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Two-dimensional speckle tracking echocardiography in heart transplant patients: three-year follow-up of deformation parameters and ejection fraction derived from transthoracic echocardiography

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Aims Non-invasive diagnosis of allograft dysfunction is a major objective in the management of heart transplant (HTX) recipients. Speckle tracking echocardiography (STE) permits comprehensive assessment of myocardial function. It is well established that deformation indices are reduced in HTXs when compared with control subjects. However, it is unclear if the reduction in strain is a chronic progressive phenomenon in HTX patients.

Method and results Follow-up transthoracic echocardiography (TTE) was performed 3 years after initial TTE in 20 'healthy' HTX patients (13.2 years post-transplantation at time of follow-up) with normal ejection fraction and angiographically ruled out allograft vasculopathy. Grey-scale apical views were recorded and stored for automated offline speckle tracking (EchoPAC 7.0, GE) of the 16 segments of the left ventricle. Strain analysis was performed in 320 segments 34.3 ± 3.7 months after initial assessment. Automated tracking of myocardial deformation for determination of longitudinal systolic strain was not possible in 24 (7.5%) segments at baseline and in 32 (10.0%) segments at follow-up (P = ns). The left ventricular ejection fraction (LVEF) was 61.9 ± 8.1% at the initial examination vs. 62.8 ± 5.8% 3 years afterwards (P = ns). Global longitudinal peak systolic strain was −14.0 ± 4.0 vs. −14.4 ± 2.8%, respectively (P = ns).

Conclusion This is the first study describing follow-up deformation parameters in HTX patients undergoing STE. 'Healthy' HTX patients with normal coronary arteries and normal ejection fractions showed no deterioration of longitudinal strain values 3 years after the initial assessment. Apparently, deformation values remain stable over the years as long as the LVEF is preserved.

Keywords Speckle tracking echocardiography • Heart transplantation • Follow-up • Deformation parameters

Introduction

Accurate evaluation of left ventricular systolic function has important therapeutic and clinical implications in the management of heart transplant recipients. Conventionally, left ventricular ejection fraction (LVEF) is calculated based on the biplane Simpsons's rule algorithm. However, this method which includes a visual definition of the endocardial border is often rather subjective, especially when the endocardial border cannot be clearly defined. In contrast, two dimensional (2D) speckle tracking echocardiography (STE) allows user independent assessment of the myocardial function.[1–3] Strain analysis is a sensitive and reproducible technique for the non-invasive quantification of regional and global myocardial contractility and has been shown to reveal changes in systolic

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function at an earlier sub-clinical stage than measurements of the ejection fraction.[4,5] Especially longitudinal peak systolic strain which assesses the motions from the base to the apex of the myocardium has been described to be a sensitive index for detection of early left ventricular dysfunction.[6–9]

Recent publications revealed that STE-derived strain analysis is feasible and practical in heart transplant subjects.[10,11] 'Normal' global strain values in healthy transplant patients 1 year after transplantation were defined by Saleh *et al.*,[11] while our group described normal regional and global deformation values in transplant patients 10 years after transplantation.[10] Both of these studies demonstrated that even though 'healthy' transplant recipients without coronary artery disease exhibit normal global systolic function, deformation indices are reduced. Hence, it may be assumed that strain analysis may have prognostic implications by detecting early changes in cardiac graft function in periodic examinations. However, it is unclear if the reduction in strain is a chronic process and deteriorates further over years, or if this is the immediate result of transplantation. Hence, it is unclear if these patients exhibit altered strain values in serial follow-up analysis. This information would be of importance when interpreting strain values in the setting of graft dysfunction. Therefore, the objective of our study was to assess and compare baseline and 3-year follow-up strain values in 'healthy' heart transplant patients with normal ejection fraction and angiographically ruled out allograft vasculopathy.

Methods

We prospectively reviewed the electronic medical records of heart transplant patients who underwent transthoracic echocardiography (TTE) between November 2007 and December 2008. Patients were excluded if they had histologic evidence of acute rejection, reduced LVEF (<55%), significant coronary vasculopathy (epicardial coronary narrowing >50% assessed by coronary angiography), significant valvular disease, major cardiac events since baseline examination, or poor echocardiographic image quality. Twenty cardiac allograft recipients were enrolled in the study protocol and 3-year follow-up TTE was performed in these 'healthy' heart transplant patients.

