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The role of imaging for the diagnostic approach of cardiovascular pathology

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Summary

In the diagnostic approach of cardiovascular pathology the potential of established imaging techniques like ultrasound has been expanded in recent years and new imaging techniques have been developed. These new techniques are magnetic resonance imaging, multi-detector computed tomography and electron-beam computed tomography; a common characteristic is that the images of the heart and vessels are obtained non-invasively. The imaging tools have deepened the insight in the acute and chronic manifestations of atherosclerosis. They have also replaced or at least diminished invasive diagnostic procedures in the diagnostic work-up of patients with heart valve defects and complex congenital heart disease. Furthermore, in other common cardiovascular disorders like hypertension, aortic pathology, heart tumours and pericardial disease the diagnostic approach has also been changed dramatically by the aforementioned imaging tools.

Resumen

El papel de la imagenología en el diagnóstico de enfermedades cardiovasculares

En el diagnóstico de enfermedades cardiovasculares, el potencial de técnicas establecidas como el ultrasonido se ha expandido, desarrollándose también nuevas técnicas de visualización. Estas nuevas técnicas son la resonancia magnética, la tomografía computarizada por multidetector y la tomografía computarizada por haz de electrones, cuya característica común es que las imágenes del corazón y de los vasos se obtienen no invasivamente. Estas herramientas han permitido profundizar en las manifestaciones de la aterosclerosis aguda y crónica, remplazando o disminuyendo procedimientos diagnósticos invasivos en pacientes con defecto de válvulas cardíacas y enfermedad cardíaca congénita. Adicionalmente, este enfoque diagnóstico ha cambiado dramáticamente gracias a las técnicas mencionadas.

Key words: Cardiac imaging. Ultrasound. Magnetic resonance imaging. Multi-detector computed tomography. Electron-beam computed tomography.
Palabras clave: Imagenología cardíaca. Ultrasonido. Resonancia magnética. Tomografía computarizada por multidetector. Tomografía computarizada por haz de electrones.

Introduction

In a wide range of cardiovascular pathology several methods of invasive and especially non-invasive imaging have multiplied diagnostic opportunities in recent years. In the next presentation we will describe diagnostic imaging tools for atherosclerotic cardiovascular disease (I), heart valve defects (II), congenital heart disease (III) and other common cardiovascular pathology like hypertension, aortic pathology, heart tumours and pericardial diseases (IV).

I Atherosclerosis

Atherosclerosis is a systemic disease, but its clinical expression will differ depending on the affected circulatory bed, i.e. the heart, cerebrum, aorta or the peripheral arteries. Furthermore, in contrast to vulnerable plaques in the coronaries, which are lipid-rich and with thin cap, the high-risk lesions in the carotid arteries are fibrotic and severely stenotic. Besides differences in the circulatory bed, each individual lesion has also its own characteristics, which will determine whether the lesion is more or less vulnerable (dis-

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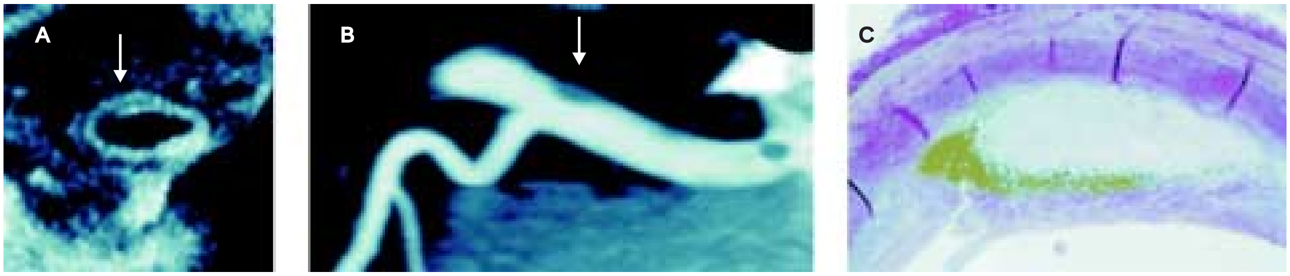

Fig. 1. MR and CT plaque characterization. Coronary artery lipid-rich plaque. A, Cross-sectional ex-vivo T_2-weighted MR image of a human LAD with a lipid-rich lesion (arrow). B, Multislice CT image of the same lesion (arrow), showing the typical low density of lipid-rich tissue. C, Corresponding histopathologic section with a large extracellular lipid pool. *(From Fayad et al, Circulation 2002; 106: 2026-2034).*

