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Recanalisation of Chronic Total coronary Occlusions: 2012 consensus document from the EuroCTO club

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Introduction

The EuroCTO club was established in December 2006. In 2007 it published its first consensus document on the recanalisation of Chronic Total Occlusions (CTOs), aiming to set standards on clinical indications, equipment, procedural safety, operator training and centre qualifications, as well as provide an update on material and technical developments. Since that time there have been considerable advances in techniques (both antegrade and retrograde) and dedicated equipment (wires, micro-catheters and CTO dedicated devices) that have changed the landscape of CTO angioplasty. In an effort to promote widespread application of CTO recanalisation in Europe, the EuroCTO club has written this updated consensus document reflecting the views of European operators. It is based on published evidence where available, and on consensus among the authors where issues of technique and strategy are concerned and no studies are available. The following is a summarised overview of the document. A complete, unabridged version is available online.

Definitions

The consensus among the group is to define a CTO as "the presence of TIMI 0 flow within an occluded arterial segment of greater than three months standing". Non-intra-lesional ipsilateral bridging collaterals may give antegrade flow to the vessel beyond the occlusion and give a false impression of a functional incomplete occlusion. The presence of flow in such collaterals should be differentiated from flow within the occluded segment by careful frame-by-frame assessment in different angiographic projections. Intralesional microchannels by contrast do play a role in facilitating wire crossing, but pathological examination demonstrates that these are usually below the threshold of angiographic resolution.

OCCLUSION DURATION

As previously described we suggest three levels of certainty: a) certain (angiographically confirmed), b) likely (clinically confirmed), and c) undetermined.

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Collateral circulation in CTOs

Collaterals are interarterial connections that provide blood flow to a vascular territory whose original supply vessel is obstructed. The size of such collaterals varies between 40 and 200 µm. With digital angiography (resolution 200 µm), their visualisation is limited. Rentrop described an angiographic grading system that does not rate the collaterals *per se*, but their effect in filling the occluded segment. Werner proposed a grading of collateral connections (CC grade 0=no continuous connection between collateral supplying and receiving vessel; CC1=threadlike continuous connection; CC2=side branch like connection) validated with reference to physiologic measures of collateral function. This grading provides the foundation for the assessment of collateral access in contemporary retrograde techniques.

Collaterals develop through arteriogenesis, recruiting pre-existing interarterial connections mainly driven by shear forces along the pressure gradient that develops when the native vessel is occluded. Some of these connections may be preformed to such an extent that they are immediately recruitable during vessel occlusion, as shown during balloon occlusion in non-diseased coronary arteries. In patients without well-developed collaterals, a period of 2-12 weeks is required to become fully functional.

Collaterals development does not appear to be dependant on viability of the supplied myocardium. Collaterals may prevent myocardial necrosis and may even uphold metabolic supply to maintain full contractile capacity. Functional assessment of collateral circulation with systemic infusion of adenosine however indicates that flow and pressure changes distal to a CTO are well below standard significant cut-off values (CFR >2 and FFR >0.75 respectively) established for the assessment of the functional reserve in non-occlusive obstructions. Therefore, even well-developed collaterals only rarely prevent ischaemia during exercise.

Collateral regression starts immediately after the re-established antegrade flow and extends further for many months. Acute re-occlusion, for example in late or very late stent thrombosis might lead to an acute coronary syndrome (ACS), since recruitment is not instantaneous in the majority of patients.

Rationale for CTO recanalisation

The aim of revascularisation in CTOs is to improve symptoms and/or prognosis. Several studies have documented that successful percutaneous coronary intervention (PCI) of CTOs leads to an improvement in anginal status, normalisation of functional tests, improvement of left ventricular function and avoidance of coronary artery bypass graft surgery (CABG). Data from retrospective studies and prospective registries show that patients with a successful CTO PCI have better survival and reduced need for CABG compared to patients with unsuccessful procedures. Patients with untreated CTOs face a threefold increase in cardiac mortality or complications in case of future acute events.