Twenty-two age-matched healthy subjects without history of any ischaemic or cardiac disease served as controls.

Standard transthoracic echocardiography

All images were obtained with a standard ultrasound machine (Vivid 7 digital ultrasound system, General Electric, Inc.) with acquisition of apical four-, three-, and two-chamber views using the highest possible frame rates (between 55 and 90 frames/s). Imaging was performed by the same investigator at baseline and at follow-up.

Global and segmental longitudinal strain values were determined offline (Echo Pac system, General Electric, Inc. as described previously).[10] If automated tracking quality was poor, the operator could manually correct the contours. Strain results were displayed as a bull map.

The ejection fraction was calculated with the biplane Simpson's method from apical four- and two-chamber views.

Statistics

Data were expressed as frequencies or percentages for discrete variables and means ± standard deviation for continuous variables. Comparisons between baseline and follow-up were made using the χ^2 test for categorical variables and Student's *t*-test for continuous variables. Statistical analysis was performed with statistics software JMP, SAS Institute, Inc., Cary, NC, USA. Statistical significance was considered if $P \leq 0.05$.

Results

Clinical data

Overall we enrolled 20 heart transplant patients [18 male, 2 female; 158.5 ± 73.8 months (13.2 years) post-transplantation at time of follow-up] with mean age, 68.0 ± 9.2 years and body mass index, 27.0 ± 3.6. Follow-up echocardiography was performed at 34.3 ± 3.7 months after initial examination. The heart rate at baseline was 84.9 ± 11.2 vs. 81.3 ± 12.4 bpm at follow-up (P = ns), plasma creatinine 1.4 ± 0.3 vs. 1.4 ± 0.3 mg/dL, respectively (P = ns), and pro-Brain-type Natriuretic Peptide (pBNP) 681.5 ± 649.5 vs. 673.1 ± 922.3 pg/mL, respectively (P = ns). Of the total patients, 63.2% suffered from hypertension, 21.1% from diabetes.

There were no significant differences between baseline values of transplant patients and control subjects regarding age or body mass index (64.2 ± 10.5 years and 26.6 ± 2.6, respectively in control subjects). While 66.7% control subjects suffered from hypertension, none from diabetes.

Significant differences between baseline values of the transplant patients and control subjects were found for the heart rate (84.9 ± 11.2 vs. 68.7 ± 12.3, respectively, $P < 0.01$), plasma creatinine (1.4 ± 0.3 vs. 1.0 ± 0.2 mg/dL, respectively, $P < 0.01$), and pBNP (681.5 ± 649.5 vs. 134.8 ± 102.2 pg/mL, respectively, $P < 0.01$).

Echocardiographic data

Strain analysis was performed in 320 segments at baseline and at follow-up examination. Automated tracking of myocardial deformation for determination of longitudinal systolic strain was not possible in 24 (7.5%) segments at the time of the initial examination and in 32 (10.0%) segments at follow-up (P = ns). Manual correction of contours was performed in all these segments. The percentage of individual segments which could be analysed is listed in *Table 1*. No significant difference was found regarding feasibility of automated tracking within the individual segments between initial examination and follow-up. The basal posterior segments and the basal lateral segments most frequently required manual correction of contours (25.0% at baseline and 25.0% at follow-up in the basal posterior segments; 20 and 30%, respectively, in the basal lateral segments), followed by basal anterior segments (20% manual correction both at baseline and at follow-up).

Global longitudinal peak systolic strain (GLPSS) was −14.0 ± 4.0% at baseline vs. −14.4 ± 2.8% at the time of the follow-up examination (P = ns) (*Figure 1*). Segment-based differences are listed in *Table 2*. No significant difference was found between baseline and follow-up deformation parameters in any of the 16 segments.

