Comparing Clinical Efficacy of Artificial Intelligence-powered Ultrasound with Pulse Index Continuous Cardiac Output for Monitoring Critically ill Patients

Yi Fang
Shanghai Tenth People's Hospital, School of Medicine, Tongji University
Di Lv
Shanghai Tenth People's Hospital, School of Medicine, Tongji University
Haidong Zhou
Shanghai Tenth People's Hospital, School of Medicine, Tongji University
Xiaoxiao Sun
Shanghai Tenth People's Hospital, School of Medicine, Tongji University
Yuanzhuo Chen
Shanghai Tenth People's Hospital, School of Medicine, Tongji University
Yugang Zhuang (zhuangyugang@tongji.edu.cn)
Shanghai Tenth People's Hospital, School of Medicine, Tongji University https://orcid.org/0000-0002-6304-6765

Research

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Abstract

Background: To compare safety and clinical efficacy of artificial intelligence (AI)-powered ultrasound with pulse index continuous cardiac output (PiCCO) for monitoring critically ill patients.

Methods: Patients who were admitted to our hospital from April to June 2020 were recruited. PiCCO was employed to monitor cardiac output (CO) and extravascular lung water index (ELWI). Simultaneously, an AI-powered ultrasound was used to automatically monitor CO and the left ventricular outflow tract velocity time integral (LVOT-VTI), and Lung ultrasound B line.

Results: A total of 41 patients were enrolled, the male/female ratio was 26:15, and the patients' median age was 73.6±8.85 years old. There was no significant difference between PiCCO and AI-powered ultrasound in monitoring of CO ($t = 1.01$, $P = 0.316$), and the correlation between these two techniques was significant ($r=0.911$; 95% confidence interval (CI): [0.82; 0.96]; $P < 0.001$). Similarly, the correlation between lung ultrasound and ELWI was significant $r=0.770$ (95%CI: [0.58; 0.88]; $P < 0.001$).

Conclusions: Clinical management of critically ill patients can be achieved via monitoring techniques, such as PICCO and AI-powered ultrasound.

Background

Emergency critically ill patients are characterized by complex pathogenesis and transient multi-system and multi-organ damage, as well as rapid response to treatment, in which evaluation of hemodynamic treatment is particularly important, including cardiac output (CO), extravascular lung water index (ELWI), etc. Pulse index continuous cardiac output (PiCCO) is an efficient advanced procedure of continuously monitoring the hemodynamic status in clinical practice. The procedure is based on the use of a specific thermodilution arterial (femoral, brachial, or axillary) catheter and a central venous line [1–3]. As a part of monitoring and evaluation of acute and critically ill patients, critical care medicine (CCM) ultrasound is more convenient, intuitive and accurate, and its guidance and adjustment for critical care treatment, especially hemodynamic treatment and volume management is more precise. The most commonly used echocardiographic techniques are transthoracic echocardiography to evaluate the left ventricular outflow tract velocity time integral (LVOT-VTI), a echocardiographic parameter, which is a non-invasive echocardiographic parameter for the evaluation of stroke volume. The American Heart Association recommends CCM echocardiography as a priority for monitoring patients with hemodynamic instability [4]. In the present study, we employed artificial intelligence (AI)-powered ultrasound to automatically identify reliable data and quantify CO and lung B-lines. We aimed to combine AI-powered ultrasound with PICCO to monitor the relevant hemodynamic parameters of acute and critically ill patients, and provide clinical guidance for evaluation of treatment response.

Methods

Study subjects

Patients who were admitted to the Emergency Intensive Care Unit of Shanghai Tenth People's Hospital (Shanghai, China) from April to June 2020 were recruited. This study was approved by the Ethics Committee of Shanghai Tenth People's Hospital, and the written informed consent was obtained from all the study subjects.

