation and provides a promising result towards developing a computer aided tool for accurately segmenting imaging patterns associated with LUS PE that can be used for diagnosis and treatment.

17:35

Domain Generalization using a Pre-trained Model for LUS Patterns Classification

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Domain shift refers to change of data distribution between the training and testing dataset. It is a common problem in practical applications of machine learning algorithms and may result in significant degradation in classification performance. When it comes to medical imaging, domain shift is extensive specifically for multi-center studies. Different medical centers may use different scanners, imaging protocols, subject populations, etc. To mitigate this effect, domain generalization (DG) has been used over the time and has captured significant interest within the research community. In this study, we are also aiming to address this issue using a pre-trained model for lung ultrasound (LUS) pattern classification among pneumonia patients. In the DG setting, LUS data from one medical center (Brescia) is considered as source domain whereas the data from another medical center (Rome) is considered as target domain. ResNet-18 model pre-trained on ImageNet dataset is employed. The pre-trained model is initially trained on the source dataset using linear probing (LP) i.e., replacing the last layer of the pre-trained model and re-training it. Furthermore, after LP, fine-tuning (FT) is also performed i.e., re-training the entire model. Training is performed in three splits with 1: N-1, N/2: N/2, and N-1:1 as ratios of training to validation for each split respectively. Here N refers to the total number of patients in Brescia i.e., 13. Cross-validation method was used at each split for fair evaluation. It was found that the pre-trained model was able to generalize much better over the target dataset when it underwent LP+FT rather than only LP. With N-1 patients in the training set, mean F1-Score of 0.638 was achieved using LP+FT, in-comparison to 0.38 using LP only. These findings encourage the use of pre-trained models to generalize across different medical centers for LUS data analysis. Furthermore, they indicate that one medical center as the source dataset can be enough to generalize across other medical centers. Doing so, a comparable performance with state-of-the-art, for LUS pattern classification in pneumonia patients, was achieved.

17:55

Effectiveness of deep learning models on domain adaptation from adults to pediatrics for frame-based pneumonia classification

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Hand-held ultrasound devices are emerging as a promising intervention to aid in diagnosing deadly early childhood pneumonia in the developing world. Lung ultrasound (LUS) data, however, can be difficult to read and interpret accurately, and thus require trained professionals. A variety of deep learning (DL) models have been developed to aid professionals in this task, but the difficulty curating quality training datasets limits the generalization capabilities of these models. To combat this data scarcity, we utilized a variety of DL models trained on LUS data collected from adult COVID-19 patients in Italy and were able to apply transfer learning to increase pneumonia related imaging pattern classification in LUS data from children and infants in rural Zambia. We found on a model architecture which otherwise achieved an F1 score of 0.19 when trained from scratch, domain adaptation with full model finetuning was able to achieve an F1 score of 0.81. Similar performance increases were seen independent of model architecture. These findings indicate the promising potential for developing generalizable AI for LUS classification in diverse contexts given limited data. This analysis demonstrates that DL models effectively transfer their capabilities when fine-tuned on a new population demographics; allowing the possibility to clinically deploy these models without the need to acquire large amounts of new data.

QUANTITATIVE LUS SIMULATIONS AND PHANTOMS

9:00

Ultrasound imaging of lung disease and its relationship to histopathology: an experimentally validated simulation approach (INVITED)

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Lung ultrasound (LU) provides clinicians with real-time data for making critical diagnostic and therapeutic decisions in a wide variety of pulmonary and extrapulmonary diseases. It outperforms chest radiography in diagnostics of pneumonia, pneumothorax and cardiogenic pulmonary edema. However, the interpretation of lung ultrasound images relies on imaging patterns that are artifactual and depend on the complex interaction of wave propagation, including, reverberation and multiple scattering, and the physical properties of lung parenchyma, such as high reflectivity of the air, parenchymal micro-architecture. Here we develop highly accurate numerical simulations of wave propagation in anatomical representations of lung and body to establish a link between LU and resultant B-mode images and to link clinically meaningful parenchymal properties, such as aeration and tissue composition, to the specific sonographic patterns and metrics. Photography cryosection images of human chest wall and lung histopathology are used as an input for the simulations. To study relations between temporal reverberation metrics, lung aeration, fibroproliferative progression and LU score, propagation of focused imaging ultrasound pulse (6.25 MHz, 2.5 cycle, 100 kPa) emitted by L12-5 ATL transducer is simulated in lateral superior right chest wall along with 8 grades of aeration from 21 to 80% and 12 grades of connective tissue impregnation from 5 to 78%. Aeration and connective tissue presence were varied synthetically. Imaging patterns consistent with normal LU (A-lines) and lung interstitial syndrome (B-lines) are observed in generated B-mode images. Simulated images in cases of lung aeration up to 35% were scored as LUS=2 (multiple coalescent B-lines in more than 50% of the image laterally), aeration from 35 to 64% was associated with LUS=1 (B-lines take less than 50%), aeration of 64-80% - had LUS=0. Maximum connective tissue portion (78%) was associated with lower signal level (- 3.7 dB) at the pleural line compared to the case of maximal (78%) fluid portion in parenchyma. Reverberation time (characteristic of decrease of back emission signal from lung surface) decreased consistently from 56 to 30 μs with increase of connective tissue portion from 5 to 78% in the lung. This approach demonstrates how differences of reverberation and backscattering from diseased lung depend on its structure at the microscopic level.

