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Editorial

Language of CTO interventions – Focus on hardware

Keywords:
CTO
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Tip load
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Fielder
Gaia
Miracle
Conquest
RG3
Finecross
Corsair
Tornus
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Turnpike
CrossBoss
Stingray
Navifocus
Opticross

A B S T R A C T

The knowledge of variety of chronic total occlusion (CTO) hardware and the ability to use them represents the key to success of any CTO interventions. However, the multiplicity of CTO hardware and their physical character and the terminology used by experts create confusion in the mind of an average interventional cardiologist, particularly a beginner in this field. This knowledge is available but is scattered. We aim to classify and compare the currently used devices based on their properties focusing on how physical character of each device can be utilized in a specific situation, thus clarifying and simplifying the technical discourse.

1. Introduction

Interventions in chronic total occlusion (CTO) represent a niche area of percutaneous coronary interventions (PCI). The essential difference lies in the character of the lumen which is occluded in CTO PCI (versus patent in a garden variety of PCI). This difference culminates into not only increased complexity and difficulty of the procedure but also makes it more prone to complications. Clearly the niche area requires an optimal utilization of a broader range of hardware. Thus for a regular PCI only few hardware and their use need to be known. On the other hand if CTO PCI is to be undertaken, Knowledge of a whole gamut of accouterment need to be acquired (both their characteristics and utilization) and their use mastered. In general guidewires are the key to success of any CTO procedure but additionally knowledge and handling of several other devices needs to be perfected.

2. Guidewires

Depending on its construction guidewires have different properties which can be used to an advantage in different situations.[1,2]

2.1. Penetrability

Penetrability is the ability to puncture a lesion, the stiffer the lesion the more penetrability is required; wire in the lumen $<$ micro-channel $<$ lipid plaque $<$ proteoglycan $<$ colla-collagen/elastin $<$ calcium. The penetrability depends on:

(1) Tip load
(2) Tapered tip
(3) Wire support (micro-catheter/OTW Balloon, anchoring techniques, child-in-mother catheter)
(4) Lateral support of the wire

2.2. Pushability

Pushability is the amount of force needed to advance the wire or the ease of advancing the wire once it has penetrated a lesion. Pushability depends on (a) the characteristic of the tissue a wire has to traverse as well as the (b) length of the tissue to be traversed along the CTO. This feature is determined by the lateral support provided by the wire.

2.3. Trackability

Trackabilty is the ability of the device to track over a guidewire during insertion especially around bends. This feature is determined by the lateral support provided by the wire.

2.4. Torquabilty

1:1 transmission of bend.

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Table 1
Properties of guidewires.

Wire	Core	Tip	Tip coat	Tip dia	Tip load (g)	Polymer coating	Radio-opaque length (mm)	Lat supp at 155 mm	Penetrating power: tip load/area of tip (kg/m^2)	Comments
Sion Blue	High tensile steel	Dual-core coil, 200 mm	Hydrophilic	014	0.5	No	30			Lowest tip load
Sion Black	High tensile steel	Dual-core coil, 200 mm	Hydrophilic	014	0.8	Yes, 200 mm	30			Dual-core, polymer coated
Gaia First	Stainless steel	Composite core, Micro-cone tip	Hydrophilic	010		No	150			Torquable wire, main feature is composite coil with a central core wire, wrapped by six acetone wires, with spring coil in periphery
Gaia Second	Stainless steel	Composite core, Micro-cone tip	Hydrophilic	011		No	150			
Gaia Third	Stainless steel	Composite core, Micro-cone tip	Hydrophilic	012		No	150			
Whisper MS	High tensile steel (Durasteel)	45 mm coil	Hydrophilic	014	1	Yes, 290 mm	30			
Pilot 150	High tensile steel (Durasteel)	45 mm coil	Hydrophilic	014	2.7	Yes, 290 mm	30	8 (9)		
Pilot 200	High tensile steel (Durasteel)	45 mm coil	Hydrophilic	014	4.1	Yes, 290 mm	30	8 (9)		
Fielder FC	Stainless steel	110 mm spring coil	Hydrophillic	014	0.8	Yes, 220 mm	30	9 (15)		
Fielder XT	Stainless steel	110 mm spring coil	Hydrophillic	009	0.8	Yes, 220 mm	160	9 (15)	19	
Fielder XT-R	Stainless steel	Composite coil, 160 mm	Hydrophillic	010	0.6	Yes, 170 mm	160			Fielder family but composite coil
Fielder XT-A	Stainless steel	Composite coil, 160 mm	Hydrophillic	010	1	Yes, 170 mm	160			Fielder family but composite coil
Crosswire NT	Nitinol	Polyurethane + tungsten in polymer coil	Hydrophillic	014	4	Yes	40			
Choice PT	Unibody stainless steel	No coil	Hydrophilic	014	2.1	Yes, 380 mm	350	Light		
PT Graphix	Unibody stainless steel	No coil	Hydrophilic	014	1.7	Yes	30			
Cross IT 100	Stainless steel	300 mm coil	Hydrophillic	0105	1.7	No	30	24 (30)	20	
Cross IT 200	Stainless steel	300 mm coil	Hydrophillic	0105	4.7	No	30	24 (48)	54	
Cross IT 300	Stainless steel	300 mm coil	Hydrophillic	0105	6.2	No	30	24 (40)	72	
Cross IT 400	Stainless steel	300 mm coil	Hydrophillic	0105	8.7	No	30	18 (64)	101	
Miracle Brothers 3	Stainless steel	110 mm spring coil	Hydrophobic	014	3.9	No	110	23 (60)	32	
Miracle Brothers 4.5	Stainless steel	110 mm spring coil	Hydrophobic	014	4.4	No	110	23 (60)	36	
Miracle Brothers 6	Stainless steel	110 mm spring coil	Hydrophobic	014	8.8	No	110	23 (60)	106	
Miracle Brothers 12	Stainless steel	110 mm spring coil	Hydrophobic	014	13	No	110	23 (60)		
Conquest 9	Stainless steel	200 mm coil	Hydrophobic	009	8.6	No	200	7 (10)	135	
Conquest 12	Stainless steel	200 mm coil	Hydrophobic	009	12	No	200	7 (10)		
Conquest Pro 9	Stainless steel	200 mm coil	Hydrophillic	009	9.3	No	200	7 (10)	146	Distal most 1 mm of tip is uncoated
Conquest Pro 12	Stainless steel	200 mm coil	Hydrophillic	009	12	No	200	7 (10)	195	Distal most 1 mm of tip is uncoated
Conquest Pro 8-20	Stainless steel	200 mm coil	Hydrophillic	008	20	No	200			Highest penetrating wire
RG3	Stainless steel	80 mm platinum coil	Hydrophillic	010	3	No	30			For externalization

2.5. Steerability

Steerability is the ability and responsiveness of the wire tip to navigate vessels and torquability is the response of the wire to turning by the operator when navigating vessels (the ability to transmit torque from the proximal end to the distal end of the wire). This property is important in drilling strategy where wire is rotated in a controlled manner to search for path of least resistance. It depends on:

(1) Single core wire – force transmission is not dampened by the terminal coil.
(2) Lateral support provided by the wire.
(3) Specially designed wires capable of torque transmission (wires with dual or composite core).

2.6. Bending

Ability to bend is required to circumvent a very stiff tissue e.g. calcium. Coil structure at the end of the wire allows for this property (while single core wire resists it).

2.7. Lubricity

Resistance is encountered while moving the wire in a vessel or through any lesion. Lubricity is the ease of this passage. The resistance encountered depends on

1. The tissue encountered: vessel lumen << micro-channel< lipid plaque < proteoglycan < collagen/elastin.
2. Bends (tortuous lesions)
3. Length of the lesion

In general resistance offered is as follows: Polymer coat < hydrophilic < hydrophobic < non coated.

Guidewires in CTO are chosen according to strategy employed in crossing the CTO.[1] Comparison of various guidewires useful in CTO PCI is done in Table 1.

