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AUGMENTING THE PHYSICAL EXAMINATION: STETHOSCOPY AT LAST!!

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By extending the sense of hearing, the introduction of the stethoscope opened the door to a whole new world of clinical signs and it became the primary diagnostic tool for the interpretation of heart sounds and murmurs. However, confidence in its use has declined parallel with the availability of echo/Doppler evaluation and notable shortcomings in examination skills and more particularly of the auscultation have been documented (Mangione and Nieman, 1997, Attenhofer Jost et al., 2000). Indeed, our ability to obtain images of the beating heart together with blood flow information has taken a tremendous leap forward and has definitively changed the physical examination and the practice of cardiology. It is also recognised that the diagnosis of many common cardiac conditions such as "silent" valvular disease, pericardial effusion, intracardiac mass lesions, abdominal aortic aneurysm, early cardiomyopathy, and early left ventricular dysfunction are a challenge even to the most experienced cardiologist and are now better diagnosed and even quantified by a limited echo/Doppler examination (Popp, 1998). It appears that the ability of cardiologists to detect cardiovascular abnormalities by a standard physical examination alone is relatively poor.

Portable ultrasound devices

Miniaturised and digital techniques allow the construction of high resolution battery-powered small portable ultrasound imaging devices (SonoHeartTM, SonoSite, Inc., Bothell WA, USA, and OptiGoTM, Philips Medical Systems, Eindhoven, NL).

They can be used anytime anywhere just like a conventional stethoscope and significantly extend the physical examination by seeing the heart in the chest at the point-of-care. Therefore, these devices should be more appropriately named "ultrasound stethoscopes" (stethos = chest and skopein = see), while the standard stethoscope should be named a "stethophone" (phone = sound).

Several companies are currently developing small ultrasound imaging devices, even in pocket size. These devices should not be confused with the larger portable desktop systems which are full featured systems.

It must be emphasised that the performance and diagnostic potential of the small devices should not be compared with or evaluated against the full-featured high-end ultrasound systems but against the yield and diagnostic conclusions of the physical examination.

Clinical uses

A more accurate diagnosis, answering limited but basic clinical questions and screening for specific cardiac conditions with these devices will take diagnostic ultrasound imaging to many different clinical scenarios.

Augmenting the physical examination

Seeing the heart during the physical examination at the point-of-care provides additional information beyond what we can perceive with inspection, palpation and auscultation (Table 1). It extends our clinical perception and provides quantitative information by direct "visualising the invisible pathology". Subclinical pathology is identified and murmurs and abnormal movements are directly related to structural, functional and flow abnormalities. A major cardiac abnormality (valve disease, shunt, cavity dilatation, hypertrophy, pericardial effusion, mass lesion, wall motion abnormality) is rapidly identified and often a definitive diagnosis is made (Figures 1-5). Unanticipated abnormalities are diagnosed in approximately 20% of patients. The physical cardiovascular examination can be extended by imaging and measurement of the abdominal aorta and inferior vena cava.

A major strength of a limited echo/Doppler examination is its specificity that allows to exclude a cardiac abnormality with great certainty in any clinical setting.

PORTABLE ECHOCARDIOGRAPHY Augmenting the yield of the physical examination
Higher sensitivity and specificity
Early (preclinical) diagnosis
Incidental (unexpected) findings
Functional assessment
Blood flow information
Quantitative information
Abdominal aorta
IVC collapse

Table 1: *Portable echocardiography complements and enhances the physical examination in an era of the paradigm shift to early "presymptomatic" detection of disease.*

