ORIGINAL ARTICLE

Image acquisition of transthoracic echocardiography in mechanically ventilated ICU patients

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Key words: Critically ill; Transthoracic echocardiography; Image

Objective This study is aimed to determine which echocardiographic parameters are more likely to be affected in a critical care setting.

Methods Ninety Mechanically ventilated ICU patients were enrolled into the study group. The control group consisted of 90 patients underwent an interventional therapy. The transthoracic echocardiography examined eyeballing parameters [visual assessment of right ventricular size and septal kinetics (RV eyeballing), visual assessment of left ventricular ejection fraction (LVEF eyeballing)], M-mode parameters [tricuspid annular plane systolic excursion (TAPSE), mitral annular plane systolic excursion (MAPSE)], pulse-Doppler parameters [right ventricular outflow tract velocity-time integral (RVOT VTI), left ventricular outflow tract velocity-time integral (LVOT VTI)] and endocardium-tracing parameters [right ventricular fraction of area change (FAC), left ventricular ejection fraction (LVEF Simpson)]. We compared the differences in these parameters obtained by the transthoracic echocardiography between the two groups.

Results There were significantly fewer patients in the study group who had optimal images for parameters from M-mode method, pulse Doppler method and endocardium-tracing method than in the control group (P<0.05); The two groups showed no significant difference in the number of patients with optimal images for RV eyeballing and LVEF eyeballing. In the study group, there were significantly fewer patients with optimal images for FAC than for TAPSE and RVOT VTI (P<0.001); there were also fewer patients with optimal images for LVEF Simpson than for MAPSE and LVOT VTI (P<0.001).

Conclusion TTE images tend to be obtained less in mechanically ventilated ICU patients, but eyeballing method could be an alternative. Among the quantitative parameters, M-mode based longitudinal function and pulse Doppler-based VTI were obtained more than endocardium-tracing based parameters.
Introduction

Early and repeated echocardiography is a valuable tool for the management of hemodynamic instability in the ICU because an echo examination allows the clinician to interpret the shock state and to develop an effective strategy. Skill at bedside transthoracic echocardiography should be a key element of intensivists’ training.¹

Several studies have demonstrated that it is completely feasible for non-cardiologists to master the skill of heart function and hemodynamic assessment through echocardiographic examination.²,³ Left ventricular systolic function is of great importance, whereas the right heart function should also be assessed through qualitative and quantitative methods.⁴ However, image acquisition is often more difficult in critically ill patients than non-ICU patients due to patient position, positive ventilation, surgical incisions and drainage, etc. Parasternal view, apical view and subcostal view are the common TTE examination sites. Jensen MB et al noted that only 34% of patients had usable images from all three sites.⁵ However, to our knowledge, which parameters are more easily affected in the critical setting have never been investigated.

Our study aimed to determine the ratio of adequate image acquisition in mechanically ventilated ICU patients, and to investigate which echocardiographic parameters are more likely to be affected.

PATIENTS AND METHODS

Study population

This is a prospective observational study conducted at a tertiary hospital. Critically ill patients admitted to the ICU were enrolled as the study group. Patients were excluded if they had any of the following conditions: without informed consent, without endotracheal tube and mechanical ventilation.

All enrolled patients received a transthoracic echocardiographic evaluation within 6 hours of ICU admission. Physiologic parameters, including hemodynamic data and current vasoactive medications, were recorded at the time of echocardiography. The control group consisted of patients underwent interventional therapy who were 1:1 matched with the study group (age difference within 5 years old and BMI difference within 3kg/m²). All patients in the control group were diagnosed with hepatic carcinoma and received femoral artery puncture for infusion chemotherapy.
Echocardiography

Heart rate and blood pressure were obtained from the monitor at the onset of examination. Echocardiograms were obtained using an echocardiograph (Sonosite, M-Turbo, California, USA) with a 2.5-MHz phased-array probe within the first 6 hours of ICU admission. Patients were in the semi-left lateral position during examination unless there was absolute contraindication for this position. Parasternal view, subcostal view and apical view would all be tried to obtain, unless the site is not available due to surgical incision or drainage tube.