The LVEF was 61.9 ± 8.1% at the time of the initial examination vs. 62.8 ± 5.8% 3 years afterwards (P = ns) (*Figure 1*).

GLPSS was significantly lower in transplant patients at baseline than in control subjects (−14.0 ± 4.0 vs. −18.0 ± 3.2%,

Table 1 Automated analysis of regional strain by Speckle Tracking Echocardiography

	Baseline, control subjects, %	Baseline, heart transplants, %	Follow-up, heart transplants, %
Basal anterior wall	80.0	90.0	80.0
Mid anterior wall	85.0	90.0	95.0
Apical anterior wall	100.0	90.0	90.0
Basal anterior septal wall	100.0	95.0	80.0
Mid-anterior septal wall	100.0	100.0	100.0
Apical septal wall	100.0	95.0	90.0
Basal inferoseptal wall	90.0	100.0	95.0
Mid-inferoseptal wall	100.0	100.0	100.0
Basal inferior wall	75.0	100.0	95.0
Mid-inferior wall	90.0	100.0	95.0
Infero-apical wall	90.0	100.0	100.0
Basal posterior wall	80.0	85.0	75.0
Mid-posterior wall	100.0	85.0	95.0
Basal lateral wall	65.0	90.0	70.0
Mid-lateral wall	80.0	95.0	85.0
Apicolateral wall	80.0	95.0	95.0

Percentage of segments in which automated tracking of the contours was possible without the need of manual correction.

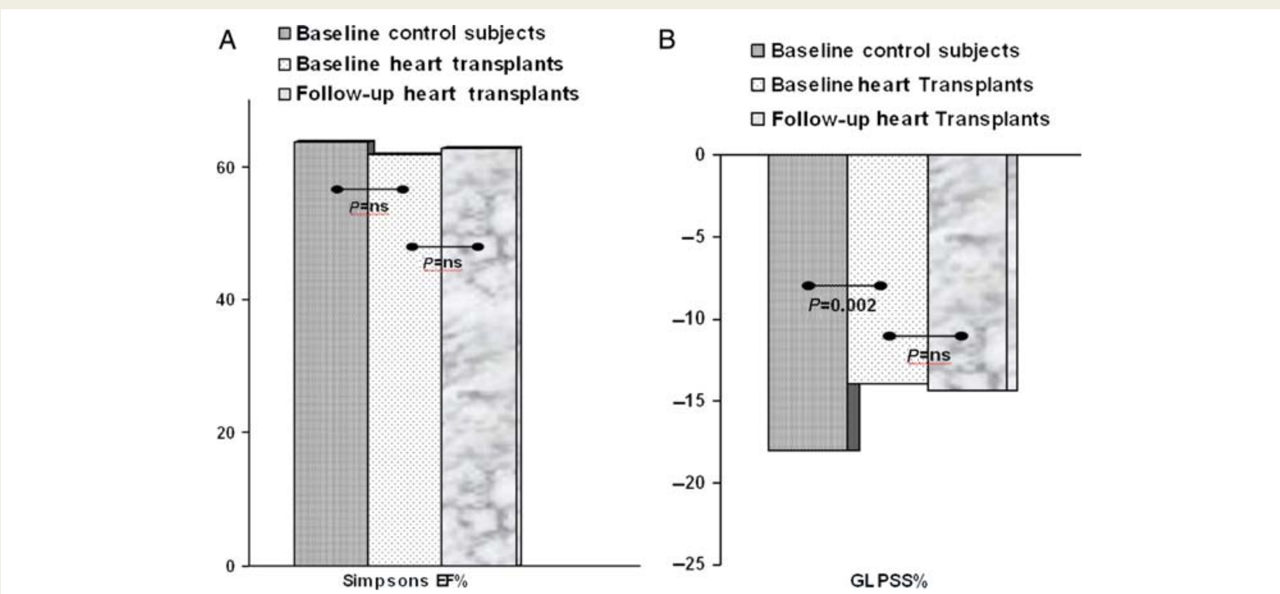

Figure 1 (*A*) Simpson's ejection fraction (EF%) and (*B*) global longitudinal peak systolic strain (GLPSS%).

respectively, $P = 0.002$). Segment-based results for control subjects are listed in *Tables 1 and 2*. There was no significant difference in the LVEF between transplant patients at baseline and control subjects (61.9 ± 8.1 vs. 63.7 ± 6.7%, respectively) (*Figures 1 and 2*).