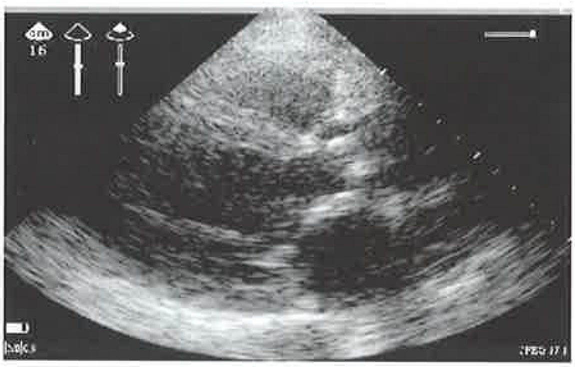

Figure 1a: *Aortic stenosis*

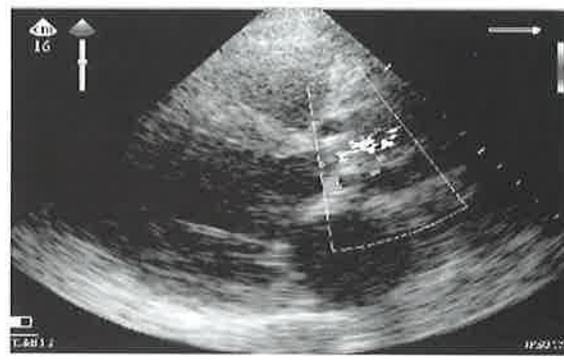

Figure 1b: *Aortic stenosis, mosaic pattern*

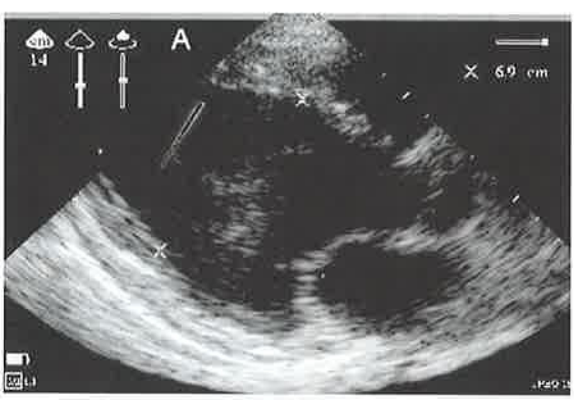

Figure 2: *Dilated cardiomyopathy*

Figure 3: *Mass lesion in left ventricle*

Figure 4a: *Aortic regurgitation*

Figure 4b: *Aortic regurgitation, color Doppler*

Goal-oriented and follow-up echocardiography

Standard echocardiography involves a comprehensive examination with complex equipment by an operator with considerable training and experience. However, the diagnosis and follow-up of most cardiac conditions requires only a fraction of the potential of these expensive facilities and a specific clinical question can often be answered within little time and with little examination protocols. Portable echocardiography is very suitable for such a limited "goal-oriented" examination to answer basic clinical questions and for the follow-up of specific conditions such as te resolution of a pericardial effusion, cardiac dimensions and left ventricular function and LV hypertrophy (Vourvouri et al, 2002).

Emergency and intensive care environment

Portable echocardiography can effectively assist in the initial evaluation and rapid diagnosis of potentially life threatening conditions or in situations where quick-decision making is essential and standard echocardiography or other imaging methods are not immediately available. The ultrasound stethoscope provides data inaccessible by clinical examination and allows to immediately diagnose a potentially treatable cause of pulseless electrical cardiac activity such as tamponade, hypovolemia, a massive pulmonary embolism or a dilated heart and valvular pathology in a low output state (e.g. calcific aortic stenosis). Immediate echocardiographic assessment in the emergency room has been reported to considerably shorten the time to diagnosis and therapy and thus improving chances of survival. Right ventricular involvement and mechanical complications of a myocardial infarction are readily diagnosed. Pericardiocentesis can be guided and the effects of acute interventions monitored through estimation of cavity dimensions, ejection fraction, and inferior vena cava collapse. Croft et al (2002) reported that even after limited training the use of a portable device in the critical care environment resulted in diagnostic and management changes in approximately 25% of patients.