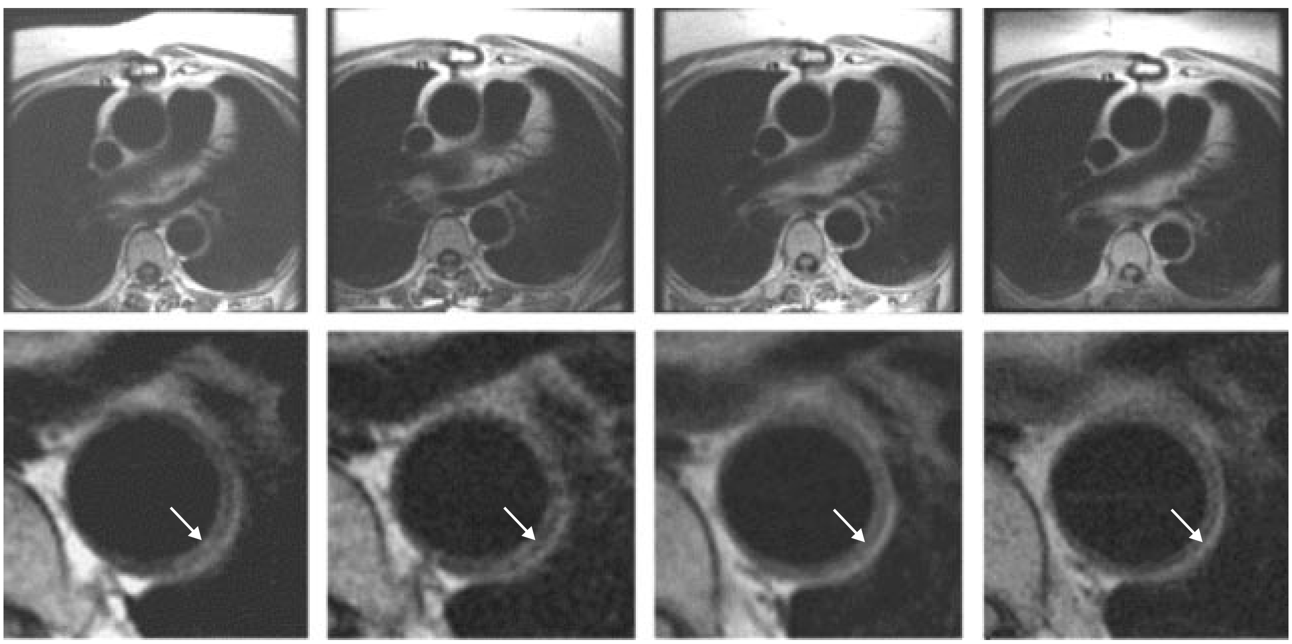

Fig. 2. Effect of lipid lowering on human atherosclerotic lesions (follow-up time of 24 months). Serial T_2-weighted images of the same patient. Note the adequate matching of the images with similar pattern of the coronary vessels (top). Detail of the descending aorta (bottom): arrows indicate the atherosclerotic plaque at its maximal thickness *(from Corti et al, Am J Cardiol 2003; 91(suppl): 17A-26A).*

ruption-prone). Because of this heterogeneity of atherothrombotic lesions, even within one individual, it will be very helpful for clinical practice to have a reliable non-invasive imaging tool to detect early lesions in the various regions and to characterize the composition of the different plaques. Intravascular ultrasound (IVUS) has already shown that plaque composition rather than severity of stenosis determine the risk of thrombotic complications associated with acute coronary syndrome.[1]

Magnetic resonance imaging (MRI) and multidetector computed tomography (MDCT), often enhanced with intravenously given contrast-agents, currently have a spatial resolution of resp. 0.6 x 0.6 x 1.0 mm3 and 0.25 x 0.25 x 2.0 mm3, which has resulted in acceptable visualization of the coronary vasculature in a non-invasive way *(Fig. 1)*.[2] MRI is able to discriminate and characterize the plaque components on the basis of biophysical and biochemical parameters. Mitsumori et al. reported the ability of high-resolution MRI to visualize fibrous cap thickness and rupture in human atherosclerotic carotid plaque *in-vivo*.[3] It has recently been shown that it is possible to target molecules with antibodies coupled to a contrast molecule, which can be detected with MRI.[4] These new non-invasive imaging techniques have