Discussion

Speckle tracking 2D echocardiography is a new technology, which permits comprehensive assessment of myocardial contractility.[1,3,8,9] The spectrum of potential clinical applications is very wide since it is able to detect early systolic dysfunction. Previous studies have shown that systolic strain values are reduced in transplant recipients.[10,11]

In our previous study, we established STE-derived global and regional strain in long-term heart transplant recipients.[10] We found significantly reduced deformation parameters in healthy transplant patients in comparison with control subjects (GLPSS: −13.9 vs. −17.4%, respectively). These findings were in accordance with

Table 2 Segmental longitudinal peak systolic strain

	Baseline, control subjects (%) (column 1)	Baseline, heart transplants (%), (column 2)	Follow-up, heart transplants (%) (column 3)	*P*-value (column 1 vs. column 2)	*P*-value (column 2 vs. column 3)
Basal anterior wall	−17.7 ± 6.0	−11.5 ± 9.5	−11.6 ± 8.8	0.05	0.97
Mid-anterior wall	−15.5 ± 5.6	−11.1 ± 8.4	−12.2 ± 5.8	0.1	0.61
Apical anterior wall	−17.3 ± 5.6	−14.9 ± 6.5	−12.4 ± 8.4	0.2	0.32
Basal anterior septal wall	−18.2 ± 9.4	−12.4 ± 7.1	−10.3 ± 8.0	0.06	0.40
Mid-anterior septal wall	−20.3 ± 5.5	−16.0 ± 4.0	−13.7 ± 6.4	0.01	0.22
Apical septal wall	−20.5 ± 4.5	−16.9 ± 4.3	−17.0 ± 5.1	0.03	0.94
Basal inferoseptal wall	−17.7 ± 3.2	−14.4 ± 4.0	−14.1 ± 7.3	0.03	0.79
Mid-inferoseptal wall	−19.6 ± 2.3	−16.7 ± 3.1	−17.6 ± 4.6	<0.01	0.49
Basal inferior wall	−21.0 ± 3.8	−16.8 ± 4.9	−15.2 ± 6.8	0.02	0.44
Mid-inferior wall	−21.2 ± 3.5	−16.0 ± 7.2	−14.9 ± 6.4	0.02	0.64
Infero-apical wall	−18.9 ± 8.2	−16.5 ± 5.8	−15.8 ± 4.9	0.3	0.70
Basal posterior wall	−18.8 ± 7.3	−13.8 ± 8.6	−10.8 ± 11.1	0.09	0.39
Mid-posterior wall	−18.5 ± 4.6	−13.8 ± 6.5	−13.7 ± 6.2	0.03	0.93
Basal lateral wall	−17.0 ± 7.0	−12.8 ± 9.5	−13.5 ± 5.9	0.2	0.82
Mid-lateral wall	−13.5 ± 6.9	−14.1 ± 6.7	−13.1 ± 6.4	0.8	0.66
Apicolateral wall	−15.8 ± 5.5	−15.9 ± 4.5	−16.5 ± 4.8	0.9	0.72