Inclusion and exclusion criteria

Inclusion criteria were as follows: patients who aged over 14 years old with hemodynamic instability, unknown volume status, increased extravascular lung water, septic shock, cardiogenic shock, traumatic shock, acute respiratory distress syndrome (ARDS), severe burn, acute pancreatitis, high-risk surgery, etc. Exclusion criteria were as follows: contraindications for use of PiCCO (allergy to heparin, existence of infection in puncture site, severe hemorrhagic disease or thrombolysis, anticoagulation with high-dose heparin, arteritis, arterial stenosis, treatment with intra-aortic balloon counterpulsation, severe pneumothorax, massive pulmonary embolism, pulmonary space-occupying lesion, intracardiac shunt, ventricular septal defect, severe mitral regurgitation, aortic stenosis, or aortic aneurysm), diseases associating with great errors in ultrasonic imaging (e.g., malignant arrhythmias, atrial fibrillation, non-sinus rhythm, lesions associated with aortic root abnormalities, aortic valve replacement), refuse to perform PICCO or ultrasound examination, or refuse to participate in this study.

Study protocol

Two-Lumen Central Venous Catheterization Set (CS-27702-E; Arrow International Inc., Reading, PA, USA), PiCCO Monitoring kit (PULSION Medical Systems SE, Feldkirchen, Germany), CVP pressure sensor and its accessories (MX9505T; Smiths Medical ASD Inc., Dublin, OH, USA) were used. The vital signs of the patients who met the criteria were stable for 5 to 10 min after implantation of PiCCO. The central venous pressure (CVP) when venous return equals zero is the Pmcf. CO and ELWI of the patients were monitored via repeated measurements for 3 times, and then, their average values were accordingly calculated.

At the same time, an AI-powered ultrasound machine (GE Medical Systems, Milwaukee, WI, USA) was used for measurement, which was equipped with phased array probe (3Sc-RS Wide Band Phased Array, 1.6-4.5 MHz), convex array probe (C1-5-RS Wide Band Convex, 1.5-6 MHz), automatic VTI measurement software, and automated B-line scoring on thoracic sonography (Fig. 1). After successfully performing the experiments by two critical care physicians, the following parameters were obtained according to the 2016 guideline presented by the American Echocardiography Society.

First, to measure LVOT, scan the parasternal left ventricular long axis, and measure the LVOT within the 5 mm side of the aortic valve (Fig. 2a).

Secondly, we attempted to automatically identify and quantify VTI and CO; scan the standard section of the apical five-chamber heart. The ultrasound system uses artificial intelligence technology to automatically optimize the position of the pulsed Doppler sampling frame, record the Doppler spectrum, automatically track and trace VTI spectrum, automatically calculate the average VTI spectrum, and automatically calculate the HR, and its built-in calculation formula was as follows: LVOT area (cm^2) = π × (LVOT Diam (cm)/2) 2, SV (ml) = LVOT area (cm^2) × VTI (cm), CO (L/min) = SV (L) × HR (beats/minute, bpm); CO can be calculated automatically (Fig. 2b,c,d).

Thirdly, total number of B lines was calculated as follows: B lines were defined as discrete laser-like vertical hyperechoic reverberation artifacts extending from the pleural line to the bottom of the screen without fading and moving synchronously with the lung slide. The probe was placed in the intercostal space using the 8-zone method, that is, from the parasternal to the anterior axillary line as the anterior wall, from the anterior axillary line to the posterior axillary line as the lateral wall, while the anterior wall was bounded. In brief, the measurement point of the anterior region was located at the second intercostal space (area 1) and the fourth intercostal space (area 2) behind the midline of the clavicle, and the lateral area was located at the fourth intercostal space (area 3) and the sixth intercostal space (area 4) behind the level of the midline of the armpit. Each chest wall was divided into 4 regions, with 8 areas on both sides.

After each probe was placed and stabilized in each intercostal gap, the automatic counting software was run, which could automatically detect B-lines, select an image with the greatest number of B-lines from the 6-second sequence, and provide the number of B-lines from 0 to ≥ 5. The specific criteria of the built-in scoring system are as follows: 0 point: normal lung volume (that is, normal lung or 1-2 well-separated B lines); 1 point: moderately decrease of lung gas content, the presence of pulmonary interstitial syndrome (3-4 isolated B lines) or focal pulmonary edema (fusion of B lines during vertical scanning < 50% of the intercostal space); 2 points: severe decrease of lung gas content with alveolar edema, that is, ≥ 5 or diffuse fusion B lines, occupying all intercostal spaces; 3 points: complete disappearance of lung gas content and lung consolidation, that is, hepatoid change of lung tissue with or without bronchial inflation sign. The lowest score is 0, and the highest is 24; 0 is normal, otherwise, it is abnormal, the higher the score, the more serious the disease (Fig. 3). The measurements of PiCCO and AI-powered ultrasound were completed by two professionally trained physicians.