Despite this evidence, the issue of a prognostic benefit remains unresolved, especially in view of the results of the COURAGE trial, even though complex lesions like CTOs were not included in that trial of stable coronary artery disease (CAD) patients treated medically or interventionally. However, in that trial, patients with a large ischaemic burden had better outcomes with PCI than with medical treatment. A 10% to 12.5% of myocardium at risk was recognised to be the cut-off point above which percutaneous treatment shows clear survival benefit. To resolve the open question of the prognostic impact of CTO PCI, a randomised trial versus medical therapy is needed. Such a trial to Evaluate the Utilisation of Revascularisation or Optimal Medical Therapy for the Treatment of Chronic Total Coronary Occlusions (EURO-CTO trial) is being launched by the European CTO club, with non-invasive assessment to confirm ischaemia and viability in the territory of the occluded artery as a prerequisite before randomisation. Currently, the reopening of a CTO in the presence of symptoms or objective evidence of viability/ischaemia in the territory of the occluded artery of more than 10% is fully sanctioned by the current guidelines on myocardial revascularisation.

CLINICAL ASSESSMENT AND FUNCTIONAL TESTING

Radionuclide techniques and dobutamine stress echocardiography have similar positive and negative predictive values with respect to prediction of potential improvement in regional function. Both gadolinium-enhanced and dobutamine/adenosine magnetic resonance imaging are able to provide objective evaluation of pharmacologically-induced wall motion changes with the early and late phases of gadolinium distribution providing precise quantitation of myocardial fibrosis and perfusion, and more importantly viability. Limited or no late enhancement is an excellent predictor of late left ventricular recovery after CTO recanalisation. Clinically, ECG evidence of Q waves, at least for the right or left anterior descending coronary artery in the absence of a bundle branch block, can also predict left ventricular recovery.

Clinical presentation and treatment strategy

The clinical presentation of CTOs can be quite variable ranging from patients with stable angina, silent ischaemia or heart failure of ischaemic origin to those with new-onset angina or undergoing primary PCI due to acute occlusion in a different culprit vessel, and in whom a CTO is revealed as an incidental finding.

ELECTIVE CTO PCI

Elective cases with multivessel disease including a CTO, present a particular dilemma. There is a tendency to refer to surgery rather than embarking on a multivessel PCI with the risk of incomplete revascularisation due to the CTO. However, the presence of a CTO should not serve as main argument against revascularisation with PCI if the other lesions are suitable for PCI.

If the decision is to undertake PCI, a staged approach is a reasonable strategy in multivessel disease in order to avoid excessively long procedures. Consideration of which artery to tackle first, the CTO or the non-occluded vessel(s), should be based on the importance of the occluded vessel; if the vessel and the amount of viable myocardium is important, the CTO should be approached first, whereas in cases with poor contralateral flow or an intended retrograde approach a stenosis in the contralateral vessel may need to be treated first. Moreover, inverted collateral flow through the recanalised CTO may protect the

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myocardium at risk during high risk complex lesions in the collateral donor vessel. It is important that each case is considered individually and carefully, and the consequences of success or failure of the individual lesion treatments are taken into account.

ACUTE CORONARY SYNDROMES

Patients presenting with ACS require expedited recanalisation of the culprit vessel. Whenever a CTO in a non-culprit vessel is incidentally found, the patient should be given time to recover from the cardiac, vascular and renal effects of ACS and PCI. A minimum of one to two weeks should elapse between treatment of the culprit lesion and planned treatment of a CTO. Proper evaluation of the lesion complexity and the estimated success rates as well as procedural complexity and potential complications are critical for decision making in these patients.

There is evidence that leaving a totally occluded artery untreated is associated with higher mortality at short and long-term follow-up post-STEMI. An ongoing randomised trial is exploring the benefit of CTO recanalisation of a non-culprit vessel within seven days after primary PCI.