2.8. Sliding wires

Fielder wires are classical CTO wires with a polymer jacket known for their use in young CTOs, for picking up micro-channels. These wires are soft (tip load ~1), highly lubricious (hydrophilic and polymer coated) and have slightly more lateral support than a work-horse PCI wire like BMW or RunThrough. Fielder FC or XT (Asahi Intecc, Nagoya, Japan) are a good example[3,4] (Figs. 1 and 2).

Fielder FC – Specifications

•Tip load	0.8 g
•Radio-opaque length	3 cm
•Coil	11 cm
•Diameter	0.014 in.
•Polymer cover	Full polymer
•Coat	Hydrophilic
•Support	Moderate

Fielder XT – It has same tip load but it has got a penetrating tip (009) but it has a long radio-opaque segment (160 mm) and therefore has to be replaced by a work-horse wire once the lesion is crossed.

•Tip load	0.8 g
•Radio-opaque length	16 cm
•Coil	16 cm
•Diameter	0.014 in.
•Tip diameter	0.009 in.
•Polymer cover	Full polymer
•Coat	Hydrophilic
•Support	Moderate
•Length	190 cm

The only limitations of Fielder wires; plain, FC or XT is that because of being covered by a polymer jacket there may not have a good torque transmission from the proximal "working region" to the tip leading to limited torquability. This problem has been solved to a great extent by the next generation of Fielder wires. Fielder XT-A (Asahi Intecc, Nagoya, Japan) for example has a composite coil at the tip which makes it more flexible and torquable.

Fielder XT-A – It has a higher tip load with a tapered tip (010), polymer jacket with hydrophilic coating (like any Fielder wire). However, its unique feature is a composite wire core at the tip which allows 1:1 torque transmission culminating in increased penetration performance and maneuverability, useful in recent CTOs without a stump. The only limitation of this wire is a long radio-opaque segment (160 mm) which requires this wire to be exchanged with a every-day wire before stent implantation otherwise visualization may be deficient. Fig. 3

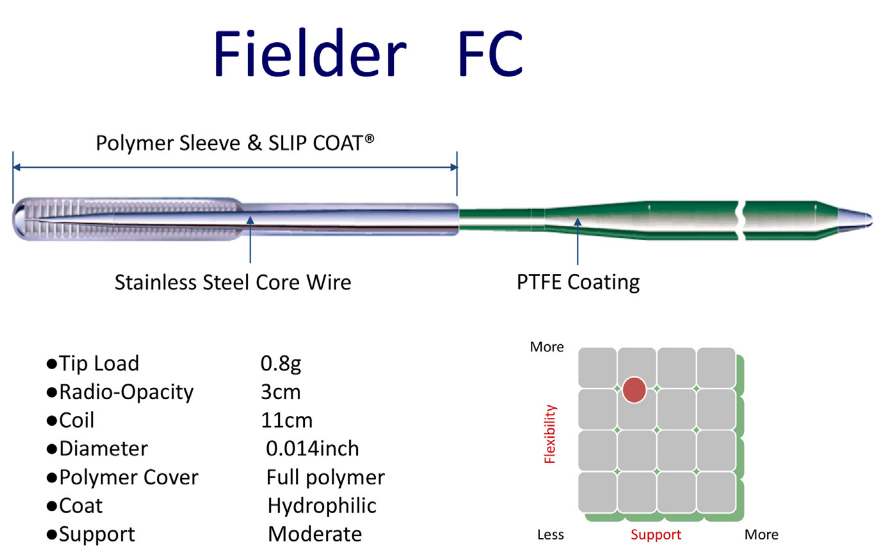


Fig. 1. Fielder FC.

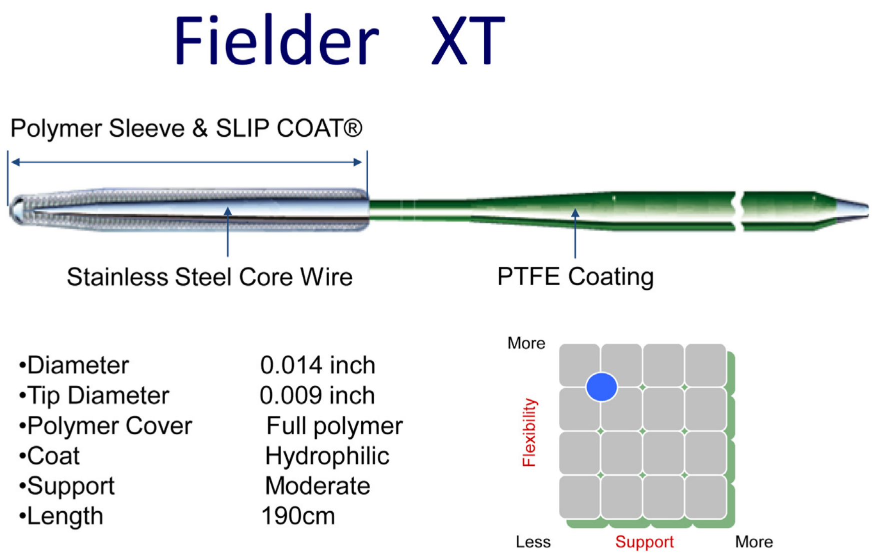


Fig. 2. Fielder XT.

specifications:

•Tip load	1.0 g
•Coil	16 cm
•Diameter	0.014 in.
•Tapered tip	0.010 in.
•Polymer jacket	17 cm
•Hydrophilic coating	17 cm
•Radio-opaque length	16 cm
•Torque transmission	1:1
•Length	190 cm and 300 cm

Method of use: These wires are generally used in sliding technique of wiring, trying to pick up micro-channels.

2.9. Wires with improved torquability

These wires are characterized by a specially constructed composite coil which allows for increased torque transmission. Fielder XT-R/A and Sion wires (Asahi Intecc, Nagoya, Japan) have increased torquability but **Gaia** (Asahi Intecc, Nagoya, Japan) wires come with additional features. In composite core wires the classic linear core is wrapped with another layer formed by twisted wires (rope-coil) joined at the tip. In Gaia wires, the most characteristic feature is the specially constructed composite (dual) core which has a central core wire, wrapped by six acetone wires, with spring coil in periphery. Further, these wires could be thinner (010–014) with hydrophilic coating with a moderate tip load (1.5–4.5) and a special dual-core core with a micro-core, pre-shaped 1 mm tip for penetrating fibrous cap and hard tissue. In general polymer (plastic) jacket wires have lowest friction and therefore are helpful in crossing long occlusions. However, since their spring coils are embedded deep inside, covered by the jacket, the attempted external rotations of the wire, via the central core are not readily communicated to the tip, which leads to building up of torque force (torque delay) and a sudden release known as "whip motion" phenomenon. Further, tactile information from the tip cannot be accurately communicated proximally to the working hand (plastic jacket or even hydrophilic coat acting as an insulator). In non-coated wires this transmission both ways is much better, which eliminates the whip motion effect and enables a more gradual but precise tip rotation. However, composite core like that in Gaia

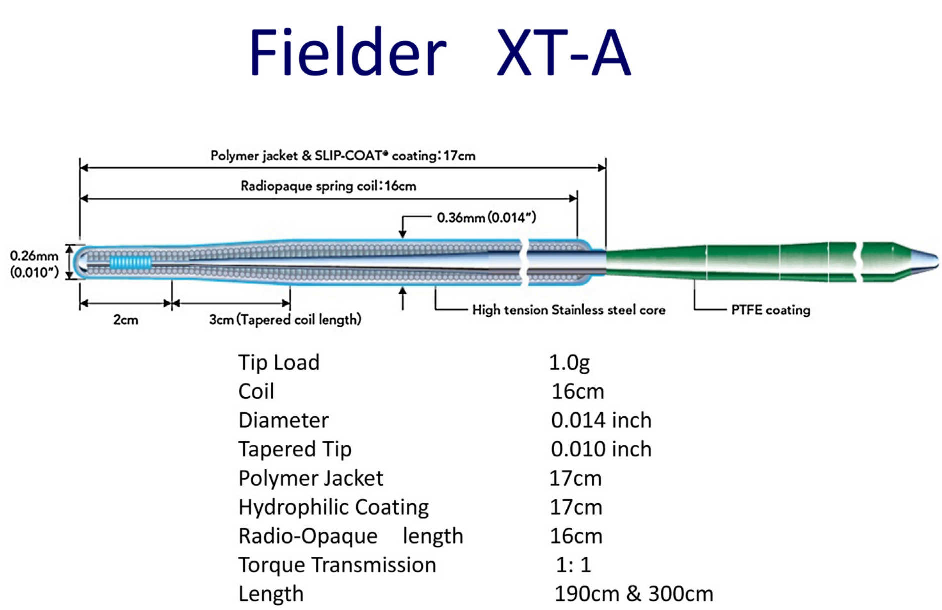


Fig. 3. Fielder XT-A.

