Validity of acoustic quantification colour kinesis for detection of left ventricular regional wall motion abnormalities: a transoesophageal echocardiographic study†

T. HARTMANN, N. KOLEV, A. BLAICHER, C. SPISS AND M. ZIMPFER

Summary

Transoesophageal echocardiography is a sensitive monitor for intraoperative myocardial ischaemia. Colour kinesis is a new technology for echocardiographic assessment of regional wall motion based on acoustic quantification. We have examined the feasibility and accuracy of quantitative segmental analysis of colour kinesis images to provide objective evaluation of systolic regional wall motion during the perioperative period using transoesophageal echocardiography (TOE). Two-dimensional echocardiograms were obtained in the transgastric short-axis and long-axis views in 60 patients with coronary artery disease undergoing non-cardiac surgery. End-systolic colour overlays superimposed on the grey scale images were obtained with colour kinesis to colour encode left ventricular endocardial motion throughout systole. These colour-encoded images were divided into segments and compared with corresponding conventional two-dimensional images. Six hundred of a potential 720 left ventricular wall segments were of sufficient resolution for grading by experts; they diagnosed wall motion abnormalities in 61 of these segments by a conventional method. In comparing the conventional TOE method with colour kinesis, there were 60 true positives, 482 true negatives, 57 false positives and 1 false negative result. This yielded a sensitivity of 98%, specificity of 89%, positive predictive value of 51% and negative predictive value of 100%. Translational and rotational movement of the heart and papillary muscle interference were common problems accounting for false positive diagnoses. We conclude that colour kinesis provides a basis for objective and online evaluation of left ventricular regional wall motion which is a sensitive but non-specific method. It may be a useful aid for the less experienced because it can potentially direct the anaesthetist’s attention towards specific segments. (Br. J. Anaesth. 1997; 79: 482–487).

Key words


Transoesophageal echocardiography (TOE) is a sensitive and specific monitor for intraoperative myocardial ischaemia in patients with coronary artery disease. However, conventional assessment of wall motion, based on visual interpretation of endocardial excursion, is experience-dependent and subjective. To facilitate more objective evaluation of left ventricular endocardial motion, colour kinesis, a new technique based on acoustic quantification, has been developed and incorporated into a commercial ultrasound system (Hewlett-Packard Sonos 2500 and Vingmed CFM 800). Recently, Lang and colleagues reported that colour kinesis images provided accurate and quantitative diagnosis of regional wall motion abnormalities using a transthoracic approach. Therefore, we compared prospectively left ventricular segmental wall motion patterns assessed by experts with those of colour kinesis in patients at risk of myocardial ischaemia undergoing TOE during non-cardiac surgery.

Patients and methods

The study was approved by our Institutional Review Board and written informed consent was obtained from each patient. We studied 60 patients (39 males) with coronary artery disease (CAD), at risk of CAD or hypertensive heart disease, aged 42–79 yr (mean 53 yr) who were in sinus rhythm with a heart rate of 45–101 beat min⁻¹ (mean 65 (SD 14) beat min⁻¹). All patients were ASA class II of the multifactorial index of cardiac risk in non-cardiac surgery with total predictive points of 6–12. The majority was undergoing peripheral vascular surgery. Criteria for entry into the study included the presence of one of the following: (a) defined CAD, as indicated by previous myocardial infarction, typical angina or atypical angina with an ischaemic ECG response to exercise, or scintigraphic evidence of a myocardial perfusion defect; (b) high risk of CAD, suggested by previous or current vascular surgery or the presence

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of at least two of the following cardiac risk factors: age >65 yr, hypertension, current smoker, serum cholesterol >6.2 mmol litre\(^{-1}\) or diabetes mellitus. We defined a previous myocardial infarction using ECG Minnesota Code criteria. Typical angina was defined as a history of chest pain with at least three of the following four characteristics: substernal location, precipitation by exercise or stress, duration <15 min and resolution after rest or nitroglycerin treatment. Atypical angina required two of the characteristics in addition to an ischaemic ECG response to exercise. Patients were excluded if they had abnormal myocardial repolarization (e.g. left bundle branch block, digitalis effect, left ventricular hypertrophy) or non-ischaemic causes of abnormal wall motion (e.g. bundle branch block, ventricular pacing, prosthetic valve, myocarditis or infiltrative disorder of the left ventricle).\(^5\) Patients were studied at the University Hospital of Vienna between June 1994 and May 1996.

