

Original Article

Safety and efficacy of a novel traction balloon technique for guide-extension advancement in complex coronary interventions: a case series

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Abstract: *Background:* Severe coronary tortuosity and calcification frequently result in difficult device delivery during percutaneous coronary intervention (PCI). Conventional techniques for guide-extension (GE) insertion have reported success rates of 88-98.7% with complication rates of 1.6-5.9%. We aimed to evaluate the feasibility and safety of a novel traction balloon technique (TBT) to facilitate GE insertion to overcome these limitations and achieve reasonable procedural outcomes in complex coronary anatomy. *Methods:* We conducted a retrospective single-center case-series of consecutive patients who underwent GE-assisted PCI with TBT between December, 2020 and September, 2025. PCI cases in which, conventional methods of coronary device-delivery and/or GE insertion were unsuccessful were evaluated for GE-assisted PCI using TBT. The technique enables passive tracking of the GE through active traction to a large anchor-balloon inflated distally. Clinical characteristics, procedural-details, efficacy and safety endpoints were analyzed. *Results:* A total of 225 vessels from 214 patients (mean age 62.24 ± 9.8 years) underwent GE-assisted PCI using TBT. Clinical presentations included acute coronary syndrome (n=182, 85.05%), effort-angina (n=25, 11.68%), and heart-failure (n=7, 3.27%). Mean lesion-length was 52.15 ± 22.7 mm. All lesions were American College of Cardiology/American Heart Association type-C (n=225); and Society of Cardiovascular Angiography and Interventions type-2 (n=161, 71.56%) or type-4 (n=64, 28.44%) lesions. Median tortuosity-score was 2 (1-3) with extreme tortuosity in 75.56% of cases. Median calcification-grade was 2 (1-4) with heavy calcification in 40% of cases. Procedures were performed via upper-limb (n=194, 86.22%) or femoral (n=31, 13.78%) access. The indications for GE included distal delivery of balloons (n=195), stents (n=222) and others (n=199). The balloon-to-artery diameter ratio was 0.91 ± 0.1 . The GE was inserted a median of 2 (1-6) times/vessel, achieving a mean maximum depth of 55.32 ± 17.9 mm. A total of 351 stents were deployed in 31 (12-131) minutes, with 100% procedural success. Complications included transient bradycardia and/or hypotension (n=2) and non-flow-limiting dissection (n=2). At a median follow-up of 22 (1-58) months, all patients remained asymptomatic, except for three patients who died. *Conclusion:* TBT-assisted GE insertion is a feasible and safe technique for device delivery during complex PCI, with high procedural success.

Keywords: Complex percutaneous coronary intervention, guide-extension catheter, tortuosity, coronary calcification, traction balloon technique, interventional cardiology

Introduction

With aging populations and persistent native coronary artery disease progression, percutaneous coronary intervention (PCI) is often complicated by difficult device delivery to distal hemodynamically significant lesions [1]. The rising prevalence of diabetes mellitus, chronic kidney disease etc. give rise to more and more diffuse and calcific lesions precluding coronary

device delivery. The growing complexity of cases involving severely calcified lesions, tortuous vessels, and chronic total occlusions has increased procedural challenges [2]. Advancements in coronary hardware and percutaneous coronary intervention (PCI) techniques have made it possible to treat increasingly complex coronary anatomies [3-5]. Devices, including but not limited to versatile guide wires with variable stiffness and torque characteristics, low-

