New echocardiographic technologies in the study of acute myocardial infarction

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Echocardiography has a key role in the diagnostic and prognostic evaluation of patients in the different phases of acute myocardial infarction. Despite this important role of the conventional echocardiographic technologies, novel echocardiographic applications are under development or already used in the clinical practice.

It is very difficult to distinguish which of these techniques will play a consistent role and will cover important diagnostic, prognostic and therapeutic use. The wise cardiologist will be the one who will choose the appropriate technology for the right subset of patients.

In this review paper we try to assign to each novel echocardiographic technique its actual clinical weight in every pathophysiological condition: myocardial contrast echocardiography, contrast opacification of the left ventricle, coronary flow reserve study, integrated backscatter, tissue Doppler and strain rate imaging.

For the best treatment choice, each patient has to be perfectly diagnosed and characterized in order to have a tailored therapy. A correct diagnosis of the extension of myocardial necrosis cannot ignore the transmural wavefront development, the amount of viable myocardium or the presence of microvascular damage. Also the simple echocardiographic wall motion akinesia can be caused by a variable extension of non-contracting, scarred myocardium. The different anatomic and functional intramyocardial patterns represent the basis for different functional outcome of regional and hence global left ventricular function. The greatest understanding of the pathology always leads to the best treatment.

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Introduction

Among the cardiac imaging techniques employed to evaluate coronary heart disease, echocardiography has covered a primary role since the beginning of its application. All the different technologies of echocardiography, from M-mode to the most recent technical developments, have been extensively used in the diagnostic and prognostic evaluation of acute and subacute myocardial infarction.

The key point of echocardiography is its repeatability and reproducibility, even among different observers. So it is used in all the different phases and evolution of cardiac diseases. It has a key role in the early diagnostic phase, indicating the presence of coronary heart disease and/or ruling out other pathologies. During the acute ischemic phase we use the different echocardiographic modalities to quantify the extension of myocardium with necrosis or at jeopardy, with implications for therapeutic strategies (even with surgical indications) and pharmacological challenges. In the predischarge phase, this same technique guides therapy and the follow-up rehabilitation programs.

During follow-up, it is still echocardiography that identifies the first sign of the asymptomatic ventricular dysfunction (both systolic and diastolic) and the chamber dilation with left ventricular remodeling.

In this widespread application all the conventional modalities of echocardiography have been used. Nowadays novel applications are studied in the research and clinical practice, and the acute and subacute phases of myocardial infarction are the most important fields to test these technologies. However, it is very difficult to distinguish which of these techniques will play a consistent role and will cover important diagnostic, prognostic and therapeutic use. The wise cardiologist will be the one who will choose the appropriate technology for the right subset of patients.

In the following pages we will try to assign to each novel echocardiographic technique its actual clinical weight in every pathophysiological condition (Fig. 1).

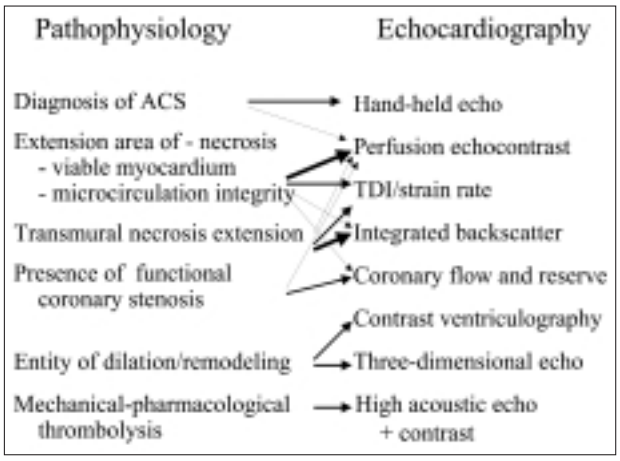

Figure 1. *Schematic figure which illustrates each novel echocardiographic technique with its actual clinical weight in every pathophysiological moment of acute myocardial infarction. ACS = acute coronary syndrome; TDI = tissue Doppler imaging.*

Contrast echocardiography: myocardial perfusion, and left ventricular opacification

For acute myocardial infarction (AMI) and generally for myocardial ischemia, the use of contrast media in conjunction with echocardiography has been recently applied as perfusion myocardial contrast echocardiography (MCE) to evaluate the microvascular perfusion at baseline and during vasodilation, but also as a better delineation of endocardial border in technically difficult echocardiographic exams. Both these applications are very new in the field of echocardiographic technology and raise the greatest expectation for obtaining data in several pathophysiological situations (Fig. 1). Some of these aspects have already been studied in humans, some other are still in the experimental investigational status. Both these applications will be exploited in the next paragraphs, while the use of contrast to enhance the low-intensity flow of coronary blood flow, to study the coronary flow reserve (CFR), will be described separately.

Use of myocardial contrast echocardiography in the study of perfusion during myocardial infarction. In the research papers recently published, MCE has been used to study myocardial perfusion in the different phases of myocardial infarction, from the first early diagnosis in the emergency department, to the study of myocardial viability, collateral circulation, microvascular reperfusion, residual ischemia, ventricular remodeling, and clinical prognosis.

However, in our country, as in many other countries including the United States, contrast echocardiography has not been approved yet for the study of myocardial perfusion, but only for the improvement of endocardial contour or the increase of low Doppler signals (e.g. valvular stenosis, pulmonary venous flow, coronary flow).

Moreover, at least for the short-term period, we hypothesize that MCE for myocardial perfusion will not be used for the routine initial triage of acute chest pain in all the patients with suspected AMI. Conversely, it can be used as a precise diagnostic tool in those patients with suspected or confirmed AMI who need a challenging therapeutic strategy, an early discharge or a subtle diagnostic refinement in the light of invasive interventional catheterization or bypass graft surgery.

Therefore, in the light of the published researches, we will try to comment on the possible clinical uses of MCE in the different phases of the diagnostic algorithm of patients with myocardial infarction, from the early diagnosis to the long-term follow-up.

Myocardial contrast echocardiography at the emergency department for acute myocardial infarction diagnosis. Diagnosis of acute myocardial infarction. Some authors suggested the use of MCE for the initial triage of acute chest pain in the emergency department, when patients do not have typical chest pain or ST-T modifications or new wall motion abnormalities[1], because of the sensitivity of this technique to detect myocardial ischemia in the early phase of the ischemic cascade[2-4]. However, except for the use of contrast for left ventricular cavity opacification, allowing a more reliable diagnosis of wall motion abnormalities in patients with poorly delineated endocardium, current guidelines and recommendations do not suggest the use of MCE in the initial diagnosis of AMI. This consideration is also reinforced by the difficulties in performing the optimal MCE study (with contrast infusion, quantification after bubble destruction, etc.) in the acute phase of myocardial infarction, with the ongoing chest pain for the patient and the difficult logistic of echocardiography in the emergency department (uncomfortable bed, bad light setting, etc.).

Use in patients with left bundle branch block. An interesting setting for the use of MCE in the initial triage of acute chest pain in the emergency department is when patients show a complete left bundle branch block at initial ECG. In these patients often the ECG do not show any acute change (neither for occlusion nor for recanalization of the coronary vessel) and often echocardiography is non-diagnostic for wall motion abnormalities. In this small subset of patients, MCE may play a role for the confirmation of AMI as the origin of the acute chest pain, and can help in the diagnosis of recanalization of the coronary vessel.

In fact a preliminary study demonstrated the accuracy of MCE in the assessment of septal perfusion in patients with left bundle branch block, particularly for septal wall motion abnormalities, also in the presence of discordance with thallium-201 myocardial scintigraphy[5].