The examinations were performed by two ultrasound fellowship-trained intensivists with more than 5 years of experience in echo. Both were blinded to the study protocol. They both performed echocardiography at least 200 examinations a year which guarantee their competency in this area. They made the judgement whether the image quality was adequate for specific parameters. The appraisal of image quality was based on the following steps:

One, they tried to gain images from all the three sites and had to determine if the basic structure was discernible, like the endocardium of both ventricles, the mitral and tricuspid ring, which was done according to the image quality rating scale in the Emergency Ultrasound Standard Reporting Guideline(Table 1). Two, if images from any site was less or equal 3, then they had to determine whether the image was good enough for eyeballing methods. Three, if the score of images were equal or above 3, they will continue to make the quantitative measurement to make sure the specific parameter exam could be achieved.

The video clips of parasternal longitudinal and short-axis plane, apical four-chamber and two-chamber plane, subcostal four-chamber and short axis plane were to be stored and so were the measurements of each parameter. All images were double-checked by another cardiologist who have done echocardiography for 10 years before the final judgement was made.
Visual assessment of right ventricular size and septal kinetics (RV eyeballing) include whether the right ventricle is enlarged and whether there is septal paradoxical movement. Visual assessment of left ventricular function (LVEF eyeballing) is the estimation of ejection fraction with eyeballing method, which has been reported to correlate well with quantitative measurement.

M-mode longitudinal function parameters included mitral annular plane systolic excursion (MAPSE) and tricuspid annular plane systolic excursion (TAPSE). They were taken from the apical 4-chamber view with the cursor at the left and right sites of the atrioventricular rings.

Left ventricular outflow tract velocity-time integral (VTI) was obtained from pulsed Doppler by putting the sample volume at LVOT approximately 0.5 cm below the aortic valve. And the RVOT VTI was obtained from the short-axis plane of aortic root either from the parasternal site or from subcostal site where the RVOT can be readily seen.

Endocardium-tracing based ventricular function included Simpson’s biplane method measurement of LVEF and RV FAC. RV FAC was measured by tracing the RV endocardium both in systole and diastole from the annulus, along the free wall to the apex, and then back to the annulus, along the interventricular septum.

**Statistical analysis**

Statistical analysis was performed using the SPSS 13.0 statistical software package (SPSS Inc., Chicago, Illinois). Continuous data were expressed as the mean ± SD. Categorical variables were presented as the number and the percentage. Continuous variables were compared with the use of Student’s t-test or Mann-Whitney test or One-way ANOVA. Categorical variables were compared with the Chi-square test or Fisher Exact test. Statistical significance was defined as p < 0.05.

**RESULTS**

**General characteristics of all patients.**

A total of 120 consecutive patients admitted to the ICU from July 1st, 2016 to September 1st, 2016 were screened for enrolment. Five were excluded due to lack of informed consent, and 25
were excluded due to lack of mechanical ventilation. Ultimately, 90 patients were selected as the study group. Another 90 non-ICU patients from the interventional radiology ward were selected as the control group.

The mean ages were 58.7 years old and 55.8 years, old, respectively, and 45.6% vs 53.3% were men. Patients in the study group were admitted for shock, respiratory failure and high-risk surgery. The control group consisted of patients who received intervention therapy. The study group had higher APACHEII scores (14.5 vs 9.7, p=0.000). No difference was found in the ratio of comorbidity between the two groups. All patients in the study group were on mechanical ventilation, with the PEEP 5.4 cmH₂O and plateau pressure 14.1 cmH₂O. No patients in the control group were on mechanical ventilation. In the study group, 27.8% of patients had an epigastric surgical wound, and 5.6% of patients had a subcostal drainage tube. (Table 2)

**Echocardiographic image obtainment**

(1) **Comparison between the study group and control group**

There was no significant difference in the number of patients with optimal images for RV eyeballing between the two groups (86.7% vs 94.4%, p=0.074). There was also no significant difference in the number of patients with optimal images for LVEF eyeballing between the two groups (88.9% vs 97.8%, p=0.119).