Statistical analysis

Herein, SPSS 23.0 software (IBM, Armonk, NY, USA) was used to perform statistical analysis. The measured data were expressed as mean ± standard deviation (± s), and t-test was used to compare data between the groups. $P < 0.05$ was considered statistically significant.

Results

Included cases

A total of 41 patients were enrolled, and male/female ratio was 26:15, with a median age of 73.6 ± 8.85 years old.

CO was simultaneously measured by echocardiography and PiCCO

First, the diameter of LVOT was measured on the standard long axis of parasternal left ventricle, and then the VTI was detected by AI-powered ultrasound. The mean value of VTI in AI-powered ultrasound was 19.40 ± 3.32 cm, the mean value of CO detected by ultrasound was 4.87 ± 1.04 L/min, the mean value of CO measured by PiCCO was 5.11 ± 1.05 L/min, and there was no significant difference in CO value between measurement by ultrasound and PiCCO ($t = 1.01$, $P = 0.316$). Pearson correlation analysis suggested a significant correlation between these two diagnostic tools ($r = 0.911$, (95% confidence interval (CI): [0.82; 0.96]; $P < 0.001$).

Comparison of lung ultrasound score and ELWI

The Spearman correlation analysis showed that, the mean lung ultrasound score was 8.11 ± 2.45 and the mean value of ELWI was 6.27 ± 2.37 ml/kg. There was a significant correlation between lung ultrasound score and ELWI value ($r = 0.770$, (95% CI [0.58; 0.88]; $P < 0.001$). It was confirmed that both methods could be used to assess pulmonary edema.

Discussion

The concept of hemodynamic treatment for acute and critically ill patients has been deeply studied. The PiCCO is based on the use of a specific thermodilution arterial (femoral, brachial, or axillary) catheter and a central venous line. The technique is minimally invasive, and can quantify different hemodynamic parameters reflecting the vascular tone, preload, and cardiac function. Cardiac function profiles that can be discerned from PiCCO include cardiac output, intrathoracic blood volume (ITBV), global enddiastolic volume (GEDV), ELWI, and peripheral vascular resistance. Monitoring these parameters can enable a clinician to optimize volume status, myocardial contractility, and tissue perfusion. It has been recognized as an invasive hemodynamic monitoring method in the field of critical care medicine [5–7]. However, PiCCO is an invasive procedure, and it is not highly appropriate for patients with severe bleeding, coagulation disorders, peripheral vascular disease, severe cardiopulmonary disease, the risk of catheter-related infection, and being costly.

The consensus recommendation presented by Chinese CCM ultrasound experts released in 2016 demonstrated that CCM ultrasound is a dynamic, real-time, repeatable, problem-oriented and multi-objective evaluation process for critically ill patients. Together with other monitoring methods, significant data can be obtained to provide timely and accurate guidance for diagnosis and treatment of critically ill patients, especially for the direction adjustment of hemodynamic treatment. Continuous and dynamic qualitative and quantitative evaluation of AI-powered ultrasound is helpful to the management of critically ill patients, and can quickly and accurately evaluate the cardiac function of patients [8]. Some studies have shown that for patients with emergency hypotension, immediate ultrasound examination may reduce the misdiagnosis rate from 50–5% compared with delayed ultrasound examination [9]. Cardiac ultrasound can change or supplement the treatment of more than half of patients hospitalized at intensive care unit (ICU) [10, 11].

