Coronary imaging is the ultimate challenge. During the last decade there have been great advances in this imaging technique, partly as a result of improved scanner hardware, but more because of advances in microprocessor technology.

Non-invasive coronary imaging techniques to detect significant coronary stenosis (> 50 % lumen diameter stenosis)

<table>
<thead>
<tr>
<th>EBCT</th>
<th>MS-CT</th>
<th>MR-CA Free breathing</th>
<th>MR-CA Breath-hold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessability (%)</td>
<td>80</td>
<td>70</td>
<td>75</td>
</tr>
<tr>
<td>Sensitivity (%)</td>
<td>80</td>
<td>80</td>
<td>50</td>
</tr>
<tr>
<td>Specificity (%)</td>
<td>95</td>
<td>95</td>
<td>90</td>
</tr>
<tr>
<td>Accuracy (%)</td>
<td>90</td>
<td>90</td>
<td>85</td>
</tr>
</tbody>
</table>

EBCT, electron beam computed tomography; MS-CT, multi-slice computed tomography; MR-CA, magnetic resonance coronary angiography.

Abbreviations: EBCT, electron beam computed tomography; IVUS, intravascular ultrasound; MR-CA, magnetic resonance coronary angiography; MRI, magnetic resonance imaging; MS-CT, multi-slice computed tomography; OCT, optical coherence tomography.
such as a larger number of thinner detector rows (to 16 rows), will increase spatial resolution (in particular Z axis resolution) and will allow faster data acquisition (to 20 second breathhold), whereas ECG triggered tube current modulation will reduce x ray exposure. A further increase of the gantry rotation speed will also contribute to a better temporal resolution and shorter acquisition time.

Three dimensional image reconstruction allows post-processing algorithms to construct coronary artery fly-through films, thereby creating virtual angioscopic imaging.3 In this issue an MS-CT coronary imaging data set was used to create “virtual coronaroscopy” which may evolve into a new method to assess complex coronary obstructions.9 Virtual angioscopy challenges any imaging technique and requires the highest resolution (ideally resulting in isotropic voxels) and high quality images to generate a reliable “scopy”. At present, the quality of non-invasive coronary imaging with MS-CT, as well as with EBCT, allows virtual angioscopy, although the images are rather crude.5 6 Future studies will determine whether angioscopy offers diagnostic information additionally to existing two dimensional and three dimensional image representations.

**IDENTIFYING THE VULNERABLE PLAQUE**

Disruption (rupture or erosion) and intracoronary thrombosis of coronary plaques is a critical event, leading to an acute coronary syndrome, and healing often results in plaque growth. Disruption (rupture or erosion) and intracoronary thrombosis of coronary plaques is a critical event, leading to an acute coronary syndrome, and healing often results in plaque growth. It has become customary to classify coronary plaques: as stable with a low likelihood of disrupting; as vulnerable plaque with a high likelihood of rupture; or as unstable when it has actually ruptured. The holy grail in coronary plaque imaging is a reliable in vivo method to discriminate between vulnerable and stable plaques. Several, invasive, catheter based techniques and non-invasive techniques are nowadays available to assess coronary plaque characteristics, which may provide clues concerning the stability or vulnerability of the plaque. The most important features of coronary plaques and related imaging modalities which are able to depict these features are presented in table 3.

The vulnerable plaque has a large lipid pool and a thin fibrous cap, which contains large numbers of macrophages, in particular at the shoulders of the plaque. Intracoronary angioscopy can establish the presence, but not the size, of a yellow lipid lesion and is therefore limited in assessing vulnerability.1 Intracoronary ultrasound can accurately provide the dimensions of the coronary plaque, but is not able to offer consistent detection of a lipid pool, although a hypocogeneric zone within a plaque is highly suspicious for the presence of a lipid pool.1 2. The thickness of the fibrous cap is critical and a cap with a thickness less than 150 µm has a high likelihood of rupturing. The resolution of standard intracoronary ultrasound is inadequate to measure thin caps, but with a dedicated ultrasound acquisition technique it appears possible to visualise thin rupture prone fibrous caps.11 Discrete rises in temperature at coronary plaques that have ruptured and led to acute coronary syndromes can be detected with recently developed catheters,12 and it appears that the presence of a temperature rise is a predictor of adverse cardiac events.13 This technique appears quite promising, but it needs to be combined with a visualisation technique to assess precisely the localisation of the vulnerable plaque within the coronary tree.

“Accurate detection of calcium in the coronary vessel wall, which is evidence of the presence of coronary atherosclerosis, can be achieved with EBCT and MS-CT”

Table 3 In vivo coronary plaque imaging

<table>
<thead>
<tr>
<th>Pathology</th>
<th>Imaging modality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lipid pool (presence, size)</td>
<td>2, 3, 5</td>
</tr>
<tr>
<td>Fibrous cap</td>
<td>2</td>
</tr>
<tr>
<td>Calcium</td>
<td>6, 2, 1</td>
</tr>
<tr>
<td>Inflammation (temperature)</td>
<td>4</td>
</tr>
<tr>
<td>Remodelling</td>
<td>2</td>
</tr>
<tr>
<td>Intracoronary thrombus (rupture)</td>
<td>3, 1</td>
</tr>
<tr>
<td>Endothelial dysfunction</td>
<td>1 (acetylcholine challenge)</td>
</tr>
<tr>
<td>Luminal stenosis</td>
<td>1, 2, 5, 6</td>
</tr>
</tbody>
</table>

Coronary imaging techniques: 1 Diagnostic angiography; 2 Intracoronary ultrasound; 3 Intracoronary angiography; 4 Thermometry; 5 Magnetic resonance imaging, 6 x ray computed tomography (EBCT or MS-CT).

