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ORIGINAL ARTICLE

Continuous hands-free monitoring of echocardiographic exercise test using probe fixation device

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Abstract

Background: *Stress echocardiography has been widely used in clinical practice for decades and has recently gained even more importance in diagnostic approaches to ischemic heart disease. However, it still has numerous limitations. Despite advantages of physical exercise as most physiologic stressor, it is impossible to continuously monitor the cardiac function during treadmill test and difficult to maintain an optimal acoustic window during cycle ergometer exercise tests. The aim herein, is to assess the feasibility of probe fixation for use during exercise echocardiography.*

Methods: *Forty-eight subjects (47 men, mean age 42 ± 17 years, 25 healthy volunteers, 23 patients with suspected coronary artery disease) were included in this study. All subjects underwent exercise stress test on treadmill (32 cases) or cycle ergometer (16 cases). Both sector and matrix probes were used (in 17 and 31 tests, respectively). The semi-quantitative quality of acquired apical views were assessed at each stage using a four-point grading system.*

Results: *The mean time required for probe fixation was 9 ± 2 min. At baseline, 10 patients had at least one apical window of quality precluding reliable analysis. Twenty-five patients required probe repositioning during exercise (more often on a treadmill). During peak exercise quality of images in all views declined, but for diagnostic purposes it remained sufficient in 29 patients. Thus, 76% of performed tests (60% study population) had sufficient image quality.*

Conclusions: *Probe fixation offers the possibility of continuous acquisition of echocardiographic images during physical exercise. The device is suitable almost exclusively for male patients and in some patients requires repositioning.* (Cardiol J 2023; 30, 6: 957–963)

Key words: stress echocardiography, probe fixation, continuous monitoring

Introduction

Stress echocardiography (SE) is one of the most commonly used diagnostic imaging techniques in patients with suspected coronary artery disease. It can be performed using several stress protocols. The most physiologic technique is based on exercise tests with the use of a bicycle ergometer or treadmill [1–3]. Exercise echocardiography also plays an important role in other clinical scenarios, including valvular heart disease and heart failure with preserved ejection fraction [4–6].

Both forms of physical exercise impede stable position of the ultrasound probe, which together with a patient's hyperventilation affect the image quality and thus, reliable diagnosis [7]. While the bicycle test allows for continuous echocardiographic imaging, in the case of treadmill tests the imaging can be performed only after cessation of

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exercise. Post-exercise imaging limits the diagnostic yield of SE [8].

Therefore, the aim of the present study was to assess the feasibility of a recently developed device allowing fixation of the sector or matrix probe to the patients' chest while performing the exercise SE.

Methods

Probe fixation device

Probe fixation device (Probefix, USONO; Fig. 1) contains a probe holder and adjustable straps. The probe is placed into a holder consisting of three rings, which allows placement of the probe in accurate acoustic window and for repositioning when needed. The probe can be rotated to obtain different apical views while performing the stress test. By using different elastic rings, ultrasound probes of different sizes and produced by various manufacturers can be affixed using this device [9]. The holder is attached to the chest with a horizonal strap and vertical strap which surrounds the neck.

Study group

Forty-eight subjects were enrolled in the study: 25 healthy volunteers and 23 patients with suspected coronary artery disease. The patients were recruited both from the Cardiology Department and from the out-patient clinic. The focus was mostly on men (47), because during pilot study we found that the device was difficult to stabilize and painful for women due to pressure on the breasts. This was the reason only one woman was included in this study.

There were attempts to perform 32 exercise stress tests on the treadmill and 16 exercise stress tests on the cycle ergometer. Tests with a poor quality of imaging were excluded as reliable analysis were terminated. Table 1 presents demographic and clinical characteristics of the patients.

Echocardiographic data acquisition and visual analysis

Two types of exercise SE were performed; most of them on a treadmill. Various echocardiographic probes were used: 17 tests were performed with sector probes (GE Vivid 7, GE Vivid E9 and Siemens CV70) and 31 tests using matrix probes (GE Vivid E95 and Phillips IE33). The probe was attached to the patient's chest and the 12-lead electrocardiogram (ECG) was recorded during the test (Fig. 2).