Ruling out of ischemia for patients without wall motion abnormalities after initial triage. Another role for MCE, thanks to its sensitivity in detecting coronary stenoses

comparable to myocardial single-photon emission computed tomography study, is the ruling out of myocardial ischemia in patients with suspected AMI, after initial triage. Several studies demonstrated the possibility of using MCE, also in conjunction with quantitative analysis of microvascular perfusion, to detect early signs of myocardial ischemia, with a reduction of myocardial perfusion at MCE preceding the ECG changes or the appearance of new echocardiographic wall motion abnormalities[2-4].

Intravenous bolus injection and trigger or real-time echocardiography. During the acute phase of myocardial infarction the use of MCE is limited by patient's symptoms and logistic difficulties. Therefore, all the studies are mostly aimed to evaluate microvascular damage by qualitative analysis, as the presence or absence of myocardial perfusion in the different myocardial segments. Contrast media are infused intravenously as a bolus and the preferred technique is real-time low-intensity echocardiography.

This technical suggestion allows for an easier performance of the MCE exam, and allows to obtain images that can have an accuracy of the perfusion defect delineation, sufficient to guide reliably the clinical therapeutic decision. The performance of quantitative analysis have to be left to the subacute phase of myocardial infarction, when it is possible to have a continuous pump infusion and to obtain images of a sufficient quality to perform confidently an off-line analysis.

Myocardial contrast echocardiography during the coronary care unit period of acute myocardial infarction. Diagnosis of recanalization/failure of thrombolysis. One of the most interesting clinical applications of MCE during the early period of AMI is the diagnosis of recanalization of the coronary artery responsible for the AMI. This is useful to test if thrombolysis or primary coronary angioplasty (PTCA) have been successful, in order to attempt supplementary recanalization procedures.

Myocardial perfusion can be assessed immediately after thrombolysis. A large area with a perfusion defect would indicate unsuccessful reperfusion and these patients might undergo rescue PTCA. A completely normal perfusion or a near complete myocardial opacification would indicate an almost complete myocardial salvage (except for the cases of underestimation of the infarct size because of reactive hyperemia)[6,7].

For these reasons MCE is appealing, because it is capable of immediately providing the information whether thrombolysis has been successful, and of visualizing the spatial resolution of myocardial perfusion. With a single echo exam it is possible to assess myocardial perfusion in addition to the evaluation of cardiac morphology, wall motion, and contractility[8].

Therefore, after the analysis of the conventional signs of post-thrombolysis recanalization (chest pain and ST-segment resolution or reperfusion arrhythmias), the cardiologist has the MCE study as additional information for the immediate clinical decision. In fact, MCE have recently been reported to be superior to ST-segment resolution on the 180 min ECG, corrected Thrombolysis in Myocardial Infarction (TIMI) frame count, and myocardial blush grade in predicting wall motion score index within the risk area at 4 weeks[9].

Diagnosis of transmurality. Due to the pathophysiological and clinical importance of transmural extension in the diagnosis of myocardial ischemia[10], MCE has strongly been searched for diagnosing the transmural differences in perfusion[11,12]. In fact it detects a reduction in the subendocardial flow with a good correlation with the myocardial flow studied by radioactive microspheres[11]; but some studies disagreed on this capability[13].

In patients with coronary artery stenosis, the stress test (pacing or pharmacological) induces a decrease in the MCE subendocardial/subepicardial gray-level ratio only in segments supplied by a stenotic coronary artery, indicating the occurrence of subendocardial myocardial ischemia[14,15]. Similar data have been obtained with echocardiographic tissue characterization[16].

Several steps beyond have been done with the advent of real-time MCE and especially with the replenishment curve after contrast destruction, indicating the ability of this technique to separately measure contrast opacification in the different myocardial layers[17,18].

Diagnosis of heart rupture. When chest pain appears in the early phase of AMI and at early echocardiography pericardial effusion is observed a small heart rupture of the free wall can be suspected, especially if invasive procedure have been performed. In a small group of patients the MCE can give a supplementary information: if the intravenous administration is followed by the appearance (even late) of contrast in the pericardial space, a strong suspect of heart rupture of the free wall can have a direct confirmation[19].

Use of myocardial contrast echocardiography in detecting the effects of supplementary drugs for post-acute myocardial infarction reperfusion. In the early phase of AMI, MCE can be useful also to test the efficacy of supplementary adjunctive recanalization therapy. Although not used in ST-elevation AMI or after recanalization therapy, glycoprotein IIb/IIIa inhibitors have been tested with MCE in dogs with complete coronary artery occlusion and reopening. In this setting glycoprotein IIb/IIIa inhibitors improved microvascular flow and reduced the infarct area[20]. These data demonstrate the usefulness of MCE in assessing microvascular flow and searching novel evidence for the role of platelets in the early phase of reperfusion injury.

Myocardial contrast echocardiography before hospital discharge. Diagnosis of microvascular no-reflow. During the hospital stay MCE can be performed to evaluate the extent of microvascular damage. In fact, the recanalization of the infarct-related artery does not necessarily imply adequate myocardial reperfusion. The "no-reflow" phenomenon (absence of reperfusion in the presence of adequate recanalization of the epicardial coronary artery) is the expression of microvascular damage[21]. In fact it has been largely demonstrated, also in clinical settings, that a significant group of patients undergoing early and complete recanalization of a coronary vessel with a TIMI grade 3, show inadequate or even absent microcirculatory perfusion of the myocardium[6,7,22,23]. Patients with TIMI 3 and no-reflow show a myocardial contraction behavior similar to that observed in patients with incomplete coronary recanalization (TIMI < 3)[24,25]. Therefore, the presence of a salvaged microvascular network is a necessary prerequisite to preserve myocardial viability after AMI, even in the presence of optimal TIMI grade, in order to avoid an "illusionary reperfusion" after PTCA recanalization[26].

So, in patients with AMI undergoing an early reperfusion procedure (thrombolysis, angioplasty), MCE is important in the second-third day of recovery to know 1) if the myocardium has been perfused, and 2) to which extent the myocardial muscle has been salvaged. In fact it is important to perform MCE not too early to avoid the hyperacute phase, when microvascular dysfunction and post-ischemic hyperemia may occur[27].

Protective role of pre-infarction angina. MCE has also been useful in studying the protective role of pre-infarction angina on the microvascular anatomy and function. Microcirculatory dysfunction is more impaired in AMI patients without pre-infarction angina, as shown by the greater extent of no-reflow within the risk area in humans[28,29]. The beneficial effect of preconditioning on the no-reflow phenomenon extent, observed in patients with pre-infarction angina, can also be explained by a reduction in post-ischemic platelet aggregation and/or microvascular neutrophil plugging[20,30]. Because of the tendency to various levels of microcirculation protection during the acute phase of myocardial infarction, patients with or without pre-infarction angina may theoretically benefit from different therapeutic strategies aimed at preserving microcirculatory integrity and, consequently, myocardial function.