9:25

Influence of the chest wall on quantitative ultrasound markers in lung tissue

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Recent advances in quantitative ultrasound (QUS) show that metrics can be extracted from raw ultrasound data to assess changes in lung microstructure. In rodent studies, ultrasound parameters related to scattering such as the scattering mean free path (SMFP) or to the respective contributions of single and multiple scattering significantly correlate to the severity of pulmonary fibrosis or edema in-vivo. The studies were performed on rats because of the availability of models for pulmonary fibrosis and edema, with the probe applied directly on the animal lung. The effect of the chest wall on QUS parameters hadn't been investigated. In the present study we use the Fullwave2 finite difference time domain numerical methods to simulate ultrasound propagation through numerical models of lung tissue obtained from histology slides. Different morphologies of alveolar structures, and different levels of lung aeration modify the ultrasound field. The chest wall was modeled using the visible human data set. An inter-element response matrix was acquired in silico. SMFP was obtained by measuring the rate of growth of the incoherent halo over time. Singular value decomposition provided the distribution of singular values, allowing to extract E_x, its expected value, and λ_{max}, corresponding to the highest density of singular values. SMFP significantly correlates to lung aeration (r=-0.92, p=5e^{-4}), but is influenced by multiple scattering in the chest wall, indicating that this effect should be compensated. In the absence of a chest wall, strong and highly significant correlations are obtained between E_x and λ_{max} on one hand, and the level of lung aeration on the other hand (r=-0.96, p=3e^{-5}, r=0.93, p=3e^{-3}, resp.). When the chest wall is present these correlations decrease but remain strong and significant (r=-0.91, p=0.7e^{-4}, r=0.71, p=0.03, resp.). These results show the importance of accounting for the chest wall when using QUS to objectively characterize lung diseases.

9:45

Estimation of Lung Surface Roughness with an Ultrasound Multifrequency Approach, an in silico and in vitro study

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Lung pathologies characterized by an enlargement of air-spaces exist, e.g., chronic obstructive pulmonary diseases (COPD). The different size of air-spaces can generate different levels of roughness along the lung surface. Therefore, the roughness estimation may provide an indirect characterization of the lung state. The aim of this study is to assess the possibility to develop a multifrequency quantitative approach for the estimation of the lung surface roughness. Specifically, the presented method focuses on the analysis of the ultrasound image intensity variation along the lung surface as a function of frequency. This method was tested both in silico and in vitro. First, the k-wave MATLAB toolbox was used to study the effect of different levels of lung surface roughness on numerically generated ultrasound images. The simulated domain consisted of two media, i.e., muscle and steel. Steel was used to simulate an acoustic interface (muscle/steel) having a high reflection coefficient ($R \approx 0.93$), thus mimicking a muscle/air interface (having $R \approx 0.99$). Data were simulated with center frequencies from 3 to 10 MHz and bandwidth equal to 0.5 MHz. The same acquisition strategy was then used to acquire data from 3D printed steel models, realized with different levels of roughness. Specifically, the roughness (air-space diameter) for both in silico and in vitro analyses was varied from 200 and 600 μm with a 50-μm step size. As expected, due to diffuse scattering, the increase of the "air-spaces" diameter is linked to a decrease of the frequency at which a significant drop of intensity was observed. This ultimately provides a way to indirectly estimate lung source roughness.

10:05

Foam-based lung phantoms for the validation of lung quantitative ultrasound

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New quantitative ultrasound (QUS) methods have recently been developed, and are showing promise for the objective characterization of lung tissue. In order to develop true and reliable QUS approaches for lung assessment, unequivocal relationships have to be established between these parameters and features of lung microstructure. Developing phantoms of lung tissue should provide control over the microstructural properties, which cannot be done in human and animal studies.
We fabricated lung tissue phantoms by creating foams with varying and controlled air volume fractions. The phantoms were constructed by forcing air in hair gel through a canal, creating bubbles that mimic the behavior of alveoli from the point of view of ultrasound propagation. Two foams were constructed containing 25% air and 42% air. Inter-element matrices (IRM) were acquired using a L115V linear array connected to a Verasonics Vantage scanner. The raw data was analyzed using Random Matrix Theory. Singular Value Decomposition was performed to obtain the distribution of singular values. The expected value E_x and λ_{max} (corresponding to the highest density of singular values) were obtained for both samples. These metrics reflect the respective contribution of single to multiple scattering and are therefore highly relevant to quantitatively characterize alveolar microstructure. The measurements were repeated 5 times. For both E_x and λ_{max} highly significant differences were obtained between the levels of aeration (mean +/- SEM: E_x*_42%*=0.8336 +/- 1.6^{e-3}, E_x*_25%*=0.8506 +/- 5.6^{e-3}, p=0.0079) and (mean λ_{max} *_42%*=0.7480 +/- 5.2e^{-3}, λ_{max} *_25%*=0.7114 +/- 3.8^{e-3}, p=0.0079). Control over the structural properties of these foams will allows us to model various lung diseases, and to better model the interaction between ultrasound waves and lung structures.

QUANTITATIVE LUS 3

10:55

New international guidelines and their impact on the future of LUS (INVITED)

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Following the innovations and new discoveries of the last 11 years in the field of lung ultrasound (LUS), the new international guidelines and consensus on the use of lung ultrasound have been recently published [https://doi.org/10.1002/jum.16088]. In this document, a multidisciplinary panel of international LUS experts from six countries and from different fields (clinical and technical) reviewed and updated the original international consensus for point-of-care LUS, dated 2012. As a result, 20 statements have been produced. Each statement is complemented by guidelines and future developments proposals. The statements are furthermore classified based on their nature as technical (5), clinical (11), educational (3), and safety (1) statements. This talk focuses on the technical statements and their impact on the future of LUS. Through a review of the literature and the presentation of novel findings, the application of artificial intelligence to LUS, the role of imaging protocols

standardization, the distinction between qualitative and quantitative LUS analysis, the latest discoveries in the understanding of the physical origin of vertical artifacts, and novel results on quantitative LUS will be discussed.