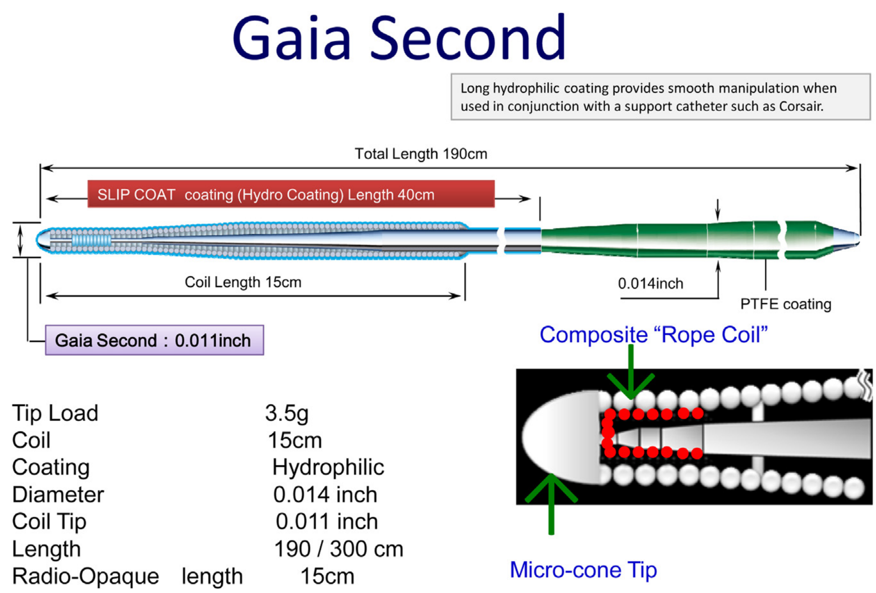


Fig. 4. Gaia second.

wires this problem is overcome to a great extent by wrapping the classic linear core with another, formed by twisted wires (rope-coil) joined at the tip which prevents this accumulation of torque at tip and subsequent whip-lash motion thus resulting in increased torquability. Further, integration of this rope coil at tip allows for a fine and durable tip-shaping. The Gaia wires come with increasing tip load (**Gaia first** – 1.7, **Gaia second** – 3.5 and **Gaia third** – 4.5) and increasing tip thickness (Gaia first – 010, Gaia second – 011 and Gaia third – 012). Gaia second is shown in Fig. 4 specifications:

•Tip load	3.5 g
•Coil	15 cm
•Coating	Hydrophilic
•Diameter	0.014 in.
•Coil tip	0.011 in.
•Length	190/300 cm
•Radio-opaque length	15 cm

Method of use: These wires are used in penetrating strategy of wiring.

2.10. *Wires with higher penetrating capability*

These wires have higher tip loads, higher lateral support, and may or may not have a tapering tip. Miracle and Conquest series are a good example.

Miracle series – The tip load can vary from 3, 4.5, 6, or 12 with a non-tapering, hydrophobic coated tip and high lateral support, therefore useful in lesions at a bend or some tortuosity. Fig. 5 specifications of Miracle 12 (Asahi Intecc, Nagoya, Japan):

•Tip load	12 g
•Radio-opaque length	11 cm
•Coil	11 cm
•Coating	Hydrophobic
•Polymer cover	None
•Diameter	0.014 in.
•Length	180 cm

Conquest series – The tip load is same as Miracle series but with a tip tapering to 010 and a very high lateral support. Thus it can be used only in straight lesions otherwise there may be a risk of

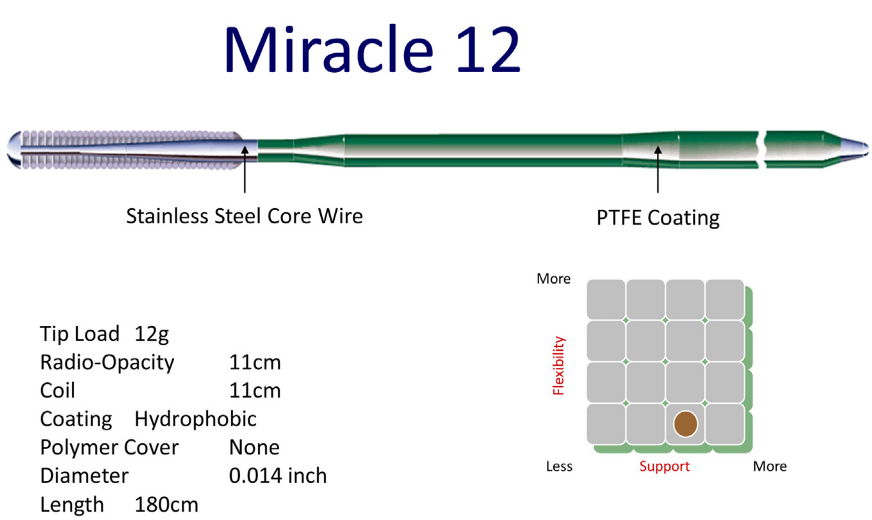


Fig. 5. Miracle 12.

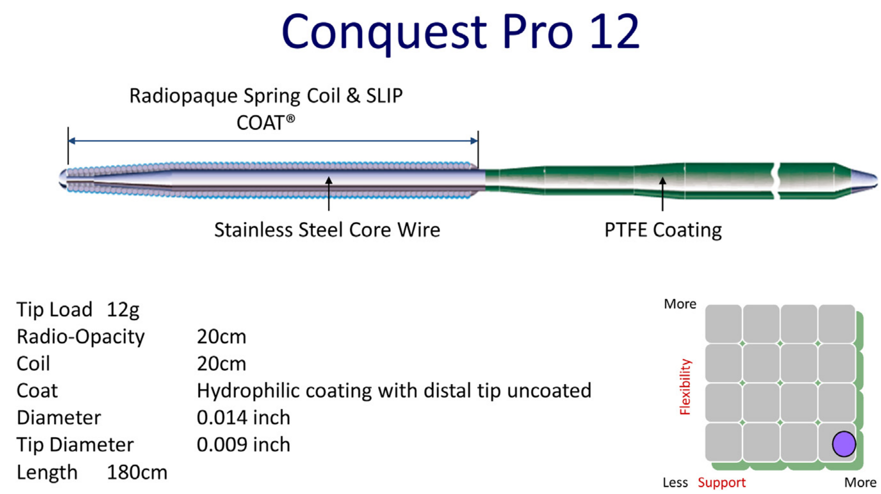


Fig. 6. Conquest Pro 12.

perforation. One special feature of Conquest wires (Asahi Intecc, Nagoya, Japan) is that the coil portion has a special hydrophilic coating (SLIP COAT®) for enhanced lubricity and easier wire manipulation but the distal most portion is uncoated to allow for transmission of tactile sensation from the tip. Another important difference is a very long radio-opaque distal segment (200 mm). Fig. 6 specifications

•Tip load	12 g
•Radio-opaque length	20 cm
•Coil	20 cm
•Coat	Hydrophilic coating with distal tip uncoated
•Diameter	0.014 in.
•Tip diameter	0.009 in.
•Length	180 cm

Method of use: These wires are used in drilling strategy, penetrating the fibrous cap but occasionally they can also be used in penetrating wire strategy.

