Editorial

Language of CTO interventions – Focus on hardware

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.

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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 accoutrement 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 < 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

Trackability 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. Torquability

1:1 transmission of bend.

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| Wire            | Core                  | Tip                  | Tip coat            | Tip load (g) | Tip dia | Polymeric coating | Radio-opaque length (mm) | Lat supp at 155 mm | Penetrating power: tip load/area of tip (kg/m²) | Comments                                                                 |
|-----------------|-----------------------|----------------------|--------------------|--------------|---------|-------------------|--------------------------|----------------------|-----------------------------------------------|--------------------------------------------------------------------------|
| Sion Blue       | High tensile steel    | Dual-core coil, 200 mm | Hydrophilic        | O14          | 0.5     | No                | 30                       | Yes, 200 mm           | 30                             | Lowest tip load                                                            |
| Sion Black      | High tensile steel    | Dual-core coil, 200 mm | Hydrophilic        | O14          | 0.8     | Yes, 200 mm        | 150                      | No                   | 150                            | Dual-core, polymer coated                                                  |
| Gaia First      | Stainless steel       | Composite core, Micro-cone tip | Hydrophilic | O10          | 0.5     | No                | 30                       | No                   | 30                             | Torque 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 | O11          | 1.1     | No                | 150                      | No                   | 150                            |                                                                         |
| Gaia Third      | Stainless steel       | Composite core, Micro-cone tip | Hydrophilic | O12          | 1.1     | No                | 150                      | No                   | 150                            |                                                                         |
| Whisper MS      | High tensile steel    | 45 mm coil           | Hydrophilic        | O14          | 2.7     | Yes, 290 mm        | 30                       | Yes, 290 mm           | 8 (9)                          |                                                                         |
| Pilot 150       | High tensile steel    | 45 mm coil           | Hydrophilic        | O14          | 4.1     | Yes, 290 mm        | 30                       | Yes, 290 mm           | 8 (9)                          |                                                                         |
| Pilot 200       | High tensile steel    | 45 mm coil           | Hydrophilic        | O14          | 4.1     | Yes, 290 mm        | 30                       | Yes, 290 mm           | 8 (9)                          |                                                                         |
| Fielder FC      | Stainless steel       | 110 mm spring coil   | Hydrophilic        | O14          | 0.8     | Yes, 220 mm        | 30                       | Yes, 220 mm           | 9 (15)                         | Fielder family but composite coil                                       |
| Fielder XT      | Stainless steel       | 110 mm spring coil   | Hydrophilic        | O09          | 0.8     | Yes, 170 mm        | 160                      | Yes, 170 mm           | 9 (15)                         | Fielder family but composite coil                                       |
| Fielder XT-R    | Stainless steel       | Composite coil, 160 mm | Hydrophilic        | O10          | 1.6     | No                | 160                      | No                   | 19 (36)                        |                                                                         |
| Fielder XT-A    | Stainless steel       | Composite coil, 160 mm | Hydrophilic        | O10          | 1.6     | No                | 160                      | No                   | 19 (36)                        |                                                                         |
| Crosswire NT    | Nitinol               | Polyurethane + tungsten in polymer coil | Hydrophilic | O14          | 4       | No                | 40                       | No                   | 36                            |                                                                         |
| Choice PT       | Unibody stainless steel | No coil             | Hydrophilic        | O14          | 2.1     | Yes, 380 mm        | 350                      | Yes, 380 mm           | Light                          |                                                                         |
| PT Graphix      | Unibody stainless steel | No coil             | Hydrophilic        | O14          | 1.7     | Yes, 380 mm        | 350                      | Yes, 380 mm           | Light                          |                                                                         |
| Cross IT 100    | Stainless steel       | 300 mm coil         | Hydrophilic        | O105         | 1.7     | No                | 30                       | No                   | 24 (30)                        |                                                                         |
| Cross IT 200    | Stainless steel       | 300 mm coil         | Hydrophilic        | O105         | 4.7     | No                | 30                       | Yes, 380 mm           | 24 (40)                        |                                                                         |
| Cross IT 300    | Stainless steel       | 300 mm coil         | Hydrophilic        | O105         | 6.2     | No                | 30                       | Yes, 380 mm           | 24 (40)                        |                                                                         |
| Cross IT 400    | Stainless steel       | 300 mm coil         | Hydrophilic        | O105         | 8.7     | No                | 30                       | Yes, 380 mm           | 24 (40)                        |                                                                         |
| Miracle Brothers 3 | Stainless steel     | 110 mm spring coil   | Hydrophilic        | O14          | 3.9     | No                | 110                      | Yes, 380 mm           | 23 (60)                        |                                                                         |
| Miracle Brothers 4.5 | Stainless steel   | 110 mm spring coil   | Hydrophilic        | O14          | 4.4     | No                | 110                      | Yes, 380 mm           | 23 (60)                        |                                                                         |
| Miracle Brothers 6 | Stainless steel     | 110 mm spring coil   | Hydrophilic        | O14          | 8.8     | No                | 110                      | Yes, 380 mm           | 23 (60)                        |                                                                         |
| Miracle Brothers 12 | Stainless steel     | 110 mm spring coil   | Hydrophilic        | O14          | 13      | No                | 110                      | Yes, 380 mm           | 23 (60)                        |                                                                         |
| Conquest 9      | Stainless steel       | 200 mm coil         | Hydrophilic        | O09          | 8.6     | No                | 200                      | Yes, 380 mm           | 7 (10)                         |                                                                         |
| Conquest 12     | Stainless steel       | 200 mm coil         | Hydrophilic        | O09          | 12      | No                | 200                      | Yes, 380 mm           | 7 (10)                         |                                                                         |
| Conquest Pro 9  | Stainless steel       | 200 mm coil         | Hydrophilic        | O09          | 9.3     | No                | 200                      | Yes, 380 mm           | 7 (10)                         |                                                                         |
| Conquest Pro 12 | Stainless steel       | 200 mm coil         | Hydrophilic        | O09          | 12      | No                | 200                      | Yes, 380 mm           | 7 (10)                         |                                                                         |
| Conquest Pro 8-20 | Stainless steel      | 200 mm coil         | Hydrophilic        | O08          | 20      | No                | 200                      | Yes, 380 mm           | 7 (10)                         |                                                                         |
| RG3             | Stainless steel       | 80 mm platinum coil | Hydrophilic        | O10          | 3       | No                | 30                       | Yes, 380 mm           | 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. 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 (Figs. 1 and 2).