Planning of the procedure

Planning CTO treatment is of paramount importance, since mistakes made during planning may be difficult to circumvent half-way through the procedure. The operator should spend time examining the diagnostic films to decide if a unilateral or bilateral approach is required, to choose appropriate vascular access routes, guide catheter shape and size, and to check availability of dedicated equipment. The occluded vessel should be reviewed in multiple projections, frame by frame, as should the contralateral vessels for a complete understanding of the anatomy, identification of the proximal and distal cap, the vessel course and side branches, the presence of calcification and the details of the collateral circulation. If bridging collaterals are present, it is essential to differentiate the true lumen from perivascular vasa vasorum which can easily be dissected or perforated with excessive wire manipulation. In complex occlusions additional imaging with multislice computed tomography may be helpful to outline the vessel course and the presence and location of calcification. The maximum allowable amount of radiographic contrast media should be defined prior to starting the procedure for each particular patient. As a rule of thumb, we define this amount as 4 x GFR (ml). Adequate hydration (including those with apparent normal renal function) or reno-protective measures must be started beforehand.

It is axiomatic that CTO angioplasty should not be rushed. It is important to open the vessel, and to allocate appropriate time to the treatment. Proper catheterisation laboratory planning to allocate a minimum of two hours is essential. Engaging in complex CTO PCI under time constraints should be avoided. The patient should be properly informed regarding the potential for dual access sites, the duration of the procedure and, as a consequence, the potential exposure to higher than normal radiation levels. Counselling about the potential need for staging the procedure is also advised.

The question of the "right operator" is a disputed one. As with all invasive procedures, experience and results usually go hand in hand. Referral to a higher volume operator with a success rate of at least 80% in CTO PCI is advisable in accordance with the 2010 ESC guidelines on myocardial revascularisation.

REPEAT PROCEDURES – WHEN TO STOP?

Repeat procedures are more common in CTO recanalisation than in other PCI procedures. This is frequently due to either failure of a specific recanalisation strategy, or to staging an otherwise progressing procedure on the grounds of its duration, patient discomfort, safety (i.e., amount of contrast given), or to procedural (i.e., vessel dissection) considerations. Many parameters should, therefore, be considered in planning a repeat procedure. Was the first attempt complete? Were all contemporary techniques and materials properly employed? Were the reasons for failure recognised? Is there a clear alternative strategy for the repeat attempt? Is the operator experienced enough to apply these techniques (potentially including the retrograde approach) or should the patient be referred to a more experienced operator?

The number of times a procedure may be re-attempted is an individual question to be jointly decided by the doctor and the patient. Often a failed procedure may be considered to have "made progress" without completing the revascularisation. In this case, the previous "investment procedure" should be allowed to continue to the anticipated "completion procedure". If, however, no progress has been made by an experienced operator, and both antegrade and retrograde attempts have been carefully planned and carried out without success, the operator may decide either to refer the patient for an alternative treatment such as CABG, or to refer to another specialist for a subsequent attempt. As a general rule, two attempts at a CTO should allow both antegrade and retrograde techniques to be used to their full potential, and if these strategies have failed, further attempts may not be beneficial. However, there are exceptions from this rule when additional attempts are reasonable because of partial progress, planned use of different equipment or strategy, and different personnel.

The art of "knowing when to stop" is key issue in CTO PCI. The risk of a procedure-related event should always be assessed and the CTO operator should be able to stop a procedure before a major complication occurs. When there is a dissection of the distal lumen, it is often better to abandon the procedure and bring the patient back after 3-4 weeks. Once an effort has been made and has failed, it can be difficult to predict how the occluded vessel will subsequently appear. The dissection will often heal with the development of small channels that will facilitate a successful recanalisation in a subsequent procedure, but there is always the risk that the false lumen will persist or completely occlude making the repeat procedure more complex. Furthermore, contrast consumption and x-ray dose should always be taken into account when a decision is made for continuing or stopping a procedure as discussed further in the relevant chapters of this report.

CTO materials and dedicated devices

Recent advancements in guidewire, microcatheter and crossing device technologies have improved the technical success of CTO PCI, increasing success rates from 50-70% to 80-90% for many interventionists.