Real-time and refilling curve. On the opposite of the very early phase of AMI, when MCE is performed only on a qualitative analysis administering the contrast media with a direct intravenous bolus, in the subacute phase of myocardial infarction the patient is asymptomatic and lies calmly in the best environmental situation (perfect light and equipment setting). In this situation it is possible to obtain images of adequate quality for quantitative off-line analysis. To obtain this goal it is necessary to have a continuous infusion pump and to acquire images of a sufficient quality to perform confidently an off-line analysis. With the last generation built-in software it is possible to deliver a high power burst, destroying the contrast in the microvasculature, and to acquire the images following the contrast destruction (Fig. 2). The off-line software can be used not only to detect the maximum quantitative videointensity reached in the myocardium, but also the refilling rate of the contrast medium in every different area we want to quantify (Fig. 3). Several studies have already utilized

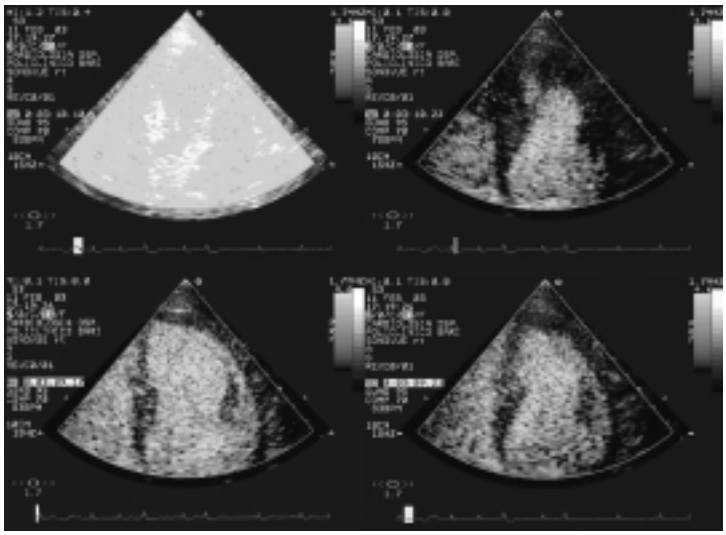

Figure 2. *Images of the power modulation method in real time with second-generation contrast (SonoVue, Bracco) destruction and refilling. It is possible to see* (upper left) *the contrast destruction frame (flash at high ultrasound intensity), followed by a wash out frame at 1 s* (upper right)*, and by a slow refilling at 4 s* (lower left) *and at 9 s* (lower right)*, difficult to see with the visual color analysis.*

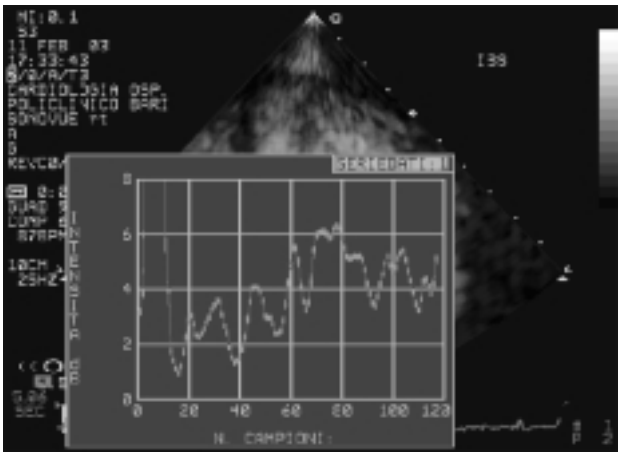

Figure 3. *Image of a densitometric curve in a myocardial segment with normal perfusion, analyzed with the tissue characterization software (it shows the curve not so visible in the previous figure 2). We utilized the power modulation method in real time with second-generation contrast (SonoVue, Bracco) destruction and refilling.*

the quantitative data to evaluate the residual coronary stenosis and the transmural distribution of myocardial perfusion[17,18].

Diagnosis of viability (wall motion recovery or dobutamine). The preservation of the microvasculature after AMI is a prerequisite for myocardial viability. In fact, patients undergoing recanalization with thrombolysis or primary PTCA with evidence of no-reflow at MCE show a worse wall motion score index and a lower ejection fraction at follow-up echocardiography, compared to patients with a good myocardial opacification of the entire risk area[6,7,22,24]. These data show that a good microcirculation inside the infarcted area is a crucial factor to preserve myocyte viability and restore myocardial contractility. Moreover, the microcirculatory integrity and the contractile reserve of post-infarction stunned myocardium evaluated at low-dose dobutamine echocardiography, although looking at different aspects of viability, are strongly linked on a pathophysiological level.

Therefore an open microcirculatory bed in the dysfunctioning infarcted area is a necessary prerequisite, but it is not always predictive of functional recovery (high sensitivity of MCE). On the other hand, the contractility reserve showed by the echocardiogram after dobutamine infusion, has more specificity in predicting functional recovery at follow-up[24].

Diagnosis of collateral circulation. In the setting of AMI, the presence of collateral circulation can be extremely important to preserve the muscle from necrosis, also for a long period of time. Intracoronary MCE allows evaluation of the blood flow distribution in the collateral circulation and to quantify the myocardium perfused by this collateral flow[31], while coronary arteriography cannot evaluate vessels with a diameter < 100 μm. Similarly, the myocardial perfusion observed with intravenous MCE is a clear sign of a collateral presence, especially when it is observed only at intermittent MCE with a very large triggering interval (1 image every ≥ 10 s)[32].

Myocardial contrast echocardiography for clinical prognosis at follow-up. No-reflow and remodeling. The different prognostic weight of myocardial infarction characteristics is important in understanding the post-infarction ventricular remodeling pathophysiology. The presence of myocardial viability has been demonstrated to be an important basis for ventricular remodeling preservation. Patients with no-reflow at intravenous MCE have progressive dilation and larger ventricular volumes at follow-up than those with reflow[25,33,34]. These results are in agreement with the fact that microvascular obstruction, detected with magnetic resonance 10 days after AMI, predicted more fibrous scar formation and left ventricular remodeling; moreover, at multivariate analysis, this microvascular obstruction was related to ventricular dilation independently of the infarct size.

The microvascular salvage has been demonstrated to be correlated with post-infarction ventricular remodeling, independently of patients' age and sex, time interval between symptom onset and coronary angioplasty, pre-angioplasty patency of the infarct-related artery and post-angioplasty residual stenosis. In fact, the extent of no-reflow after AMI is the most powerful predictor of left ventricular remodeling, suggesting a link between microvascular dysfunction and ventricular remodeling[33].

No-reflow and prognosis. The last use of MCE post-AMI data is the prediction of long-term clinical prognosis. In fact several studies demonstrated the relationship between microvascular integrity after AMI and subsequent clinical outcomes[33-35]. A recent prospective study on a large unselected population with AMI treated by means of primary PTCA, showed that microvascular dysfunction was the only independent predictor of 5-year cardiac death and combined events[34]. This, along with the ability to predict left ventricular dilation after AMI, highlights the pathophysiological relationship between microvascular dysfunction, progressive left ventricular dilation, development of congestive heart failure, and cardiac death.

Although the direct mechanisms leading from microvascular obstruction to bad post-infarction prognosis remain unknown, the possible relationship between the no-reflow and infarct size has been demonstrated with MCE and magnetic resonance[33,35]. However, controlling for infarct size did not eliminate the power of microvascular obstruction to predict the occurrence of adverse post-infarction events. In fact, myocardial reperfusion limits post-infarction ventricular remodeling and improves patient prognosis even without salvaging myocardium[35].

In conclusion, the ability of MCE to give information on the microvascular perfusion, besides the evaluation of basal wall motion abnormalities, illustrates the importance of this technique in the myocardial study in all the phases of AMI.

Left ventricular opacification with myocardial contrast echocardiography in patients with acute myocardial infarction. Despite the recent introduction of native tissue harmonic imaging in echocardiography there is still a small percentage of patients in whom, because of the poor ultrasound penetration, it is very difficult to have an accurate estimate of the ventricular dimension and sometimes of wall motion. Particularly in patients with suspected or confirmed AMI the correct evaluation of regional and global wall motion is of primary value.

Contrast media for endocardial border detection in technically difficult exams. Patients with inadequate acoustic windows often do not permit the complete visualization of the entire left ventricular endocardial border, and the tracing of the contour for volume calculation can be limited. For this reason several studies have been attempted, at first with sonicated human albumin, and then with second-generation transpulmonary contrast agents, to improve the opacification of the left ventricle and permit a satisfactory delineation of the endocardial border to determine ventricular volumes.