Patients were premedicated with diazepam 0.15 mg kg\(^{-1}\) i.v., 1 h before surgery. Anaesthesia was induced with fentanyl 3 \(\mu\)g kg\(^{-1}\) and thiopentone 4 \(\mu\)g kg\(^{-1}\). After orotracheal intubation facilitated by vecuronium 100 \(\mu\)g kg\(^{-1}\), the lungs were ventilated with 60% nitrous oxide in oxygen. Anaesthesia was maintained with increments of fentanyl and vecuronium with isoflurane up to 1%. A 7.5-

- \(9262\) fibroptic thermodilution catheter (American Edwards) was inserted via the subclavian vein and advanced to the distal pulmonary artery. Correct positioning for recording PCWP was confirmed by observing a clear change in the pressure waveform when the balloon was inflated, and by measuring oxygen saturation of blood at the tip of the catheter. Before induction of anaesthesia, PCWP was measured during normal respiration, and after induction it was measured while the patient’s lungs were disconnected temporarily from the ventilator.

**COLOUR KINESIS: DESCRIPTION OF THE METHOD**

Colour kinesis is an extension of the technology of acoustic quantification which uses changing values of tissue back-scatter between successive acoustic frames as a means of automatically tracing and displaying endocardial motion in real time. Acoustic quantification (Hewlett-Packard) has recently been validated against a variety of techniques by numerous investigators.\(^6\) Colour kinesis processes the ultrasound back-scatter data and generates a binary mask image for each frame in which each pixel is classified as either blood or tissue. The pixel values at the transition from blood to tissue in this mask image are used to track systolic endocardial motion. The first frame in each cardiac cycle is triggered with a delay after the R-wave of the ECG so that it coincides with the start of inward movement of the left ventricular wall. The delay has a heart rate related default value but may need some visual–manual fine-tuning in some circumstances. Ten more frames follow the first successive intervals of 33 ms as the left ventricle contracts. The area between each new image of ventricular blood and the corresponding image in the preceding frame is filled with different shades of colour (fig. 1, left) superimposed on the grey scale image. A series of more or less concentric but irregular rims of colour accumulate from frame to frame in a way that reflects the time–motion history of endocardial excursion over the first 363 ms of the cardiac cycle (which usually covers most of the interval between isovolumic contraction and end-systole). The sequence of colours is indicated by the colour bar, with early systole being red–orange and late systole blue–purple (fig. 1, right): a default red in the image and in a signal box in the colour bar indicates outward segmental movement during systole (paradoxical motion). The width of any colour rim at any part of its circumference shows how much that portion of ventricular wall has moved inwards during the corresponding 33-ms inter-frame interval. The overlay of all 11 preceding colours on the last frame provides a multicoloured integrated display of the timing and magnitude of the inward motion of all endocardial segments during the 363 ms of the most recent systole. Thus the end–systolic width of the composite rim of colours represents the overall wall motion during most systoles. The display is updated beat by beat.

**DATA ACQUISITION**

Immediately after tracheal intubation, a multiplane probe with a 5-MHz phased-array transducer (Hewlett-Packard) was inserted into the oesophagus. The transducer was positioned and maintained at the level of the midpapillary muscles to obtain a short-axis view (T-scan) of the left ventricle and by steering the transducer to 90° to obtain a long-axis view (L-scan). The images were recorded on
videotape (Panasonic model AG-7350) for off-line analysis. After the image quality was optimized, the acoustic quantification system for endocardial border detection was activated. Gain controls (total and lateral gain, time-gain compensation) were adjusted to optimize tracing of the blood–endocardial interface within a preferred region of interest.6 Colour kinesis was then activated for on-line encoding of endocardial excursion throughout systole. Image sequences containing colour kinesis data were obtained throughout the cardiac cycle and stored in a digital format for off-line analysis.