There were significantly fewer patients with optimal images for TAPSE and MAPSE in the study group than in the control group (72.2% vs 91.1%, p=0.001 and 84.4% vs 97.8%, p=0.002, respectively).

There were significantly fewer patients with optimal images for RVOT VTI and LVOT VTI in the study group than in the control group (71.1% vs 86.7%, p=0.011 and 85.6% vs 97.8%, p=0.003, respectively).

There were significantly fewer patients with optimal images for FAC and LVEF in the study group than in the control group (22.2% vs 64.4%, p=0.000 and 37.8% vs 81.1%, p=0.000, respectively). (Table 3)

(2) **Comparison between different quantitative methods in left and right heart function appraisal in the study group**

In the study group, there were significantly fewer patients with optimal images for FAC than
for TAPSE and RVOT VTI (22.2% vs 72.2%, p=0.000; 22.2% vs 71.1%, p=0.000).

In the study group, there were significantly fewer patients with optimal images for LVEF Simpson than for MAPSE and LVOT VTI (37.8% vs 84.4%, p=0.000; 37.8% vs 85.6%, p=0.000). (Fig. 1, Fig. 2).

DISCUSSION

In the present study, we found that ICU patients tended to have fewer optimal echocardiographic images taken than non-ICU patients. Nevertheless, similar number of eyeballing parameters in mechanically ventilated patients were obtained in comparison with control group. Among the quantitative parameters of the study group, M-mode based longitudinal function and pulse Doppler-based VTI were obtained much more than endocardium-tracing based parameters.

Transthoracic echocardiography has become more important in the evaluation of critically ill patients.\textsuperscript{11,12} Mercado P et al\textsuperscript{13} found that in critically ill mechanically ventilated patients, cardiac output estimated by transthoracic echocardiography is an accurate and precise method for estimating cardiac output. But transthoracic windows are more difficult to achieve in these patients than in non-ICU patients. Pulmonary hyperinflation is one of the limitations for Emergency and ICU patients, and positive ventilation obviously can precipitate the situation. Patient positioning is another important factor. Sometimes critically ill patients were unable to cooperate with the exam. In the usual echocardiographic examination, the patient’s left arm can be raised and brought towards the head, to widen the left-sided intercostal spaces.\textsuperscript{14,15} However, this often cannot be accomplished due to an indwelling peripheral vein catheter or arterial catheter. Another difference between ICU and non-ICU patients is surgical wounds and drainage tubes, which often leave the patient with no checking area, so high risk surgical patients often have limited windows. Studies have reported that obese patients tend to have inadequate image quality. There is an overall decrease in the quality of transthoracic echo images as BMI increases.\textsuperscript{16} Although the BMI in the two groups did not show difference, the ICU patients had higher APACHE scores, and they were more likely to be complicated with edema, which might decrease image quality.
We found that eyeballing parameters like RV eyeballing and LVEF eyeballing were obtained nearly as many as the control group. The heart function appraisal from eyeballing method is reliable. Prior study has proved the accuracy of LVEF eyeballing method.\textsuperscript{8,17} In this study, we incorporate two parameters, RV size and curvature of interventricular septum. Right ventricular size should appear smaller than the left ventricle and usually no more than two thirds the size of the left ventricle in the standard apical 4-chamber view. Visual assessment of ventricular septal curvature could help in the diagnosis of RV volume and/or pressure overload. These two parameters were also recommended in the guidelines for the echocardiographic assessment of the right heart in adults.\textsuperscript{4} Besides its accuracy, eyeballing was a method can be easily learned by clinicians. For example, the ability of physicians to determine LVEF within the broad clinically pertinent categories of “normal,” “moderately decreased,” and “severely decreased” has been repeatedly demonstrated.\textsuperscript{3} Even medical students could estimate LVEF through eyeballing method with only limited training.\textsuperscript{18} What’s more, eyeballing method is obviously less time consuming which is very important for the treatment of ICU patients.