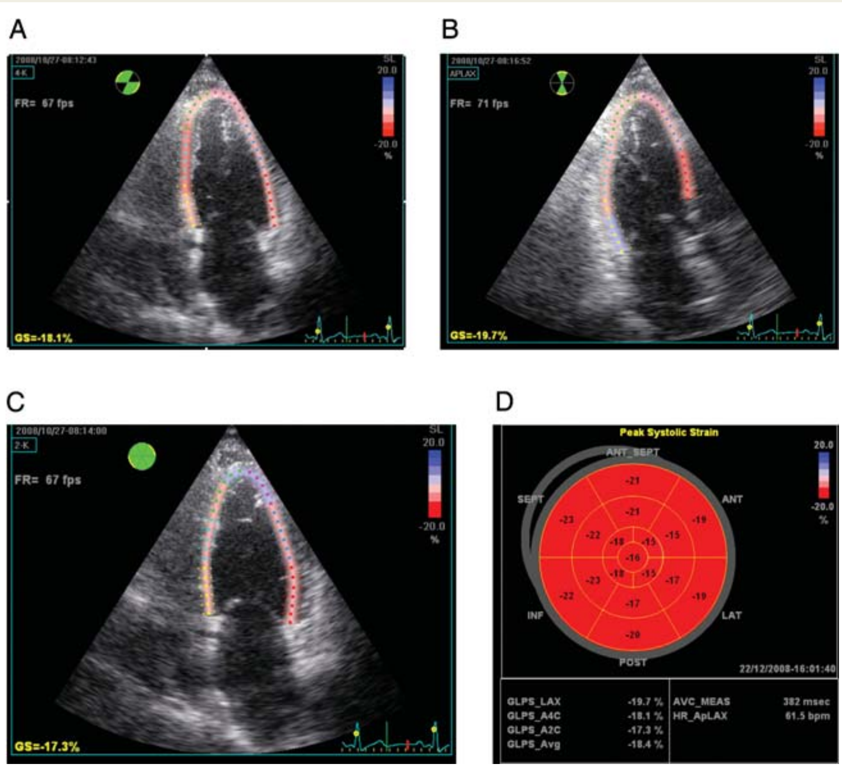

Figure 2 Speckle tracking two-dimensional strain imaging. Longitudinal global and regional strain images. Apical (*A*) four-chamber view, (*B*) three-chamber view (*C*) two-chamber view, and (D) Bull's-eye map showing segmental longitudinal peak systolic strain.

those of Saleh *et al*.,[11] where GLPSS values 1 year after transplantation were very similar to our GLPSS values 10 years after transplantation (−13.4 vs. −13.9%, respectively). Similar to our study, deformation parameters were reduced in their transplant patient cohort despite the normal LVEF. Thus, these reduced parameters may be interpreted as 'normal' strain values in 'healthy' transplant patients.

However, it is unclear if reduction in strain is a dynamic progressive process, or if this is the result of transplantation and denervation. This information would be of value since reduction in strain has also been shown to denote rejection and vasculopathy.[12,13] The lack of serial STE reference values in heart transplant patients is one of the reasons that strain has not been used to follow-up patients after heart transplantation.

Initially, myocardial deformation imaging was performed with tissue Doppler imaging (TDI).[14] TDI is accepted as a sensitive and accurate echocardiographic tool for quantitative assessment of cardiac function.[15,16] Several parameters obtained from tissue Doppler velocity analysis have been demonstrated to be useful for the diagnosis and prediction of long-term prognosis in major cardiac diseases.[17,18] It has also been shown that in heart transplant recipients TDI wall motion assessment is useful for early detection of rejection[12] and relevant transplant coronary artery disease.[13] Also its usefulness for post-transplant follow-up monitoring of cardiac function has been investigated.[19] Comparing the deformation parameters obtained from patients who underwent routine endomyocardial biopsies, Marciniak *et al*.[19] found significantly lower longitudinal peak systolic strain values in patients with acute rejection ≥grade 1B in comparison with those with biopsies graded between 0 and 1A. In patients without visible alterations in left ventricular kinetics, TDI-based strain imaging also appeared reliable for non-invasive prediction of non-significant transplant vasculopathy of main epicardial coronary arteries.[20] Eroglu *et al*.[20] found that strain and strain rate imaging in combination with dobutamine stress echocardiography is useful for early detection of transplant vasculopathy before the development of relevant stenoses detectable with conventional angiography. Eroglu *et al*.[21] previously also defined TDI-based 'normal' regional and global strain values in heart transplant patient cohort. However, due to limitations such as angle dependency (one-dimensional assessment), time consuming steps for data acquisition or the necessity of expert readers TDI-derived assessment of deformation values has found only limited use in clinical practice.[22] In contrast, STE is a more robust technique which is angle-independent and permits 2D assessment of strain parameters.[23] Because of association of velocity and distance by factor time, strain measurements obtained by these two different imaging techniques correlate well even though the deformation values are not the same (2D-strain imaging gives lower strain values).[24]