Moreover it has been demonstrated that the contrast-enhanced definition of left ventricular endocardial border translates into more accurate measurements of global and regional left ventricular systolic function[36]. In fact, some structures parallel to the ultrasound beam (e.g. most of the endocardial border in the apical views) are difficult to resolve with echocardiography. Conversely, the presence of microbubbles in the left ventricular cavity provides a surface that is perpendicular to the ultrasound beam, gives a large scattering cross-section and facilitates endocardial visualization. The advantage of contrast echocardiography is most striking in the subjects with two or more non-visualized segments on the baseline echocardiogram.

The importance of wall motion analysis is even more striking in patients in the intensive care unit, where echocontrast infusion permits that 76% of the left ventricular segments, uninterpretable with standard imaging, can be read with confidence[37]. Furthermore, in 70% of the intensive care patients with uninterpretable ejection fraction with standard imaging, the ejection fraction can confidently be read on contrast imaging. The use of contrast imaging also increases the readers' confidence in their interpretations. Interestingly, the added value of harmonic imaging without contrast is only marginal in a study of patients with very difficult images[37].

The great importance of contrast for wall motion analysis at rest is even more pronounced for wall motion analysis at peak stress. In recent trials, the use of gas-filled echocontrast and harmonic imaging yields nearly complete visualization of myocardial segments and improves interobserver agreement, compared with fundamental imaging[38]. Moreover, the use of contrast agents for wall motion evaluation can also be cost-effective: the intrinsic cost of the contrast agent can be offset by savings obtained with the reduction of repetitive testing, improved laboratory efficiency, and a lower rate of false-positive or false-negative results.

Contrast media for evaluation of ventricular volumes and ejection fraction. Many early therapeutic strategies in AMI are based on the global ventricular function, generally computed as ejection fraction. In the following phases of myocardial infarction the cardiologist has to take into account the changes in ventricular volumes and shape leading to remodeling. For both these diagnostic goals contrast echocardiography can be performed in patients with bad quality ultrasonic images[36-38].

Sometimes the contrast effect for left ventricular cavity opacification can be magnified with the use of echo color Doppler. In fact the Doppler filters are very sensitive to highlight the movement of the blood in the cavity, giving a high-velocity low-intensity signal[39]. It is very user friendly to delineate the cavity contour between bright colors from the signal of the blood (red and blue in the traditional color map) and the gray signal (or black if receiving gain is reduced) of the myocardial wall.

The improvement of contrast-enhanced echocardiographic assessments of left ventricular volumes and ejection fraction has produced a very good correlation with those calculated with contrast ventriculography or magnetic resonance imaging[36], and the interobserver variability[39].

Limitations of contrast echocardiography for left ventricular opacification. There are some evident logistic and technical limitations in the widespread use of contrast echocardiography for left ventricular opacification in AMI patients with low-quality echocardiographic images.

The first logistic limitation is the reimbursement for contrast agents. This limitation is not due to the direct cost of contrast agents (cost-analysis studies showed a valuable cost-effective balance), but most countries have not established the policy of reimbursement of these agents.

A second limitation is due to the time spent for a contrast echocardiographic exam, requiring the informed consent, the placement of an intravenous catheter, and administration of the agent during imaging.

Among technical limitations, there is the necessity of a high-end echocardiographic equipment and the need of a physician trained to perform contrast echocardiography with courses that can be expensive and time-consuming.

Sometimes, if used in conjunction with power Doppler technique, the frame rate is not high enough (10 to 20 Hz) to accurately reflect the real end-diastole and end-systole, thus leading to possible diastolic volume underestimation and systolic volume overestimation.

Moreover, the destruction of microbubbles caused by the strong acoustic emission power delivered continuously against the fragile microbubbles injected intravenously can reduce accuracy of this method. For this reason new real-time low output power methods and second-generation perfluorocarbon-filled contrast agents have been developed.

Automatic edge detection. Although echocardiography is extremely useful for qualitative and quantitative assessment of left ventricular dimensions and function, the time-consuming and tedious manual procedures needed to measure dimensional and functional parameters by traditional off-line analysis systems, make their use unpopular in routine clinical settings.

To overcome this problem an echocardiographic system has been developed, the "automatic boundary detection", that provides automatic on-line identification of acoustic blood-tissue interfaces and quantification of left ventricular cavity volumes on a frame-by-frame basis. Several studies showed a potential in the clinical setting, but only in those patients with a good image quality this method has shown reliable results. In fact, one of the most important limitations of this automatic analysis is the echo dropout affecting the endocardial border; it can at least partially be solved with the use of intravenous contrast injection[40].

Coronary flow and reserve studied with transthoracic Doppler echocardiography during acute myocardial infarction

Transthoracic evaluation of the coronary flow in acute myocardial infarction. Another clinical application of contrast echocardiography is the transthoracic contrast-enhanced Doppler echocardiographic assessment of coronary flow. Transesophageal echocardiography has been used to study the coronary flow in the left main coronary and initial part of the left anterior descending coronary artery[41].

Recently, thanks to the second harmonic imaging and intravenous injection of echocontrast agents, it has been demonstrated that such a recording with transthoracic contrast-enhanced second harmonic Doppler echocardiography[42] is simple, non-invasive, repeatable, and relatively inexpensive.

The tiny color Doppler signal is visualized thanks to the sensitive high-frequency transducer and/or the enhancement of Doppler signal with intravenous ultrasound contrast agent. The second harmonic Doppler mode is useful because echoes from the solid tissue (noise) in fundamental frequency are suppressed or attenuated and a contrast-dependent image is produced.

The important point is to use a Doppler scale set with a very low-max velocity (to detect low velocity signal from the intracoronary flow) and to obtain a modified 2-chamber view capable of visualizing the distal and mid segments of the left anterior descending coronary artery (Fig. 4).

Once obtained a good visualization of the coronary artery with color Doppler it is necessary to place the sample volume of pulsed wave Doppler in the site where we want to detect the coronary flow velocity, in order to obtain quantitative data and for the study of CFR (Fig. 5). The feasibility of this technique is very good, ranging in the different studies for the left anterior descending coronary artery between 70 and 100% of patients. Sometimes the shape of the pulsed wave

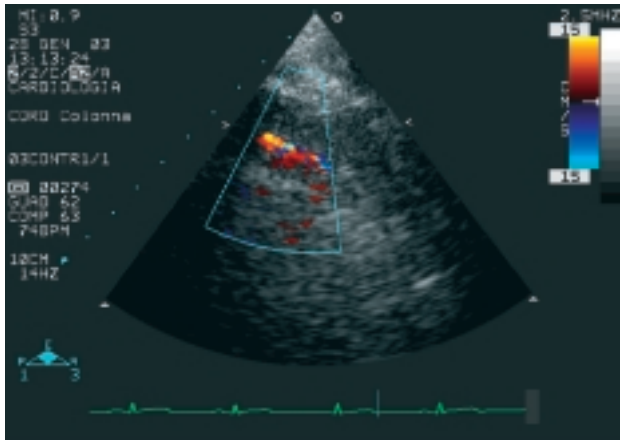

Figure 4. *Apical 2-chamber view visualizing the distal portion of the left anterior descending coronary artery. The vessel is close to the anterior wall of the left ventricle, in the interventricular sulcus. The color Doppler shows the vessel in red; the color Doppler scale is very sensitive for low velocities.*