Screening in the community

Portable echocardiography can be used for screening and identifying cardiac disorders in selected risk groups or in the general population. However, in screening programs it is important to consider not only the sensitivity of a portable device for identifying or excluding a specific condition but also the competence of the examiner. Now with the realisation that heart failure is reaching epidemic proportions and that efficient management must take place in the community setting. Brain natriuretic peptide is a sensitive marker of increased intracardiac pressure of any cause and appears to be a sensitive cost-effective screening method. Portable echocardiography can be used for an etiologic diagnosis, assessment of global left ventricular function and follow-up. Both of these tools will

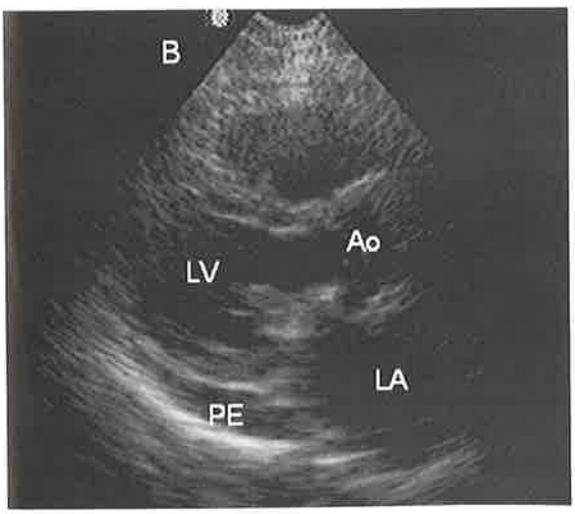

Figure 5: *Pericardial effusion*
LV: *left ventricle,* ***AO:*** *Aorta,* ***LA:*** *Left atrium*

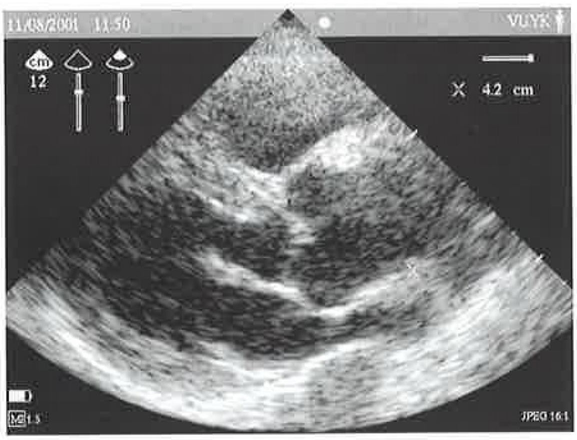

Figure 6: *Marfon syndrome*

undoubtedly be used by primary care physicians in the future.
The ultrasound stethoscope allows rapid screening for an occult aortic abnominal aneurysm in patients with risk factors (Bruce et al, 2000, Vourvouri et al, 2002). Physical examination is notably insensitive in moderately enlarged aneurysmata and obese patients.
Limited echocardiography allows to screen for left ventricular hypertrophy and to follow the effect of antihypertensive treatment in office practice (Sheps and Frohlich, 1997, Vourvouri at al, 2002).
Mitral valve prolapse can effectively be excluded or confirmed in a limited number of standard views in otherwise asymptomatic individuals (Kimura et al, 2000).
Screening of athletes may become an important application since potentially dangerous conditions can be identified at low cost. Hypertrophic cardiomyopathy, a dilated aorta (Marfan) (Figure 6) and valvular abnormalities (bicuspid aortic valve, mitral valve prolapse) are the most common disorders and are reliably detected. However, screening for cardiac disorders in young athletes and asymptomatic individuals involves a high risk of a false positive diagnosis and should be performed by experienced examiners.