profile balloons with enhanced compliance characteristics, atherectomy devices, imaging and deliverable stent platforms with improved conformability, have helped to overcome several challenges [6]. Factors affecting device delivery include tortuous vascular anatomy, heavily calcified vessels, obstructive proximal coronary lesions, poor back-up or axial alignment (leading to increased friction between rigid stent and vessel wall), and prior interventional devices that obstruct access [1, 7]. Despite improvements, procedural failure and serious adverse events are reported in approximately 5-12% of cases [8, 9]. Furthermore, complex PCI has become more challenging because of a lack of adequate guiding support while advancing devices via the trans-radial approach and inability to use large guides trans-radially [7, 10]. A good backup of the guide catheter is essential [3]. To overcome these limitations, provide a back-up support and guide catheter alignment, guide-extension (GE), a long catheter with a flexible-tip, is introduced. It is advanced through the mother guide deep down into the coronary artery. GE catheters improve backup support, coaxial alignment in a monorail system, and distal device delivery, all of which are crucial in complex PCI procedures, making it indispensable in modern PCI [2, 7]. This “mother-and-child” system has substantially refined the concept of deep intubation [5, 11-14]. It also facilitates the delivery of interventional devices and stents in unfavorable anatomies, which are otherwise unsuitable for PCI [1, 12, 15, 16]. This is achieved by increasing active support, extending the reach of traditional guide catheters, traversing difficult segments and shortening the distance required to deliver the stents [1, 5]. That said, it should be delivered as distally and as close as possible to, or across, the target lesion [5]. However, deep delivery may be difficult through tortuous, calcified or previously stented segments [5].

Although GE catheters can significantly enhance deliverability, advancing them across tortuous, calcified, or previously stented segments may be problematic and carries a risk of dissection or rarely perforation due to the “razor-blade effect”. Its deep seating is facilitated by inserting an anchor balloon, a technique known as the anchor-balloon technique (ABT) [11], or other methods, such as balloon-assisted tracking (BAT) [1, 7] or inch-worming.

However, their success is limited when several adverse factors like severe tortuosity, calcification, long lesions, anomalies, distal lesions, prior stents or vein grafts coexist. This clinical problem prompted our development of a novel Traction Balloon Technique (TBT) (Raval Technique), designed to facilitate deep insertion of GE in challenging PCI cases. In this case-series, we present a single center experience using this technique, to evaluate its technical and procedural success and safety.

Methods

Study design and ethics approval

This is a retrospective case series of consecutive patients who underwent GE-assisted PCI using novel TBT (Raval Technique) between December, 2020 and September, 2025 at a single tertiary care center.

The study was approved by the institutional ethics committee - ‘Ethics Committee - N M Virani Wockhardt Hospital, Rajkot’ (registration no. ECR/1760/Inst/G/2023). All procedures were performed in accordance with institutional policies, relevant laws and guidelines. Informed written consents for the procedures were obtained from all patients before interventions. The privacy rights of human subjects have been observed. The study adhered to the principles outlined in Declaration of Helsinki.

Patient selection

Inclusion criteria: (1) Patients undergoing PCI in whom conventional methods for coronary device delivery (extra support guides, stiff wires, buddy wires, buddy balloons, anchor wires/balloons, etc) were unsuccessful or partially unsuccessful. (2) Patients in whom various conventional methods of GE insertion (direct insertion, ABT, BAT and inch-worming) for standard GE-assisted PCI were partially or completely unsuccessful. (3) Age >18 years.

Exclusion criteria included: (1) Contrast allergy. (2) Chronic total occlusion in which the guide wire could not be advanced distally.

Data acquisition

To assess the feasibility and safety of the TBT for GE insertion in clinical practice, we retrospectively captured comprehensive medical

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records including demographic, angiographic, procedural and clinical data of consecutive patients who underwent GE-assisted PCI with TBT at our institution between December, 2020 and September, 2025. Patient characteristics, including risk factors for coronary artery disease, clinical presentations, indications of PCI, past medical and surgical details including revascularization details, and left ventricular ejection fraction were noted. The angiographic characteristics like target vessel and lesion characteristics, coronary anatomical substrate for GE-assisted PCI, American Heart Association/American College of Cardiology subtypes of coronary lesions [17], Society of Cardiovascular Angiography and Interventions class of lesions [18], tortuosity score [19], grade of calcification [20], etc., were captured. The procedural details, such as access site, sheath size, guide catheter, imaging findings, techniques for plaque modification and vessel preparation, such as pre-dilatation, cutting or scoring balloon, ultrahigh-pressure balloon, rotational atherectomy, orbital atherectomy, intravascular lithotripsy, and thrombo-suction, etc., and the other techniques used for device delivery, if any, were noted. Techniques for deep intubation of the GE, with success, partial success or failure, were also noted. The GE-related details, such as indications of GE-to facilitate device delivery, guide-catheter alignment, precise stent placement, distal contrast enhancement, and thrombo-suction; maximum depth of GE insertion; number of times the GE is inserted in a particular case; type and size of balloon used for anchoring and traction; and the balloon-to-artery diameter ratio at the level of anchoring, were mentioned. Other details, such as stents, success of device delivery, procedural success, procedure time and complications, were noted. Quantitative coronary angiography was used to determine the angulations, intubation depth of the GE and vessel diameters. All patients were followed-up at 1 month and then at 3 monthly visits prospectively, using the resources of our institution.

