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Editorial

Intravascular ultrasound: an inside view

Six years ago intravascular ultrasound imaging was first performed in humans. Technical progress since then has been steady. The newest catheters are smaller than 3 French and are sufficiently trackable to reach most lesions in the coronary arteries. The image quality from commercial systems will continue to improve, but the existing technology already provides interpretable images in most situations. This has allowed investigators to begin to address the practical questions of clinical utility and cost effectiveness—specifically, how and in which cases should intravascular ultrasound images be used to guide diagnosis and subsequent intervention?

Plaque burden

Several significant imaging studies were launched in 1993 and some intriguing preliminary findings are emerging. The most impressive observation in any centre's initial experience with intravascular ultrasound is how extensively plaque is distributed in the arteries. When a vessel with a target lesion identified by angiography is scanned it is rare to find any segment of the artery that is free from disease. This includes the angiographically "normal" reference segment used to judge the size of an angioplasty balloon or other device. Ultrasound imaging shows that a typical reference segment has a 30–40% plaque burden by area (that is, the boundary of the diseased intima is more than a third larger than expected from the angiogram). It is presently unclear whether a more accurate understanding of the overall plaque burden and vessel dimensions will be useful in the context of interventions. There are preliminary data to suggest that the plaque burden in the reference segment correlates directly and strongly with the likelihood of restenosis after percutaneous transluminal coronary angioplasty (PTCA).[1] One explanation for this finding is that a larger plaque burden in the reference segment leads to undersizing of the balloon. A randomised trial has recently been initiated to test whether aggressive sizing of balloons, based on ultrasound-determined vessel measurements, will result in more favourable short-term and long-term outcomes.

Remodelling

A second feature of plaque distribution that has been well characterised by pathologists but is invisible to angiographers is the phenomenon of remodelling—the "compensatory" dilatation of the vessel segment in a region of plaque accumulation.[2 3] This phenomenon is commonly seen with intravascular ultrasound. In our own experience remodelling has the greatest impact in the setting of directional atherectomy. A proximal left anterior descending artery that appears by angiography to be of normal calibre—3·5 mm, for example—will typically be seen by ultrasound to have a media-to-media diameter of 5 mm or greater. The influence of remodelling along with underestimation of the true vessel size because of disease in the reference segment combine to create a dramatic underestimation of the true vessel size when angiography is used as the sole source of information.

Effects of PTCA

In addition to providing a more accurate understanding of the distribution of plaque in vessels, ultrasound has produced interesting and potentially useful insights into the mechanisms of different interventional devices. For PTCA, ultrasound has clarified the role of dissection in the response of a lesion to balloon expansion. Some form of tearing of plaque can be confirmed by ultrasound in 60–70% of surveyed PTCA cases. Typically the tears originate in two places: (*a*) at the edge of an accumulation of plaque, where the more compliant normal vessel wall meets stiffer plaque; or (*b*) adjacent to localised deposits of calcium, where there is also a compliance mismatch—here between the calcium and the surrounding plaque.[4] Tearing clearly helps release the circumferential constriction a plaque imposes on the vessel segment. The acute gain (increase in lumen area) seen in coronary artery segments that tear is 20–30% larger than that which is seen in lesions that stretch but do not tear. Current trials are examining whether this translates into better long-term outcome. Interestingly preliminary studies of outcome published to date have yielded conflicting results. One study points to increased restenosis rates when there is ultrasound evidence of dissection[5] whereas another suggests that it is the absence of dissection that leads to increased restenosis.[6]

Variables that have shown a statistically powerful relation to the outcome of PTCA in these early studies are lumen area and an index of lumen area divided by total vessel area (lumen plus plaque).[7] At a first glance, these results seem to confirm the "large lumen hypothesis" advocated by Kuntz *et al*[8]—that is, the larger the lumen remaining at the end of an intervention, the better the vessel is able to tolerate the inevitable ingrowth of intimal hyperplasia and therefore remain patent in the long term. There may be a less subtle factor influencing

these outcome data, however,—namely the ability of ultrasound to demonstrate a truly poor angioplasty result when the angiogram is judged to be acceptable. In our own practice this is the most useful application of intravascular ultrasound in PTCA, identifying the roughly 10–20% cases in which there is a much worse short-term outcome in terms of lumen expansion than is appreciated by angiography. At present there are no data to suggest that further work in these lesions improves the long-term result. There is no question, on the other hand, that the lumen calibre at the time of PTCA can be improved by using information from an ultrasound scan.

Effects of atherectomy

The additional insight provided by ultrasound over angiography is even more obvious when the technique is applied to directional atherectomy. On average, a coronary segment that is "completely" debulked as judged by angiography will be shown by ultrasound to have 40–60% of its cross sectional area still filled by plaque. Angiography is also a poor indicator of where plaque is distributed in the arterial wall. Histological analyses of tissue specimens removed during coronary atherectomy show that media or adventitia is present in over half the cases when angiography alone is used for guidance.

The ability of ultrasound to visualise directly both the amount and distribution of plaque makes the technique a natural adjunct to directional atherectomy. This is in fact the setting in which intravascular ultrasound is being most rapidly accepted as a useful tool in interventional practices. Ongoing trials have already shown that guidance by ultrasound leads to greater tissue extraction and larger post-procedure lumen areas.[9 10] Our own experience also suggests that subintimal sampling rates can be reduced significantly, to $\leqslant 10\%$. Analysis of long-term results is underway and will be available later this year.

Influence of calcium

Another striking factor seen with ultrasound in both directional and rotational atherectomy is the importance of calcium in influencing the response of a lesion to the device. Localised calcium deposits are much more common than is appreciated by fluoroscopy, occurring in 50–70% of the lesions treated by catheter techniques. The distribution of calcium within a lesion is variable—it may occur at the lumen surface, deep at the medial border, or in intermediate positions within the plaque. The presence and pattern of calcification have a significant impact on the success of the procedure. Current directional atherectomy devices generally cannot cut a solid deposit of calcium within plaque. A lesion that has a rim of calcium at the luminal border, therefore, is an unfavourable candidate for this device.[11] On the other hand, this type of lesion is well suited to rotational atherectomy, where the device preferentially ablates the calcified plaque.[12] Thus effective triage for the atherectomy devices can be based on the presence and location of calcium within a lesion as shown by ultrasound.

Stents

A recently reported and potentially major application for ultrasound is in the optimisation of stent deployment. In 1993 Colombo's group showed that expansion of stents was incomplete (a localised area along the length of the stent that is not fully opened) in most stent deployments, despite a satisfactory angiographic appearance.[13] They reported that full expansion of the stent by means of ultrasound guidance may moderate or even eliminate the need for post-procedure anticoagulation. This result would obviously have significant practical and economic consequences and is being evaluated in a recently organised multicentre trial.

These potential and emerging applications for intravascular ultrasound have created an increasing enthusiasm for this new imaging technique among interventional cardiologists. With the forces of the changing health care environment at play, however, growth of intravascular ultrasound will be strongly influenced by the demonstration of its clinical benefit and cost effectiveness. We expect that the results of trials in single centres will be reported soon and that later this year the outcome data from the first multicentre trials will be published.

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