ORIGINAL ARTICLE

Feasibility and Contribution of Global and Regional 2D Strain During Exercise Stress Echocardiography

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ABSTRACT

Introduction
Although pharmacologic stress echocardiography has been used to evaluate ischemia and viability in several studies, the use of longitudinal 2D strain for the diagnosis of myocardial ischemia during exercise stress echocardiography has not been analyzed

Objectives
The goal of this study was to determine the feasibility of longitudinal 2D strain analysis and to evaluate its performance during exercise stress echocardiography.

Methods
Between February and March 2012, 93 consecutive patients (59 men, 54.9%), with mean age 58.8 ±11.8 years, underwent supine exercise stress echocardiography, in 150 kgm stages. Wall motion was visually evaluated using a semi-quantitative analysis at baseline, peak exercise and immediately after exercise. Longitudinal 2D deformation was analyzed in 16 segments at rest and immediately after exercise using a tracking algorithm of acoustic markers (AFI: automatic functional images, GE).

Results
Baseline heart rate was 76 ± 18 bpm and it increased to 133 ± 25 bpm during peak exercise. The target heart rate was achieved in 64 (68.8%) of the 93 patients evaluated; in the 29 patients who did not achieve target heart rate, 9 tests were positive and 20 were negative for coronary artery disease. Twenty-one patients (22.5%) developed ischemia diagnosed as transient regional assynergies during exercise stress. These patients were older (63.5 ± 8.7 vs. 57.4 ± 12.2 years; p = 0.03) and the prevalence of previous myocardial infarction (14.3% vs. 7%; p = 0.01) and myocardial revascularization surgery (14.3% vs. 2.77%; p = 0.04) was higher compared to those without ischemia. The value of longitudinal 2D strain in the apical segments increased in 79 (85%) of the 93 patients evaluated: only 3 of these patients (3.8%) developed new wall motion abnormalities in the same region. In the 14 patients in whom longitudinal 2D strain did not increase or decrease, 11 (78.6%) presented apical ischemia in the visual analysis (sensitivity 79%, specificity 96%; p = 0.0001). Among the 53 patients presenting increased longitudinal 2D strain in the inferior, posterior and/or lateral segments, 6 (11.3%) presented wall motion abnormalities in the same sites, whereas in the 40 patients in whom longitudinal 2D strain did not increase, 8 (20%) presented transient dyssynergias which were visually detected in the same region (sensitivity 43%, specificity 41%). Longitudinal 2D strain could be evaluated in 1472 of 1488 segments at rest (feasibility 99%), in 1452 after exercise (feasibility 97.5%) and in 1147 (77%) during peak exercise (this stage was not considered for the analysis).

Conclusions
The analysis of longitudinal 2D strain is feasible immediately after exercise. The lack of increase or decrease in longitudinal 2D strain in the apical segments was

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consistent with the presence of visually detected ischemia. Elevated heart rates were responsible for the lack of specificity in the inferior, posterior and lateral basal and mid segments. Thus, longitudinal 2D strain would only help to analyze the territory irrigated by the left anterior descending coronary artery.

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Key words > Stress echocardiography - Coronary Disease - Myocardial Ischemia - Risk Assessment

Abbreviations >

2D	Two-dimensional	**Bpm**	Beats per minute
HR	Heart rate	**CFR**	Coronary flow reserve
kgm	Kilogram-meters		

INTRODUCTION

Since the advent of stress echocardiography, new quantitative technologies have been developed to reduce the subjectivity of the method and increase its diagnostic accuracy and acceptance by the cardiology community. The evaluation of coronary flow reserve (CFR) (measured at the mid-distal portion of the left anterior descending coronary artery) and, more recently, the information provided by the parameters of deformation, provide diagnostic and prognostic value in ischemic heart disease. (1)

Most echo stress laboratories still use conventional visual evaluation of endocardial excursion and myocardial thickening changes in amplitude and synchronization. This method requires dedicated training and continuous practice and has the disadvantage of subjective interpretation. (2). Two-dimensional (2D) strain imaging, is a technique based on speckle-tracking echocardiography that may quantify regional myocardial function through a semiautomatic analysis of the heart chamber wall deformation. This software can identify the presence of ultrasound tissue images which contain natural acoustic markers (speckles). These markers are originated by the interaction between ultrasound and myocardial fibers, and tissue movement is estimated by tracking speckles through time and space.

The software analyzes and averages the information on the magnitude and direction of speckle motion and calculates several parameters (strain, strain rate, and left ventricular torsion). Because it is not based on tissue Doppler measurements, images are easier to obtain as they are angle independent. Longitudinal, radial and circumferential regional deformation of each myocardial segment may be quantified in the different views.