Procedural characteristics

Standard clinical protocols were followed for performing PCI procedures via the femoral, radial or ulnar routes, using six or seven French guide-catheters as a standard and 5.5 or six French compatible GE catheters - GuideLiner

V3 (Teleflex, USA). All patients received adequate doses of antiplatelet agents (aspirin and P₂Y₁₂ inhibitors), statins, and a body weight-adjusted bolus of unfractionated heparin according to the activated clotting time. The procedure involved positioning the guide catheter at the coronary ostium and advancing a guide wire across the target lesion. The choices of interventional approaches, imaging, lesion preparation, devices and techniques were according to current standard clinical protocols and guidelines. The GE was advanced over the guide wire through the hemostatic valve of the Y-adapter to deeply intubate it to the target coronary artery lesion. Techniques for GE insertion, such as direct insertion, BAT, ABT, and inch-worming, were implicated. When these techniques for GE insertion were partially or completely unsuccessful for deep intubation of the GE, TBT was considered.

Procedural steps of TBT

(1) In this technique, a balloon sized to vessel diameter was advanced through the GE. (2) The balloon was inflated at near-nominal pressures in the distal healthy vessel or directly at the lesion site. (3) The Y-adapter hemostatic valve was opened completely to create an “open system” for guide catheter, preventing vacuum-related inadvertent deep guide intubation. (4) Gentle traction was applied to the balloon shaft with the right hand or an artery forceps held with the right hand of the operator. This maneuver led to passive, coaxial tracking of GE into target vessel over the wire and balloon-shaft as a counter-action to the traction on the balloon. (5) Simultaneous outward counter-traction on the guide catheter at its hub was maintained with the ulnar border of the operator’s left hand. This outward traction on the guide catheter and an opened Y-adapter prevented inadvertent passive deep guide engagement and potential guide-induced proximal vessel dissection. (6) The shaft of the GE was held with operator’s left-hand fingers to avoid inadvertent outward pulling on the GE during traction on the balloon ([Video S1](#)). (7) Inch-worming is the usual final step, to make the GE negotiate the balloon inflation site. (8) Balloon was removed and interventional devices were advanced through GE as per requirements to achieve completion of the PCI procedure.

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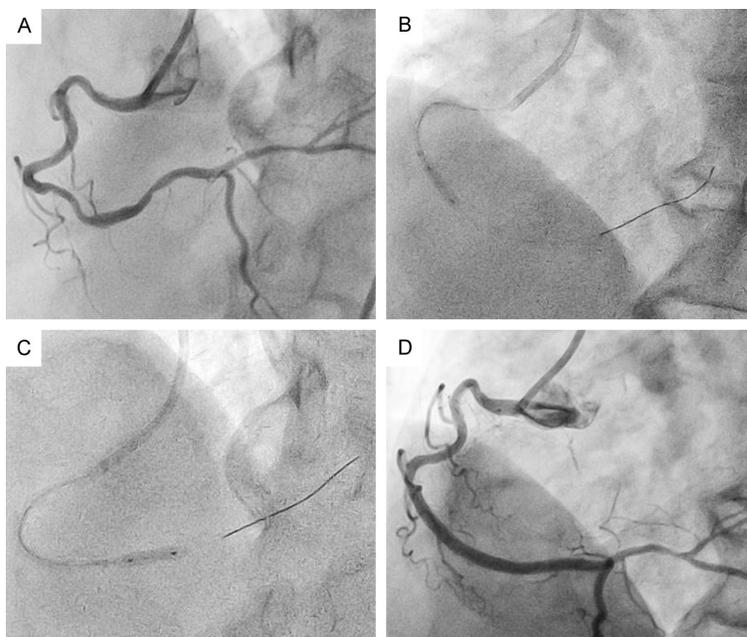