11:20

Shifting from qualitative to quantitate LUS: are we ready? (INVITED)

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Lung ultrasonography (LUS) represents a relatively recent analysis technique that is becoming increasingly popular in clinical use and in various fields of medicine. In contrast to standard ultrasonography, which was developed primarily for the evaluation of solid organs, lung ultrasonography relies mainly on the interpretation of artifacts that are generated by the interaction of the ultrasounds with the lung cortex, that is the outermost layer (approximately 2 cm) of the lung parenchyma lined by the lung pleura. Among these, the so-called vertical artifacts are particularly important as they are related to various diseases involving the lung (Picano et al. 2006; Copetti et al. 2008). They, combined with other parameters such as the continuity/regularity of the pleural line, the presence of sub-pleural micro- and/or macro-consolidations, their distribution and appearance, can point to different pathologies with primary pulmonary, cardiogenic or systemic involvement. They also provide important information about the status of pulmonary aeration. The main limitations associated with this type of analysis of artifactual ultrasound patterns remain the subjectivity and limited reproducibility, as well as the incomplete understanding of the mechanisms underlying the genesis of the aforementioned artifacts. To overcome these limitations and study vertical artifacts as a means of characterizing the lung surface, several experimental studies have recently been performed. In particular, the acoustic trap theory has been elaborated, according to which vertical artifacts originate from multiple reflections of ultrasound waves trapped in the channels that may form between alveoli when lung tissue becomes pathological due to alterations in structure and/or density. Other recent studies have demonstrated the dependence of vertical artifacts on various imaging parameters such as center frequency, bandwidth, focal point position, and beam incidence angle (Kameda et al. 2019; Chin and Demi 2020-2021). Integrating the theory of acoustic traps and the proven dependence of vertical artifacts on ultrasound frequency, Demi et al. in 2020 proposed a frequency characterization of these artifacts to indirectly estimate channel size or acoustic traps; in particular, a lower native frequency should indicate a larger trap size. The results of these in vitro studies have shown that the visual interpretation of these artifacts leads to subjective and qualitative analysis, as their appearance is highly dependent on several imaging parameters that are rarely considered in the design of clinical studies and the setting of the commercial machines used in them. Consequently, counting vertical artifacts in the image to identify a quantitative score that correlates with the extent/gravity of disease must be considered qualitative and poorly reproducible and comparable. In contrast, the main advantage of quantitative techniques is to provide a physical measure that can estimate lung surface condition, avoiding subjective assessment based only on visual interpretation of artifacts. Several approaches for quantitative ultrasound study of the lung have been prepared in recent years. However, so far, only results on relatively small and selected cohorts of diseases and patients have been obtained (Mohanty et al. 2017; Zhang et al. 2017-2019, Mento et al. 2020, Wiley et al. 2021). Currently, semi-quantitative techniques are still the main clinically available strategy to exploit LUS in lung surface status assessment. However, the use of these techniques should be guided by appropriate definitions and standardization of acquisition protocols. In particular, given the dependence of vertical artifacts on imaging parameters, standardization of imaging protocols is a key methodology to reduce confounding factors. Unfortunately, to date, many protocols are heterogeneously defined and often lack details on imaging settings (Dargent et al. 2020; Demi 2020; Zhao et al. 2020). Scoring systems, as well as the amount and location of scanning areas, are also often arbitrarily defined (Allinovi et al. 2020). On the contrary, to develop and validate appropriate imaging protocols and scoring systems to be used depending on the disease to be studied, it is critically important to compare the performance of different protocols following an evidence-based approach (Mento et al. 2021; Demi et al. 2022). For example, during the pandemic COVID-19, a standardized LUS imaging protocol was proposed (Soldati et al. 2020), tested (Mento et al. 2021; Smargiassi et al. 2020; Demi et al. 2022), and clinically validated (Perrone et al. 2021-2022). These evidences stimulated the collection of data according to standardized protocols in patients with different acute respiratory diseases in the emergency setting (acute heart failure, pneumonia, exacerbated BPCO, interstitial diseases) with both clinical and research scanners (Lusard study). Preliminary analysis of these data by semi-quantitative method again confirms the very high sensitivity of LUS in detecting a pathological lung but also the low specificity in detecting the different diseases underlying their clinical presentation. On the other hand, analysis of the pure radiofrequency (RF) data obtained with a research scanner revealed interesting differences in the different pathological patterns upon their quantitative analysis, even in comparison with old data from a population with pulmonary fibrosis. It is clear that the future of the technique is marked by clinical-laboratory integration with technical data obtained from scanners designed specifically for lung's analysis in different pathological states and in multicentre studies with standardized imaging protocols.

11:45

Lung ultrasound in acute respiratory failure: from qualitative to quantitative analysis.