It is useful to remember that the visual estimation of wall motion is best appreciated with radial strain, while contractility depends mostly on the deformation of longitudinal fibers with spiral orientation. (1) In addition, subendocardial fibers (longitudinal) are the first to be affected by myocardial ischemia. The human eye can only perceive a delayed contraction exceeding > 80 milliseconds, while ischemia produces shorter myocardial contraction delays which can only be detected by the evaluation of two-dimensional deformation. (3)

The information provided by longitudinal 2D strain during dipyridamole stress echocardiography for the diagnosis of ischemia has been documented by our group in a recent study, (1) while other authors have reported the value of longitudinal 2D strain during adenosine stress echocardiography for the assessment of myocardial viability. (4) It should be mentioned that these interventions do not produce significant increases in heart rate (HR).

The feasibility and contribution of the information provided by longitudinal 2D strain to detect ischemia at elevated heart rate is not well established. Dobutamine has been used in studies with small number of patients or in experimental studies for the assessment of ischemia and viability, (5-9) but there are no studies evaluating the value of longitudinal 2D strain for the diagnosis of myocardial ischemia during exercise stress echocardiography. Therefore, the goal of our study was to evaluate the feasibility and the performance of longitudinal 2D strain in patients undergoing exercise stress echocardiography.

METHODS

Patients

The initial population comprised 109 patients prospectively enrolled at our institution (Investigaciones Médicas, Buenos Aires) from February 29 to March 20, 2012. Patients with indication of exercise stress echocardiography who were informed about the methodology and risks related to the test and who had signed an informed consent form were included in the study. Patients with suboptimal ultrasound window, acute coronary syndrome within 5 days from symptom onset, hemodynamic instability and heart failure (functional class III-IV) were excluded from the study. Finally, 93 patients entered the study; 59 were men (54.87%), and mean age was 58.8 ± 11.8 years. The indication of stress echocardiography was coronary artery disease and/or risk stratification (chest pain or history of myocardial infarction, myocardial revascularization or significant coronary artery stenosis documented by coronary angiography) assessment.

Stress echocardiography

All the patients underwent supine exercise transthoracic Doppler echocardiography, with increases of 150 kgm every 3 minutes. Stress echocardiography tests were performed using a Vivid E9 ultrasound machine (GE Health Care, Milwaukee, USA), with multiple-frequency transducers M5S and 4D. The images were obtained from five views: the apical long axis view, 4- and 2-chamber views, parastenal short axis view, and images from the left ventricular outflow tract view obtained with pulsed Doppler echocardiography using the opening and closure of the aortic valve as reference. Images from an entire cardiac cycle were acquired at a frame rate of 50 to 90 frames per second; 12-lead ECG was continuously monitored and blood pressure was measured in each stage. Digital 2D images were obtained at rest, during peak exercise and immediately after exercise (1 to 30 seconds after exercise ended). The software was adjusted for continuous acquisition in the last stage in order to select the best quality images. For each stage, images were interpreted using a 16-segment model and a 4-point scale. (10-12) The wall motion score was calculated by visual analysis. Ischemia was defined as transient newly developed wall motion abnormalities or significant worsening of preexisting ones. The results of the studies were revised by the most experienced operator (J.L.).

Longitudinal 2D strain

Longitudinal 2D strain was analyzed at the end of the study from the apical views obtained for wall motion analysis. Using the apical long-axis view, three points were identified (2 basal points and 1 apical point) and the software tracked the internal (subendocardial) border and external (epicardial) border in a semi-automatic fashion. Tracking was accepted or rejected, and occasionally manually corrected by the operator. Aortic valve closure time was confirmed. The same procedure was followed with the 4- and 2-chamber views, using the same sequence. Finally, the software presented the result of peak systolic longitudinal 2D strain in a "bull's eye" diagram. The values expressed in the examples shown in Figure 1 correspond to the average systolic deformation in each apical view and, finally, to the average deformation in these three views.

Statistical analysis

Quantitative variables with parametric and non parametric distribution were expressed as mean and standard deviation or median and interquartile range, respectively, and comparison between two groups was made using Student's t test or Wilcoxon´s test as appropriate. Qualitative variables were expressed as percentages, using the chi square test or Fisher's exact test to determine statistical significance. A two-tailed p value < 0.05 was considered statistically significant. Statistical analyses we performed using Stata statistical package for Windows (Version 10.0, StataCorp, Texas, USA).

RESULTS

Stress echocardiography

No major complications were reported during the tests.