Among the parameters, the endocardium-tracing based parameters had the lowest rate of obtainment. This result was due to the endocardium being harder to track in critically ill patients. LVEF Simpson estimates systolic and diastolic volumes in apical 4-chamber and 2-chamber views that are perpendicular to each other. It is necessary that the endocardium be visible along the entire cavity and for the entire cycle.\textsuperscript{17} The morphology of the right ventricle is complex. The prominent trabeculations and moderator bands in the RV can make identification of the endocardial borders challenging.\textsuperscript{19,20} Positive ventilation-induced lung extension could make the right ventricular endocardium border even harder to track. As the right heart is located anterior in the chest and close to the lung, when the probe is placed at the apex, the right heart will be more easily affected by the extended lung.

Even though LVEF Simpson and FAC were obtained much less in the study group, longitudinal functions represented by TAPSE and MAPSE could be a good alternative if needed. TAPSE is one of the most feasible and reproducible parameters that can reflect RV systolic function and has important prognostic value in critically ill patients.\textsuperscript{4,21,22} MAPSE is a parameter found to be a highly accurate predictor of LV EF even by an untrained observer.\textsuperscript{23} We also found that VTI is
much easier to acquire than LVEF. There has been study pointed out that Doppler measurements are very reproducible. VTI is more useful than LVEF for the management of critically ill. Stroke volume measurements before and after fluid administration or inotrope infusion allow the effect of treatment to be quantified. This study has several limitations. First, although our ICU is a general ICU, most of the patients admitted were surgical patients. Thus, a higher proportion of patients had dressing and drainage tubes, and the situation might not be the same for a medical ICU. Second, the sample size was relatively small. Third, only the fundamental parameters of echocardiography were investigated. This study did not include segmental wall motion assessment, valve assessment and advanced measurements such as speckle tracking and three-dimensional echocardiography. Finally, the results were all based on bedside echocardiographic examination via portable echocardiogram. This could underestimate the image quality. Nevertheless, most bedside examinations in clinical echocardiographic examination are being done through the same kind of machine. We think the result is reliable in reflecting ICU echocardiographic image acquisition.

CONCLUSIONS

TTE images tend to be obtained less in mechanically ventilated patients, but eyeballing method could be an alternative. Among the quantitative parameters, M-mode based longitudinal function and pulse Doppler-based VTI were obtained more than endocardium-tracking based parameters.

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Figures

**Figure 1.** Image acquisition from different quantitative methods in right heart function appraisal in the study group.

**Figure 2.** Image acquisition from different quantitative methods in left heart function appraisal in the study group.

**Figure legends**

**Figure 1.** There were significantly fewer patients with optimal images for FAC than for TAPSE and RVOT VTI in the study group (22.2% vs 72.2%, p=0.000; 22.2% vs 71.1%, p=0.000).

**Figure 2.** There were significantly fewer patients with optimal images for LVEF Simpson than for MAPSE and LVOT VTI in the study group (37.8% vs 84.4%, p=0.000; 37.8% vs 85.6%, p=0.000).
Tables

**Table 1.** Quality assurance grading scale

| Score | Grading scale definitions |
|-------|---------------------------|
| 1     | No recognizable structures, no objective data can be gathered |
| 2     | Minimally recognizable structures but insufficient for diagnosis |
| 3     | Minimal criteria met for diagnosis, recognizable structures but with some technical or other flaws |
| 4     | Minimal criteria met for diagnosis, all structures images well and diagnosis easily supported |
| 5     | Minimal criteria met for diagnosis, all structures imaged with excellent image quality and diagnosis completely supported |