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Lung ultrasound (LUS) is widely adopted to assess the state of the lung surface, especially in the Emergency Department, thanks to its speed and handling to reach a possible patient's diagnosis. In this study, 128 patients were recruited in emergency center suffered from acute respiratory failure. Each patient underwent thoracic ultrasound according to a standardized protocol, through a commercial ultrasound machine and specific research software. For each of these patients, laboratory parameters, LUS images and conventional imaging, such as chest x rays and CT, were obtained. Ultrasound of the chest was performed in each patient according to a standard methodology with a convex and/or linear probe, obtaining 12 scans for each hemithorax: results underwent a qualitative and semiquantitative analysis, according to plural features, presence or absence of vertical artifacts, micro or macro consolidation and /or pleural effusion. A total score was obtained for each field and finally a total LUS score adding all field scores. From the clinical point of view, patients were divided into pathologic clusters, according to final diagnosis: consolidation (neoplastic, lobar pneumonia, abscess), acute heart failure, exacerbated COPD and lung interstitial covid19 pneumonia. This study has compared the sensitivity and specificity of LUS with the gold standard technique used nowadays in emergency centers all over the world (chest x rays). In addition, the LUS quantitative score was correlated with laboratory parameters in each pathological cluster. LUS has identified presence of pulmonary pathology in our group with a sensitivity of 100% and PPV of 100%. Obtained data, despite LUS was performed in emergency conditions, are in line to current literature to confirm great sensibility of LUS to detect consolidations, pleural effusion, and interstitial diseases. They also confirm the relative low specificity of the technique, especially in the evaluation of lung interstice, not permitting to identify specific pathology. As far as laboratory parameters are concerned, a significant statistically correlation was observed between quantitative LUS score and parameters such as BNP, LDH, PF, WBC and PCR and parameters such as hospitalization days and mortality rate at 60 days. Another important part of this study concerns the analysis of vertical artifacts, as they correlate with several pathologies, through a specific research machine to obtain a pure radiofrequencies date (RF). A new dataset was created by acquiring the raw radiofrequency (RF) data of 101 patients (affected by different pathologies, e.g. COVID-19 pneumonia, cardiogenic edema, COPD exacerbation). The ULA-OP research platform was used to collect the data and a multi-frequency approach implemented on the same commercial linear and convex probes was adopted. Ultrasound data were acquired using orthogonal sub-bands with a bandwidth of 1 MHz and with different center frequencies (2-6 MHz). Approximately 12,000 and 3,600 multifrequency frames were acquired with convex and linear probes. Preliminary data analysis shows that the dependence of artifacts and their characteristics from a given frequency can provide important diagnostic information able to improve the specificity of LUS.

CLINICAL LUS

14:05

Lung Ultrasound in heart failure (INVITED)

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The differential diagnosis of dyspnea/respiratory insufficiency has been the major topic of interest for the application of Lung Ultrasound (LUS) since the pioneeristic work of Lichtenstein. The so-called B pattern, characterized by the presence of vertical artifacts originating from the pleural line and moving synchronous with respiratory acts, identify the interstitial syndrome, for which congestive heart failure represents the first underlying etiology. After the 'Blue protocol', an increasing amount of evidences have been collected exploring the value of LUS in diagnosis, monitoring, guiding therapy and prognostic stratification of congestive heart failure, either in the emergency department, ICU, wards and ambulatory setting. The enormous value of this technique is mainly driven by its fast learning curve and easy applicability at the bed-side combined with a high sensitivity. In fact, the positive impact of LUS-implemented approach to the HF patient is related to a prompt differential diagnosis based of diffuse, bilateral, gravitationally distributed B-lines, to the dynamic changes in these artifacts allowing extravascular lung water monitoring and to the recognition of subclinical signs of pulmonary congestion playing an important prognostic role. These crucial elements for its applications have to be evaluated taking into account possible limits of LUS, as the low specificity, methodological/technical aspects impacting on generalizability of results, and areas of uncertainty due to the scarcity of randomized controlled studies. Even given these cautions, a definitive revolution has reached the bedside of HF patients.

14:30

Diaphragmatic Ultrasound Evaluation in Acute Heart Failure: Clinical and Functional Associations

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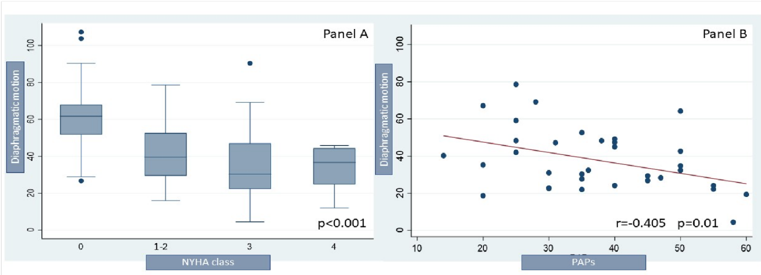
Background: Diaphragmatic evaluation by means of ultrasound represents an intriguing application in the context of lung ultrasound (LU). Few studies were focused on diaphragmatic disfunction in chronic heart failure (HF), revealing a trend to muscle thinning as a consequence of long-term disease; however there are no studies that examine diaphragmatic motility in