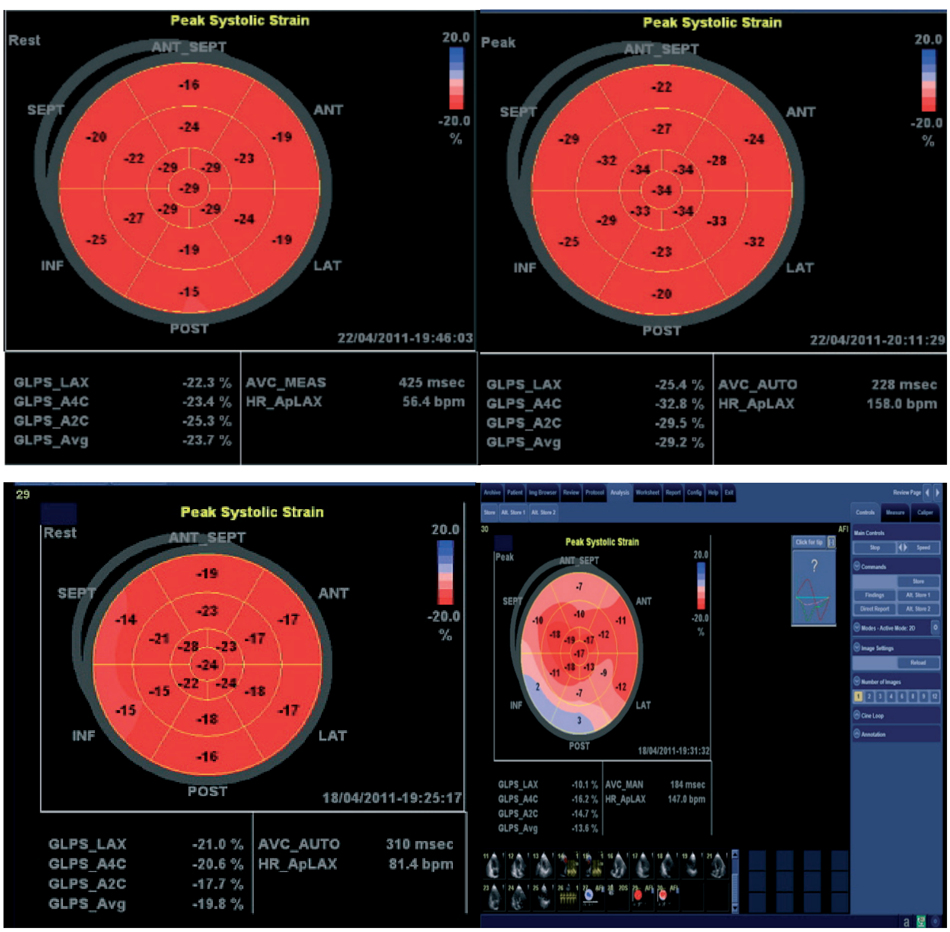


Fig. 1. Longitudinal 2D strain during exercise stress echocardiography. Bull's-eye plots.
Above: An example of a normal study (left: rest; right: after exercise).
B: an example of a normal study (left: rest; right: after exercise). GLPS_LAX, GLPS_A4C, GLPS_A2C and GLPS_Avg: global longitudinal peak strain long axis; global longitudinal peak strain apical 4-chamber; global longitudinal peak strain apical 2 chamber and global longitudinal peak strain value average (average of 3 views), respectively.
HR_ApLAX: heart rate during acquisition of the apical long axis view.

Baseline population characteristics

Baseline HR was 76 ± 18 bpm, 133 ± 25 bpm during peak exercise and 117 ± 15 bpm immediately after exercise. The target HR was achieved in 64 (68.8%) of the 93 patients evaluated. In the 29 patients who did not achieve target HR, 9 tests were positive and 20 were negative for coronary artery disease. Twenty-one patients (22.5%) developed ischemia (transient wall motion abnormalities) during exercise stress echocardiography: 7 patients in the anterior, septal and/or apical territories, 7 in the inferior, posterior and/or lateral territories and 7 in segments corresponding to both territories. These patients were older (63.5 ± 8.7 vs. 57.4 ±12.2 years; p = 0.03) and the prevalence of previous myocardial infarction (14.3% vs. 7%; p = 0.01) and myocardial revascularization surgery (14.3% vs. 2.77%; p = 0.04) was more common compared to those with normal wall motion. There were no significant differences in the history of hypertension, diabetes, dyslipidemia and smoking habits (Table 1).