Figure 1. Angioplasty of a tortuous right coronary artery (RCA) using the sequential traction balloon technique (TBT). A: Extremely tortuous RCA with a distal lesion. B: Guide extension (GE) advanced halfway using TBT. C: Distal advancement of the GE facilitated by distal balloon re-inflation. D: Final post-stenting angiogram.

Table 1. Baseline characteristics of the participants (n=214)

Gender, n (%)	
Male	177 (82.71%)
Female	37 (17.29%)
Past History* (Prior Revascularization), n (%)	
CABG	13 (6.07%)
PCI in same vessel	13 (6.07%)
PCI in another vessel	33 (15.42%)
No	167 (78.04%)
Clinical Presentations, n (%)	
STEMI	122 (57.01%)
UA/NSTEMI	60 (28.04%)
Effort angina	25 (11.68%)
Heart failure	7 (3.27%)
Echocardiographic Parameters, mean \pm SD	
Left Ventricular Ejection Fraction (%)	41.57 \pm 10.9

STEMI = ST-elevation myocardial infarction, UA = unstable angina, NSTEMI = non-STEMI, CABG = coronary artery bypass grafting, PCI = percutaneous coronary intervention, CAD = coronary artery disease, * = some patients with a past history of both CABG and PCI.

Two variations were used: (1) Simple TBT: In some patients, the anchor balloon could be directly negotiated distally. It was inflated, and the GE was inserted across the entire required length of the vessel under single traction. (2)

Sequential TBT: In the other relatively complex cases, an anchor balloon could just be inserted across proximal part of the vessel. The GE was inserted with traction on the balloon. Then, the balloon was deflated and inserted further with support of GE and inflated as distally as possible. Therefore, TBT was repeated with subsequent GE-assisted advancements of the anchor balloon and subsequent GE delivery to insert it at its full required depth (**Figure 1**).

Following PCI, dual-antiplatelet and statin therapy was continued as per standard guidelines.

Endpoints

(1) The primary efficacy outcome of procedural success for TBT was defined as delivery of the device to the target lesion. (2) Success of PCI was defined as the achievement of <20% diameter stenosis with Thrombolysis in Myocardial Infarction grade three flow in the target vessel. (3) Safety outcomes were analyzed by recording GE-related dissection, perforation, cardiac tamponed, stent damage or dislodgement, in-hospital mortality and other complications.

Statistical analysis

Normally distributed continuous variables are presented as the mean \pm standard deviation. Discrete variables are presented as counts. Non-normally distributed variables are reported as medians with ranges.

Baseline characteristics are expressed as proportions and percentages of total number of patients treated. Angiographic characteristics and procedural details are expressed as proportions and percentages of total number of