DATA ANALYSIS

Digital images were revived off-line using the continuous loop review mode of the echocardiographic system to ensure accurate tracking of the endocardial borders. In the transgastric short-axis view (T-scan), the segmentation originated from the left ventricular end-systolic cavity centroid. The zero degree line was defined by the centroid and a manually determined landmark represented by the junction between the right ventricular posterior wall endocardium and the interventricular septum.9 The left ventricle was divided into six wedge-shaped sectors according to the new recommendations of the American Society of Echocardiography10 (fig. 2, left). In the transgastric two-chamber views (2C-scan), each image was divided initially into two sectors separated by a line (defined as the long-axis) connecting the distal apical endocardium with the end-systolic cavity centroid. Then, a series of perpendicular chords to the long axis of the ventricle, from the base to the midventricle, and a series of radii from the midpoint of the long axis of the ventricle to the apex, were constructed9 (fig. 2, right). This scheme excluded mitral valve motion from the analysis.9

The type of colour kinesis throughout total ventricular systole was evaluated by reviewing the stored digital loops obtained in all patients. The fixed axis reference system was used for analysis.8,11 The radial shortening of each segments as assessed by conventional two-dimensional images and colour overlay, was graded and scored (table 1). All two-dimensional images were graded independently by two investigators using consensus, according to our laboratory published data;2 these investigators were blinded to patient identity or colour kinesis. Colour kinesis detecting endocardial motion in each segment was measured off-line by a third blinded reader using callipers. To determine the effects of inter-examination variability, 200 scrambled samples from randomly chosen patients were re-read by the same observers, by consensus, approximately 2 months after the first reading.

STATISTICAL ANALYSIS

Data are given as mean (SD). Scores from colour-encoded acoustic quantification were compared with those derived by an experienced echocardiographer from two-dimensional images alone using correlation and simple regression analysis. Inter-observer
variability for each method was also evaluated. Difference were considered significant at \( P<0.05 \). The significance of differences in inter-observer interpretation of segmental systolic wall motion with two-dimensional echocardiography and the inter-technique (colour-encoded acoustic quantification) variability were compared for the proportions of pairs; 95% confidence intervals were estimated by \( P \pm 1.96 \sqrt{P(1-P)/n} \).

CALCULATIONS
Sensitivity = true positive/(true positive + false negative); specificity = true negative/(true negative + false positive); positive predictive value = true positive/all positives; and negative predictive value = true negative/all negatives.

Results
A total of 600 left ventricular wall segments were of sufficient resolution for grading by experts. Frame-by-frame analysis showed that the normal regional time of contraction ranged between 185 and 255 ms and was found to be consistent with inter-segment variations. Figure 3 gives an example of a normal contracting left ventricle from a transgastric short-axis view showing all 11 colours. In patients with hypokinesia there were reduced numbers of colours on the end-systolic overlay and thus reduced colour width/rim (fig. 4). In the majority of cases, endocardial shortening occurred early in systole. When no motion occurred, that is akinesis, the colour was absent. In figure 5, in the lateral segment of the left ventricular short-axis image, the colour rim shows outward systolic wall movement, for example paradoxical pixel transitions, and are all assigned the same red colour, regardless of the timing of transitions. It is evident that the colour bars are not quite the same in figures 3 and 4, compared with figure 5. In particular, in the lower part of the colour bar in figure 5 there is a red box which indicates that the “dyskinesis” feature is turned on.