Table 1. Baseline population characteristics

	With wall motion abnormalities	Without wall motion abnormalities	p
Age, years	63.5 ± 8.7	57.4 ± 12.2	0.03
Hypertension, %	71.4	63.4	ns
Diabetes, %	14	9.8	ns
Dyslipidemia, %	47.6	49.3	ns
Smoking habits, %	42.8	35.3	ns
History of AMI, %	14.3	7	0.01
History of CABGS, %	14.3	2.7	0.04

CABGS: Coronary artery bypass graft surgery. AMI: Acute myocardial infarction

Longitudinal two-dimensional strain

Longitudinal 2D strain in the apical segments.

The value of 2D strain in the apical segments increased in 79 (85%) of the 93 patients evaluated and only 3 of these patients (3.8%) developed new wall motion abnormalities in the same region. In the 14 patients in whom 2D strain did not increase in the apical segments or even decreased, 11 (78.6%) presented new regional assynergies (sensitivity 79%, specificity 96%; p = 0.0001) (Figure 2).

Longitudinal 2D strain in the inferior, posterior and lateral segments.

The value of 2D strain in the inferior, posterior and/or lateral segments increased in 53 patients: 6 (11.3%) presented wall motion abnormalities in the same sites, while in the 40 patients in whom 2D strain did not increase, 8 (20%) presented transient dyssynergies visually detected in the same region (sensitivity 43%, specificity 41%) (Figure 3).

Feasibility of longitudinal 2D strain analysis during exercise.

The software could visualize 1472 of 1488 segments at rest (feasibility 99%) and 1452 after exercise (feasibility 97.5%). During peak exercise, 2D strain was measured in 1147 of 1488 segments (feasibility 77%); thus, this stage was not considered for the analysis of results (Figure 4).

DISCUSSION

Myocardial function has been usually evaluated by visual endocardial excursion and wall thickening assessment. Regional analysis is not easy and wall motion is visually estimated in 2D images. This qualitative interpretation has certain limitations, such as intra and interobserver variability, and issues related with the interpretation of subtle abnormalities, requiring

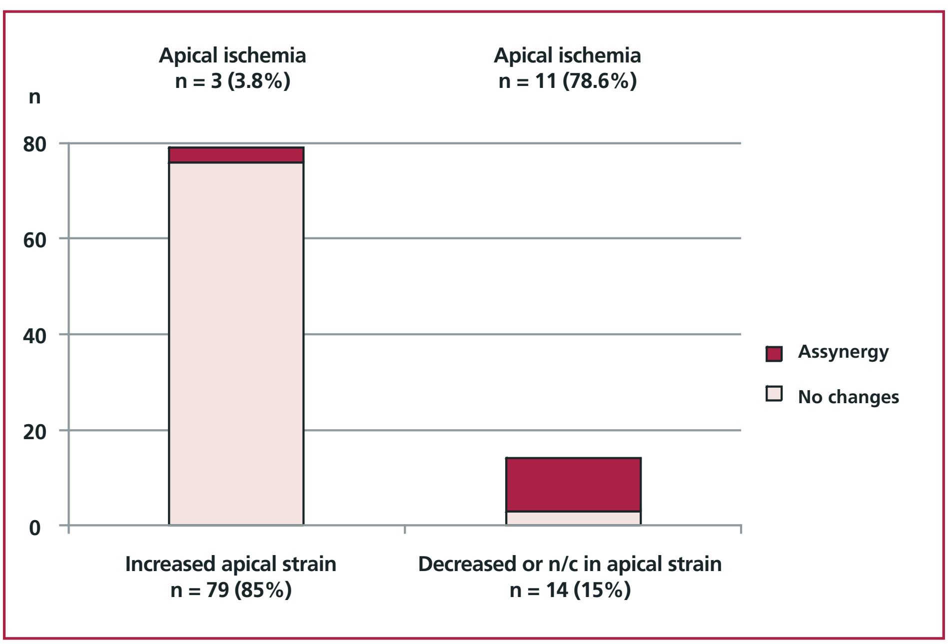


Fig. 2. Longitudinal 2D strain in the apical segments. The value of 2D strain in the apical segments increased in 79 (85%) of the 93 patients evaluated; only 3 of these patients (3.8%) developed new wall motion abnormalities in the same region, while in the 14 patients in whom longitudinal 2D strain in the apical segments did not increase or even decreased, 11 (78.6%) presented apical ischemia confirmed by visual analysis (sensitivity 79%, specificity 96%; p = 0.0001). n: Number of patients. n/c: no change

Fig. 3. Longitudinal 2D strain in the inferior, posterior and lateral segments (I-P-L). Among the 53 patients with increased 2D strain in the inferior, posterior and/or lateral segments, 6 (11.3%) presented wall motion abnormalities in the same sites; in the 40 patients in whom 2D strain did not increase, 8 (20%) presented transient dyssynergies visually detected in the same region (sensitivity 43%, specificity 41%). n: number of patients. n/c: No changes