GUIDEWIRES

There are four important features regarding CTO wires:

1. Polymer covers: these are plastic sleeves of flexible but solid material that are applied directly over the core or over spring coils covering the tip of the wire. Based on the presence or absence of a polymer, CTO wires are divided in two main categories: polymer jacket wires (by default also hydrophilic coated) and spring coil wires (some hydrophilic coated and some not).
2. Wire coatings: these affect lubricity and tracking, and facilitate smooth movement. There are two types, hydrophilic and hydrophobic. Hydrophilic coatings attract water and are applied over polymer and stainless steel, including tip coils. They are thin and non-slippery when dry and become gelatinous when wet, reducing friction. They usually cover the distal 30-35 cm of the wire. Hydrophobic coatings (Dow Corning Silicone) repel water. No wire flushing is required and they also reduce friction but not to the same extent as hydrophilic wires. These coatings usually cover the working area of wire, excluding the tip. There is an inverse relationship between lubricity and tactile feedback related to the presence or absence of coatings over coils and polymers at wire tips.
3. Core materials and tapering: the majority of CTO wires have a stainless steel core. Modern CTO wires have a transitionless parabolic core grind which provides excellent torque response and no prolapse points compared to conventional non-CTO wires built with welded sections.
4. Tip stiffness: this ranges from 0.5 to 20 grams. Usually plastic jacket wires are in the low range of stiffness and spring coil wires cover the whole range. Tip tapering strongly affects penetration power as the force is applied over a smaller cross-sectional area in tapered wires.

An extensive overview of the currently available CTO wires and other dedicated devices is available in the online version of this consensus document.

Techniques for CTO recanalisation

ACCESS ROUTE

The selection of the access route is dependent on the individual patient situation (e.g., severe peripheral vascular disease, which may mandate a radial approach) as well as on the operator's preference. Guiding catheter size is limited from the radial approach, but the radial artery should be used for contralateral injection (5 or 6 Fr diagnostic catheters). Most experts use the femoral approach for the target CTO vessel (90% in Europe) and it has not been shown that either access is preferable except for about 10% of the cases in which even experienced radial operators select the femoral route.

GUIDING CATHETER SELECTION

For chronic occlusions good passive support with coaxial alignment or ability to actively introduce the guiding catheter (over the guide wire and the balloon) into the coronary artery for active support is crucial. Passive support is greater with larger guiding catheters (7 and 8 Fr) while 6 Fr catheters offer the best balance between active and passive support. For the left coronary system extra backup–type catheters (Voda left, extra backup, geometric left, left support) are preferable, although some operators still prefer Amplatz type or even Judkins type catheters, the latter needing more manipulation to achieve optimal position and back up in complex cases. For the right coronary artery 6 Fr and 7 Fr catheters can be used with left Amplatz 0.75-2 shapes, hockey stick shapes for gentle superior origins of the RCA, Judkins shape for slightly inferior origins and IMA or SCR type guiding catheters for upward origins. One word of caution is that there is a higher risk of vessel injury at the ostium and first bend of the RCA especially with an AL shape that has a tendency to jump into the artery, and with all kinds of 8 Fr catheters. In case of ostial dissection, a soft-tipped wire must be selected and steered carefully past the dissection that needs to be fixed before continuing the procedure. Often the guiding catheter has to be changed to avoid an orientation towards the dissection.

The use of guiding extension catheters such as the GuideLiner can be useful both for increasing support but also facilitating stent placement especially in tortuous and calcified CTOs.

CONTRALATERAL INJECTION

When the distal vessel is mainly filled by retrograde collaterals, or there are bridging collaterals originating near the occlusion that are likely to have their flow impaired after wire-catheter advancement, contralateral injection is essential from the beginning of the procedure. Although most operators use a contralateral vascular access (right and left femoral or radial arteries), ipsilateral femoral artery access can also be performed by puncturing the same groin with a 4 to 6 Fr catheter, which may allow the procedure to be better tolerated. In order to spare contrast, simultaneous bilateral contrast injections are made at the beginning of the procedure for road-mapping, while guidance of wire crossing usually requires only contralateral injections. The operators of the EuroCTO Club have used contralateral injection in 62% of cases of their personal series (range 33-78%).