There are few reports on the use of STE-based strain parameters in heart transplant patients.[25,10,11] These studies clearly show that GLPSS strain is reduced in heart transplant recipients despite preserved ejection fraction. However, it is unclear how strain values develop over the years in these patients. This present paper is the first to report such follow-up strain values assessed by STE in 'healthy' heart transplant patients ('healthy' being defined as: normal resting ejection fraction, no coronary artery disease, no evidence for rejection, and absence of any major cardiac events). In this study, we performed follow-up STE assessments in patients 3 years after initial assessment. In these patients, we found no significant change/deterioration of the GLPSS over time. There were also no significant changes in segmental longitudinal peak systolic strain. Strain values were obtained in at least 90% of all segments both at baseline and at follow-up, demonstrating that the 2D STE technique is feasible and practical for most transplant patients.

Recent studies revealed strain values to be abnormal despite preserved LVEF not just in transplant patients, but also in patients with early stage chronic kidney disease[26] or in diabetic patients, even in the absence of hypertension.[27] Strain measurements also seem to be very useful for the assessment of myocardial damage after myocardial infarction, evaluation of myocardial revascularization efficiency and prediction of patient outcome with heart failure.[28,29] In a study on 137 consecutive patients with suspected congestive heart failure of different aetiologies, it was also shown that mean longitudinal left ventricular strain is closely related to plasma BNP levels.[30] This relation between pBNP and deformation parameters is also verified by this current study, where we found similar values of elevated pBNP with similar values of reduced deformation parameters despite normal LVEF both at baseline as well as at follow-up.

Our present study verifies that strain values remain stable over a longer time period in healthy transplant patients with normal left ventricular function and ruled out allograft vasculopathy. We assume that heart transplant patients exhibit reduced strain soon after the transplantation, but then stay constant as long as the patients remain 'healthy'. Thus, early assessment of 'normal' strain values in all transplant recipients could serve as a reference, which could allow identification of post-transplant complications of different aetiologies. By means of this non-invasive technique, one could presume in advance whether a patient has a possibility of coronary vasculopathy or ongoing rejection, and might reduce the frequency of biopsy and coronary angiography in stable patients. In case of a deterioration of the 'baseline' STE values one could optimize medical treatment or simply pay more attention to the clinical state of the patient. STE seems to have the potential for such a non-invasive follow-up.

Limitations

Image quality and general limitations of speckle tracking echocardiography

The importance of high image quality is a major limitation for routine clinical applicability of STE, which is still a young technique where several limitations have yet not been sufficiently addressed (differences between vendors, problem of imaging the entire heart, endocardial tracing).[31] It is also important to know that different tracking algorithms potentially produce different results and therefore it should be kept in mind that a periodical update of the software package conceivably influences reference values. However, despite these limitations, we were able to successfully perform STE in 92.5 and 90% of all segments (baseline and follow-up, respectively).

Denervation

The heart of a transplanted patient is denervated. This usually results in a sinus tachycardia which can influence strain assessment. However, in our patient cohort the heart rate remained constant over the 3 years so that the comparison of strain values was not influenced.

Conclusion

In conclusion, our results demonstrate that longitudinal deformation parameters determined with STE can be used to monitor myocardial function in heart transplant patients. The study shows that the initial reduction in strain remains constant over a period of 3 years in 'healthy' transplant subjects. We propose that 'baseline' strain values should be obtained in all transplant patients soon after the transplantation so that these values can later be used as a reference for early detection of myocardial abnormalities..

Conflict of interest: none declared.