2.11. Wires for retrograde use

The basic requirement in this category is that the wire should be longer, with lowest tip load and very low friction; hydrophilic/ polymer jacket coating.[5,6] At the same time wire should have improved torque transmission to enable it to negotiate the collaterals (composite/dual core technology). The classic wire is hydrophilic coated **Sion Blue** (Asahi Intecc, Nagoya, Japan) with a tip load of 0.5. It has a dual-core at tip which leads to precise torque response and flexibility and also contributes to shape retention at the tip. Sion Blue is shown in Fig. 7 specifications:

•Tip load	0.5 g
•Radio-opaque length	3 cm
•Coil	20 cm
•Coating	Hydrophilic
•Diameter	0.014 in.
•Length	180 cm

Fielder XT-R is an alternative wire for this use which has extremely low friction (because it is both polymer and hydrophilic coated) but still has a low tip load (0.6) at the same time having a much improved flexibility (as compared to regular Fielder series) because the tip has a tapered core composed of composite wire technology. Fig. 8 specifications of Fielder XT-R (Asahi Intecc, Nagoya, Japan):

•Tip load	0.6 g
•Coil	16 cm
•Diameter	0.014 in.
•Tapered tip	0.010 in.
•Polymer jacket	17 cm
•Hydrophilic coating	17 cm

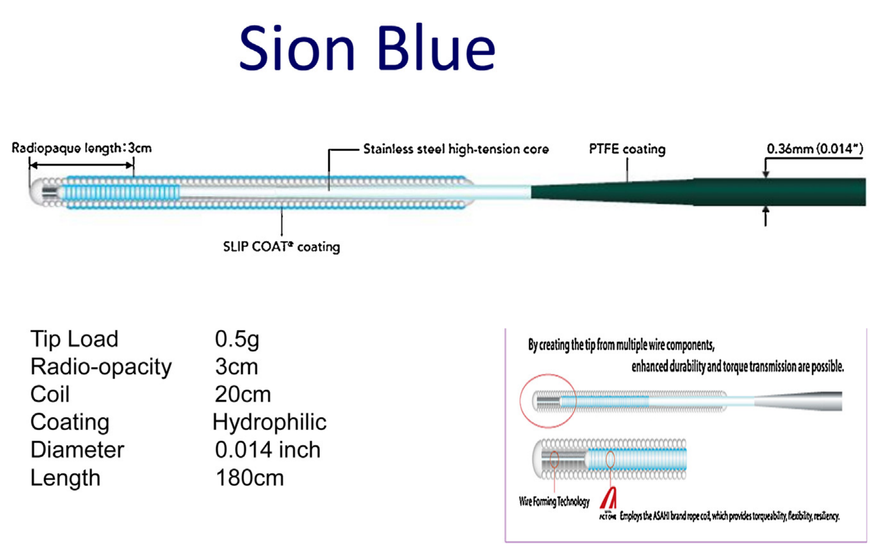


Fig. 7. Sion Blue.

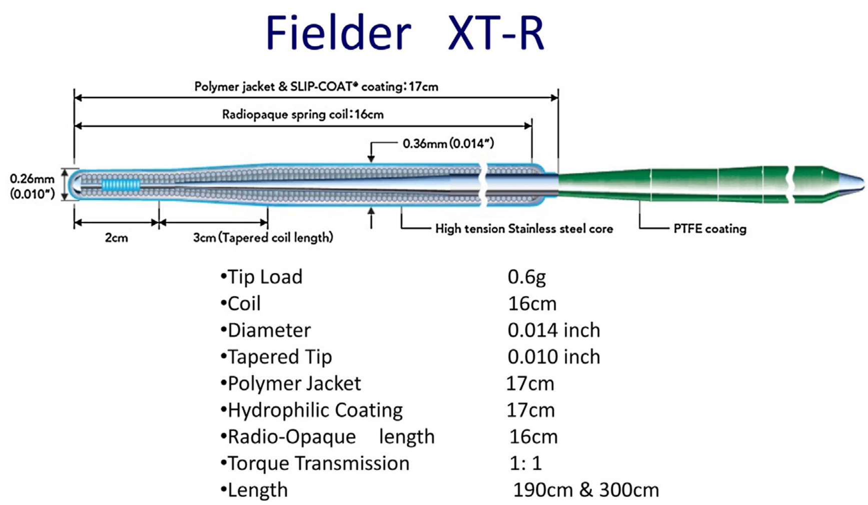


Fig. 8. Fielder XT-R wire.

•Radio-opaque length	16 cm
•Torque transmission	1:1
•Length	190 cm and 300 cm

Sion Black – Sion Black (Asahi Intecc, Nagoya, Japan) has similar characteristics as the Sion family; excellent torquabilty, low tip load – 0.8 (slightly higher than Sion blue) but is polymer jacketed and thus has a very low friction, thus achieving a kind of best of both worlds. Fig. 9 specifications:

•Tip load	0.8 g
•Radio-opaque length	3 cm
•Coil	Dual-core
•Diameter	0.014 in.
•Polymer cover	20 cm polymer
•Coat	40 cm Hydrophilic
•Length	190–300 cm

Method of use: These wires are used predominantly in retrograde technique; used to cross donor artery, collateral channel, distal segment of diseased artery before attempting penetration of distal cap.

2.12. Wires for externalization

The basic requirement for the wire used for externalizations is that it should be longer (at least 300 cm long), but at the same time thinner (so that it does not injure the collaterals while passing balloon catheters and other hardware) but at the same time have enough lateral support to enable these passages. **RG3** (Asahi Intecc, Nagoya, Japan) is one such wire which is not only 330 cm long, is thinner (010) and provides a good lateral support to deliver PCI devices (Fig. 10). **R350** (Vascular Solutions, Minneapolis, MN, USA), a 350 cm guidewire with 0.013″ wire with a platinum coil is an alternative to RG3 wire.

Method of use: It is used for externalization via antegrade catheter followed by PCI through antegrade use.

2.13. Micro-catheters

Micro-catheters are another important hardware for dedicated CTO intervention work. They serve several functions in context of CTO. The most important function is to allow for the exchange of guidewires; in addition they provide support to the wire, ensure positioning of the wire, visualization of distal vessel via injection of contrast as also negotiation of collaterals and even channel dilatation. Alternately OTW balloons can be used in some situations, however, generally micro-catheters have a more flexible tip (so increased penetrability), wider inner lumen (for manipulating wire) and the radio-opaque marker is at the tip (better assessment of distance of the lesion from micro-catheter). The only advantage OTW balloons may have is that they might be cheaper.

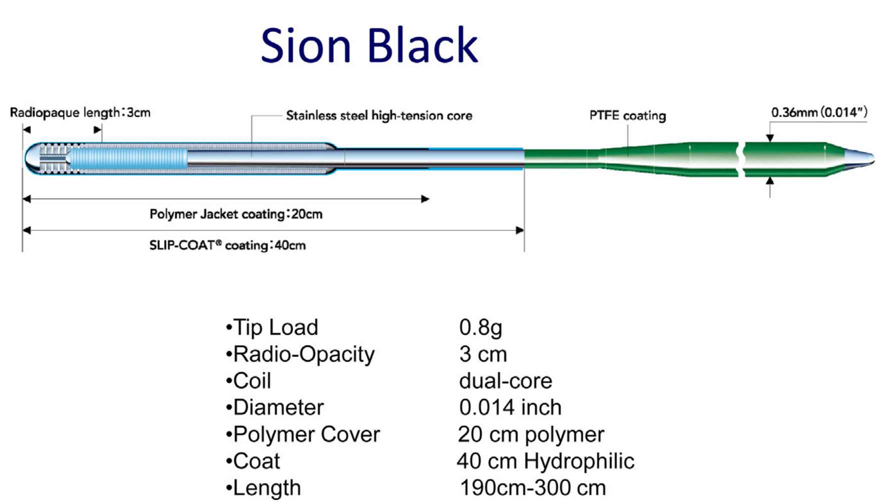


Fig. 9. Sion Black wire.