Antegrade approach

Antegrade recanalisation of CTOs has been historically the mostly used approach with success rates of 60-80% during the last 20 years. An extensive description of antegrade recanalisation can be found in the complete, unabridged version available online including wire selection and shaping, the single wire techniques, parallel-wire technique and techniques with subintimal tracking.

Retrograde approach

The retrograde techniques have a long standing history. In the late 80s, Hartzler introduced the retrograde dilatation of native artery stenosis proximal to a distal saphenous vein graft (SVG) anastomosis. In the early 90s, retrograde wire crossing of CTOs via SVG grafts were attempted. In the late 90s the invention of the bilateral approach led to the marker wire technique where the retrograde wire was used as a roadmap for the antegrade wire. In the early 2000s, initial attempts to break the distal cap with balloons were attempted and in 2005 Katoh pioneered the field introducing the Controlled Antegrade and Retrograde subintimal Tracking (CART) technique establishing

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the modern era of retrograde CTO recanalisation. Beyond the concept of retrograde dilatation within the occlusion to facilitate antegrade wire crossing, the novelties introduced in this procedure were the targeted septal collateral crossing and balloon dilatation.

The complete unabridged version of this consensus document, available online, discusses in depth the setup for the retrograde approach, the full spectrum of available retrograde techniques and also the success rates and complications when employing the retrograde approach.

What to do in case of failure to cross with a balloon

If the microcatheter or balloon with the best crossing characteristic (not necessarily the one with the lowest profile) is unable to follow the wire past the occlusion, the following techniques are helpful and will solve the problem in more than 90% of the cases:

Insert a second wire with stiff shaft proximal to the occlusion, preferably into a side branch if available to increase guiding support (wire anchoring technique).

Inflate a 2 mm balloon at the side branch for further support (balloon anchoring technique).

Exchange the balloon or micro catheter for a Tornus to enlarge the channel. The latter technique will succeed in 90% of the cases with failure of balloon crossing.

It is very important to ensure stable wire position while removing or exchanging the OTW catheters. The simplest approach is the flushing technique where the wire channel is flushed with high pressure (manually or with the inflation device). The reduced friction between wire and lumen in most cases allows the withdrawal of the catheter while leaving the wire in place. A safer option is to inflate a 2.0-2.5 mm non-wired balloon in the guiding catheter parallel and distal to the OTW catheter to trap the wire (trapping technique) ensuring it remains within the guiding catheter. Leaving the balloon inflated will allow safe advancement of other OTW devices minimising the risk of wire perforation related to this procedure.

Use of stents in CTO recanalisation

In spite of being an off-label indication, drug eluting stents (DES) were quickly adopted by interventional cardiologists for CTO treatment soon after their introduction with the hope of circumventing the well-documented high restenosis and re-occlusion rates of BMS in these lesions. Building clinical evidence has been hampered by inherent difficulties in conducting randomised clinical trials in this off-label DES indication. A recent systematic review and meta-analysis of 14 available comparative studies (4,394 patients) summarizes the efforts of individual researchers and substantially supports the use of DES in this context. The occurrence of stent thrombosis (ST) in CTOs treated with DES remains an issue of controversy.

Acute outcomes, complications and safety issues

ACUTE OUTCOMES AND COMPLICATIONS

CTO PCI is related with certain complications but traditionally is considered a low risk procedure. There are no randomised trials comparing CTO versus non-CTO PCI, but indirect comparisons demonstrate comparable low incidence of procedural events with MACE rates not exceeding 4-5%. It is reassuring that in recent years, despite the increasing complexity of CTOs treated in combination with the advanced techniques and dedicated materials used, the incidence of complications remains low. An overview of the complication rates and in-hospital outcomes (mainly with antegrade techniques) available in the literature is presented in the online version of this consensus document.