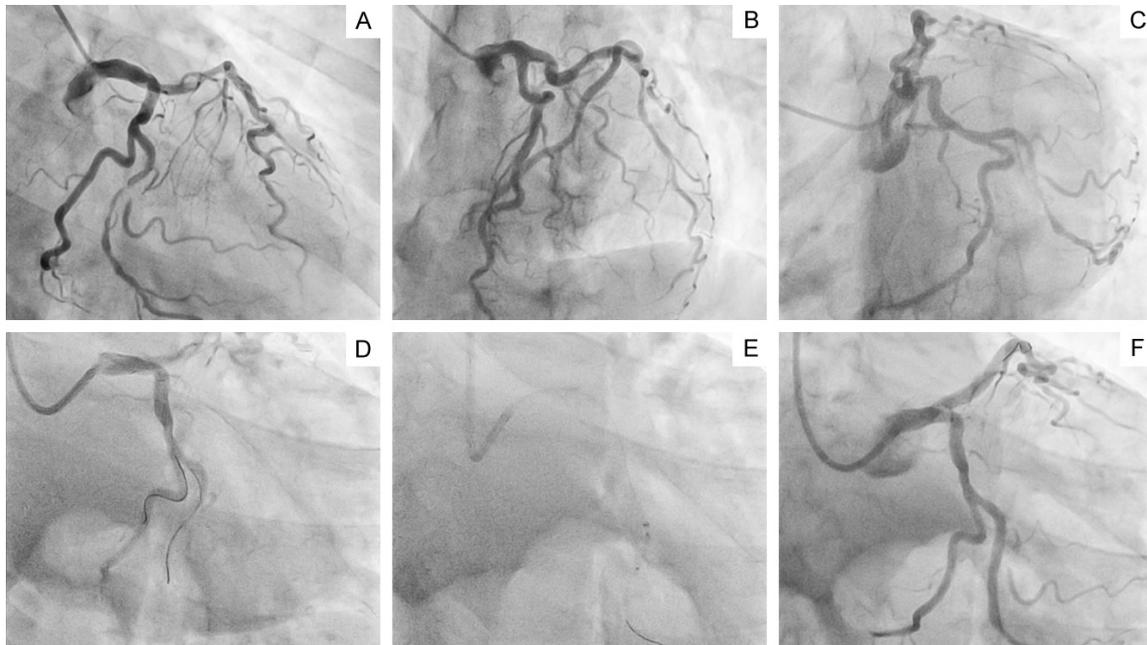


Figure 2. Angioplasty of a tortuous left Circumflex artery (LCx). A-C: Extremely tortuous LCx with a lesion in the obtuse marginal branch. D: Attempted intervention using an extra backup guide-catheter with a buddy wire and an anchor wire. E: Advancement of the guide extension using the traction balloon technique. F: Final post-stenting angiogram.

vessels treated. Statistical analysis was performed with Microsoft Excel 2021 (Microsoft Corp., USA).

Results

A total of 225 vessels from 214 patients (mean age 62.24 ± 9.8 years) underwent GE-assisted PCI for acute coronary syndrome (n=182), effort angina (n=25) or heart failure (n=7) (**Table 1**).

Procedural details

In 170 (75.56%) cases, the target vessel was tortuous, with more than one 90° band (n=154) or a 180° band (n=16) proximally (**Figures 2, 3**). The lesions were categorized as mild to moderately calcified in 135 cases and heavily calcified in 90 (40%) cases (**Table 2**). Seventeen patients presented with chronic total occlusions (**Figure 4**). PCI for in-stent restenosis was performed in ten patients. Coronary anomalies were present in 16 patients (**Figure 5**). Primary PCI for acute myocardial infarction was performed in 47 patients. Multi-vessel procedures were undertaken in 108 patients. Detailed procedural characteristics are summarized in **Table 3**.

The primary indications for GE use included enhancing backup support of the guide to facilitate balloon delivery for pre-dilatation (n=60), including cutting balloons (n=2), ultrahigh-pressure balloons (n=3), and an intravascular lithotripsy balloon (n=1); and aiding stent delivery (n=222), including delivery beyond proximally deployed stents (n=29). GE support was also used to negotiate balloons for post-dilatation (n=135), including an ultrahigh-pressure balloon (n=1), and for an intravascular ultrasound catheter insertion (n=1). Additional indications included achieving coaxial guide alignment (n=106), performing selective contrast injections (n=46), thrombus aspiration (n=1), avoiding inadvertent deep guide catheter intubation (n=14), facilitating distal wire negotiation (n=22), ensuring precise stent placement in anatomically challenging locations such as the ostia and bifurcations (n=5), and preventing balloon dilatation in unintended segments (n=4) (**Table 4**).