The bicycle stress test was performed on the ergometer in semi-horizontal position and the

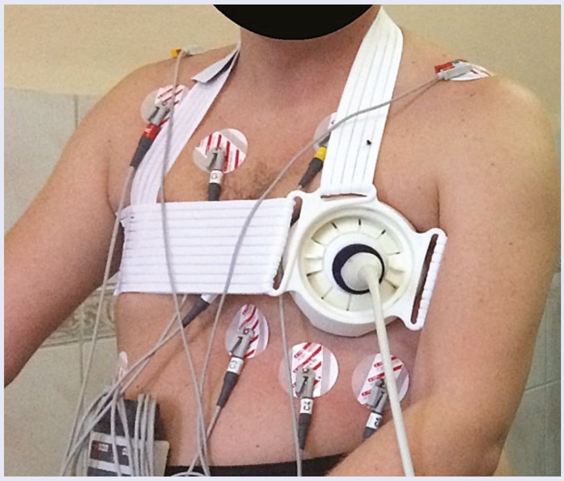

Figure 1. Overview of the Probefix device affixed to a patient's chest while performing stress echocardiography. The horizontal and vertical straps are attached to a ring with the probe inside.

Table 1. Characteristics of patients included to the study and stress test

Parameter	Mean ± SD or number (percentage) of patients
Age [years]	42 ± 18 (range: 21–80)
Gender (male/female)	47 men, 1 woman
Body mass index [kg/m^2]	26 ± 3 (range: 20.7–32.2)
Indication for stress test	Chest pain: 22 (46%)
	Arrhythmia: 1 (2%)
	Exercise tolerance assessment: 25 (52%)
Type of test	Treadmill: 23/48 (48%)
	Ergometer: 15/48 (31%)
	Inadequate baseline image quality precluding stress test: 10/48 (21%)
Reason for ending stress test	Heart rate limit: 27/38 (71%)
	Fatigue: 10/38 (26%)
	Chest pain: 1/38 (3%)
Probe	Sector: 17/48 (35%)
	Matrix: 31/48 (65%)
Vendor of echocardiograph	Siemens: 2 (4%)
	GE: 30 (63%)
	Philips: 16 (33%)

SD — standard deviation

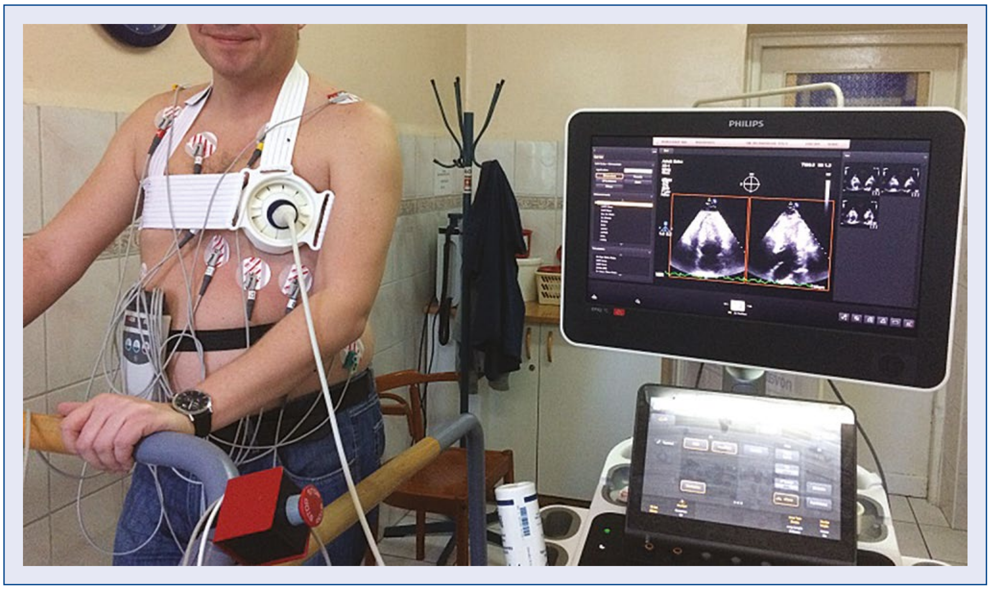

Figure 2. Stress echocardiography during a treadmill test. The echocardiograph is positioned on the left side of the treadmill to facilitate maneuvering of the probe affixed to the chest of the patient. Continuous monitoring of apical views with simultaneous electrocardiographic monitoring.