CONTRAST USE

Other issues to be considered when assessing complications of CTO include contrast-induced nephropathy (CIN), a process dependant on the contrast agent volume retained within the kidney and the resultant exposure of renal cells to the toxic impact of the agent. Although this is clearly germane to all PCIs due to the relationship of CIN with dye volume, patients undergoing CTO PCI are likely to be particularly at risk. Use of limited pre-procedural MSCT, retrogradely positioned wires as markers (rather than using contrast injections) and IVUS may all help to reduce dye load. Pre-emptive management of CIN has been well set out in published algorithms. Currently, maintaining hydration in at-risk patients is an important management strategy. Careful attention to dye load appears to be also important. Most would wish to keep dye load even in patients with normal eGFR to less than 400 ml; however, others have suggested that up to 500-600 ml can be tolerated.

RADIATION SAFETY

Exposure to radiation is an important consideration, since it is prolonged during CTO cases as compared to PCI for non-occlusive lesions. To put the radiation exposure into perspective, one chest x-ray produces an effective dose of 0.02 mSv, a Dose-area-Product (the total energy delivered to the patient) of 0.08 $Gy.cm^2$ and a background equivalent of three days. For a non-CTO PCI with one stent the equivalents are 9.0mSv, 36 $Gy.cm^2$ and 3.7 years, and for a non-CTO 3-stent PCI, 24.6 mSv, 98 $Gy.cm^2$, while for CTO procedures the values are 30-300 $Gy.cm^2$, 10.1 years. It is not surprising that CTO PCI may put the patient at particular risk. Suzuki et al measured entrance skin dose in 97 procedures and found the median value to be 4.6 Gy for CTOs versus 1.2 Gy for single stenosis procedures.

The physician should be aware that he needs to make every effort to reduce radiation exposure, and to document radiation exposure during a PCI procedure. There are two values that are documented by modern x-ray equipment which are the patient dose (Air-Kerma) as radiation energy released in the body (dimension: Gy) and the area surface product as dose times exposed surface area (dimension: $Gy{*}m^2$). The former measures the deterministic risk to the patient such as skin injury, the latter is a measure of the stochastic risk, i.e., the likelihood to induce malignancy or genetic defects in the future.

Role of imaging in CTO PCI

INTAVASCULAR ULTRASOUND

There are several procedural challenges for which IVUS can be applied to facilitate CTO recanalisation. Most of them require the use of 7 or 8 Fr guiding catheters for simultaneous use of IVUS catheter and recanalisation devices. The first is the identification of the occlusion site in stumpless CTOs. This is achieved by performing a pull-back along the branch originating at the occlusion site and filming the IVUS catheter at the time the image shows the proximal stump. More elegantly, IVUS guided wiring can be performed by leaving the IVUS catheter in a position that allows visualisation of the occluded ostium, thus ensuring that the wire has entered inside the vessel. By performing a to-and-fro movement of the IVUS catheter, the acoustic shadow of the wire can be tracked down the vessel at a distance of 5-15 mm from its ostium, depending on the angle of the occluded branch. A second use of IVUS is to document a subintimal location of the wire and to facilitate the re-entry of a second wire in the true lumen (IVUS guided re-entry). Imaging with IVUS mandates that the wire is inserted for 2-3 cm at least in the subintima and often requires gentle dilatation of the adventitia with a 1.5 mm balloon to advance the IVUS probe. The short distance between the imaging element and the catheter tip makes the electronic Eagle Eye IVUS catheter the preferred choice in order to avoid dissection extension. The principle is to start monitoring the orientation of the second wire at the level of the proximal end of the occlusion, ensuring that the second wire is steered away from the dissected lumen and towards the occluded stump of the vessel. The IVUS catheter can then be used to monitor its progression within the occluded segment. A third important application is the use of IVUS during retrograde CTO recanalisation. In these procedures, IVUS is performed antegradely to monitor the course of the retrograde wire course in the vascular structure and whenever necessary facilitate the procedure by proper balloon sizing for the subintimal space connection (IVUS guided reverse-CART), thereby avoiding potential complications and sparing contrast that its use is mostly prohibited at least from the antegrade guiding due to the risk of extending the dissections.

After wire crossing IVUS can be useful for the identification of the vessel length needed to be stented and the optimisation of stent apposition and expansion that might be crucial for long-term outcomes, especially in complex cases of multiple stents or subintimal space stenting.