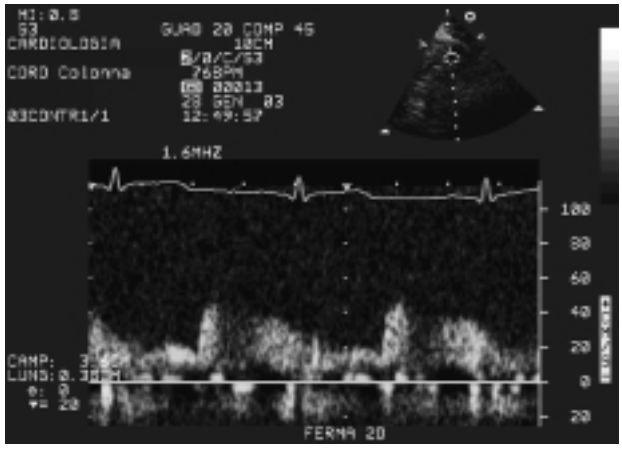

Figure 5. *Pulsed wave Doppler envelope recorded in the distal portion of the left anterior descending coronary artery. The flow velocity shows a biphasic pattern with a smaller systolic component and a larger diastolic one, typical of the normal coronary flow in large epicardial coronary arteries.*

Doppler envelope can be suboptimal, but with the addition of contrast injection also bad images can be improved.

An interesting study demonstrated that it is possible to detect the coronary stenosis percentage measuring the acceleration of flow which occurs among a reference site and the site of stenosis[43]. This opportunity can be used when studying post-AMI patients: we can detect the reopening of the infarct-related vessel (if a coronary flow is visualized) and the presence and importance of a residual coronary stenosis (if a flow acceleration is detected).

New developments of the coronary flow detection. The importance of this technique in the study of AMI patients has been raised by the recent study of all the coronary arteries and of the small perforator intramyocardial vessels.

In the past, the major limitation of this technique was that only the left anterior descending coronary artery was imaged and not the circumflex or right coronary arteries. In recent studies also the posterior descending coronary artery (as the terminal branch of either the right or the circumflex coronary artery) has been imaged by transthoracic color Doppler echocardiography[44]. The high-frequency transthoracic color Doppler ultrasound with the contrast infusion permitted to obtain a good basal detection of coronary flow in approximately 75% of patients and a complete satisfactory CFR study in 50% of patients. This lower success rate compared to the left anterior descending coronary artery depends on the remote position of the posterior descending coronary artery in the thorax; therefore the use of a low-frequency transducer in conjunction with contrast echo has improved the feasibility of this study, together with the study of the left circumflex artery.

In the acute phase of myocardial infarction, the recanalization of perforator branches emerging from the distal part of the left anterior descending coronary artery reflects adequate reperfusion and is a sign of better ventricular function at follow-up. On this basis transthoracic echocardiography has been used to detect the flow in this area in AMI patients. A good correlation with TIMI flow grade was observed, raising the idea that small perforator branches are the connection between the large epicardial artery and the microcirculation[45]. Therefore the perforator analysis may yield additional information to MCE about the status of local perfusion. In fact a cut-off value of 50% of perforators predicted good recovery of ventricular function.

Vasodilation to study the coronary flow reserve in acute myocardial infarction. Once the coronary flow has been detected, it is very important to know the functional status of the coronary artery: this is possible thanks to CFR study. Evaluation of CFR by means of transthoracic Doppler is an attractive new diagnostic modality that opens new and important clinical applications to echocardiography also in the AMI setting. In fact, coronary angiography has been considered the gold standard for defining coronary anatomy for more than 40 years, but it only depicts coronary "luminology", and there is marked disparity between the severity of lesions and their physiological effects. So coronary angiography provides accurate anatomic depiction of the lesion, but poor estimate of its functional severity which is crucial for clinical decision-making, especially in the presence of intermediate stenoses.

The resistance of a stenotic lesion varies markedly when a vessel stenosis increases from 70 to 80%. Such a change in the degree of the stenosis may result from a number of dynamic factors and is within the limits of inter- and intraobserver variability in the visual estimation of the coronary vessel.

Methods of measurement of CFR include intracoronary Doppler flow wire, nuclear techniques such as positron emission tomography and echo techniques (transesophageal and transthoracic echocardiography). While invasive CFR (measured in the cardiac catheterization laboratory) cannot be repeated because of its invasivity and cost, the transthoracic echocardiographic study is feasible and repeatable.

It is possible to use transthoracic echo Doppler to record blood flow velocity in the coronary artery at rest and after maximal vasodilation. The maximal flow velocity can be obtained with adenosine or dipyridamole (Fig. 6). The cut-off value for significant coronary disease is conventionally taken as an absolute value of 2 (the coronary velocity flow should at least double during maximal vasodilation). In patients with suspected coronary artery disease the sensitivity and specificity in detecting significant left anterior descending coronary stenosis (using a CFR value of 2 as a cut-off) have been described of 85 and 90%, respectively. A close agree-

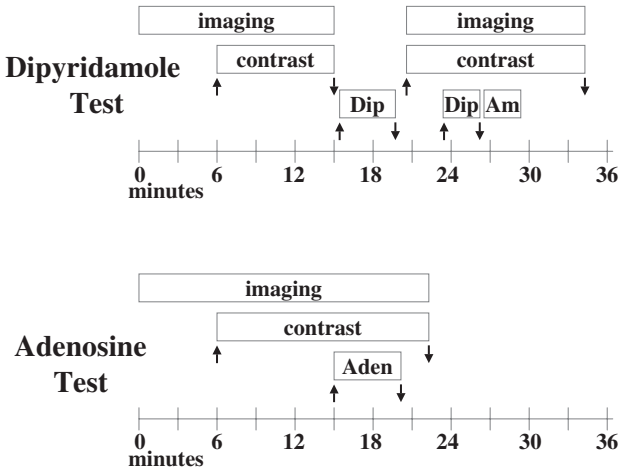

Figure 6. *Comparison among different study protocols for coronary flow reserve study: dipyridamole (Dip) vs adenosine (Aden). As evident, the limitation of the Dip test is the late effect of the drug. In fact, it is necessary to visualize the coronary flow 2 times separately: at baseline and again after Dip infusion. Am = aminophylline; ↑ = infusion start, ↓ = infusion stop.*

ment between CFR determined by this technique and intracoronary Doppler flow wire has also been reported (r = 0.88).

However, several limitations of this technique are 1) the wrong CFR measurement if performed at the stenosis site, 2) the suboptimal feasibility in coronary arteries different from the left anterior descending, and 3) the misinterpretation of the flow in left anterior descending coronary branches, which could be erroneously interpreted as the flow in the main trunk.

Clinical use of coronary flow reserve studies in acute myocardial infarction patients. Because this transthoracic technique allows CFR measurement in a non-invasive, and therefore repeatable way, it is particularly useful not only in the evaluation of the severity of coronary stenosis, but also in all clinical conditions in which the effects of therapeutic interventions aimed to improve CFR need to be monitored. It may also be useful in the study of left bundle branch block, in which stress tests are not reliable because of the high number of false-positive studies and in the monitoring of drugs used in the AMI setting. Immediately after primary PTCA for AMI the CFR measured invasively in the cath-lab can be affected by the hyperemic damage or by the microcirculatory stunning; therefore the transthoracic study of CFR at bedside, several hours after PTCA, has been demonstrated to be more precise and predictive of the real microvascular status.

Moreover, this technique has been demonstrated to have a high sensitivity and specificity in detecting coronary restenosis after PTCA intervention[46], therefore it can be used in AMI patients, when a restenosis of a PTCA is suspected.

Lastly, even with an optimal recanalization of the epicardial coronary vessel post-AMI, the presence of microvascular dysfunction (related to the "no-reflow" phenomenon) can be investigated with the study of CFR in the infarct-related vessel[47].