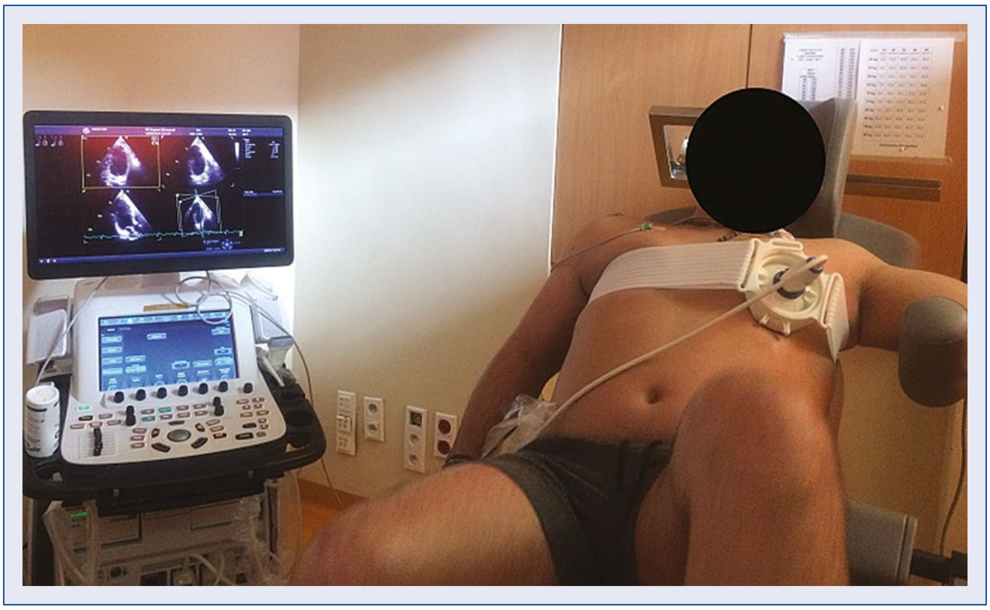

Figure 3. Stress echocardiography with the use of a cycle ergometer. The ergometer is tilted towards the left side for the best image quality of the apical view. The matrix probe (4Vc-D, GE Vivid E95) enables acquiring three apical views at the same time.

device was attached to the chest similar to the treadmill test. The position of echocardiographer enabled for adjusting and rotating the probe when it was necessary (Fig. 3).

The bicycle SE was performed with workload escalation by 25 Watts every 2 or 3 minutes, with the patient maintaining a cadence of approximately 60 revolutions per minute, until achieving the 85% of maximal heart rate limit. The treadmill echocardiography was performed with Bruce protocol — with an elevation slope of the treadmill and speed every 3 minutes until reaching the target heart rate

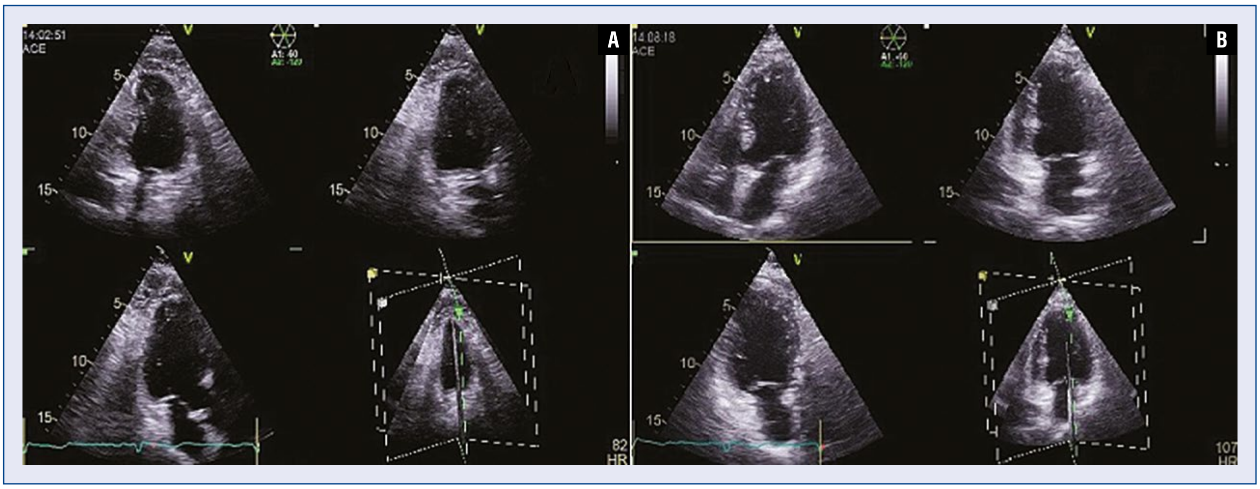

Figure 4. An example of images obtained with a matrix probe (GE Vivid E95) during bicycle stress test at baseline (**A**) and peak exercise (**B**).

or other reason for ending test (fatigue, dyspnea). The 12-lead ECG was recorded for observing ST--segment changes while exercise and the blood pressure was monitored.