Discussion

Ultrasound offers obvious advantages over other imaging modalities for practical use and the construction of a small personal imager. We constructed and used a small ultrasound imager as early as 1978 (Roelandt et al, 1978). However, imaging performance and reimbursement issues did not stir the enthusiasm of cardiologists who were confronted in those days with the rapidly expanding capabilities and applications of full-featured ultrasound systems. Studies have shown that complementing the routine physical examination with a small personal imager increases its diagnostic accuracy varying from 34%-51% (Kimura et al, 1998, Spencer et al, 2001, Croft et al, 2002, Vourvouri et al, 2003). Small personal imagers will also have an impact on the use of high-end echocardiography and other imaging modalities by targeted referral. A major application will become their use in the critical care environment. Small personal imagers are extremely suited for a limited "focussed" ultrasound examination to screen for cardiac abnormalities follow the course of a disease or to test the effect of therapy in office practice.
Training of clinicians and non-echocardiographers is an important issue and should focus on criteria of identifying a normal heart and diagnosing major and acute cardiac disorders. In fact, the device should be used in a way comparable to auscultation; whenever there is doubt, further echo/Doppler is always examination indicated. In the future, advances in tele-communication and software will allow for diagnostic support from experienced laboratories or intensive care units.

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ULTRASOUND IMAGING, IMAGES AND IMAGINATION

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Before the development of cardiovascular imaging techniques, clinicians could only imagine how the heart of their patients were contracting. It was not until the introduction of contrast ventriculography and quantitative methods for analysis in the early 1960s that objective data could be substituted for the subjective bedside observations. These developments irrevocably changed cardiology from an art to a science. Computer-aided systems were subsequently developed for more accurate analysis and reproducible measurements.

In the past 20 years, advances in digital techniques and the imagination and creativity of many have resulted in an enormous progress and advances in complex cardiac imaging modalities including ultrasound imaging, SPECT, multislice-CT, MR and PET. These advances will accelerate and our reliance on imaging techniques for management of cardiovascular disease will undoubtedly continue to increase.

Who could have predicted 30 years ago the impressive evolution of ultrasound imaging systems? The technique did not mimic other diagnostic imaging modalities and introduced new diagnostic concepts. As a consequence, it opened new horizons for clinical research and has made important and unique contributions to our understanding of cardiac disease. With its increasing number of modalities and functions which can be applied in a wide variety of clinical scenarios it has become the most widely disseminated cardiac imaging technology (Table 1). Currently, more than one out of every four medical imaging studies is performed with ultrasound and the proportion is increasing.

Table 1: *Cardiac ultrasound modalities and functions*

• Transthoracic echocardiography (M-mode and 2D)
• Pulsed-, continuous wave and colour Doppler
• Transesophageal/substernal echocardiography
• Stress echocardiography (pharmacologic, exercise)
• Contrast echocardiography
• Tissue characterisation
• Acoustic quantification (colour kinesis)
• Tissue Doppler imaging (velocity, stress and strain rate)
• Newer features (2nd harmonic, pulse inverse imaging, etc.)
• Three-dimensional echocardiography (gated, real-time)
• Intracoronary imaging
• Intracardiac imaging

With the progress in miniaturisation and digital techniques we have now arrived at a point where we have at one end the high-end full featured systems which integrate most of these modalities and functions and at the other end the small hand-held systems with less functions but good imaging quality. Another direction of development are the portable and special dedicated systems (Figure 1).