Accurate detection of calcium in the coronary vessel wall, which is evidence of the presence of coronary atherosclerosis, can be achieved with EBCT and MS-CT. Calcium quantification may have prognostic value, particularly when adjusted for age, but whether this is additive to the conventional risk factors or Framingham score remains controversial.14 The presence of calcification should not be interpreted as a sign of stability, nor can the absence of calcification exclude the presence of a coronary plaque, even of a vulnerable plaque, although the likelihood is low.15 It has recently been shown that, using intracoronary ultrasound: (1) the presence of an unstable plaque is positively associated with remodelling16; (2) large plaque area containing an echolucent zone is at increased risk of instability17; and (3) yellow plaques (detected with angioscopy) with increased distensibility and compensatory enlargement are predictive of a vulnerable plaque.18 However, the predictive value of each of these findings is too low to be clinically useful.

**EVOLVING NEW TECHNIQUES TO DETECT VULNERABLE PLAQUE**

Two catheter based techniques, Raman spectroscopy19 and optical coherence tomography (OCT),20 have the ability to distinguish between lipid plaques, fibrous plaques, and calcification; OCT is also able to measure fibrous cap thickness, as a result of its excellent spatial resolution (axial resolution 2–30 µm and lateral resolution 5–30 µm). However, both techniques have significant problems, the most important being the absorbency of the signal by blood, which makes it difficult to use in human coronaries. Elastography is an ultrasound based technique that assesses the mechanical properties of components of the plaque on the basis of difference in hardness.21 The technique uses the radiofrequency data of a regular intravascular ultrasound (IVUS) system. In vitro studies have shown that elastography can discriminate between lipid rich and fibrous components22 and elastography is now being tested in the clinical setting.

Two dimensional, high resolution transthoracic echocardiography is able to measure left anterior descenderd wall thickness and external diameter and may evolve as a technique to monitor subclinical coronary atherosclerosis.23 Plaque composition can be assessed by MS-CT on the basis of x ray attenuation differences (Hounsfield units) of the various plaque components. The technique crudely allows investigators to distinguish between soft, intermediate, and calcific plaques, similar to the classification of plaques into soft, fibrous, and calcific using IVUS, to which these measurements were compared.24 In large arteries high resolution non-invasive MRI allowed detection of carotid and aortic atherosclerotic plaques, and the effect of lipid lowering on these plaques can be assessed using serial MRI studies.25 Preliminary data have shown that using high resolution MRI (in plane resolution 0.5–1.0 mm, slice thickness...
3–5 mm), it was also possible to image non-invasively the cor-
ony wall and the coronary plaque in a few patients.\textsuperscript{24–26}

Serial in vivo MRI in atherosclerotic rabbits allowed the
assessment of arterial remodelling,\textsuperscript{27} which is expected to be
possible in the larger arteries in humans.

So far, radiotracer techniques to image coronary thorny
have not been successful enough to be used in clinical practice.
But recently it was demonstrated that labelling a glycoprotein
IIb/IIIa receptor inhibitor to technetium 99\textsuperscript{m} allowed identifi-
cation of an arterial thrombus in the left descending coronary
artery in a canine model.\textsuperscript{28} This method is currently being
tested in humans.

STABILISATION OF THE PLAQUE

Monitoring the efficacy of an intervention on progression of
the plaque has until now exclusively been assessed with
repeated angiography. Intracoronary ultrasound appears to be
a more sensitive method in the detection of early plaque for-
mation and changes in plaque volume,\textsuperscript{29} Change in the com-
position of the plaque can be induced by statin treatment\textsuperscript{30}
and this process can be monitored by intracoronary ultrasound,
because the plaque echogenicity changes. For example, a hypo-
ecogenic zone within a plaque (suggesting a lipid pool)
may turn into a hyperechogenic zone (suggesting fibrous
tissue).\textsuperscript{31} However, although these echographically assessed
changes in composition of the plaque are quite suggestive, this
requires confirmation from histological studies which have
not yet been performed.

CONCLUSION

The non-invasive coronary lumen imaging techniques MR-
CA, EBCT, and MS-CT are emerging as important techniques,
but so far these techniques lack sufficient and consistent
image quality to replace diagnostic coronary angiography. It
may take another few years before these techniques have fully
matured to make coronary angiography redundant. Various
invasive and non-invasive coronary plaque imaging tech-
niques are being developed and tested in the preclinical
setting, but these are only in the early stages of research
and development. Intracoronary ultrasound is currently the most
advanced and clinically applicable tool to provide adequate
information about coronary plaque dimensions and remodel-
ing; however, this technique needs improvement in order to
be able to assess vulnerability and stability of coronary plaques
reliably. Intracoronary temperature measurement is feasible
and clinical studies have just begun to assess its diagnostic
and prognostic value.

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