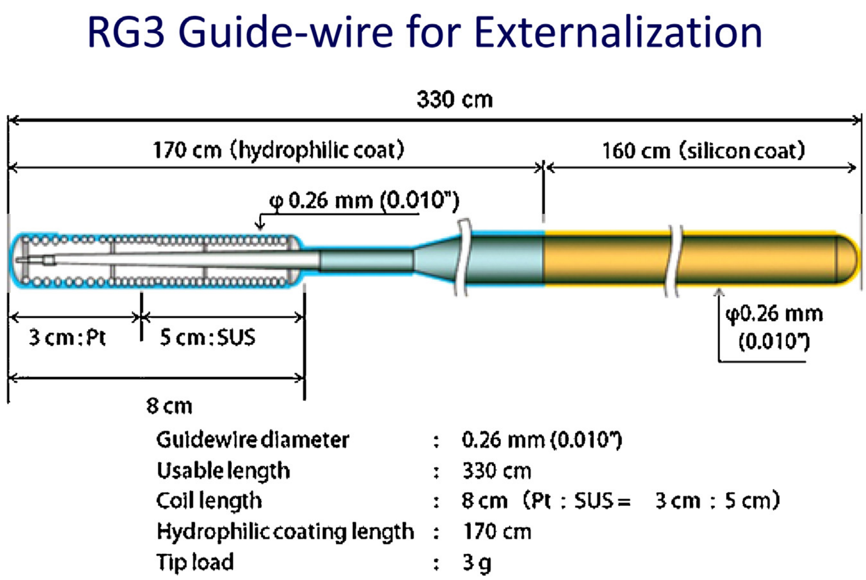
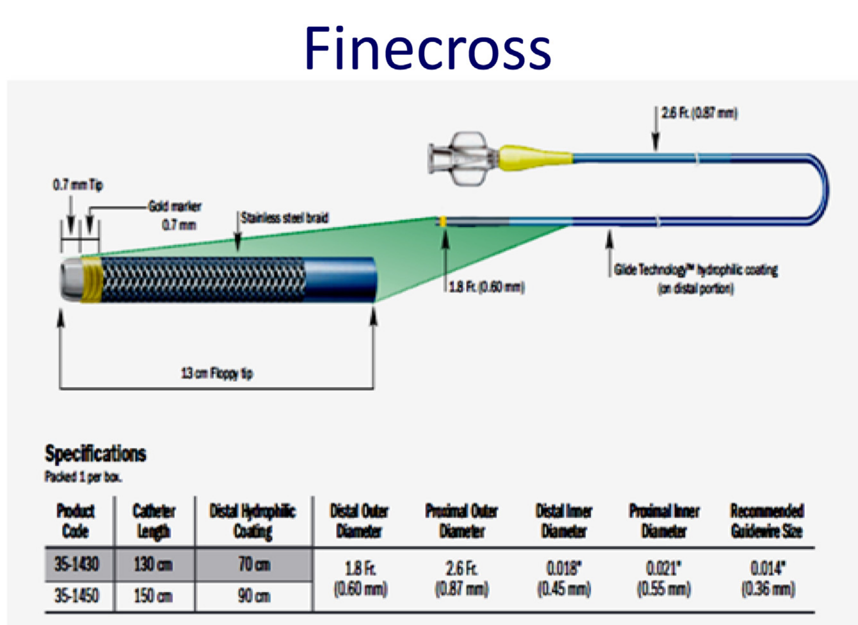


Fig. 10. RG3 wire.

FineCross – FineCross (Terumo Interventional Systems, Tokyo, Japan) are generally the lowest profile catheters and can be used to cross the smaller sized collaterals. They have a fully stainless steel braided shaft which provides strong guide wire support, tapered inner and outer lumen which provides for enhanced crossability but at the same time provide an optimal guide wire support. PTFE coated inner layer facilitates manipulation of the guide wire. The proximal lumen is adequate (2.6 Fr/0.87 mm) which enables buddy wire technique in 6 Fr guiding catheter and distal large lumen to allow for optimal guide wire handling as well as contrast injection. While the profile of this micro-catheter is lowest among all, the pushability is least. FineCross is generally most commonly used micro-catheter because of its lower profile and M-coating which permits smooth advance into narrow CTO space. **FineCross GT** has a tapering distal entry tip profile 1.7 Fr (0.57 mm). This wire can be advanced into even smaller vascular lumens and tortuous lesions. The structure of FineCross catheters is shown in Fig. 11. The specifications of **FineCross MG** are:

•Distal outer diameter	•1.8 Fr (0.60 mm)
•Distal inner diameter	•0.018″ (0.45 mm)
•Proximal outer diameter	•2.6 Fr (0.87 mm)
•Proximal inner diameter	•0.021″ (0.55 mm)
•Guide wire compatibility	•Maximum diameter 0.014″
•Radio-opaque marker	•0.7 mm gold single marker located at 0.7 mm from the tip
•Coating	•Hydrophilic

Corsair micro-catheter – Corsair (Asahi Intecc, Nagoya, Japan) catheter is OTW hybrid micro-catheter/septal dilator useful both for antegrade but especially retrograde CTO PCI (Fig. 9). Its base is "Shinka" shaft made up of 8 smaller (0.07 mm) stainless steel wires braided (wound) around 2 larger (0.12 mm) stainless steel wires, the inside of which is lined by a tungsten braiding. This construction allows for enhanced pushability but not on cost of flexibility. It has a kink resistant soft, radio-opaque and a very low



Product Code	Catheter Length	Distal Hydrophilic Coating	Distal Outer Diameter	Proximal Outer Diameter	Distal Inner Diameter	Proximal Inner Diameter	Recommended Guidewire Size
35-1430	130 cm	70 cm	1.8 Fr. (0.60 mm)	2.6 Fr. (0.87 mm)	0.018" (0.45 mm)	0.021" (0.55 mm)	0.014" (0.36 mm)
35-1450	150 cm	90 cm					

Fig. 11. FineCross micro-catheter.

profile tapered tip (0.016″/0.42 mm). The 5 mm tip is composed of tungsten powder (but no steel braid) and has a 0.8 mm platinum marker coil just proximal to it. The flexible, kink-resistant tip facilitates easy crossing as well as dilating of micro-channels and narrow tortuous vessels/lesions. The braided portion (distal 60 cm) of the catheter is covered with polyamide elastomer which allows bi-directional torque transmission and contributes to excellent maneuverability, and the inner lumen of the shaft is lined with a fluoropolymer layer that enables tip injections and facilitates the guidewire movement. The stainless braid is lined with an additional inner braid of tungsten and tungsten powder on tip. In addition there is platinum marker, all of which contributes to enhanced radio-opacity. This feature helps detect torque accumulation and catheter tip entrapment within the CTO thus improving safety. Whole braid is lined with tungsten. This wire is available in two lengths – 135 cm for antegrade and 150 cm for retrograde use. Has inner lumen allows for wire support and manipulation as well as contrast injection. In comparison with other micro-catheters, Corsair micro-catheter has the smallest outer and inner diameter for the distal tip (easy entry into channel), the smallest inner diameter and the larger outer diameter for the distal part (improved wire support), and the smallest inner diameter and the larger outer diameter for the proximal part, which gives better crossability of the distal tip and better backup guidewire support compared with conventional micro-catheter[7] (Fig. 12).

Method of use: Overall, braided, spiral structure allows the bidirectional rotation. Thus the advance of this catheter involves pushing with gentle rotation (30° in both directions) which permits not only traversing the entire length of the collateral channel (in retrograde technique) but also allows channel dilation (the passage of increasing larger caliber of micro-catheter; 0.42 mm at tip to 0.87 mm at proximal part, to 0.93 mm at distal part).

Tornus micro-catheter – Tornus (Asahi Intecc, Nagoya, Japan) catheter has among highest pushability and thus useful even in calcified lesions but also carries the high risk of complications. In contrast to Corsair micro-catheter (2 large wires), it is composed of 8 larger wires braided together. In Tornus (2.1 Fr) each wire is of 0.12 mm diameter whereas in Tornus 88Flex (2.6 Fr) it is 0.18 mm. Like Corsair the shaft is a long taper from proximal end to tip (Tornus from 0.71 mm proximal shat to 0.61 tip; Tornus 88Flex from 1.0 mm proximal part to 0.88 distal shaft to 0.70 tip). The tip has a radio-opaque platinum marker for enhanced visibility and distal 30 cm is covered by a tube to prevent blood leakage. The proximal part of catheter (5 cm) has a safety-release valve to indicate when the device has reached maximum rotation and thus prevent over-rotation leading to catheter breakage. Composed of thicker wires, having higher tip stiffness and higher screw pitch, penetrating power of Tornus 88Flex is highest among all micro-catheters but overall Tornus catheter is more useful as a support catheter (to give support to guidewire, mainly useful in antegrade technique) rather than a "collateral catheter" because of its higher profile and risk of damage when used to traverse the collaterals. On the other hand, since the use of Tornus also enlarges the vessel through which it is passed it can also be used as a "Channel Dilator" (Fig. 13).