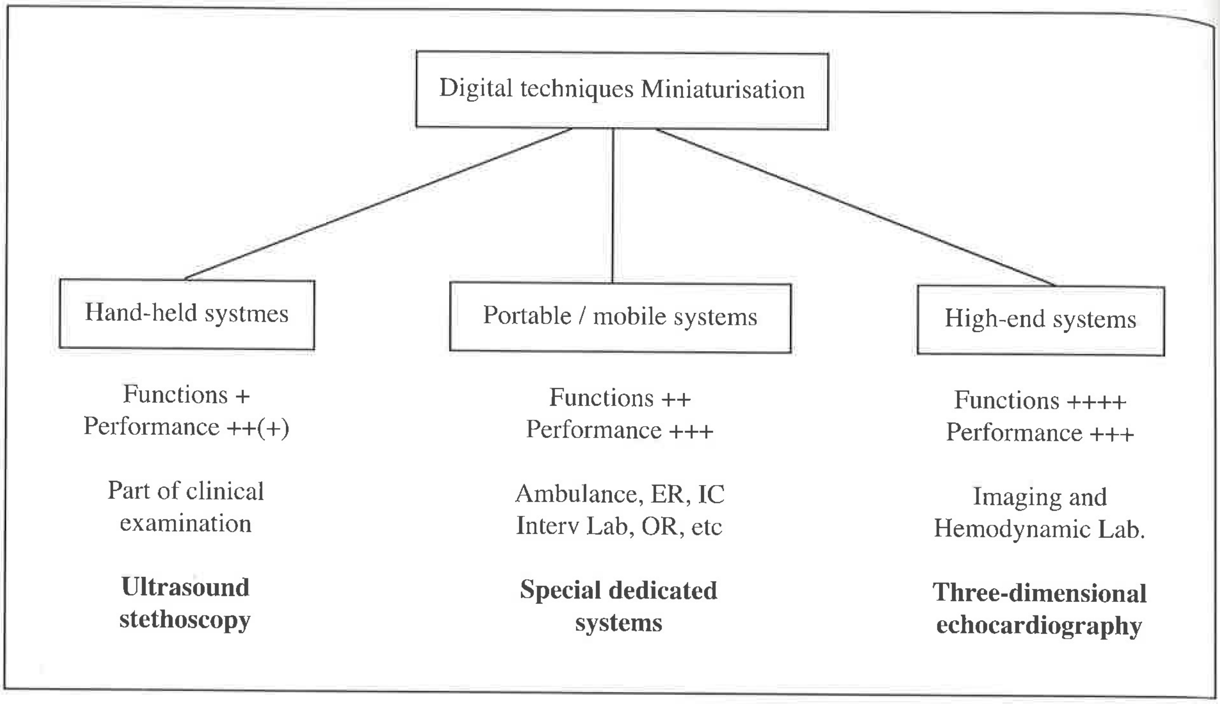

Figure 1: *Digital techniques Miniaturisation*

High-end ultrasound systems

Currently available high-end ultrasound systems integrate many functions and allow an integrated assessment of cardiac function and hemodynamics with an unprecedented versatility. The echocardiography laboratory can therefore appropriately be called "the non-invasive imaging and hemodynamic laboratory". The impact on our diagnostic capabilities has been enormous and the practice of cardiology has been changed permanently. In day-to-day cardiological practice, ultrasound imaging and Doppler assessment are now the first cardiac examination whenever cardiac disease is suspected and a definitive diagnosis is often made at a relatively low cost. However, the high-end ultrasound systems are becoming very complex and some functions are only used for clinical research and for testing pathophysiological concepts. In fact, the competition between manufacturers has been largely responsible for the incorporation of many functions even before their impact on patient management and outcome was validated.

The latest development in cardiac ultrasound is dynamic three-dimensional imaging which can be by the reconstruction of volumetric data-sets from gated image acquisition or by real-time volumetric acquisition. The future of three-dimensional imaging lies in its potential to provide new and clinically useful information. In comparison with two-dimensional imaging, volumetric imaging more faithfully replicates the complex cardiac morphology and its contents. Quantitative methods allow to exploit the spatial information which is inherently present in the volumetric presentation for more accurate measurements of surfaces, volumes and shapes than with two-dimensional echocardiography. In the future, three-dimensional imaging in combination with computer-assisted data manipulation and display will allow exciting data presentations of otherwise nonvisible dynamic cardiac phenomena such as electrical depolarisation, magnetism, metabolism, etc. With further developments in microprocessor technology, the number of visualised dynamic cardiac (patho)-physiologic phenomena and their imaging solutions appears infinite. The imagination of researchers and the new visual displays with modern computer graphics will help to elucidate and to better understand the complex functions of the heart. Another important medical frontier is virtual reality, the immersive environment which is created by a computer combining three-dimensional data-sets of a patient with e.g. all the information that you know about people in general or from e.g. the "visible human". Virtual reality allows the physician to interact with these data and heralds a revolution for medical training, internet-based distance learning, on-line research between centres via ultra-high speed networks, diagnosis and treatment by e.g. remote robot interventions.