Integrated backscatter and tissue characterization in acute myocardial infarction

Clinical use of integrated backscatter and tissue characterization. The integrated backscatter tissue characterization is a technique developed a couple of decades ago, with recent interesting development, but with technical limitations that make its use very unusual in the everyday clinical scenario. However, it can be useful for research purposes and for particularly specific information to be studied in well-defined subgroups of patients. The aim of this paragraph will be to define the new pieces of information that this consolidated technique can obtain in the AMI setting.

The tissue characterization technique studies the structural and functional status of the myocardium, providing quantitative indexes of its physical properties and variations along the cardiac cycle. It is also capable of evaluating the functional status of the different layers of the myocardial transmural thickness, while conventional echocardiography cannot differentiate the relative contribution of each layer.

The built-in software, currently available for tissue characterization, measures the waves that are scattered and redirected back to the same transducer. It is then possible to select a region of interest to calculate the integrated backscatter values in a particular segment or layer of myocardium.

The integrated backscatter value changes along the cardiac cycle with the contraction and relaxation of normal myocardium. These cyclic variations of integrated backscatter (IBScv) are consistent and reproducible along the cardiac cycle, with higher values near end-diastole and lower values at end-systole. These IBScv are an expression of regional intramural myocardial contractile performance and are related to contractility, but are not directly dependent on the inotropic state[48].

Integrated backscatter during ischemia and acute myocardial infarction. The IBScv have been studied during ischemia and during the different phases of myocardial infarction. During stress-induced myocardial ischemia the IBScv are blunted and, after stress interruption, they recover earlier than myocardial thickening[49]. A similar dissociation between blunting of gray-level cyclic variations and segmental dysfunction has been observed in patients studied immediately after coronary artery occlusion during angioplasty or during intraoperative ischemia.

In the akinetic myocardial segments of AMI patients the IBScv are blunted; the values of IBScv in these segments are significantly lower in patients with an occluded infarct vessel than in those with a patent infarct vessel[50]. The limitation of this study is the lack of echocardiographic parameters more specifically related to myocardial viability, such as wall motion functional recovery at follow-up or at dobutamine echocardiography.

An important added value of IBScv is its independence of conventional echocardiographic wall motion abnormalities after acute ischemia, being earlier and more sensitive in the detection of myocardial viability. In the acute phase of myocardial infarction treated with primary PTCA the early IBScv normalization (3 days after primary PTCA) was a predictive sign of functional recovery at 3 weeks of follow-up[51].

Recently, in AMI patients undergoing thrombolysis, a difference of < 15% (or 1.5 dB) in IBScv among infarcted and normal myocardial segments showed a sensitivity of 92% and a specificity of 75% in detecting the recanalization of the infarct-related vessel[52]. Moreover, the IBScv was the best parameter (sensitivity 96% and specificity 90%) to identify those patients with a spontaneous coronary recanalization (TIMI 3), already obtained prior to undergo primary PTCA[53].

Transmural heterogeneity of backscatter in ischemia and infarction. The contribution of different transmural layers to myocardial contraction is difficult to be studied, but can provide very important information for the diagnostic and prognostic evaluation of ischemic and non-ischemic cardiac pathologies. In fact myocardial ischemia and tissue necrosis progress along the different transmural layers, from the subendocardium to the subepicardium, creating the "necrosis wavefront phenomenon". In normal human beings a transmural heterogeneity of myocardial contraction at rest has been recently determined with the use of integrated backscatter ultrasound technique. In fact it is possible to place the region of interest in different transmural layers (Fig. 7), obtaining a selective behavior of IBScv correlated with myocardial contraction in that particular myocardial layer[16,54] (Fig. 8). The calculation of IBScv in different layers of the myocardium can be limited by a) the imprecise definition of IBScv curves due to the difficult positioning of the sample volume, b) the intrinsic cardiac movements with various orientation in the different myocardial layers (twisting, longitudinal or circumferential shortening).

During acute ischemia, the subendocardium suffers a severe reduction in perfusion and wall motion (detected with intramyocardial electronic crystals), and the ultrasonic backscatter technique can detect subendocardial ischemia[16].

In the AMI setting the necrosis progresses from the endocardium to the epicardium and this wavefront phenomenon is not dependent on the collateral circulation. This sequence of events cannot be demonstrated with conventional echocardiography, which studies myocardial wall thickening, because of the "necrosis transmural threshold". In fact, when the histological necrosis exceeds the threshold of 20%, a total absence of myocardial thickening is observed[55]. Therefore a subendocardial necrosis involving the inner 30% of the myocardial layers produces a wall motion akinesia similar to that of a transmural myocardial infarction. In this particular setting, the analysis of IBScv in the different transmural layers could supply important clinical data.

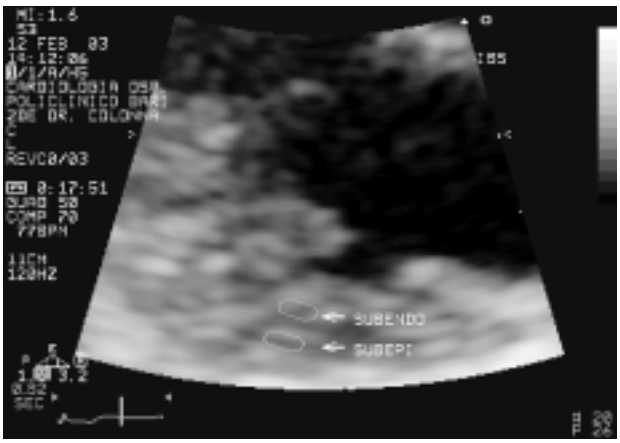

Figure 7. *Example of integrated backscatter cyclic variations calculated by means of transthoracic echocardiography in the subendocardium and subepicardium of a normal patient. We zoomed the image and placed the region of interest separately at first in the subendocardium and then in the subepicardium of the myocardial posterior wall. The regions of interest are the orange ovals.*

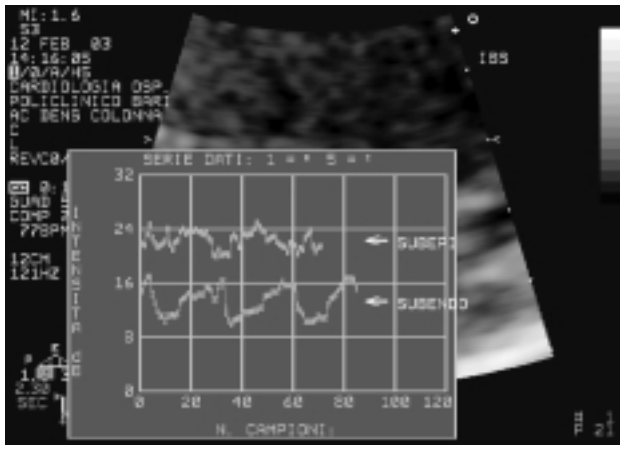

Figure 8. *Example of integrated backscatter (IBS) cyclic variations calculated by means of transthoracic echocardiography in the subendocardium and subepicardium of a normal patient. The graph shows that the IBS cyclic variations are greater in the subendocardium than in the subepicardium (the region of interest has been placed separately at first in the subendocardium and then in the subepicardium of the myocardial posterior wall).*

Limitations of the technique. However, at present the tissue characterization technology shows some limitations: the method is time-consuming and it gives results in a unattractive format (a videodensitometric systo-diastolic cyclic variation graph). Moreover, due to anisotropy, it is necessary to have an insonification angle (of the ultrasonic beam) perpendicular to the myocardial segment to obtain precise IBScv curves. This problem can be at least partially solved with the transesophageal approach.