acutely decompensated subjects, nor those clinical and functional correlates of its mobility. Objectives: The aim of this prospective observational study is to evaluate the association between acute HF and diaphragmatic motion reduction. Materials and methods: Patients with acutely decompensated HF admitted to the Emergency department at Campus Bio-Medico University and Teaching Hospital were enrolled. Medical history and comprehensive physical examination were collected, together with lung ultrasound, including diaphragmatic motion and thickness both at tidal volume (TV) and total lung capacity (TLC). Collected data were compared versus a reference group of 100 healthy volunteers and adjusted for age and sex. Pearson's correlation was obtained for most echocardiographic parameters and multiple regression models were developed, adjusting for age, sex, BMI and other potential confounders (systolic pulmonary artery pressure (sPAP), pulmonary edema, cava vein cross sectional diameter, central venous pressure, ejection fraction, P/F ratio, PaO2, PCO2, pleural effusion, interstitial ultrasound syndrome). Results: 72 patients (48% males) with HF showed a statistically significant diaphragmatic hypomotility versus controls at TLC (respectively 38.7 mm (SD 2.0) vs 60.9 mm (SD 14.4), $p<0.001$). Diaphragmatic motion was inversely associated with NYHA score (Figure 1, Panel A) and inversely correlated with sPAP (Figure 1, Panel B), with a beta score of -0561 (p-value=0.02), still significant after adjustment for potential confounders ($\beta=-0.499$; p-value=0.05). Discussion and conclusion: Acute heart failure is associated with reduced diaphragmatic motion. The sPAP represent the only correlate after adjustment for other confounders. Future studies should confirm this provisional finding and provide further insight on the heart-diaphragm axis and clarifying the potential of lung ultrasound in emergency management of acute heart failure.

14:50

Ultrasonographic assessment of diaphragm and parasternal intercostal muscles function in critically ill subjects (INVITED)

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Bedside-available measures of patient effort are essential to properly titrate the level of pressure support ventilation. We investigated whether the tidal swing in esophageal (ΔPes) and transdiaphragmatic pressure (ΔPdi), and the ultrasonographic changes in diaphragm (TFdi) and parasternal intercostal (TFic) thickening are reliable estimates of respiratory effort. The effect of diaphragm dysfunction was also taken into account. Twenty-one critically-ill patients were enrolled; a three-level pressure support trial was performed: baseline, 25% (PS-medium) and 50% reduction (PSlow). We recorded the esophageal and transdiaphragmatic pressure-time products (PTP), work of breathing (WOB), diaphragm and intercostal ultrasound. Diaphragm dysfunction was defined by the Gilbert Index. ΔPes was significantly associated with the esophageal PTP ($R^2=0.8681$, $p<0.001$) and the WOB ($R^2=0.6826$, $p<0.001$). ΔPdi was significantly associated with the transdiaphragmatic PTP ($R^2=0.8203$, $p<0.001$). TFdi was only weakly correlated with the esophageal PTP ($R^2=0.3255$, $p<0.001$), and the correlation improved after excluding patients with diaphragm dysfunction ($R^2=0.8870$, $p<0.001$). TFdi was higher and TFic lower in patients without diaphragm dysfunction: 33.6 (18.2) vs. 13.2 (9.2)% and 2.1 (1.7) vs. 12.7 (9.1)%,$p<0.0001$ (Figure 1). In conclusion: ΔPes and ΔPdi are adequate estimates of inspiratory effort. Diaphragm ultrasound is a reliable indicator of inspiratory effort in the absence of diaphragm dysfunction. Additional measurement of parasternal intercostal thickening may discriminate a low inspiratory effort or a high effort in the presence of a dysfunctional diaphragm.

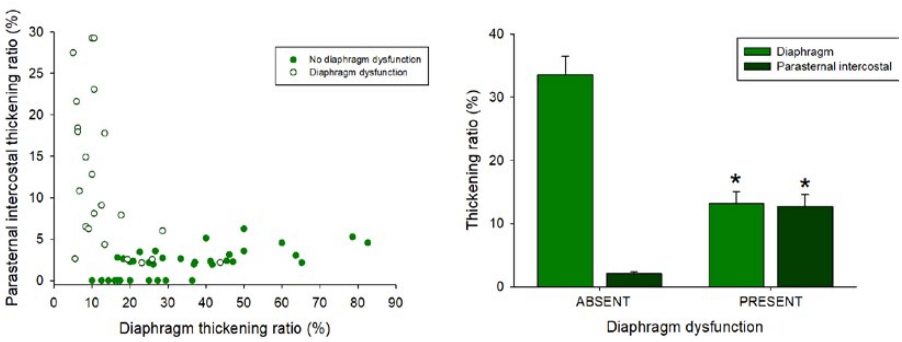

Figure 1: Relationship between diaphragm and intercostal inspiratory thickening (left panel) and comparison of diaphragm and intercostal inspiratory thickening in patients with or without diaphragm dysfunction (right panel).

15:15

Diaphragmatic ultrasound: a promising technique for respiratory assessment of patients with facio-scapulo-humeral muscular dystrophy (FSHD)

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A restrictive respiratory impairment has been described in up to 40% of patients affected by Facio-scapulo-humeral muscular dystrophy (FSHD), one of the most prevalent muscular dystrophies in adults. Spirometry may underestimate early respiratory alterations in these patients, as inspiratory muscle impairment may occur before Forced vital capacity (FVC) variation. Ultrasonography has recently emerged as a non-invasive tool to assess the main inspiratory muscle, the diaphragm. The aim of this study was to thoroughly characterize the respiratory function of a small cohort of FSHD comparing spirometric and ultrasonographic data. Genetically confirmed adult FSHD patients were enrolled. US diaphragmatic thickness at the end of a normal expiration (basal-DT), after a maximal inspiration (max-DT) and diaphragmatic excursion were calculated. The difference between max-DT and basal-DT represented "diaphragmatic thickening". FVC, forced expiratory volume in first second (FEV1), total lung capacity (TLC) and residual volume (RV) were also assessed by spirometry. Values were compared to normative data. Twenty FSHD patients (14 male and 6 female) were enrolled. Asymmetric abnormalities were found on US evaluation in 9 patients (45%), especially in diaphragmatic kinetic: median "diaphragmatic thickening" was 1,8 mm (range 0-4,6). A smaller portion of patients showed alteration on spirometric indexes. Inspiratory dysfunction with low TLC was detected in 5 (25%) patients, three of whom also displayed a restrictive pattern with a low FVC. This pilot study suggests that diaphragmatic US could be a promising technique to identify early inspiratory dysfunction in FSHD patients and these results need to be confirmed in larger cohort.