**Table 2.** General characteristics of the two groups

| Categories                          | Study group(n=90) | Control group(n=90) | t/X² value | p value |
|-------------------------------------|-------------------|---------------------|------------|---------|
| Age (yr)                            | 58.7±15.3         | 55.8±15.5           | 1.538      | 0.215   |
| Sex (male, %)                       | 41(45.6%)         | 48(53.3%)           | 1.089      | 0.371   |
| BMI                                 | 23.2±3.2          | 22.7±3.3            | 1.257      | 0.367   |
| APACHEII                            | 14.5±6.4          | 9.7±3.2             | 7.706      | 0.000   |
| reason for admission                |                   |                     |            |         |
| Shock                               | 15(16.7%)         | 0                   | -          | -       |
| Pneumonia                           | 21(23.3%)         | 0                   | -          | -       |
| High risk surgical patients         | 54(60%)           | 0                   | -          | -       |
| Intervention therapy                | 0                 | 90(100%)            | -          | -       |
| Comorbidities                       |                   |                     |            |         |
| HTN(%)                              | 37(41.1%)         | 26(28.9%)           | 2.955      | 0.086   |
| CAD(%)                              | 20(%)             | 14(15.6%)           | 1.305      | 0.253   |
| DM(%)                               | 19(21.1%)         | 17(18.9%)           | 0.139      | 0.709   |
| CRF(%)                              | 7(7.8%)           | 4(4.4%)             | 0.871      | 0.351   |
| COPD(%)                             | 3(3.3%)           | 2(2.2%)             | 0.206      | 0.650   |
### Table 3. Images obtained for parameters of left and right ventricular function

| Image obtained                      | Study group(n=90)       | Control group(n=90)     | X² value | p value |
|-------------------------------------|-------------------------|-------------------------|----------|---------|
| **Eyeballing parameters**           |                         |                         |          |         |
| RV function eyeballing (n, %)       | 78(86.7%)               | 85(94.4%)               | 3.183    | 0.074   |
| LVEF eyeballing (n, %)              | 82(88.9%)               | 87(97.8%)               | 2.421    | 0.119   |
| **M-mode parameters**               |                         |                         |          |         |
| TAPSE (n, %)                        | 65(72.2%)               | 82(91.1%)               | 10.724   | 0.001   |
| MAPSE (n, %)                        | 76(84.4%)               | 88(97.8%)               | 9.878    | 0.002   |
| **Pulse Doppler parameters**        |                         |                         |          |         |
| RVOT VTI (n, %)                     | 64(71.1%)               | 78(86.7%)               | 6.538    | 0.011   |
| LVOT VTI (n, %)                     | 77(85.6%)               | 88(97.8%)               | 8.800    | 0.003   |
| **Endocardium-tracing based parameters** |                         |                         |          |         |
| FAC (n, %)                          | 20(22.2%)*              | 58(64.4%)               | 32.670   | 0.000   |
| LVEF Simpson (n, %)                 | 34(37.8%)#              | 73(81.1%)               | 35.051   | 0.000   |

BMI: body mass index; APACHE: acute physiology and chronic health evaluation; HTN: hypertension; CAD: coronary arterial disease; DM: diabetes mellitus; CRF: chronic renal failure; COPD: chronic obstructive pulmonary disease; PEEP: positive end expiratory pressure; Pplat: plateau pressure.

High risk surgical patients include patients underwent abdominal, cardiac, thoracic, orthopaedic, urinary surgery

Intervention therapy patients include those with hepatic carcinoma underwent infusion chemotherapy.
RV eyeballing: visual assessment of the right heart function including whether the right ventricle is enlarged and whether there is septal paradoxical movement; LVEF eyeballing: visual assessment of left ventricular ejection fraction; LVEF: left ventricular ejection fraction; TAPSE: tricuspid annular plane systolic excursion; MAPSE: mitral annular plane systolic excursion; Sa: tissue Doppler velocity measurement of the mitral annulus; SaT: tissue Doppler velocity measurement of the tricuspid annulus; FAC: fraction of area change of the right ventricle; LVEF Simpson: LVEF measured with Simpson’s rule.

*number of patients with optimal images for FAC was much less than those for TAPSE and RVOT VTI in the study group, P=0.000 and P=0.000, respectively.

#number of patients with optimal images for LVEF Simpson was less than those for MAPSE and LVOT VTI in the study group, P=0.000 and p=0.000, respectively.