Method of use: Tornus catheter is screwed into a lesion in a counter-clockwise fashion; 20 counterclockwise rotations, up to the maximum, in order to advance the catheter. As the catheter moves forward, rotation is curtailed and wire advanced, once wire is advanced some more advancement of catheter till the entire expanse of lesion is traversed. It is important to stabilize the guidewire while the Tornus catheter is rotated and the Tornus catheter while guidewire is advanced; the guidewire and the Tornus catheter must not rotate at the same time or there will be a risk of vessel perforation. Withdrawal of the Tornus catheter requires a reverse, clock-wise rotation. It does not have a separate lumen for contrast injection.

Turnpike catheter – The Turnpike (Vascular Solutions, Minneapolis, MN, USA) family of catheters are OTW catheters constructed with a unique multi-layer shaft that provides superior flexibility, torque and tracking over a 0.014″ guidewire. The catheters are called "turn pike" because when they are rotated (turn) they advance down the artery (pike). There are three versions of the Turnpike are called the Turnpike catheter (standard version), the Turnpike Spiral catheter, and the Turnpike Gold catheter. All three versions of the Turnpike catheter have the same multi-layer shaft which is a unique hybrid construction of both a

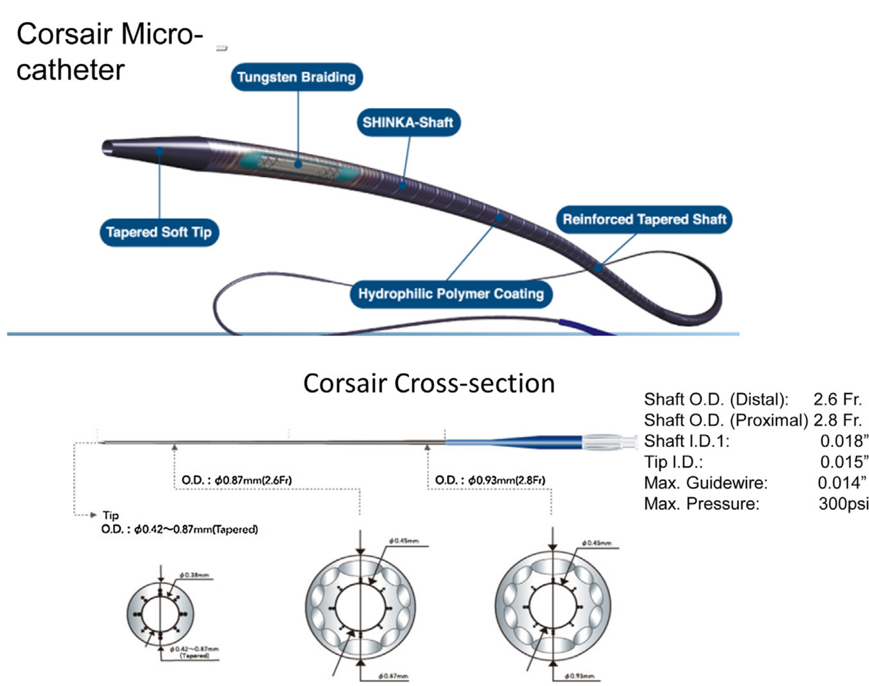


Fig. 12. Corsair micro-catheter.

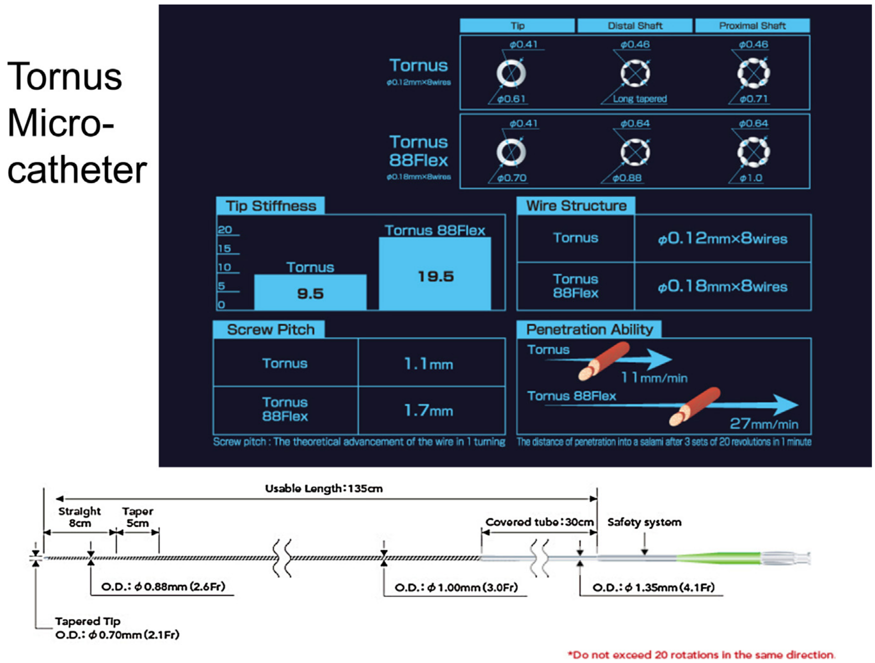


Fig. 13. Tornus micro-catheter.

braid and a dual-layer coil encapsulated between two polymer layers (5 layers in total). The braid and two coil layers combine to provide a superior combination of flexibility and torque response, making the Turnpike shaft both incredibly deliverable and kink-resistant. The Pebax (polymer) outer layer provides a smooth outer surface for delivery, with hydrophilic coating on the distal 60 cm for excellent lubricity. The PTFE ("Teflon") inner layer provides for excellent guidewire movement, all the way to the tip of the catheter. The tip has somewhat higher entry profile (0.021″–0.53 mm) but metallic tip provides additional support to guidewire. Thus this catheter is more of a support catheter but can be used in CTO PCI (Fig. 14).

Crusade catheter – Crusade (Kaneka Corp, Osaka, Japan) catheter is a dual lumen (both OTW and rapid exchange lumen) catheter which has a low profile tapered flexible tip (0.017″) and flexible but strong shaft. Two radio-opaque markers on the rapid exchange port 0.5 mm apart make it easy to estimate the length of the lesion. This micro-catheter is useful in antegrade parallel wire technique (Fig. 15).

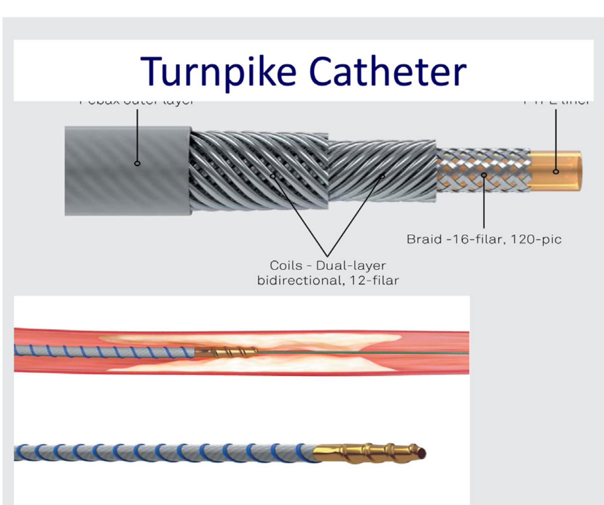


Fig. 14. Turnpike catheter.