15:35

Pulmonary involvement in EBV infection in an immunocompetent patient: A case report

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Epstein-Barr virus (EBV), a ubiquitous herpesvirus of humans. The causal relationship between EBV and infectious mononucleosis (IM) was observed in 1968. Typically, patients present with fever, pharyngitis and lymphadenopathy; splenomegaly is usually found on physical examination. Although there are a few reports describing severe clinical manifestations of the EBV infection in immunocompetent patients, the pulmonary involvement appears to be rare (8%). We describe a case of a 34 years old male patient arrived in March 2022 at our Emergency Department complaining a one week history of fever (40°C), headache and dyspnea. He had no past or chronic conditions except for monoclonal gammopathy recently found. Physical examination revealed splenomegaly (confirmed by abdomen ultrasound), laterocervical adenopathy and maculopapular rash (which may follow the administration of penicillin at home few days before recovery). Chest auscultation showed decreased breath sound on left side. A thorax X-ray showed a left lower consolidation. Lung ultrasound was performed later using an ultrasound scanner (MyLab X6, Esaote, Genova, Italy) with a 3.5 MHZ convex probe in transversal scan and each emitorax is systematically divided into six regions: it documented bilateral B-lines, minimal bilateral

pleural effusion and a small subpleural consolidation at right pulmonary apex. Initial laboratory values were as follows: white cell count 8/mm3 (with 32% segmented neutrophils, 56.5% lymphocytes, 9.5% monocytes), C-reactive Protein 50.3 mg/l (normal 6 mg/l), erythrocyte sedimentation rate 39 mm/h (normal 35 mm/h), alanine aminotransferase 224 U/l (normal 10-65 U/l), aspartate aminotransferase 329 U/l (normal 5-40 U/l), alkaline phosphatase 141 U/l (normal 30-120 U/l), gamma-glutamyl transpeptidase 179 U/l (normal 10-80 U/l), lactate dehydrogenase 463 U/l (normal 87-241 U/l) and prothrombin time ratio 1.37 (normal 0.85-1.15). The other parts of the chemistry profile were unremarkable. Group A Streptococcus, Legionella pneumophila, Mycoplasma pneumoniae, Bordetella pertussis and respiratory virus (included SARS- CoV-2) were excluded. Blood cultures, hepatitis B, C, HIV and Cytomegalovirus serologies were negative, while EBV VCA- IgM antibodies were positive (121 U/ml). Serum EBV DNA quantification confirmed this result. In this patient no invasive diagnostic procedure was done. While EBV VCA- IgM antibodies were positive (121 U/ml). Serum EBV DNA quantification confirmed this result. The patient was then hospitalized and treated with acetaminophen for fever: he did not require oxygen administration and he was discharged after a week. Pulmonary involvement was considered an EBV- related complication, after exclusion of other causative agents. Studies show the presence of interstitial infiltrates in 3-5 % of cases, while pleural effusion has rarely been reported in association with mononucleosis. EBV pneumonia is a rare condition, however it one of the three most common cause of severe viral community acquired pneumonia (CAP), along with influenza and adenovirus. EBVpneumonia should be considered in patients with atypical lymphocytes and mildly elevated serum transaminases. The pathophysiology of lung involvement in patients affected with infectious mononucleosis is still unclear and it could be related to mononuclear infiltrations in the perivascular and peribronchial tissues. Two proposed mechanism for the interstitial edema includes accumulation of the virus due rapid viral replication versus the body own immune reaction to the infection or a combination of both However, symptomatic pneumonia and hypoxemia are very uncommon and radiographic and sonography findings often appear to be clinically insignificant: for this reason, it is possible that pulmonary involvement is more common in infectious mononucleosis than previously reported. Further systematic studies are needed to establish the real incidence of pulmonary involvement in EBV- infection. Lung sonography could be helpful to detect pleural effusion and consolidation in patients asymptomatic for hypoxemia.

15:55

CHEst PHysical Examination integrated with UltraSound – Phase 1 (CHEPHEUS1). A survey of Accademia di Ecografia Toracica (AdET)