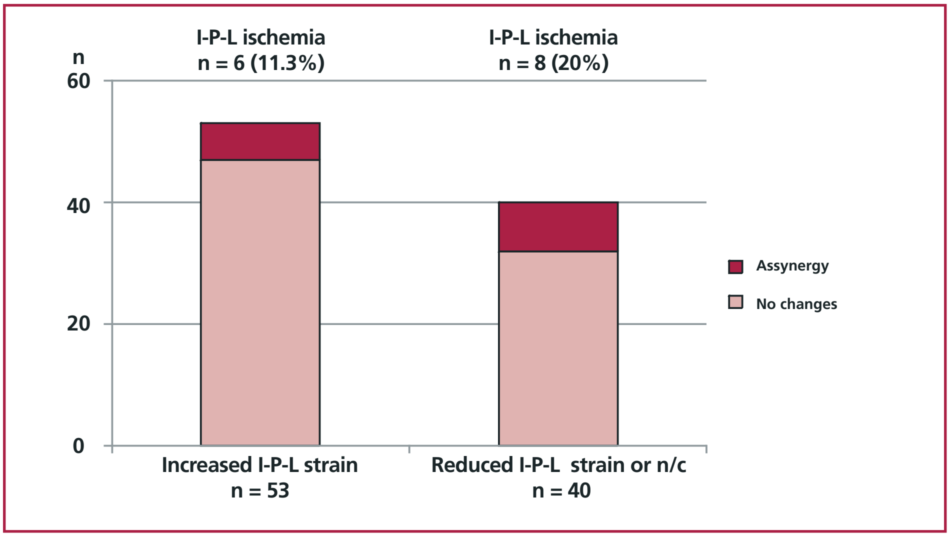
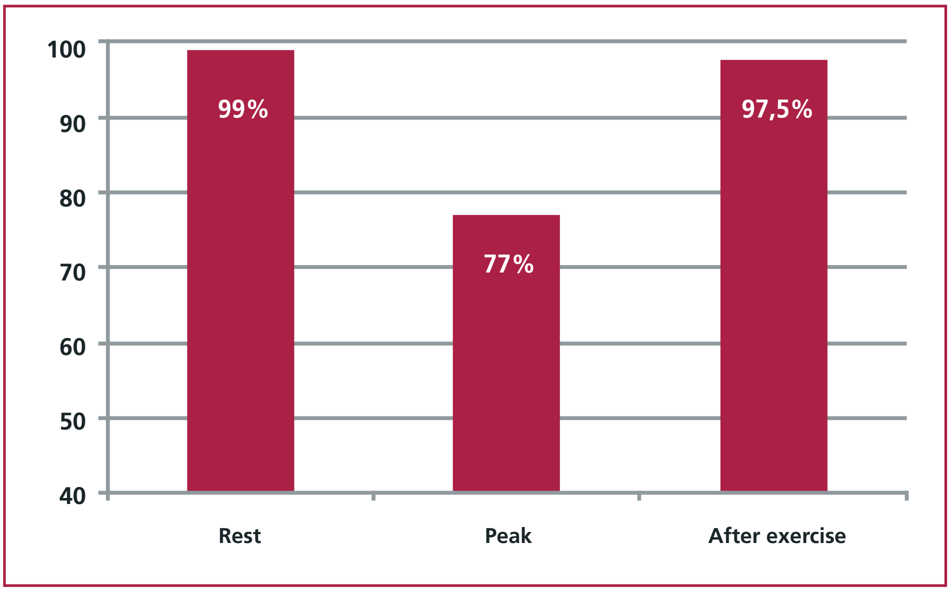


Fig. 4. Feasibility of longitudinal 2D strain during exercise (expressed as percentages). The software could visualize 1472 of 1488 segments at rest (feasibility 99%) and 1452 after exercise (feasibility 97.5%) Peak exercise was not considered for the analysis of 2D strain due to low feasibility of segmental wall motion analysis (77%).



significant experience. It is useful to remember that the visual estimation of wall motion is best appreciated with radial strain, while contractility depends mostly on the deformation of longitudinal fibers with spiral orientation. Strain is defined as the ratio of the change in length with respect to the original length or the percent change from the original dimension. Non-Doppler 2D strain imaging is a novel technique that analyzes motion by tracking speckles (natural acoustic markers) that are equally distributed throughout the myocardium. Each speckle can be identified and followed accurately from frame to frame in order to evaluate the magnitude and direction of local wall motion. Tissue velocity, strain (deformation) and strain rate (local rate of deformation per unit time) can be calculated from 2-dimensional echocardiography imaging. Non-Doppler 2D strain imaging has the advantage of being simple to perform and can be rapidly interpreted. It requires only one cardiac cycle and images are acquired in 3 views. Because it is not based on tissue Doppler measurements, images are angle independent and may be applied to all the myocardial segments. Its results are validated by sonomicrometry and tagged magnetic resonance imaging. (1)