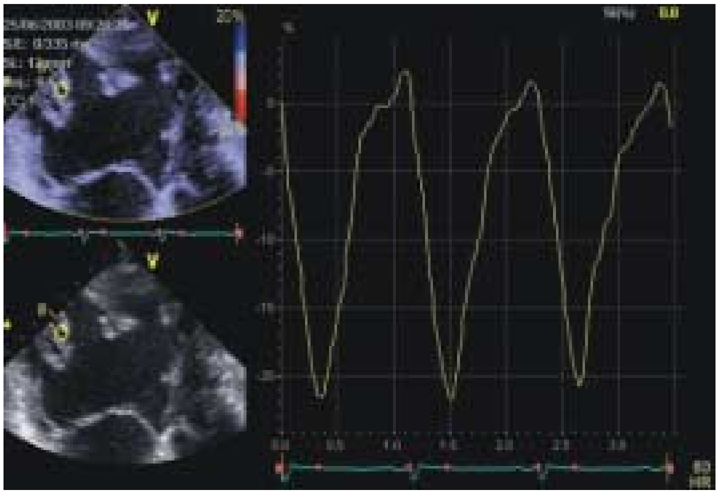

Fig. 3. Strain analysis for evaluation of ventricular function. Apical 4 chamber view *(upper left strain-coded, lower left grayscale image)*. Using tissue velocity imaging myocardial velocities were obtained in a systemic right ventricle of a patient with complete transposition of the great arteries and atrial switch operation. Relative longitudinal deformation, strain, can be computed in selected areas during the cardiac cycle. As the RV shortens during systole, negative strain curves are obtained *(right)*. Strain rate, i.e. rate of deformation can also be computed from the same data-set.

Fig. 4. CT image of type A dissection. Transverse slice at the level of main pulmonary artery. Clearly visualized dissection flap *(see arrows)* in ascending aorta *(AoAsc)* and descending aorta *(AoDesc)*. Thrombus in false lumen.

enabled to do *in-vivo* biologic observations in men, which help to test new hypotheses of plaque formation and to monitor therapeutic interventions *(Fig. 2)*.[5] The significance of MRI for evaluating myocardial viability and the transmural extension of necrosis is also well established. Another new imaging technique for diagnostics in coronary artery disease is electron-beam computed tomography (EBCT), which since the early 1990s has become the "gold standard" for the assessment of calcified plaques.[6] A high coronary calcium score is a sensitive but not a specific marker for obstructive CAD. EBCT is now especially used to discover preclinical stages of CAD and it has been suggested that measurement of the coronary calcium load by EBCT may be independent and superior to conventional risk factors as a predictor for future cardiac events.

Imaging techniques also offer diagnostic opportunities to monitor vessel wall changes as surrogate marker of atherosclerosis. In comparison with the former mentioned sophisticated MRI, MDCT and EBCT, the B-mode ultrasonography of the intima-media thickness in the carotid and/or femoral arteries is an easy and cheap bed-side measurement to be used as evaluation of interventions with lipid-lowering therapy.[7,8]

Furthermore, established imaging techniques like 2D-echo/Doppler are widely used to stratify the risk of patients after myocardial infarction.[9] In atrial fibrillation echocardiography has also been useful to define patients at highest risk for cardioembolic events, even if no clinical risk factor is present.[10] Finally, transesophageal echocardiography (TEE) plays an important role perioperatively in cardiac surgery and also in critically ill patients in the intensive care.[11]

In atherosclerotic heart disease myocardial perfusion single photon emission computed tomography (SPECT) is also a widely utilized noninvasive imaging modality for the diagnosis, prognosis, and risk stratification of coronary artery disease. The strength of SPECT images is largely derived from the three-dimensional, volumetric nature of its image. Thus, this modality permits three-dimensional assessment and quantitation of the perfused myocardium and functional assessment through electrocardiographic gating of the perfusion images.[12]

II Heart valve defects

Until recently hemodynamic assessment of heart valve defects could be obtained only by the invasive approach of catheterization. In the last years echocardiography with Doppler flow analysis has demonstrated, that this non-invasive method gives almost similar results and sometimes even better.[13] Echocardiography has the advantages that it can be performed at the bedside, it is a rapid and very safe method and it is relatively inexpensive. Furthermore, it has offered the opportunity to re-evaluate the hemodynamic alterations of the heart as frequent as necessary, which can be used for optimizing medical treatment and establishing the right moment for surgical repair, if necessary.

Exact visualization of valve morphology is also possible with the cross-sectional imaging modalities, magnetic resonance imaging (MRI) and the recently introduced technique of multi-detector computed tomography (MDCT). However, these more sophisticated techniques are only used, if other non-invasive imaging modalities, like echocardiography, fail or provide insufficient information. This commonly occurs in the assessment of right ventricular valves.