A recent study showed moderate consistency in hemodynamic assessment of mechanically ventilated patients with septic shock using PiCCO and CCM echocardiography [12]. The correlation between CO calculated by manual VTI and CO measured by PiCCO is about 0.95 as reported previously [13]. The corresponding correlation in the present study is 0.911, which seems to be slightly lower than that of manual determination. However, it should be noted that the authors of the current article are all non-ultrasound professionals and are unlikely to do a series of experiments, specifically for ultrasound measurement at the bedside, thus, the manual determination of CO by ultrasound is unstable and uncertain, which may change with the variation of observation window and section. Therefore, the application of traditional ultrasound in CO is limited. Previous researches have shown that the correlation between CO measured by the proposed AI-powered ultrasound and CO measured by PiCCO seems to be better than manual measurement of CO. It may be related to the importance of taking multiple VTI averages under the condition of low blood volume [14]. The present research demonstrated that there was no significant difference between the CO automatically measured by the proposed method and CO measured by PiCCO, while a significant correlation was noted. Although the correlation seems to be slightly worse than the traditional one, it still has a relatively satisfactory consistency, and in the follow-up observations, it may be more instructive to carry out specific etiological research.

Processized ultrasound, which combines cardiac ultrasound with pulmonary ultrasound, can effectively assist physicians to assess the condition and exclude the possible causes of shock [8]. Pulmonary ultrasonography has been gradually improved and standardized, which is an important part of CCM ultrasound and enables rapid visualization of pulmonary lesions. Each sign is the response of the physiological and pathophysiological nature of a patient's lung, and plays a significant role in the diagnosis and treatment of a variety of diseases [15]. Since the 1990s, the "comet tail" artifact (Comet-Tail) described by Lichstein was later named "B-line" and was regarded as a sign of alveolar interstitial lesions, which led to an imbalance between air, water and connective tissue in subpleural lung tissue [16]. B-line is an ultrasonic sign of interlobular septal thickening due to increased fluid or collagen tissue changes (i.e. inflammation or fibrosis) [17]. At present, several evidences support the diagnostic value of ultrasound B-line in various lung diseases, such as heart failure, respiratory failure, pneumonia or pulmonary involvement in connective tissue disease-associated interstitial lung disease. [18] Traditionally, B-line quantification of lung in ultrasound imaging could be carried out, indicating that a high level of operational experience is required in this process, because accurate B-line counting is essential to pathologically classify a patient's lung as normal or abnormal. Venue GE's built-in software allows automatic real-time detection and quantification of lung B-line features, which may reduce reliance on operators for condition assessment. A research revealed that the B-line automatic counting system is highly consistent with the visual system operated by experts [19]. The results of the present study suggest that there is a significant correlation between the automatic quantization score of B-line and ELWI in PiCCO.

Conclusions

In brief, the current study compared the two detection methods, and the results indicated that the monitoring data were more consistent, and both could reflect a patient's CO and pulmonary edema. The condition of critically ill patients is rapidly changing. The automatic quantification of AI-powered ultrasound can simplify the process, and relatively reduce the subjective error and operator dependence. The present research contains a number of limitations. Firstly, the echocardiographic deviation of VTI measurement and calculation of CO may be due to the error calculated from the angle of radiation, incorrect measurement of LVOT, incorrect measurement of HR, etc. Secondly, one of the disadvantages of the B-line automatic quantitative scoring software used in this study is that it cannot provide us with more than 5 B-lines as the visual system does. However, this limitation is hardly relevant in clinical practice because the existence of more than 3 B-lines per intercostal space is considered pathologically feasible. Therefore, the AI-powered ultrasound still needs to be combined with other hemodynamic evaluation methods to make a comprehensive qualitative and quantitative evaluation of circulatory and respiratory disorders, particularly for critically ill patients.

Abbreviations

AI: artificial intelligence

PiCCO: pulse index continuous cardiac output

CO: cardiac output

ELWI: extravascular lung water index

LVOT-VTI: left ventricular outflow tract velocity time integral

CI: confidence interval

PiCCO: pulse index continuous cardiac output

CCM: critical care medicine

ARDS: acute respiratory distress syndrome

CVP: central venous pressure

ITBV: intrathoracic blood volume

GEDV: global enddiastolic volume

ICU: intensive care unit

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of Shanghai Tenth People's Hospital, and the written informed consent was obtained from all the study subjects.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

YF contributed to acquisition of data and drafted the manuscript. DL and XS contributed to acquisition of data. HZ contributed to analysis of data. YC contributed to design and critically revised manuscript. YZ contributed to design and gave final approval. All authors read and approved the final manuscript.