Hand-held ultrasound systems

Microcomputer technology has resulted in the development of hand-held ultrasound systems. These small imagers with excellent imaging performance but limited function can be used (ultrasound stethoscopes) as part of the physical examination at the point-of-care and in new healthcare arenas – office practice, war zones, remote and difficult accessible areas, space travel, etc. It augments the yield of the physical examination by completing our physical senses by directly seeing the heart and its pathology inside the chest (ultrasound stethoscopy). Traditionally, our physical cardiac examination has been dependent on inspection, palpation and auscultation and is now completed by seeing the 'invisible' pathology (table 2).

Table 2: Seeing the invisible pathology during the physical examination

- Higher diagnostic specificity and sensitivity
- Early (pre-clinical) diagnosis
- Silent valve disease
- Functional assessment
- Intracardiac blood flow information
- Quantitative measurements
- Inferior vena cava (right heart filling pressure)
- Abdominal aorta dimension

Currently available systems provide excellent image quality that rivals that of standard equipment together with colour Doppler flow. Recent systems include pulsed- and continuous wave Doppler allowing a complete comprehensive echo/Doppler examination anytime, anywhere. The advantages of these small devices are their direct availability and their use with greater flexibility than standard equipment in a variety of clinical scenarios. However, physicians will have to learn how to use these devices and how to interpret the images of basic cardiac conditions, but, properly managed, this shift in practice will greatly benefit the patients.

Special dedicated ultrasound systems

There are many cardiac conditions and clinical scenarios in which the clinical question to be answered is limited and only a limited number of functions with little examination protocols are needed. Follow-up of most patients often requires only to measure left ventricular function. Intraoperative testing the surgical closure of an intracardiac defect, the repair of a mitral valve or the rapid screening for a major cardiac problem in the emergency and intensive care room requires limited modalities and functions. In these situations a portable system with good imaging performance and colour flow imaging allows to answer most of the questions. Guiding interventions in the electrophysiology laboratory (placing catheters) and monitoring device closure in the interventional laboratory can be achieved with portable systems equipped with intracardiac imaging catheters.

Conclusion

Bias or subjectivity can be introduced into image interpretation through our emotional awareness of a patient's condition. This can diminish the value of any imaging system. Computer-aided analysis and quantitative data extraction is therefore mandatory. The major challenge of clinicians is to understand the characteristics of new imaging modalities, to integrate them in an intelligent and cost-effective way into the clinical decision-making process and to extract from them the maximum of objective information. Indeed, the real value of any imaging technology is intimately dependent on our intellectual contributions: how, when and what clinical scenario it will have its optimal clinical impact. This calls upon our imagination.

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MAGNETIC RESONANCE IMAGING IN CARDIOLOGY

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The clinical role of cardiovascular magnetic resonance imaging (CMRI) has recently expanded due to the availability of rapid imaging sequences, broader use of contrast media and new indications. In most patients, CMRI is used to complete or add information when image quality by echocardiography is sub-optimal. Typical clinical situations include the assessment of left and right ventricular function, pericardial disease and tumours, aortic disease and congenital heart disease. MRI is also useful to clarify the presence of cardiac thrombi.

New indications include the detection and quantification of myocardial infarcts and the precise definition of residual viable myocardium. This is possible as new pulse sequences have become available optimizing the difference in relaxation time T1 between infarcted and non-infarcted myocardium. Even small infarcts such as those associated with coronary interventions are reliably detected by CMRI(1). Such small infarcts can usually not be localized electrocardiographically or detected by finding regional wall motion abnormalities by echocardiography. Even perfusion scintigraphy fails to detect such infarcts(2). The high spatial resolution of CMRI permits assessment of infarct transmurality which in turn helps to predict recovery of myocardial function following infarction with and without revascularisation. A new and unexpected finding is the dissociation of wall motion abnormalities and myocardial necrosis suggesting a more important role for stunning of periinfarcted myocardium than previously suspected. CMRI will also become an important tool to study the healing of infarcts and the formation of fibrous scar. The precise depiction of necrotic and scarred tissue will also permit to study the influence of various interventional and medical therapies directed at the prevention of ventricular remodelling.