According to documented information, longitudinal 2D strain during stress echocardiography using vasodilators does not produce significant increases in HR. Our team reported a pioneering study comparing the simultaneous analysis of 2D strain, coronary flow reserve and wall motion during dipyridamole stress echocardiography versus single-photon emission computed tomography (SPECT) scan. The study demonstrated that longitudinal 2D strain was a quantitative and feasible method, as effective as CFR and superior to visual wall motion analysis to detect myocardial ischemia in the left anterior descending coronary artery territory. (1) The usefulness of longitudinal 2D strain with adenosine for the diagnosis of viability has also been reported. (4)

The role of longitudinal 2D strain to detect ischemia at elevated HR has not been clearly established. Dobutamine stress echocardiography has been used for the evaluation of ischemia and viability in studies with limited number of patients or in experimental research, (5-9) but to the best of our knowledge, no studies evaluating the use of longitudinal 2D strain for the diagnosis of myocardial ischemia during exercise stress echocardiography have been performed.

In the present work, the feasibility of longitudinal 2D deformation analysis at rest and immediately after exercise was high (99% and 97.5%, respectively). Lack of increase or reduction of longitudinal 2D deformation in the apical segments was consistent with the presence of ischemia visually detected in 78.6% of the studies, while in 96.2% of the cases in which ischemia was not detected by wall motion criteria, apical deformation increased.

It is assumed that elevated heart rates were responsible of the lack of specificity in the farther inferior, posterior and lateral basal and mid segments. Several mechanisms could explain this behavior. We know that lateral resolution is reduced when the field depth increases. If lateral resolution is reduced, the resulting image is blurred and lateral speckles cannot be easily tracked. In addition, tracking the basal and mid segments is also more difficult due to the translational movement of the heart during exercise. (13) When HR is high, the change from frame to frame is abrupt; the independence of the angle starts to disappear with a lower line density (information) which can track the near field but not the farther field. It is expected that these limitations may be overcome in a near future, with microprocessors capable of analyzing large data volume and with transducers with greater number of micro-crystals providing more density of information. In this way, excellent image quality may be obtained despite high HR which is critical for deformation analysis.

Of importance, the use of this new technique is not intended to replace visual analysis of regional wall motion; on the contrary, it adds important information that is equivalent to that of CFR. (14-17) Both parameters, wall motion and longitudinal 2D strain, should be considered additive and complementary methods rather than alternative techniques during stress echocardiography. The availability of a relatively simple, objective and rapid method is important in echo-stress laboratories, where time is limited.

In an Editorial by Eugenio Picano published in 2010 in the Revista Argentina de Cardiología, (18) about the previously mentioned study performed by our group (1), the author identified the three most important periods of stress echocardiography: the initial period at the beginning of the '80s with 2D echo, the second at the end of the '90s during which 2D echo was combined with transthoracic echocardiography with drugs for the evaluation of CFR, and the current period corresponding to the "third generation" of stress echo with the advent of quantitative evaluation of wall motion through advanced technology systems that translate the data into numbers and transfer them to a bull's-eye diagram.

Study limitations

The study was conducted in a single center, with a small number of patients. Wall motion analysis was qualitative and subjective, performed by echocardiography operators who are experts in the technique. Although the readings were not performed by a central committee, the results of the studies were reviewed and approved with the most experienced operator. The impossibility of an anatomo-functional correlation, which was not a goal of this paper, should be evaluated in future studies.

We should mention that 2D strain is a technique that depends on image quality and may produce artifacts in the presence of elevated HR, particularly in the basal sectors. At present, it cannot be considered by itself as an unequivocal marker of ischemia due to the scarce information reported.

CONCLUSIONS

The analysis of longitudinal 2D strain is feasible immediately after exercise. The lack of increase or decrease of longitudinal 2D strain in the apical segments was consistent with the presence of visually detectable ischemia. Elevated HRs were responsible for the lack of specificity in the inferior, posterior and lateral basal and mid segments. Thus, 2D strain would only help to analyze the territory irrigated by the left anterior descending coronary artery.

RESUMEN

Factibilidad y aportes del análisis de la deformación longitudinal 2D global y regional durante el eco estrés con ejercicio

Introducción

La factibilidad del análisis de la deformación longitudinal 2D en ejercicio y la contribución de su información para detectar isquemia a frecuencia cardíaca alta no están bien establecidas; si bien se han realizado estudios de eco estrés farmacológico para la evaluación de isquemia y viabilidad, no se conocen trabajos que hayan evaluado el uso de la deformación longitudinal 2D para el diagnóstico de isquemia miocárdica durante el eco estrés con ejercicio.