2.14. Comparison of micro-catheters

Table 2 shows comparison of commonly used micro-catheters for CTO application. In general tip OD co-relates with penetrability, Tip ID with amount of contrast that can be delivered and wire handling, distal OD with compatibility with a small vessel and proximal OD with handling or pushability. In addition other features of micro-catheter may also impact; for example metallic tip improves pushability while soft tip improves entry and crossability. Thus Corsair catheter will has lowest entry profile and highest crossability but low tip ID, in addition it can cause channel dilation. Thus it is generally the work-horse micro-catheter when retrograde technique is required. Finecross has the overall lowest profile of workable segment but a good tip ID for wire handling and contrast injections. It can be a mainstay micro-catheter where channel dilation is not required. Tornus 88Flex, Turnpike and Crusade, all three of them have a larger proximal shaft (≥1 mm) for enhanced pushability but Tornus has a singular screw like forward motion which increases pushability. On the other hand, Turnpike has the largest among them and in addition it has a metallic tip and thus it might have highest pushability.

3. Over-the-wire balloon catheters

The essential requirements here are low profile and long length (especially for use in retrograde work). **Ryujin Plus OTW** (Terumo Interventional Systems, Tokyo, Japan) has 148 cm long shaft model which is suitable for distal lesions and CART technique. **Tazuna** (Terumo Interventional Systems, Tokyo, Japan) is a high performance balloon with a lower profile of 0.4 mm for its 1.25 model and a 145 cm usable length. Fig. 16 specifications:

Shaft diameter	1.9 Fr (0.63 mm) Proximal, 2.4 Fr (0.80 mm) Distal for 1.25–2.00 mm
Usable length	145 cm
Nominal pressure	6 atm
Rated burst pressure	14 atm
Lesion entry profile	0.40 mm (1.25–2.25 mm/10 mm) 0.42 mm (1.25–2.25 mm/15–20 mm)
Coating	Hydrophilic

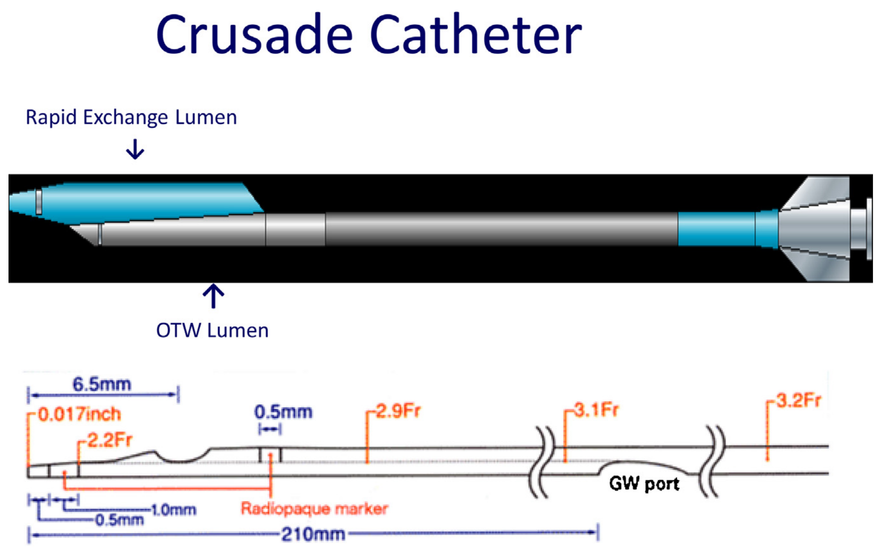


Fig. 15. Crusade catheter.

Table 2
Comparison of micro-catheters.

Micro-catheter	Tip OD	Tip ID	Distal OD	Proximal OD	Additional features
Finecross GT	0.57 mm (022″)	0.45 mm (018″)	0.6 mm	0.87 mm	Lowest profile for working segment
Corsair	0.42 mm (016″)	0.38 mm (015″)	0.87 mm	0.93 mm	Soft, kink resistant tip and braided, hydrophilic coated shaft with taper from proximal to distal allowing channel dilation
Tornus	0.61 mm (024″)	0.41 mm (016″)		0.71 mm	Large braided shaft for enhanced pushability with safety valve to relieve accumulation of torque
Tornus 88Flex	0.7 mm (028″)	0.41 mm (016″)	0.88 mm	1 mm	
Turnpike	0.53 mm (021″)	0.38 mm (015″)	0.86 mm	1.02 mm	Metallic tip, Shaft with complex braid and a dual-layer coil encapsulated between two polymer layers
Crusade	0.57 mm (022″)	0.43 mm (017″)	0.97 mm	1.07 mm	

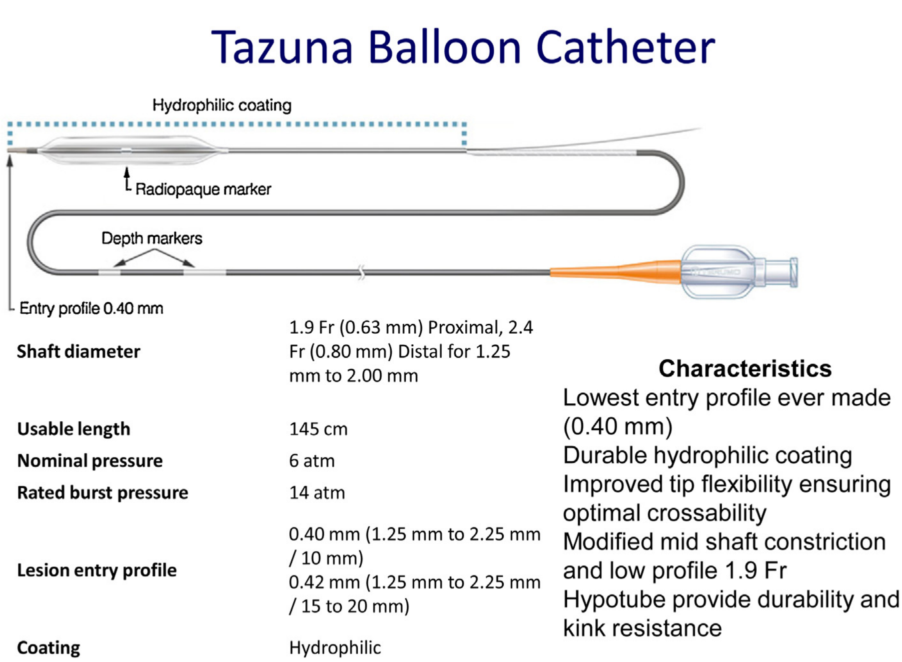


Fig. 16. Tazuna balloon dilatation catheter.

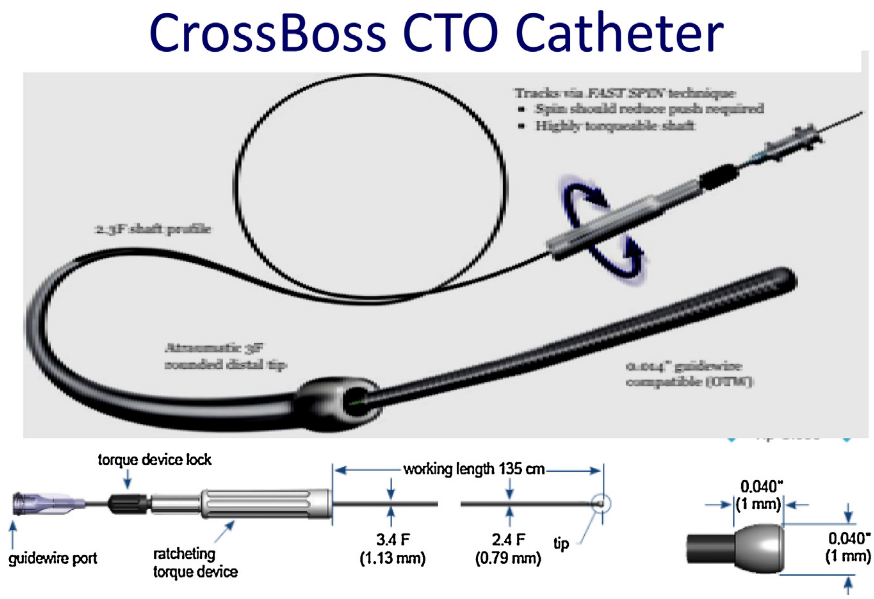


Fig. 17. CrossBoss CTO catheter.