In contrast with CTO practice in Japan where IVUS is routinely implemented, its penetration in Europe is only 2% reflecting the necessity for 7 of 8 Fr GCs (not routinely used in Europe), the additional skills in image interpretation and different reimbursement policies.

MULTISLICE COMPUTED TOMOGRAPHY

Multislice computed tomography (MSCT) has been used as an imaging technique for planning CTO recanalisation by a considerable number of operators in order to assess 1) the length and three-dimensional course of the occluded arterial segment; 2) the presence of calcium at the CTO; 3) the vessel size and vessel remodelling (either positive or negative); and 4) the quality of the vessel distal to the CTO.

To ensure that in MSCT simultaneous antegrade and retrograde vessel opacification yield images closer to bilateral angiography coronary images, CT acquisition time should be long enough to allow for adequate filling of the distal bed through collaterals. Spiral CT protocols with dose modulation (ECG triggered) are preferred during image acquisition for more detailed post-processing. Since automatic path tracking algorithms cannot be applied, manual reconstruction of the CTO segment is required. Cross-sectional CT images allow a much better differentiation between tissues than conventional angiography, and areas of calcium and iodine within the CTO are used as landmarks in the reconstruction. The current resolution level of MSCT does not allow reconstruction of thin intraluminal channels nor thin septal, epicardial or peri-adventitial collateral circuits. Ideally, the reconstruction should be made jointly with or by the CTO operator himself. Planar curved reconstructions in MIP mode are used to assess the structure of the occluded segment, and volume rendering to assess three-dimensional morphology. Translation of 3D reconstruction to two-dimensional angiography projections is recommended for guidance during PCI. Co-registration of CT images with angiography may be the ultimate way of integrating CT information in the PCI procedure, but this feature is seldom available.

Although there are no comparative studies assessing the value of MSCT in CTO recanalisation, the reported series consistently identified occlusion length and the presence of calcification as determinants of procedural success. Other authors have also identified additional independent predictors of wiring failure, like the presence of bends, negative remodelling or shrinkage. A good agreement between MSCT and IVUS imaging during CTO recanalisation has been reported.

One of the major concerns about using MSCT in CTO recanalisation is the effective radiation dose received by the patient. In a study by Garcia Garcia et al, the contribution of MSCT to total radiation dose was 22.4 mSv: 19.2±6.5 mSv for contrast-enhanced scan, 3.2±1.7 mSv for calcium scoring scan. This concern is particularly relevant in CTO recanalisation, with associated longer fluoroscopy times than any other type of PCI. It is foreseeable that the use of new generation MSCT equipment will lower the effective radiation dose; however, the ALARA (As Low As Reasonably Achievable) principle should be always applied to using MSCT in CTO recanalisation on the grounds of case complexity and patient risk profiles.

Conclusions

During the last five years dramatic advancements have been achieved in the field of CTO PCI, largely related to dedicated device and technical developments, and an increase in operator skills, many of them by European experts. The current report summarises how these changes were adopted and adapted in Europe and their impact on routine clinical practice. With contemporary antegrade and retrograde techniques success rates have reached a ceiling of 90-95% in complex CTOs, very close to the success rates of non-occlusive CTO PCI, but they remain in the hands of few dedicated expert operators. Further technical and strategic developments in this field will certainly follow in the years to come but the biggest challenge is the widespread adoption of these techniques by larger numbers of interventional cardiologists to meet the needs of thousands European patients with occluded coronary arteries. The aim of the EuroCTO club is to be at the forefront of these developments and to contribute to the training of interventional cardiologists in contemporary CTO techniques. One should remember that there is no easy way to cross a CTO; it requires patience, perseverance and experience, gleaned from proper training, and learning from the procedures *per se*.

Consensus statements

CONSENSUS ON DEFINITION

Lesions can be classified as CTOs when there is TIMI 0 flow within the occluded segment and an occlusion duration >3 months.

CONSENSUS ON INDICATION

CTO recanalisation is indicated in patients with symptoms and evidence of ischaemia. In patients with prior Q-wave myocardial infarction viability should be confirmed.