References

1. Leitman M, Lysyansky P, Sidenko S, Shir V, Peleg E, Binenbaum M *et al.* Two-dimensional strain-a novel software for real-time quantitative echocardiographic assessment of myocardial function. *J Am Soc Echocardiogr* 2004;**17**:1021–9.
2. Reisner SA, Lysyansky P, Agmon Y, Mutlak D, Lessick J, Friedman Z. Global longitudinal strain: a novel index of left ventricular systolic function. *J Am Soc Echocardiogr* 2004;**17**:630–3.
3. Leitman M, Lysyansky P, Gurevich J, Friedman Z, Sucher E, Rosenblatt S *et al.* Real-time quantitative automatic assessment of left ventricular ejection fraction and regional wall motion by speckle imaging. *Isr Med Assoc J* 2007;**9**:281–5.
4. Weidemann F, Kowalski M, D'hooge J, Bijnens B, Sutherland GR. Doppler myocardial imaging. A new tool to assess regional inhomogeneity in cardiac function. Review. *Basic Res Cardiol* 2001;**96**:595–605.
5. D'hooge J, Heimdal A, Jamal F, Kukulski T, Bijnens B, Rademakers F *et al.* Eur J Echocardiogr. Regional strain and strain rate measurements by cardiac ultrasound: principles, implementation and limitations. Review. *Eur J Echocardiogr* 2000;**1**:154–70.
6. D'Andrea A, Cocchia R, Caso P, Riegler L, Scarafile R, Salerno G *et al.* Global longitudinal speckle-tracking strain is predictive of left ventricular remodeling after coronary angioplasty in patients with recent non-ST elevation myocardial infarction. *Int J Cardiol* 2010 Sep 13. [Epub ahead of print].
7. Tsai WC, Liu YW, Huang YY, Lin CC, Lee CH, Tsai LM. Diagnostic value of segmental longitudinal strain by automated function imaging in coronary artery disease without left ventricular dysfunction. *J Am Soc Echocardiogr* 2010;**23**:1183–9.
8. Mignot A, Donal E, Zaroui A, Reant P, Salem A, Hamon C *et al.* Global longitudinal strain as a major predictor of cardiac events in patients with depressed left ventricular function: a multicenter study. *J Am Soc Echocardiogr* 2010;**23**:1019–24.
9. Choi JO, Cho SW, Song YB, Cho SJ, Song BG, Lee SC *et al.* Longitudinal 2D strain at rest predicts the presence of left main and three vessel coronary artery disease in patients without regional wall motion abnormality. *Eur J Echocardiogr* 2009;**10**:695–701.
10. Syeda B, Höfer P, Pichler P, Vertesich M, Bergler-Klein J, Roedler S *et al.* Two-dimensional speckle tracking echocardiography in long-term heart transplant patients: a study comparing deformation parameters and ejection fraction derived from echocardiography and multislice computed tomography. *Eur J Echocardiogr* 2011;Jun 2. [Epub ahead of print].
11. Saleh HK, Villarraga HR, Kane GC, Pereira NL, Raichlin E, Yu Y *et al.* Normal left ventricular mechanical function and synchrony values by speckle-tracking echocardiography in the transplanted heart with normal ejection fraction. *J Heart Lung Transplant* 2010;Dec 28. [Epub ahead of print].
12. Kato TS, Oda N, Hashimura K, Hashimoto S, Nakatani T, Ueda HI *et al.* Strain rate imaging would predict sub-clinical acute rejection in heart transplant recipients. *Eur J Cardiothorac Surg* 2010;**37**:1104–10.
13. Dandel M, Wellnhofer E, Hummel M, Meyer R, Lehmkuhl H, Hetzer R. Early detection of left ventricular dysfunction related to transplant coronary artery disease. *J Heart Lung Tranplant* 2003;**22**:1353–64.
14. Heimdal A, Stoylen A, Torp H, Skjaerpe T. Real rime strain rate imaging of the left ventricle by ultrasound. *J Am Soc Echocardiogr* 1998;**11**:1013–9.
15. Sutherland GR, Stewart MJ, Groundstroem KW, Moran CM, Fleming A, Guell-Peris FJ *et al.* Color Doppler myocardial imaging: a new technique for the assessment of myocardial function. *J Am Soc Echocardiogr* 1994;**7**:441–58.