4. Re-entry devices

4.1. CrossBoss sting ray system for antegrade sub-intimal tracking and re-entry

The **CrossBoss** (Boston Scientific, Maple Grove, MN, USA) is actually a metal OTW micro-catheter with a very soft non-penetrating round tip, used to safely traverse the sub-intimal expanse over occluded CTO. It has a 2.3 F shaft profile, 3 F rounded atruamatic distal tip which tracks via fast spin technique, rotating in either direction and is advanced without a wire sitting in it. Once the entire length of occlusion is traversed, CrossBoss is exchanged over a 014″ guidewire with Sting Ray balloon (Fig. 17).

4.2. Stingray CTO orienting balloon catheter and the Stingray™ CTO re-entry guidewire

The balloon catheter has a 2.9 Fr shaft profile, compatible with 6 Fr guide-catheter and 014″ guidewire. The self orienting balloon at the tip has a flat shape, 014″ crossing profile and two offset exist ports opposite to each other with a radio-opaque marker just distal to the port (to mark its orientation toward the true lumen) for Stingray CTO re-entry guidewire. When inflated this balloon assumes a flat shape (which is non-damaging) and allows orientation of the penetrating wire (Sting Ray wire) toward the true lumen, radio-opaque markers denominating the 2 exist ports. The port which is oriented toward the true lumen is chosen to pass the Sting Ray wire which is a tapered wire with a high penetrating force. Once it enters into true lumen the whole apparatus is removed and the channel created used to pass a regular penetrating CTO wire and cross into the true lumen. Finally, this wire is exchanged for a regular work-horse wire and the procedure is completed over it (Fig. 18).

5. Imaging catheters

IVUS guided wiring is a very useful strategy in achieving success in CTO PCI, particularly in penetrating the fibrous cap and entering

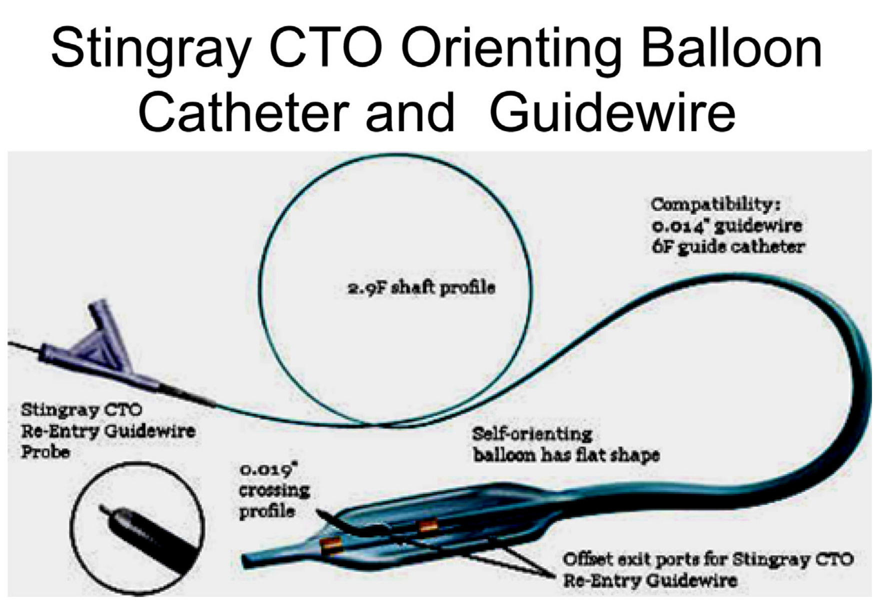
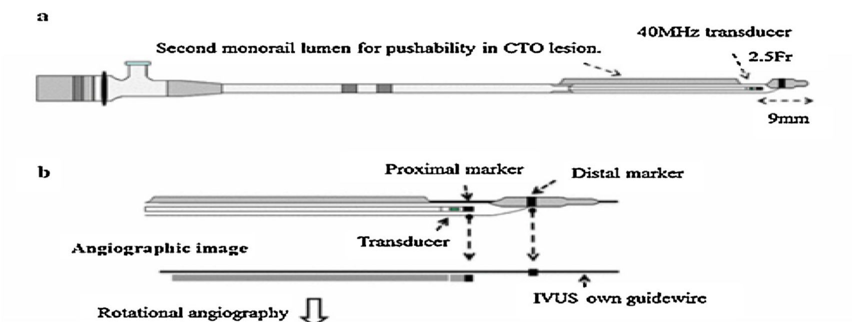


Fig. 18. Stingray™ CTO orienting balloon catheter and the Stingray™ CTO re-entry guidewire.

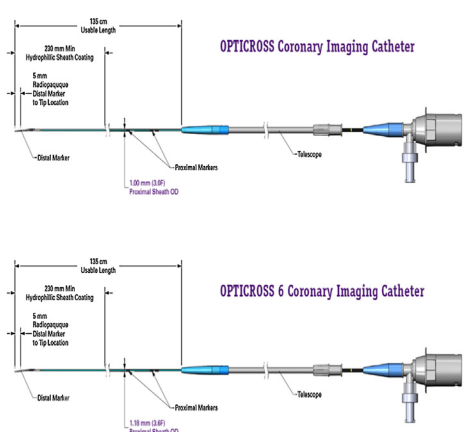
Navifocus WR



	Specifications
Transducer profile	2.5 Fr
Tip to transducer distance	9 mm
Lumen	Double monorail lumen
Proximal lumen	260 mm
Sheath size for IVUS+ micro-catheter	7 Fr
Transducer frequency	40 MHz

Fig. 19. Navifocus WR IVUS.

OptiCross



	OPTICROSS	OPTICROSS 6
Entry Profile	0.026 inch	0.017 inch
Crossing Profile	3.1 F	3.1 F
Hydrophilic Coating	Bio-Slide	Z-Glide
Center Frequency	40 MHz	40 MHz
Axial Resolution	38 µm	38 µm
Wide Band Technology	Yes	Yes
GC Compatibility	5F	6F
Motor Drive	MDU5 PLUS	MDU5 PLUS
Tip to Transducer	20 mm	20 mm
Tip Color	White	Red

Fig. 20. OptiCross IVUS.

the true lumen whether it is antegrade or via retrograde route. However, the classical IVUS catheters restricted not only by their size but also by the fact that transducer (the eye) is not at the tip but at a substantial distance from the tip so that the catheter is unable to "look forward." In this context **Navifocus WR** (Terumo Corp., Tokyo, Japan) has the lowest profile catheter (2.6 Fr) and the transducer is closest to the tip (9 mm) with a long proximal lumen (26 cm). Further, it has a double monorail lumen (1 for the wire of the IVUS catheter and the other for directing wire through it toward the true lumen). The small profile allows it to be used alongside a FineCross micro-catheter and both of them fitting into a 7 Fr sheath[8] (Fig. 19).

OPTICROSS (Boston Scientific, Maple Grove, MN, USA) is a new IVUS developed by Boston Scientific which has a slightly lower profile (3.1 Fr) and a transducer which is somewhat closer to tip (20 mm) as compared to regular Atlantis SR Pro2 (Boston Scientific, Maple Grove, MN, USA) (Fig. 20). The comparison of older with new generation IVUS is shown in Table 3.

Table 3
Specifications of old and new IVUS.

Specification of IVUS	Atlantis SR Pro2	Volcano Eagle Eye	OPTICROSS	Navifocus WR
Frequency	40 MHg	20 MHg	40 MHg	40 MHg
Profile at imaging window	3.2 Fr	3.5 Fr	3.1 Fr	2.6 Fr
Distance from tip to transducer	26 mm	10.5 mm	20 mm	9 mm

6. Conclusions

To circumvent the difficulties associated with CTO PCI several specialized devices have been invented. Each device solves a particular problem associated with this technique. It is important to know the properties of individual hardware, how its specific property can be used in clinical context and the method of use of the device.

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