In the present study three apical views were recorded at baseline and at peak exercise. The matrix probe of the GE Vivid E95 allowed acquisition of three apical views in a single cardiac cycle, while the matrix probe of the Phillips IE33 allowed simultaneous acquisition of two apical views in a single cardiac cycle with the third view obtained by additional manual positioning of the probe (Fig. 4). When using the sector probe, the probe was rotated manually. All acquired views were visually assessed by two independent echocardiographers.

An 18-segment model of the left ventricle (LV) was used for standardized assessment of ventricular regional myocardial function and quality of visualization during the exercise test.

A semi-quantitative score system was used to assess the quality of each of three acquired apical views at baseline and peak exercise:
- 3: optimal (endocardial border of all LV segments clearly visible);
- 2: acceptable (1 segment not clearly visible);
- 1: suboptimal (2 segments not clearly visible);
- 0: poor (3 or more segments not clearly visible).

For baseline and peak exercise, the sum of scores of three apical views was assessed. Assuming that for clinically sufficient visualization the global score (sum of three apical views) there should be at least 6 with each view's quality being assessed as a minimum of 2.

The study protocol was approved by the local ethics committee and all patients gave their written informed consent.

Statistical analysis

All quantitative variables were initially analyzed for compliance with the normal distribution using the Kolmogorov-Smirnov test. If the variable had a normal distribution, the values were presented as the mean and standard deviation, in case of non--compliance with the normal distribution, the values of a given variable were presented as the median and the upper and lower quartiles. Statistical analysis was performed using MedCalc Software, Frank Schoonjans, Belgium, version 12.2.1.0.

Results

The mean time required for probe fixation and obtaining a proper acoustic window at rest was 9 ± 2 minutes (range 5.8–14 min) with a decreasing trend as the learning curve was climbed. In 10 patients quality of images sufficient could not be obtained for reliable analysis and those were excluded from further investigation.

Table 2 presents the mean value of visibility of three apical views at baseline and at the peak exercise in 38 patients, who completed the exercise test.

During peak exercise the quality of images decreased in all views, but remained clinically sufficient in 29 patients (76% for performed tests, 60% for all study population). Among the successfully finished tests there were 18 treadmill tests and

Table 2. Image quality of apical four- (4CH), two- (2CH) and three-chamber (3CH) view at baseline and peak exercise in 38 patients with sufficient baseline quality (n = 38).

N = 38	Baseline			Peak		
	4CH	2CH	3CH	4CH	2CH	3CH
Mean	2.39	2.37	2.39	1.97	2.03	2.05
Range	2.0–3.0	2.0–3.0	2.0–3.0	1.0–3.0	1.0–3.0	1.0–3.0
Median	2.0	2.0	2.0	2.0	2.0	2.0

Table 3. Comparison between results of treadmill and ergometer stress tests.

	Treadmill	Ergometer	P
Performed tests (n)	23	15	
Diagnostic tests (n)	18	11	
Mean left ventricle quality score (sum of scores for 3 apical views):			
Baseline	6.7 Me (6.25; 9.0)	7.7 Me (6.25; 9.0)	0.29
Peak	5.8 Me (5.25; 6.0)	6.5 Me (4.5; 8.0)	0.52
Score per view — baseline:			
4-chamber	2.3 (2.0; 3.0)	2.5 (2.0; 3.0)	0.73
2-chamber	2.2 (2.0; 2.75)	2.6 (2.0; 3.0)	0.66
3-chamber	2.3 (2.0; 2.0)	2.6 (2.0; 3.0)	0.06
Score per view — peak:			
4-chamber	1.9 (1.25; 2.0)	2.1 (1.25; 3.0)	0.6
2-chamber	1.9 (2.0; 2.0)	2.2 (2.0; 3.0)	0.38
3-chamber	2.0 (2.0; 2.0)	2.1 (2.0; 3.0)	0.36

Me — mean

11 bicycle tests. In 21 cases a matrix probe was used. The apical lateral and apical anterior segments were more prone to deterioration of image quality was noted, but a relatively low number of patients precluded statistical analysis of individual segment quality (Table 3).

Twenty-five (66% of performed stress tests) patients required some probe repositioning during exercise (78% of tests performed on treadmill and 18% of tests performed on bicycle ergometer). There were 8 successfully finished tests with use of the sector probe and 87% of them required probe repositioning. Among 21 clinically sufficient tests with the matrix probe there were 9 (42%) that required probe repositioning.

The differences in mean score of visibility between ergometer and treadmill did not reach statistical significance. In both types of exercises the mean view quality score at the peak significantly dropped compared to baseline (1.2 and 0.9 for ergometer and treadmill, respectively).