High signal intensities following the application of gadolinium based contrast media can also be found in patients with acute myocarditis. These areas of inflammation and necrosis are not uniformly distributed within the left ventricle but are found preferentially at the lateral free wall (Fig. 1). Although not all patients with clinically suspected myocarditis and not even all with severe forms of myocarditis show regional increases of signal intensity MRI is helpful to direct biopsy in those with signal increases. Current research is directed towards determining whether the infectious agent responsible for the myocardial inflammation determines the extent and frequency of signal enhancement. Furthermore, the time course of inflammation observed by MRI needs to be related to patient outcome and development of myocardial failure. Thus, MRI may become the most important non-invasive technique to identify and follow-up patients with inflamed myocardium.

Pathologic studies revealed that a substantial number of patients with hypertrophic cardiomyopathy suffer from transmural infarcts despite normal epicardial coronary arteries. These patients are at high risk of developing large hypocontractile ventricles and severe heart failure. Moreover, intramyocardial scar was shown to be a risk factor for sudden cardiac death. Until recently such scars could only be identified at post-mortem examinations. This has changed as contrast enhanced CMRI is now able to detect myocardial scars in patients with hypertrophic cardiomyopathy and thus opens a new road for early identification of patients at risk for sudden death and the development of heart failure(3). In a recent study, 17 of 21 patients with hypertrophic cardiomyopathy who were predominantly asymptomatic showed scarring. Such scarring occurred only in hypertrophied regions (≥10 mm), was patchy with multiple foci, and predominantly involved the middle third of the ventricular wall. All 17 patients had scarring at the junction of the interventricular septum and the right ventricular (RV) free wall. On a regional basis, the extent of scarring correlated positively with wall thickness and inversely with wall thickening.

The application of CMRI for depicting the coronary arteries and especially the coronary walls is an exciting field for continued research. Depiction of the coronary arteries is hampered by motion artifacts caused by the rapid motion of the heart, the blood and breathing. Despite the fact that appropriate compensation algorithms have been developed, high resolution imaging of the coronary arteries is not possible in every patient. Moreover, the spatial resolution achievable with CMRI is currently inferior to that of state-of –the-art CT with 16 and more slices. Therefore, replacement of invasive coronary angiography by CMRI is not yet possible. Current indications for MR coronary angiography include the depiction of aberrant coronary arteries and the detection of bypass graft patency. Based on work in the carotid arteries, new pulse sequences such as free breathing 3D black-blood spiral image acquisitions now permit depiction of the coronary walls by CMRI providing isotropic spatial resolution of

1.0x1.0x1.0 mm^3[4]. Using this technique, the thickness of the coronary wall is significantly thicker in subjects with nonsignificant coronary artery disease (10% to 50% x-ray angiographic diameter reduction) than in normal volunteers. Thus CMRI holds promise for non-invasive characterization of plaque components and monitoring of the arterial remodelling process, which in the future may result in improved risk stratification.

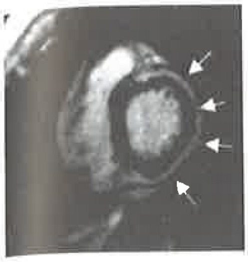

Figure 1: Inversion recovery CMR image in patient with resuscitated sudden cardiac death. The lateral wall (arrows) shows high signal intensity indicating the presence of myocardial inflammation. This patient had none of the classical clinical signs of myocarditis. MR guided biopsy directed towards the lateral wall of the left ventricle showed healing myocarditis. Parvovirus B19 and human herpes virus 6 were detected in the biopsies. The patient has received an implantable automatic defibrillator and has fully recovered. Due to the presence of the device, follow-up studies by MRI cannot be performed.

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