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Chest physical exam (CPE) is based on the pillars of classical semiotics: inspection, palpation, percussion, auscultation. With basic instruments (hands, ears, eyes, stethoscope) is possible to acquire signs to work out a diagnosis. However, the specificity and sensibility of the signs collected are low and, as other diagnostic tools, could be affected by operator's expertise and clinical ability. In the last decades, chest ultrasound is increasingly being used in several clinical scenarios, due to increasing image quality, device portability and diagnostic power, to the point that, often, literature refers to the ultrasound as "the new stethoscope". The role of ultrasound in the physical exam, to date, is left to experts' opinion and data on the clinical validity and feasibility of this tool have not been provided yet. The aim of our study was to explore the role of chest ultrasound in the traditional CPE among physicians with different US experience. An online survey was submitted to chest US users of the AdET group. They were asked to state, among classical semiotics and chest US, what item of the CPE was more useful. The answers were graded as follows: 0 = only semiotics; 1 = mainly semiotics; 2 = both are useful; 3 = mainly US; 4 = only US. Survey was opened for 30 days and was spread through AdET's social media channels. Responders were asked also to define (years) their experience with US (years) and it they used US mainly for diagnostic or interventional purposes. 103 participants answered the survey. The distribution of experience with US was: 20% ≤2 years, 35.2% 2-5 years, 44.8% ≥5 years. Thirteen respondents (12.6%) used US for diagnostic purposes ≤30% of the time and were excluded from the analysis. The mean ± standard deviation score was: 2.0±1.1 for inspection vs US, 2.1±1.1 for palpation vs US, 2.3±1.0 percussion vs US; and 1.8±1.0 auscultation vs US. The survey showed that among US users, US is generally preferable to palpation and percussion, indicating at least a complementary/necessary role during the CPE. Further studies are needed to evaluate the possible superiority of US during the CPE, to evolve future of semiotics into an approach based on inspection, ultrasound evaluation and auscultation.

AI FOR LUS ANALYSIS 2

16:45

Machine Learning technologies for automatic lung ultrasound interpretation and detection of complex lung pathologies (INVITED)

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In lung ultrasound imaging multiple pathologies typically need to be properly identified to perform correct diagnoses. These include pleural effusion, atelectasis, consolidations, interstitial syndrome etc. In some cases, moreover, further investigation is needed to identify more in detail the specific type, as for example oedema vs. non-oedema interstitial syndrome. Ideally, identification, severity evaluation, segmentation and even tracking should be performed in real time at the bed side in a point-of-care scenario. Machine learning based strategies are the only current possible solution to these problems. We have developed algorithms to automatically detect, classify, segment multiple lung pathologies with accuracies comparable or superior to the clinical experts, but with higher efficiency and reliability. State-of-the-art network architectures including Convolutional Neural Networks and Transformers have been trained, following protocols which have been specifically optimized to require minimal annotations, using datasets provided by the University of Melbourne. The results were validated against multiple clinical assessments, incorporating accurate intra- and inter-observer variation estimates. In Figure 1 two examples are reported showing automatic pleural effusion segmentation and automatic consolidation classification. The next step in the project is deployment in the clinical environment, which will lead to early diagnosis, better and improved patient outcomes at reduced healthcare costs.

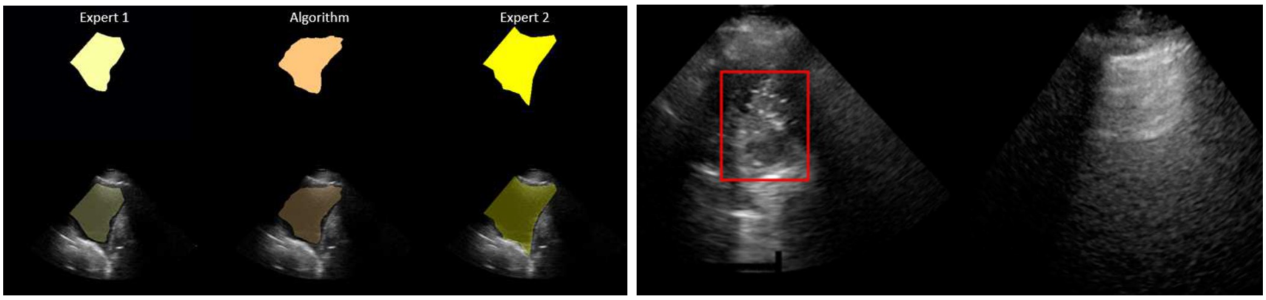

Figure 1: On the left, an example of a lung ultrasound image and corresponding segmentations generated by expert 1, expert 2 and the algorithm respectively. On the right, automatic identification of the consolidations in an unhealthy patient with bounding box (red, left), compared to a healthy patient (right).

17:10

Synthetic Lung Ultrasound Data Generation Using Autoencoder with Generative Adversarial Network

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There was a gap in the state of the art in the development of a robust methodological approach focusing on class imbalance issues for Lung Ultrasound (LUS) data. In this study, we introduced a strategy for improving classification performance on a medical problem with limited and imbalanced data by generating synthetic medical images. Several methods have been proposed including geometric transformation and affine transformation. These approaches unfortunately provide quasi-duplicated original data, which causes an overfitting issue during training. For this reason, we introduced a novel method for oversampling the minority classes with the help of generative models. Specifically, we introduce a supervised autoencoder generative adversarial network (SA-GAN) with a customized gradient penalty loss function. During training, the generator utilized the weights of the decoder and conditional latent space to generate the synthetic images whereas the discriminator utilized the weights of the encoder together with the class labels. This also allows classifying each synthetic image into different classes. This approach is tested on an imbalanced dataset consisting of 5500 LUS images, collected from different Italian hospitals. As a result, 1000 synthetic images were generated to balance the minority classes. The quality of the synthetic images was evaluated through similarity measures. Furthermore, after generating a balanced dataset, we applied deep convolutional discriminator architecture for multiclass classification. The proposed approach achieved a significant improvement with respect to frame level classification of up to 5% in the F1 score (62% to 67%) when comparing synthetic augmentation through SA-GAN over the classic data augmentation method. These results also show an improvement with respect to the state of the art performance previously reporting an F1 score of 65% [10.1109/TMI.2020.2994]. This approach could potentially be applied to other medical imaging data.