Objetivos

Se consideró de interés determinar la factibilidad del análisis de la deformación longitudinal 2D y evaluar su comportamiento durante el eco estrés con ejercicio.

Material y métodos

Entre febrero y marzo de 2012 se les realizó un eco estrés en camilla supina, en etapas de 150 kgm, a 93 pacientes consecutivos (59 hombres, 54,9%), edad promedio de 58,8 ± 11,8 años. Se determinó la motilidad semicuantitativa visual en condiciones basales, en el pico del ejercicio y en el posesfuerzo inmediato y se analizó la deformación longitudinal 2D de 16 segmentos en reposo y en el posejercicio inmediato mediante un algoritmo de seguimiento de marcadores acústicos (AFI: automatic functional images de GE). Simultáneamente

se evaluaron los síntomas, el electrocardiograma de 12 derivaciones y la tensión arterial en cada etapa.

Resultados

La frecuencia cardíaca basal fue de 76 ± 18 lat/min, alcanzó 133 ± 25 lat/min en el pico del ejercicio y 117 ± 15 lat/min en el posesfuerzo inmediato. Las pruebas fueron suficientes en 64 (68,8%) de los 93 pacientes evaluados; de los 29 pacientes con pruebas insuficientes, 9 fueron positivas y 20 negativas. Desarrollaron isquemia durante la prueba 21 pacientes (22,5%), diagnosticada como asinergias regionales transitorias (7 casos en territorio anterior, septal y/o apical, en otros 7 afectó las caras inferior, posterior y/o lateral, mientras que 7 pacientes tuvieron trastornos en segmentos de ambos territorios), los cuales eran más añosos (63,5 ± 8,7 vs. 57,4 ± 12,2 años; p = 0,03), con mayor antecedente de infarto de miocardio (14,3% vs. 7%; p = 0,01) y de cirugía de revascularización miocárdica (14,3% vs. 2,77%; p = 0,04) respecto de los pacientes que no desarrollaron isquemia. No se encontraron diferencias significativas en los antecedentes de hipertensión arterial, diabetes, dislipidemia y tabaquismo. El valor de la deformación longitudinal 2D apical se incrementó en 79 (85%) de los 93 pacientes evaluados, en los que solo 3 (3,8%) presentaron trastornos contráctiles en la misma región, mientras que de los 14 pacientes en los que la deformación longitudinal 2D apical no aumentó o disminuyó, 11 (78,6%) presentaron isquemia apical visualmente confirmada (sensibilidad 79%, especificidad 96%; p = 0,0001). De los 53 pacientes en los que se incrementó el valor de la deformación longitudinal 2D inferior, posterior y/o lateral, 6 (11,3%) presentaron trastornos contráctiles homozonales, mientras que de los 40 pacientes en los que no aumentó la deformación longitudinal 2D, en 8 (20%) se constataron visualmente asinergias transitorias en la misma región (sensibilidad 43%, especificidad 41%). La deformación longitudinal 2D se pudo evaluar en 1.472 de 1.488 segmentos en el reposo (factibilidad 99%), en 1.452 en el posesfuerzo (factibilidad 97,5%) y en 1.147 de 1.488 (77%) en el pico del esfuerzo (esta etapa no se consideró para el análisis).

Conclusiones

El análisis de la deformación longitudinal 2D resultó factible en el posesfuerzo inmediato. La falta de aumento o la disminución en la deformación longitudinal 2D de los segmentos apicales fueron concordantes con presencia de isquemia detectada visualmente. Las frecuencias cardíacas altas fueron responsables de la obtención de resultados poco específicos en los segmentos inferoposterolaterales basales y mediales, por lo que el strain 2D longitudinal solo sería de ayuda para analizar territorio irrigado por la arteria descendente anterior.

Palabras clave > Ecocardiograma de estrés - Enfermedad coronaria - Isquemia miocárdica Evaluación de riesgos

Conflicts of interest

None declared.

REFERENCES

1. Lowenstein J, Darú V, Amor M, Carlessi A, Descalzo M, Zambrana G et al. Simultaneous Analysis of Two-Dimensional Strain, Coronary Flow Reserve and Wall Motion during Dipyridamole Stress Echocardiography. Comparative Outcomes.. Rev Argent Cardiol 2010;78:499-506.