CONSENSUS ON CLINICAL PRESENTATION AND CTO TREATMENT

- Meticulous procedural planning is of paramount importance in CTO PCI. *Ad hoc* angioplasty is not recommended.
- In ACS a minimum of 1 to 2 weeks should elapse between treatment of an acute lesion and planned treatment of a CTO preferably after documentation of ischaemia/viability at the CTO territory.

CONSENSUS ON PROCEDURAL PLANNING

- Operators should select cases according to their experience and expertise in order to achieve a successful recanalisation in about 80% of these cases. More complex cases should be referred to expert operators.
- Repeat procedures should be planned with contemporary techniques and material selection, after understanding the reasons for the initial failure.
- A CTO PCI should be stopped when complications occur, when the volume of contrast reaches 4 x GFR ml or when radiation reaches a maximum of 10 Gy (the operator should be alerted at the level of 5 Gy).
- CABG or medical therapy should be considered in case of failure with contemporary CTO techniques and materials by experienced operators.

CONSENSUS ON MATERIALS AND TECHNIQUES

- Visualisation of distal target vessel, with contra-lateral injection whenever necessary, is a prerequisite during CTO recanalisation.
- Wire manipulation should be supported by OTW systems preferably modern braided microcatheters. OTW balloons are a reasonable option in simpler CTOs to reduce material cost.
- Soft (<1 gr) tapered polymer jacket wires should be the standard wires to begin the recanalisation process as they have high success rates and low risk of distal vessel damage in case of failure to cross.
- The parallel wire technique is a cornerstone technique and should be considered early in the course of subintimal wire penetration.
- Subintimal tracking techniques (STAR, mini STAR, Micro-channel) should be applied only as bail-out.
- Dedicated CTO devices can facilitate success and should be used in well selected CTOs with anatomic characteristics best fitting their specifications.

CONSENSUS ON THE RETROGRADE APPROACH

- The retrograde technique represents a breakthrough in CTO recanalisation with success rates exceeding 90% in complex CTOs and have comparable complication rates with contemporary antegrade techniques.
- Current evidence suggests that they should be reserved for second attempts after antegrade failure, or as strategies of choice in very complex CTOs where the expected antegrade success rate is <50%.
- Recent trends in practice suggest implementation of the retrograde techniques after short antegrade failures (aiming at reducing procedure duration, contrast consumption and radiation exposure), but until more data become available this approach should be reserved for very experienced operators.
- Retrograde techniques should be reserved for very experienced antegrade operators (>300 CTOs and >50 per year). A minimum of 50 retrograde procedures (25 as second operator and 25 as first under supervision) are required before a cardiologist becomes an independent retrograde operator.

CONSENSUS ON STENT TYPE FOR CTOs

- DES should be used in all CTO cases unless contraindicated.

CONSENSUS ON IVUS IMAGING FOR CTOs

- IVUS can be used for the identification of the proximal cap in stumpless CTOs, for wire redirection in cases of subintimal wire entry, to monitor the course of the retrograde wire course during retrograde procedures and optimisation of stent placement especially in complex CTOs.
- In the absence of randomised efficacy data IVUS cannot be recommended as a routing procedural imaging tool for CTO PCI.

CONSENSUS ON MSCT IMAGING FOR CTOs

- MSCT can reliably visualise CTO length, morphology and composition, but there is no evidence to suggest that it helps in increasing success rates.
- In the absence of randomised efficacy data MSCT cannot be recommended for routing pre-procedural imaging for CTO PCI.
- MSCT can be recommended for complex CTO lesions with expected success rate <50% and in cases of repeat procedures after initial CTO recanalisation failure.

CONSENSUS ON TRAINING AND CENTRE/OPERATOR COMPETENCY

- All Interventional Trainees should have the theoretical knowledge for appropriate patient and lesion selection and the practical experience to avoid the most common mistakes in CTO recanalisation.
- Sufficient training to work as independent primary operator for most angioplasty procedures does not automatically translate into an ability to approach any CTOs.
- The minimal number of 50 CTOs per year to maintain competency translates into a model where only a limited number of operators and centres should perform CTO treatment.