Fielder FC – Specifications

| Specification       | Value |
|---------------------|-------|
| 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.

| Specification       | Value |
|---------------------|-------|
| 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

![Fielder FC](image_url)

Fig. 1. Fielder FC.
**Fielder XT**

**Specifications:**
- **Tip load**: 1.0 g
- **Coil**: 16 cm
- **Diameter**: 0.014 inch
- **Tapered tip**: 0.010 inch
- **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 Intec, Nagoya, Japan) have increased torquability but Gaia (Asahi Intec, 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 wire 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

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**Fielder XT-A**

**Specifications:**
- **Tip Load**: 1.0 g
- **Coil**: 16 cm
- **Diameter**: 0.014 inch
- **Tapered Tip**: 0.010 inch
- **Polymer Jacket**: 17 cm
- **Hydrophilic Coating**: 17 cm
- **Radio-Opaque length**: 16 cm
- **Torque Transmission**: 1:1
- **Length**: 190 cm & 300 cm

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**Fig. 2.** Fielder XT.

**Fig. 3.** Fielder XT-A.
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 – 0.10, Gaia second – 0.11 and Gaia third – 0.12). Gaia second is shown in Fig. 4 specifications:

| Specifications        | Gaia Second |
|-----------------------|-------------|
| Tip Load              | 3.5 g       |
| Coil                  | 15 cm       |
| Coating               | Hydrophilic |
| Diameter              | 0.014 inch  |
| 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):

| Specifications          | Miracle 12 |
|-------------------------|------------|
| Tip Load                | 12 g       |
| Radio-opaque length     | 11 cm      |
| Coil                    | 11 cm      |
| Coating                 | Hydrophilic|
| 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
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).

**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. 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**:

| Specification          | Value          |
|------------------------|----------------|
| 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):  

| Specification          | Value          |
|------------------------|----------------|
| 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          |
Fielder XT-R

- 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 torqueability, 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
- Coaxial: 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.

**Sion Black**

- Tip load: 0.8 g
- Radio-Opaqu: 3 cm
- Coaxial: dual-core
- Diameter: 0.014 inch
- Polymer Cover: 20 cm polymer
- Coat: 40 cm Hydrophilic
- Length: 190 cm – 300 cm

Fig. 9. Sion Black 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

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**FineCross**

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**RG3 Guide-wire for Externalization**

![RG3 Guide-wire for Externalization](image)

**Fig. 10.** RG3 wire.

**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 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 (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
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).

![Tornus Micro-catheter](image)

**Fig. 13.** Tornus micro-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 have 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:

| Specification           | Value                                      |
|-------------------------|--------------------------------------------|
| 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)               |
| Coating                 | Hydrophilic                                |

![Turnpike Catheter](image)

**Fig. 14.** Turnpike catheter.
Crusade Catheter

![Crusade Catheter Image]

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 | 1.02 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 | Metallic tip, Shaft with complex braid and a dual-layer coil encapsulated between two polymer layers |
| Turnpike       | 0.53 mm (021") | 0.38 mm (015") | 0.86 mm | 1.02 mm | |
| Crusade        | 0.57 mm (022") | 0.43 mm (017") | 0.97 mm | 1.07 mm | |

Tazuna Balloon Catheter

![Tazuna Balloon Catheter Image]

Characteristics
- Lowest entry profile ever made (0.40 mm)
- Durable hydrophilic coating
- Improved tip flexibility ensuring optimal crossability
- Modified mid shaft constriction and low profile 1.9 Fr
- Hypotube provide durability and kink resistance

![Fig. 15. Crusade catheter.]

![Fig. 16. Tazuna balloon dilatation catheter.]

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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 atrumatic 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 0.014” 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 denoting 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
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 (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**

| Specification of IVUS | Atlantis SR Pro2 | Volcano Eagle Eye | OPTICROSS | Navifocus WR |
|----------------------|-----------------|------------------|------------|-------------|
| Frequency            | 40 MHz          | 20 MHz           | 40 MHz     | 40 MHz      |
| 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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