Quantification of valve stenosis is possible by calculating valve orifice area, which can be performed with MRI and MDCT. An estimation of the instantaneous peak gradient can only be achieved by MR flow measurements. MR flow measurement is a reliable method to quantify the degree of mild to moderate stenoses. Quantification of valve regurgitation is possible by measurement of the regurgitation fraction with MR flow measurements as well as with MR volumetry/CT volumetry. But only the MR flow measurement is suitable for the quantification of valve regurgitation in patients with multiple valves involved or cardiac shunting. MRI and probably MDCT are the most reliable methods in the evaluation of ventricular volumes and therefore suitable for the follow-up in patients with valvular heart disease, because changes in volumes are important for therapeutic decisions in these patients. The crucial advantages of MRI compared to CT in the diagnostic of valvular heart diseases however are the absence of radiation exposure, the possibility of quantitative evaluation of valves function using flow measurements and the higher temporal resolution as compared to MDCT.[14]

III Congenital heart disease

Echocardiography with Doppler remains the cornerstone of diagnostics in congenital heart disease.[15] Recent advances with tissue Doppler, strain rate, and integrated backscatter have expanded the potentials of echocardiography in this field. Strain rate values at different moments within the heart cycle might become important parameters in the assessment of myocardial impairment.[16] Further studies are indicated to assess the correlation of these parameters with the severity of stenosis, left ventricular hypertrophy and irreversible myocardial function changes *(Fig. 3)*.

MR and MDCT complement the echocardiographic examination in pediatric and adult patients with congenital heart disease. They are useful means of explicitly demonstrating chamber morphology and, in particular, morphologic changes caused by physiologic changes brought on by particular defects. The high-contrast resolution of spin echo acquisition provides important morphologic detail. Cine gradient echo techniques complement spin echo acquisition by providing functional and flow information. Often angiocardiography may not be replaced by these studies, but at least shortening examination time is obtained, and decreasing morbidity in diagnostic workups of these patients.[17,18]

IV Hypertension, aortic pathology, heart tumours and pericardial diseases

Hypertension: Organ damage by hypertension has been evaluated in the past by fundoscopy and the presence of left ventricular hypertrophy (LVH) on the ECG. Nowadays echocardiographic determination of left ventricular mass is used, being a more sensitive and specific marker for cardiovascular risk stratification and for monitoring the effect of antihypertensive treatment.[19]

Aortic pathology: The pathologies of penetrating aortic ulcer and intramural aortic hematoma were virtually unknown in the era when angiography was the diagnostic standard for aortic pathology; these pathologic entities have appeared with the introduction of the new imaging techniques like MRI, MDCT and transesophageal echocardiography. Intramural aortic hematoma is discussed as a variant of aortic dissection and penetrating aortic ulcer is discussed along with other manifestations of atherosclerotic disease.

In aortic dissection the newer diagnostic tools have revealed that retrograde aortography is not as sensitive as previously thought and aortography has the usual risks of any invasive procedure. MDCT and MRI are nowadays the preferred procedures for diagnosis of aortic dissection; they are rapid and non-invasive *(Fig. 4)*.[20]

Transesophageal echocardiography is also an excellent test for patients with suspected aortic dissection, requiring only 5-18 minutes, and it can also be continued peroperatively without affecting the performance of the operation.[21]

Heart tumours: It is obvious that the newer imaging techniques have also revolutionized the diagnostic and treatment strategies of heart tumours. Echocardiography, MDCT and MRI have replaced cardiac catheterization and selective angiography. Contrast imaging has even enhanced the results. Echocardiography is often sufficient to make the diagnosis and assist in the designing of the surgery. MRI has demonstrated to be useful to distinguish malignant from benign cardiac and paracardiac masses.[22]

Pericardial disease: In the evaluation of pericardial disease, computed tomography (CT) and magnetic resonance (MR) imaging traditionally have been used as adjuncts to echocardiography. However, CT and MR imaging are particularly useful as sensitive and noninvasive methods for evaluating loculated or hemorrhagic pericardial effusion, constrictive pericarditis, and pericardial masses. Both CT and MR imaging provide excellent delineation of the pericardial anatomy and can aid in the precise localization and characterization of various pericardial lesions, including effusion, constrictive pericarditis and pericardial thickening, pericardial masses, and congenital anomalies such as partial or complete absence of the pericardium. Both modalities provide a larger field of view than does echocardiography, allowing the examination of the entire chest and detection of associated abnormalities in the mediastinum and lungs. Soft-tissue contrast on CT scans and MR images also is superior to that on echocardiograms. Given the many potential applications of these modalities in the evaluation of pericardial diseases, familiarity with the CT and MR imaging features of these diseases is important.[23]

Conclusion

New diagnostic imaging techniques, most of them non-invasive, have opened the possibility of biologic observations *in-vivo*; the results will improve therapeutic management in the acute and chronic phase of atherosclerosis. In many cases of hemodynamic evaluation of heart valve defects and understanding of complex congenital heart disease invasive diagnostic procedures can be replaced or their examination time can be diminished. Diffusion of the newest imaging techniques of MRI, MDCT and EBCT on a wider scale will only be possible if there is direct collaboration between cardiologists and radiologists.

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