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Figures

Figure 1

Venue GE new artificial intelligence ultrasound machine

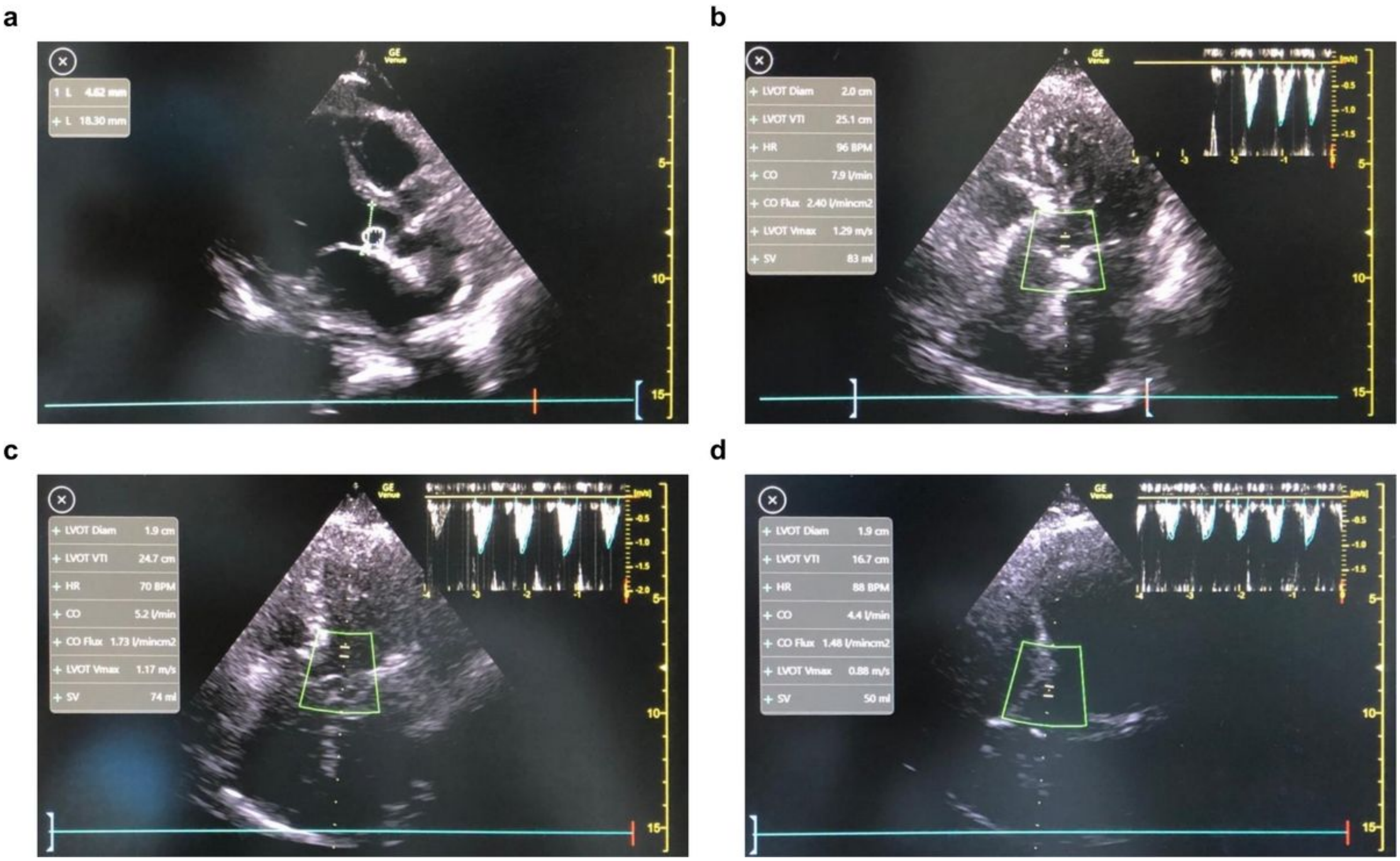

Figure 2

Measurement of cardiac output by artificial intelligence-powered ultrasound. The automatic identification and measurement of VTI and CO systems was turned on. (a) LVOT Diam was used to measure the diameter of left ventricular outflow tract at the Standard section of the long axis of the parasternal left ventricle. (b-d) at standard section of the apical five-chambered heart, artificial intelligence was used to optimize the position of the pulse Doppler box, record the doppler spectrum of 4S, track the contour of VTI, average all VTI recorded, and automatically identify and quantify VTI and CO.