16. Stoylen A, Heimdal A, Bjornstad K, Torp HG, Skjaerpe T. Strain rate imaging by ultrasound in the diagnosis of regional dysfunction of the left ventricle. *Echocardiography* 1999;**16**:321–9.
17. Waggoner AD, Bierig SM. Tissue Doppler imaging: a useful echocardiographic method for the cardiac sonographer to assess systolic and diastolic ventricular function. *J Am Soc Echocardiogr* 2001;**14**:1143–52.
18. Sengupta PP, Mohan JC, Pandian NG. Tissue Doppler echocardiography: principles and applications. *Indian Heart J* 2002;**54**:368–78.
19. Marciniak A, Eroglu E, Marciniak M, Sirbu C, Herbots L, Droogne W *et al.* The potential clinical role of ultrasonic strain and strain rate imaging in diagnosing acute rejection after heart transplantation. *Eur J Echocardiogr* 2007;**8**:213–21.
20. Eroglu E, D'hooge J, Sutherland GR, Marciniak A, Thijs D, Droogne W *et al.* Quantitative dobutamine stress echocardiography for the early detection of cardiac allograft vasculopathy in heart transplant recipients. *Heart* 2008;**94**:e3.
21. Eroglu E, Herbots L, Van Cleemput J, Droogne W, Claus P, D'hooge J *et al.* Ultrasonic strain/strain rate imaging: a new clinical tool to evaluate the transplanted heart. *Eur J Echocardiogr* 2005;**6**:186–95.
22. Urheim S, Edvardsen T, Torp H, Angelsen B, Smiseth OA. Myocardial strain by Doppler echocardiography. Validation of a new method to quantify regional myocardial function. *Circulation* 2000;**102**:1158–64.
23. Langeland S, D'hooge J, Wouters PF, Leather HA, Claus P, Bijnens B *et al.* Experimental validation of a new ultrasound method for the simultaneous assessment of radial and longitudinal myocardial deformation independent of insonation angle. *Circulation* 2005;**112**:2157–62.
24. Perk G, Tunick PA, Kronzon I. Non-Doppler two-dimensional strain imaging by echocardiography—from technical considerations to clinical applications. *J Am Soc Echocardiogr* 2007;**49**:1903–14.
25. Sato T, Kato TS, Kamamura K, Hashimoto S, Shishido T, Mano A *et al.* Utility of left ventricular systolic torsion derived from 2-dimensional speckle-tracking echocardiography in monitoring acute cellular rejection in heart transplant recipients. *J Heart Lung Transplant* 2011;**30**:536–43.
26. Edwards NC, Hirth A, Ferro CJ, Townend JN, Steeds RP. Subclinical abnormalities of left ventricular myocardial deformation in early-stage chronic kidney disease: the precursor of uremic cardiomyopathy? *J Am Soc Echocardogr* 2008;**21**:1293–8.
27. Ma H, Xie M, Wang J, Lü Q, Wang X, Lu X *et al.* Ultrasound speckle tracking imaging contributes to early diagnosis of impaired left ventricular systolic function in patients with type 2 diabetes mellitus. *J Huazhong Univ Sci Technolog Med Sci* 2008;**28**:719–23.
28. Cheuk-Man Y, Sanderson JE, Marwick TH, Oh JK. Tissue Doppler imaging a new prognosticator for cardiovascular diseases. *J Am Coll Cardiol* 2007;**20**:234–43.
29. Dandel M, Lehmkuhl H, Knosalla C, Suramelashvili N, Hetzer R. Strain and strain rate imaging by echocardiography—basic concepts and clinical applicability. *Curr Cardiol Rev* 2009;**5**:133–48.
30. Yoneyama A, Koyama J, Tomita T, Kumazaki S, Tsutsui H, Watanabe N *et al.* Relationship of plasma brain-type natriuretic peptide levels to left ventricular longitudinal function in patients with congestive heart failure by strain Doppler imaging. *Int J Cardiol* 2008;**130**:56–63.
31. Korinek J, Kjaergaard J, Sengupta PP, Yoshifuku S, McMahon EM, Cha SS *et al.* High spatial resolution speckle tracking improves accuracy of 2-dimensional strain measurements. *J Am Soc Echocardiogr* 2007;**20**:165–70.