Tissue Doppler and strain rate imaging

How tissue Doppler imaging works. Among the other ultrasound techniques, tissue Doppler imaging (TDI) and the derived strain rate analysis are extensively used to study AMI, ischemia and stunning, with the quantitative assessment of myocardial function. These techniques derive from conventional Doppler ultrasound, implemented in all the echocardiographic equipment. Conventional Doppler echocardiography detects any signal in the ultrasound beam with high velocity, despite the low intensity; in this case the filters remove signal with low velocity and high amplitude. TDI system enhances the wall motion signal and suppresses the blood flow: in fact the filters remove all the low amplitude and high-velocity signal (derived from blood flow)[56].

Myocardial wall movement can be displayed and represented by TDI as: A1) M-mode color Doppler

TDI, A2) two-dimensional color Doppler TDI; both these displays use a color map similar to that used for conventional color Doppler: red for the wall moving toward the transducer, blue for the wall moving away from the transducer; B) pulsed wave TDI, with a map very similar to that obtained with conventional pulsed wave Doppler, which is mostly utilized to evaluate diastolic dysfunction.

Use of tissue Doppler imaging to study acute myocardial ischemia and infarction. In the clinical setting, a good correlation of Doppler tissue velocity with conventional M-mode echocardiography was observed[57]. Moreover, experimental and clinical reports have shown the potential value of longitudinal myocardial velocities in the quantification of acute ischemia-induced regional asynergy.

Moreover, the greatest potential of this technique is to obtain velocity information in the different transmural layers. When a normally contracting myocardium is studied by TDI the presence of a gradation in velocity is evident, with the endocardium moving faster than the epicardium reflecting the rate of increase in wall thickness[48]. This pattern has been described as myocardial velocity gradient, can be defined as the difference in myocardial velocity between the endocardium and the epicardium, and is represented with M-mode as a range of brightness of the color from the subendocardium to the subepicardium[58,59].

This myocardial velocity gradient can be calculated by TDI in normal subjects and in different pathologic myocardial states, in echocardiographic parasternal views; more recently it has been developed and it can be applied also in the apical views (see later the longitudinal strain rate). M-mode TDI overcomes the temporal resolution problems inherent to the B-mode approach, analyzes in real time endocardial and epicardial velocities, and provides new indexes of transmural myocardial function[58,59].

In fact, experimental studies using two-dimensional and pulsed TDI have demonstrated that TDI can quantify ischemia-induced regional myocardial dysfunction[60], and can characterize transmural distribution of velocities during ischemia and reperfusion[61].

A next successful step has used M-mode TDI and myocardial velocity gradient to differentiate transmural from non-transmural myocardial infarction in a canine model of irreversible ischemic injury, directly comparing TDI results to histological assessment of viability[62].

Tissue Doppler imaging limitations. Despite the above-mentioned studies, TDI in clinical practice has not been extensively employed. It is mainly limited by the influence of the tethering between segments and by the translocation movement of the heart: the transducer is stationary on the chest wall and the heart moves in the thoracic cavity along the cardiac cycle. The translocation affects the different velocities calculated in the posterior and anterior segments or in the analysis from apical echocardiographic views[63]. In fact, the ventricular apex is essentially stationary along the cardiac cycle, while the myocardium close to the mitral ring moves much more than the apex. Thus, the myocardium close to the mitral ring has a TDI velocity obtained as the addition of all longitudinal shortening between the apex and the base. Therefore, the presence of akinesia in the mid-apical region reduces the TDI velocity not only in the affected region (mid-apical), but also in the non-ischemic basal portion of the ventricle.

Strain rate measurement to overcome tissue Doppler imaging limitations. To overcome this TDI limitation, strain rate imaging (SRI), a novel echocardiographic modality based on TDI, has recently been developed[64]. It allows quantitative assessment of regional myocardial wall motion independent of passive movements. In fact, the strain is a dimensionless measure, represents the deformation of the tissue (compression or expansion) and is calculated as the change in length (L - L0) divided by the basal length (L0): strain $\varepsilon = (L - L0)/L0$.

This myocardial strain can be *directly* measured only by techniques investigating the real length deformation (e.g. tagged magnetic resonance imaging). However, the rate of deformation (strain rate) defined as the difference of tissue velocities between two distinct points along the scan line of the echo beam, can be calculated from myocardial TDI velocities and it reflects how fast regional myocardial shortening or lengthening occurs.

In the past the strain rate has also been defined as myocardial velocity gradient, when investigating the transmural contractility in the parasternal view (radial strain)[58,59,61,62].

The strain rate calculated from TDI (SRI) is independent of the translocation movement that affects TDI, because it investigates TDI velocities in two different points (V1 and V2) at two different locations separated by a distance. Since V1 and V2 are different, there is a deformation of the tissue interposed. When the two points get closer, there is myocardial shortening, and when the two points are moving apart, there is lengthening of the tissue. This is the basis of the independence of SRI from transmitted movements.

Strain rate imaging measurement in the everyday practice. To perform strain rate and SRI the ultrasound system has to be implemented with a TDI software equipment, available in most of the high-end ultrasound systems. A loop of the left ventricle obtained in TDI modality can be analyzed with an *ad hoc* software, in devoted off-line personal computer. This opportunity is time-consuming and often does not supply all the data necessary for a transmural analysis of all the parameters in all the myocardial segments.

It is also possible to obtain the SRI in two-dimensional color Doppler directly on-line in the ultrasound system and to complete off-line the analysis in the different transmural layers of many myocardial segments (e.g. GE/VingMed Vivid FiVe with EchoPac software). The autotracking method helps in keeping the sampling volume over the same area of tissue despite its motion, although it is very time-consuming and requires placing the sample volume at different times on the same myocardial segment.

When the velocities are analyzed in the parasternal view we look at the radial strain (and so to the "myocardial velocity gradient" or to the "regional thickening fraction"); when we perform an apical velocity analysis, we look at the longitudinal strain (and so to the "regional shortening fraction"). In both these situations SRI of the subendocardium can be differentiated from SRI of the midmyocardium and subepicardium, positioning the sampling volume in the different regions. A limitation is that the sampling points are often very close to each other, and a requisite for their spatial discrimination is a good signal-to-noise ratio and good lateral resolution, so that enough wall texture is available to differentiate wall layers without the sampling point extending beyond the three wall zones.

Moreover, SRI is more angle-dependent than other Doppler modalities, and hence, derived error is enlarged, especially around the apex.

Use of strain rate imaging in myocardial infarction and ischemia. A visual qualitative wall motion evaluation is unable to identify small changes in regional contraction and may fail to identify ischemia-induced myocardial dysfunction. In fact, visually detectable alterations can be preceded by changes in longitudinal shortening during ischemia.

Since the use of strain and SRI can quantify regional myocardial motion and deformation, early experimental and clinical reports have shown the potential value of longitudinal myocardial velocities[60] and ultrasonic strain indexes[64,65] in the quantification of acute ischemia-induced regional asynergy. Besides, preliminary clinical studies showed the utility, during ischemia and in chronic myocardial infarction, of regional myocardial function assessed measuring radial and longitudinal deformation parameters[66,67].

Also in the setting of acute myocardial infarction the longitudinal systolic SRI and strain, but not TDI velocities, could accurately differentiate abnormally from normally contracting segments[68]. This confirms that deformation, but not motion, could discriminate normally from abnormally contracting myocardium within the infarct group[68].

We already mentioned the utility of SRI in the detection of transmural function with the analysis of myocardial velocity gradient (the radial strain rate examined in the parasternal echocardiographic view). Moreover, this technique is able to differentiate transmural from non-transmural myocardial infarction early after reperfusion therapy[62].