2. Moonen M, Lancellotti P, Zacharakis D, Pierard L. The value of 2D strain imaging during stress testing. Echocardiography 2009;26:307-14. http://doi.org/cb5wd6

3. Cianciulli T, Prezioso H, Lax J. Nuevas técnicas en ecocardiografía. 1.a ed. 2012. Cap 8: Enfermedad coronaria. p. 161.

4. Ran H, Zhang PY, Fang LL, Ma XW, Wu WF, Feng WF. Clinic value of two-dimensional speckle tracking combined with adenosine stress echocardiography for assessment of myocardial viability. Echocardiography 2012;29:688-94. http://doi.org/qxr

5. Reant P, Labrousse L, Lafitte S, Bordachar P, Pillois X, Tariosse L, et al. Experimental validation of circumferential, longitudinal, and radial 2-dimensional strain during dobutamine stress echocardiography in ischemic conditions. J Am Coll Cardiol 2008;51:149-57. http://doi.org/frgd5x

6. Hanekom L, Cho GY, Leano R, Jeffriess L, Marwick TH. Comparison of two-dimensional speckle and tissue Doppler strain measurement during dobutamine stress echocardiography: an angiographic correlation. Eur Heart J 2007;28:1765-72. http://doi.org/ds4q7g

7. Yu Y, Villarraga HR, Saleh HK, Cha SS, Pellikka PA. Can ischemia and dyssynchrony be detected during early stages of dobutamine stress echocardiography by 2-dimensional speckle tracking echocardiography? Int J Cardiovasc Imaging 2013;29:95-102. http://doi.org/qxs

8. Ng AC, Sitges M, Pham PN, Tran da T, Delgado V, Bertini M, et al. Incremental value of 2-dimensional speckle tracking strain imaging to wall motion analysis for detection of coronary artery disease in patients undergoing dobutamine stress echocardiography. Am Heart J 2009;158:836-44. http://doi.org/b6h2wn

9. Bansal M, Jeffriess L, Leano R, Mundy J, Marwick TH. Assessment of myocardial viability at dobutamine echocardiography by deformation analysis using tissue velocity and speckle-tracking. JACC Cardiovasc Imaging 2010;3:121-31. http://doi.org/fdt65d

10. Sicari R, Nihoyannopoulos P, Evangelista A, Kasprzak J, Lancellotti P, Poldermans D, et al; European Association of Echocardiography. Stress echocardiography expert consensus statement: European Association of Echocardiography (EAE) (a registered branch of the ESC). Eur J Echocardiogr 2008;9:415-37. http://doi.org/dvxvq8

11. Armstrong WF, Pellikka PA, Ryan T, Crouse L, Zoghbi WA. Stress echocardiography: recommendations for performance and interpretation of stress echocardiography. Stress Echocardiography Task Force of the Nomenclature and Standards Committee of the American Society of Echocardiography. J Am Soc Echocardiogr 1998;11:97-104. http://doi.org/d7njcn

12. Pellikka PA, Nagueh SF, Elhendy AA, Kuehl CA, Sawada SG; American Society of Echocardiography. American Society of Echocardiography recommendations for performance, interpretation, and application of stress echocardiography. J Am Soc Echocardiogr 2007;20:1021-41. http://doi.org/bn7jkf

13. Stoylen A. Measurements of strain and strain rate by ultrasound. Norwegian University of Science and Technology.

14. Lowenstein J, Tiano C, Marquez G, Presti C, Quiroz C. Simultaneous analysis of wall motion and coronary flow reserve of the left anterior descending coronary artery by transthoracic Doppler echocardiography during dipyridamole stress echocardiography. J Am Soc Echocardiogr 2003;16:607-13. http://doi.org/d2g25c

15. Caniggia C, Lowenstein Haber D, García A, Amor M, Casso N, Porley C y cols. El grado de reducción de la reserva coronaria es la llave pronóstica del eco estrés farmacológico (resumen). Rev Argent Cardiol 2011;79 (Suplemento 3):100.

16. Rigo F, Cortigiani L, Pasanisi E, Richieri M, Cutaia V, Celestre M, et al. The additional prognostic value of coronary flow reserve on left anterior descending artery in patients with negative stress echo by wall motion criteria. A Transthoracic Vasodilator Stress Echocardiography Study. Am Heart J 2006;151:124-30. http://doi.org/b2rx3k

17. Cortigiani L, Rigo F, Sicari R, Gherardi S, Bovenzi F, Picano E. Prognostic correlates of combined coronary flow reserve assessment on left anterior descending and right coronary artery in patients with negative stress echocardiography by wall motion criteria. Heart 2009;95:1423-8. http://doi.org/fkwf59

18. Picano E. ¿Es el comienzo del eco estrés de tercera generación? (editorial). Rev Argent Cardiol 2010;78:474-5