Table 2  Analysis of 600 left ventricular wall segments of which 61 showed conventional TOE-defined segmental wall motion abnormalities compared with whether the colour kinesis correctly diagnosed segmental wall motion abnormalities

<table>
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<tr>
<th>Ischaemia</th>
<th>No ischaemia</th>
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<tr>
<td>Colour kinesis</td>
<td>60 482</td>
</tr>
<tr>
<td>Ischaemia</td>
<td>60 57</td>
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<tr>
<td>No ischaemia</td>
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the same red colour, regardless of the timing of transition.

Wall motion abnormalities were found in 61 of 600 segments by a conventional method. Comparing the conventional TOE method and colour kinesis, there were 60 true positives, 482 true negatives, 57 false positives and 1 false negative. This yielded a sensitivity of 98%, specificity of 89%, positive predictive value of 51% and negative predictive value of 100% (table 2). Inter-observer variability in the interpretation of regional systolic wall motion based on two-dimensional echocardiograms was 13.5%. The inter-technique variability between the conventional interpretation of two-dimensional echocardiograms and the above-described automated detection was found to be 26.2% (P<0.05).

Discussion

We have described our initial experience with a new technique, colour kinesis, designed to evaluate online ventricular regional wall motion patterns using TOE during operation. We chose to use a fixed reference system to analyse end-systolic conventional two-dimensional and colour kinesis images. This choice was made because colour kinesis adopts a fixed reference system for tracking endocardial motion by identical pixels in successive acoustic frames; in other words, a fixed frame of reference is used when colour kinesis images are created. Moreover, as each pixel in the colour overlay cannot be assigned more than one value, information regarding multiple pixel transition resulting from translation and rotation is not reflected in the end-systolic colour overlay. Although no consensus exists, floating reference systems have been recommended when attempting to quantify regional wall motion in the presence of translation.11,12 These systems use superimposition of a systolic and diastolic centroid. When regional wall motion abnormalities are present, however, the systolic centroid is displaced towards the abnormality, thereby exaggerating the apparent wall motion in affected regions and diminishing the apparent wall motion in adjacent regions.13,14 Because of this phenomenon, floating reference systems do not localize regional wall motion abnormalities as well as fixed reference systems in the absence of translation.9

This study demonstrated that colour kinesis correctly diagnosed 60 of 61 segmental wall motion abnormalities. Tracking of papillary muscles, instead of endocardium, accounted for one failure. However, colour kinesis falsely diagnosed 57 other segmental wall motion abnormalities. Translation and rotational movement of the heart, and prolongation of the pre-ejection period (in cases of ischaemia)8 were common problems causing false positive diagnoses.

Recently, Lang and colleagues4 used a transthoracic approach and colour kinesis (Hewlett-Packard), dividing colour-encoded images into segments using custom software. In each segment, pixels of different colours were counted and displayed as stacked histograms reflecting the magnitude and timing of regional endocardial excursion. The same authors found that histograms were highly consistent and reproducible in normal subjects. The patterns of contraction obtained in normal subjects were used as a reference for the objective automated interpretation of regional wall motion abnormalities, defined as deviations from this pattern. The inter-technique variability between the conventional interpretation of two-dimensional echocardiograms and the above-mentioned automated detection was found to be 17.0%. This inter-technique variability was not significantly different from the inter-observer variability of the conventional interpretation. They concluded that segmental analysis of colour kinesis images provided accurate quantitative diagnosis of regional wall motion abnormalities.

The time resolution of colour kinesis is limited to 33 ms by the present frame rate of 30 frames per second. This restricts the definition of endocardial motion at increased heart rates so that it is not accurate enough to provide sufficiently exact indices of regional motion of the left ventricular endocardium. On the other hand, the limited number of colours currently available for encoding may confound accurate acquisition in patients with heart rates less than 45 beat min⁻¹ because the 363 ms duration of colour encoding may not be sufficient to cover enough of the systolic period. These limitations could be overcome by using faster frame rate imaging, together with an extended colour scale.

References