Another potential of SRI is the detection of post-ischemic viable myocardium. In dogs with temporary coronary ligation, the systolic SRI was the most sensitive echocardiographic technique in detecting dobutamine-induced postischemic recovery in contractility, when compared to conventional wall motion and systolic strain[65].

Duncan et al.[69] recently demonstrated the value of SRI associated with the dobutamine stress test in the detection of ischemia also in the presence of left bundle branch block. In fact, the quantitative SRI long-axis function during stress identified the presence of coronary artery disease in dilated cardiomyopathy with a greater sensitivity and specificity than standard wall motion analysis, particularly in the presence of left bundle branch block.

Another demonstration of SRI sensitivity in detecting localized small myocardial infarction without depression of global function is in the septal ablation for treatment of patients with hypertrophic obstructive cardiomyopathy. SRI, and not TDI, was able to accurately assess regional function and to detect the peri-infarct and non-ischemic zones[70].

From the data described, SRI appears to be very useful in the analysis of myocardial function and ischemia. Recent three-dimensional applications, together with the correction of the limitations of this technique (noise and angle dependency) will probably make myocardial SRI a clinically useful method, easy to apply in the everyday clinical practice.

Conclusions

Nowadays, several important goals are possible for the treatment of myocardial infarction: new thrombolytic strategies, early intervention with primary PTCA, the use of adjunctive antithrombotic or anticoagulant drugs or the early application of established therapies (statins, ACE-inhibitors, etc.).

However, choosing the most appropriate treatment, each patient has to be perfectly diagnosed and characterized in order to have a tailored therapy. A correct diagnosis of the extension of the myocardial necrosis cannot ignore the transmural wavefront development, the amount of viable myocardium or the presence of microvascular damage. Any echocardiographic wall motion akinesia may be caused by a variable extension of non-contracting, scarred or viable myocardium; the important role is played by the extent of salvaged myocardium beyond the scar. Such a myocardium may show a different functional status (alive and normocontracting; alive but stunned and temporarily dysfunctioning; alive but chronically dysfunctioning). These different anatomic and functional intramyocardial patterns represent the basis for different functional out-

come of regional and hence global left ventricular function.

The new technologies based on ultrasounds, described in this paper, can precisely characterize each patient in the different phases of AMI, from the early admission to the late follow-up and can supply all the data for the best treatment for any pathophysiological status. The greatest understanding of the pathology always takes to the best treatment.

Riassunto

L'uso dell'ecocardiografia è di vitale importanza nella valutazione diagnostica e prognostica dei pazienti nelle differenti fasi dell'infarto miocardico acuto. Nonostante la grande utilità dell'ecocardiografia convenzionale, le nuove applicazioni tecnologiche vengono costantemente sviluppate e sono già notevolmente utilizzate nella pratica clinica.

È difficile ipotizzare quali di queste tecniche giocheranno un ruolo importante e verranno utilizzate nell'importante ruolo diagnostico, prognostico e per l'indirizzo terapeutico. Il cardiologo saggio sarà colui che sceglierà la tecnologia appropriata per il giusto sottogruppo di pazienti.

In questo lavoro di revisione valutiamo il peso di nuove tecniche nella diagnosi fisiopatologica dei diversi stadi dell'infarto miocardico acuto.

La perfusione miocardica studiata con l'ecocontrastografia assume una notevole importanza quando la coronaria è stata riaperta con trombolisi o con angioplastica primaria; permette di determinare se la riperfusione è stata "reale", ovvero ha espletato una riperfusione completa del microcircolo coronarico o è stata soltanto "cosmetica" ottenendosi una mera ricanalizzazione del vaso epicardico coronarico senza riperfusione. In questo caso si verifica un danno della rete microvascolare, per cui ad un'efficace riapertura del vaso coronarico non segue un'efficace riperfusione del microcircolo coronarico. Nella fase iperacuta l'ecocontrastografia ha un valore informativo prognostico addizionale all'angiografia coronarica. Infatti nei soggetti con totale pervietà dell'arteria correlata all'area infartuale (con valore TIMI 3) soltanto i segmenti opacizzati all'ecocontrastografia recuperano nel tempo la funzione meccanica, mentre quelli senza ecocontrasto non hanno alcun miglioramento nonostante la pervietà della coronaria responsabile dell'infarto.

Il contrasto può essere utilizzato anche per una migliore opacizzazione della cavità ventricolare sinistra permettendo, soprattutto nei pazienti con anomalie della cinetica segmentaria, un miglior riconoscimento del bordo endocardico ed una migliore valutazione di volumi, funzione globale e regionale del ventricolo sinistro.

Inoltre le coronarie (in prevalenza la coronaria discendente anteriore) possono essere direttamente visualizzate anche per via transtoracica con trasduttori ad elevata frequenza di emissione e contrasto endovenoso, consentendo anche un'accurata stima della riserva coronarica. Le informazioni ottenibili con questa nuova tecnica possono caratterizzare i pazienti con infarto miocardico o cardiopatia ischemica cronica con parametri quali la velocità di flusso coronarico o la riserva coronarica, che non è mai stato possibile utilizzare in precedenza. Si può così valutare, anche in maniera ripetibile e non dannosa, la riapertura del vaso che aveva prodotto la necrosi con le sue importanti implicazioni prognostiche e terapeutiche, ed ottenere informazioni più particolareggiate sulla validità della riserva coronarica dopo ricanalizzazione con angioplastica.

Nella valutazione dell'infarto miocardico la caratterizzazione tissutale del muscolo cardiaco mediante ultrasuoni, seppur con numerosi anni di storia alle spalle, sta conoscendo un rinnovato entusiasmo grazie alla potenzialità nella valutazione della struttura e dello stato funzionale del miocardio. Infatti tale tecnica fornisce indici quantitativi sulla struttura fisica dei tessuti e sulle fisiologiche variazioni di tali indici durante il ciclo cardiaco. Oggi la caratterizzazione tissutale è anche in grado di analizzare i diversi strati del miocardio lungo lo spessore transmurale.

Le ultime metodiche descritte per lo studio del comportamento della funzione regionale del ventricolo sinistro nella fase acuta del miocardio sono il Doppler miocardico ad immagini ed il derivato "strain rate imaging". Esse sfruttano il mappaggio color Doppler modificato per visualizzare e misurare le velocità del movimento delle pareti cardiache e sono strettamente correlate alle reali velocità di contrazione. È anche possibile evidenziare una gradazione di colore, e quindi di velocità, lungo lo spessore della parete miocardica, con il subendocardio che mostra il colore più luminoso e il subepicardio quello meno. Tale scala di luminosità riflette l'eterogeneità di velocità di contrazione normalmente presente lungo lo spessore della parete miocardica. L'analisi e il calcolo di questo gradiente velocimetrico transmurale appare promettente perché permette una stima affidabile dello stato della contrazione e del rilasciamento miocardico nei diversi strati transmurali del ventricolo sinistro anche durante infarto miocardico.

In conclusione, ogni paziente deve ricevere la diagnosi più completa e la migliore caratterizzazione per poter essere sottoposto ad una terapia individualizzata. La corretta diagnosi dell'estensione del miocardio necrotico non può trascurare lo sviluppo del fronte di necrosi lungo lo spessore transmurale miocardico, la quota di miocardio vitale o la presenza di danno microvascolare. Anche una semplice alterazione della motilità regionale ecocardiografica può essere causata da una variabile quota di miocardio stordito e di cicatrice miocardica. I diversi aspetti anatomo-funzionali intramiocardici rappresentano la base per il differente recupero a distanza della funzione ventricolare sinistra regionale e globale. La migliore comprensione della patologia porta sempre alla migliore opzione terapeutica.

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