Discussion

Findings herein, confirm that the probe fixation device offers the possibility of continuous acquisition of echocardiographic images during physical exercise. Thus, it introduces a possibility of obtaining true peak-exercise images even during treadmill tests, which had not been possible before. However, the device is suitable almost exclusively for male patients. Moreover, in some patients it required repositioning.

Imaging stress tests have become more popular nowadays because of updated guidelines on chronic coronary syndromes [4, 5], where the imaging stress tests are recommended as superior to the ECG treadmill test [10, 11]. The sensitivity and specificity of dobutamine SE in diagnosing ischemic heart disease are very similar [4]. There are many other indications for performing SE, such valvular heart defects evaluation [12]. One of the main advantages of SE is good sensitivity and specificity with complete lack of harmful effects in contrast to radionuclide imaging or computed tomography, when patients are exposed to radiation [13].

The echocardiographic exercise stress tests are low cost, noninvasive and have great potential. However, this test is very sensitive to the quality of obtained images and prone to failure due to loss of imaging capabilities. Some authors advise instructing the patient to inhale for a shorter period of time than usual and exhale for a longer period of time, so that the echocardiographer would be able to record many views during exhalation [14]. The most challenging was performing the treadmill test, because of difficulties with recording the peak exercise views; it usually requires image recording shortly after completion of the exercise. This can lead to missing the ischemic changes, which may be resolved before being visualized. In a study of Hecht at al. [15] authors proved the superiority of peak exercise echocardiography to post exercise treadmill echocardiography in detection of coronary artery disease especially in patients with multivessel disease. Caiati et al. [16] published the study on comparison of peak upright bicycle and post-treadmill echocardiography in detecting coronary disease. The authors found the upright bicycle test was more sensitive with no significant difference in specificity.

There are very limited data about exercise stress tests with probes attached to a patients' chest. Chandraratna et al. [17] tested a prototype probe attached to the chest directly on intercostal space, thus recording a left ventricular short axis view. The limitation of this study was the small number of participants (10 healthy men) and only provided one view. The same group of authors published another study, concerning continuous monitoring myocardial infarction. It showed feasibility of the device for monitoring the patients for a longer period of time (up to 12 h), however only one cross-sectional view of LV could be obtained [18]. Therefore, this transducer could not provide sufficient visualization to perform SE [19].

Nakashiki et al. [19] tested another transducer for treadmill SE. Their transducer was attached to the chest with rubber belts and had a possibility of being moved in any direction. They managed to record a long axis, 4-chamber and 2-chamber view by rotating the transducer during the patient's exercise. The tests were undertaken in 36 patients with coronary angiography performed after the echo study. The continuous monitoring of LV wall motion was feasible in most patients. More than 90% of left ventricular segments were well visualized at rest, but this number decreased to 77% during peak exercise [19]. The authors did not mention the fixation time.

The next technological advancement was a device (Probefix), the fixation of which is neither very complicated nor time consuming. Salden et al. [20] studied the feasibility of this device for supine and upright bicycle SE. The authors examined 12 patients, with the vast majority undergoing the supine bicycle test. The test was feasible in 10 out of 12 patients performing a stress test [20]. Blans et al. [9] examined 10 patients in an intensive care unit for monitoring cardiac output with the device attached to the patient's chest. The authors were able to obtain good visibility in 8 out of 10 patients. Another study with this device was performed to assess the shoulder abduction in echocardiographers while using the device for transthoracic examination. The outcome of this showed that the muscle overload can be significantly reduced with this method [21].

The present study showed that this device opens new possibilities in SE, especially on the treadmill, allowing continuous recording of images. The best and easiest observed way to obtain images was with the use of the matrix probe of GE Vivid e95, although being unable to simultaneously record all three apical views. The better quality was also easier to obtain on supine bicycle compared to the treadmill. It is relevant to mention that many of performed tests required repositioning.

Unfortunately, the device could not be used in all patients — in 10 (20%) patients from the study group, the stress test could not be performed because of a poor acoustic window at baseline. The device is very challenging to use in women, because the breasts of women are interfacing with the optimal position for probe fixation. The disadvantage may by also the fixation time. It was shortened while climbing the learning curve, but one must take into consideration that it takes time to fix the device.

Conclusions

Echocardiographic stress testing is feasible with the use of the probe fixation device. The advantage of probe fixation is the possibility of continuous acquisition of echocardiographic images during physical exercise, which is unique on a treadmill. However, the device is suitable almost exclusively for male patients and in most treadmill tests there was a need for repositioning to maintain sufficient image quality.

Conflict of interest: None declared

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