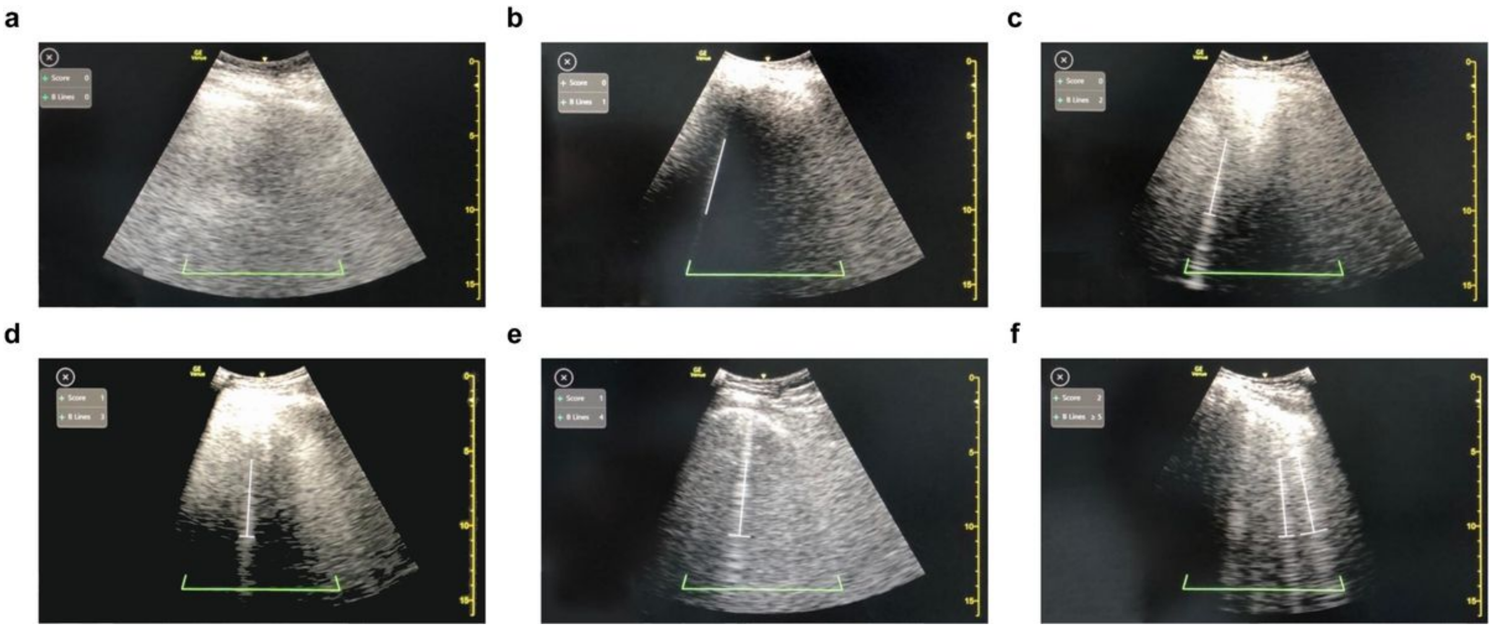

Figure 3

Assessment of ELWI by artificial intelligence-powered ultrasound. Open automatic lung ultrasonic scoring system, the convex array probe on the rib clearance, can be automatically measured B line number, and gives the corresponding score. (a) B line and score 0, (b) score 0 and 1 B line, (c) score 0 and 2 B lines, (d) score 1 and 3 B lines, (e) score 1 and 4 B lines, (f) score 2 and 5 B lines or more.