17:30

Automatic Thoracic US-MRI Volume Registration Using a Generative Adversarial Network

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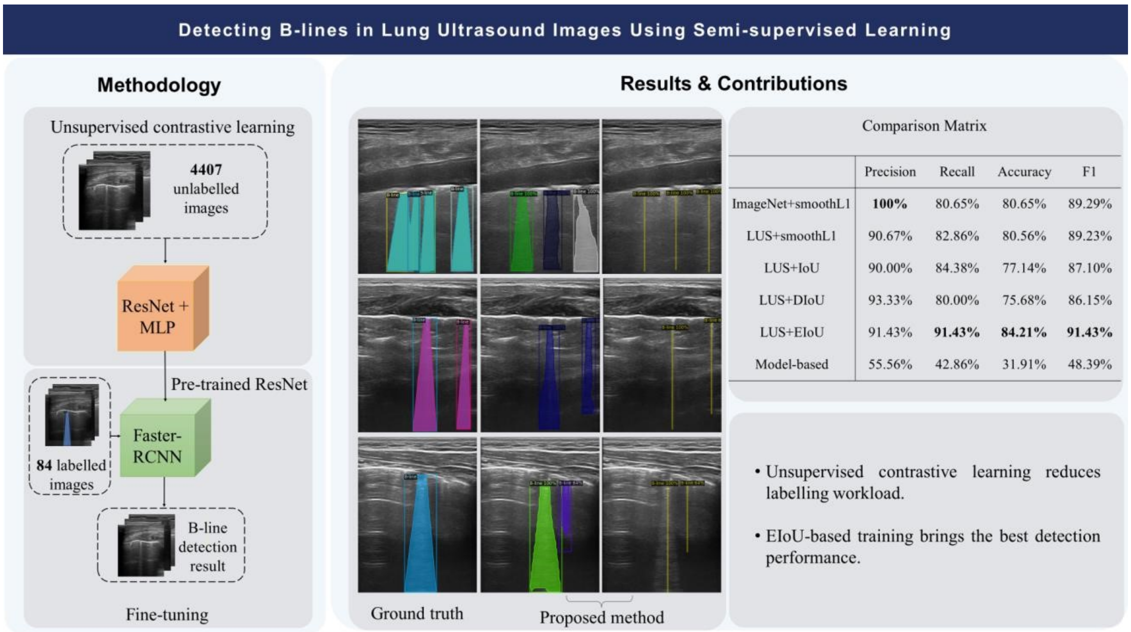
CSIRO Health and Biosecurity, The Australian eHealth Research Centre, Herston, QLD 4029, Australia. An MRI or CT reference image is taken before any musculoskeletal or respiratory procedures are done along with a post operation image to monitor patient progress during planned treatments. Currently there is no real-time guidance and tracking capabilities that allow the surgeon to perform their procedure using the familiarity of the reference imaging modality. In this work we propose a real-time volumetric US/MRI registration using a deep learning approach, where the fusion of the multi-imaging modalities will allow for guidance and tracking of surgical procedures in real time using US and show the resultant changes in the clinical friendly reference imaging modality of MRI. This study implements a deep learning approach that involves the use of a set of Generative Adversarial Networks (GANs) known as CycleGAN that performs an image-to-image translation resulting in the generation of US or MRI volumes that are spatially aligned to their respective input volume (MRI and US).



17:50

Detecting B-lines in Lung Ultrasound Images Using Semi-supervised Learning

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Research has demonstrated that the number of B-lines identified in lung ultrasound images has a significant statistical correlation with the amount of extravascular lung water, which is crucial for hemodialysis treatment. However, manually assessing B-lines requires specialized expertise and is time-consuming, and automating the modelling process is currently challenging due to the lack of reliable ground truth data. To address this issue, we propose a novel semisupervised learning approach for B-line detection based on contrastive learning in this paper. Through multi-level unsupervised learning on unlabelled lung ultrasound images, we train the algorithm to learn features of the artefacts. In the downstream task, we incorporate a fine-tuning process on a small number of labelled images using the EIoUbased loss function. Our proposed method not only reduces the workload of data labelling but also outperforms model-based algorithms, achieving a recall rate of 91.43%, an accuracy rate of 84.21%, and an F1 score of 91.43%.

18:10

Anomaly Detection In Pediatric Lung Ultrasound Using Consistency BiGAN

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Data scarcity plagues most applications of AI for medical diagnostics, and lung ultrasound is no exception. Datasets used for classifying pathology in lung ultrasounds are consistently hindered by having too few positive samples while having too many negative ones. This class imbalance can confound many classification tasks and are usually addressed with a combination of strategic sampling and data augmentation. In contexts such as these, unsupervised anomaly detection models have proven helpful as one such data augmentation technique. Anomaly detection models use unsupervised training to faithfully recreate the features of negative samples, while being unable to recreate certain features of positive samples. Passing new images through such a model, features which are not represented in the negative sample distribution are removed. By comparing the processed images with the original images, features which are not mutually present are highlighted and are likely features which are associated with non-negative class samples. This work leverages a unique dataset composed of lung ultrasound videos taken from only healthy pediatric patients. The consistency BiGAN (cBiGAN) demonstrates its ability to clearly and accurately recreate healthy samples, its ability to imperfectly recreate diseased samples, and the ability to use consistency to increase class separability. Alone, this model cannot classify specific pathology, however this approach demonstrates promise to help improve AI and clinician diagnostic performance across a variety of conditions by highlighting anomalies for increased attention and consideration.

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