Upfront use of the GE without attempting other techniques was chosen in 33 out of 225 of our cases when difficulty in the direct stent delivery was encountered or anticipated. However, in these patients, TBT was implemented

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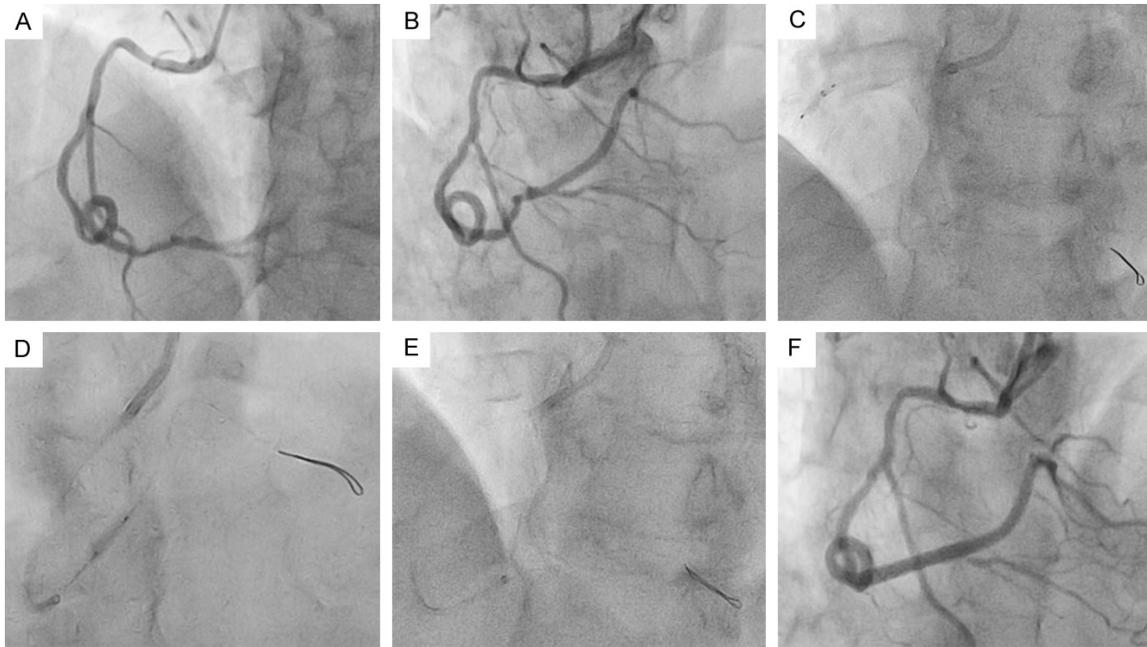


Figure 3. Angioplasty of a tortuous right coronary artery (RCA). A, B: Extremely tortuous RCA with a distal lesion. C: Guide extension (GE) advanced only proximally using balloon-assisted tracking. D, E: Distal advancement of the GE achieved using the traction balloon technique. F: Final post-stenting angiogram.

Table 2. Angiographic characteristics (n=225)

Vessel with target lesions, n (%)	
Left Anterior Descending artery	53 (23.56%)
Left Circumflex artery	50 (22.22%)
Left Main to Left Circumflex artery	3 (1.33%)
Left Main to Left Anterior Descending artery	7 (3.11%)
Right Coronary Artery	109 (48.44%)
Saphenous vein graft	3 (1.33%)
Segment of coronary artery with target lesions*, n (%)	
Ostial and/or Proximal	194 (86.22%)
Mid	189 (84.00%)
Distal	82 (36.44%)
Branch	61 (27.11%)
Lesion Characteristics	
ACC/AHA type, (n), (%)	C (n=225) (100%)
SCAI type, (n), (%)	2 (n=161) (71.56%) 4 (n=64) (28.44%)
Tortuosity Score, median (range)	2 (1-3)
Grade of Calcification, median (range)	2 (1-4)
Length (mm), mean \pm SD	52.15 \pm 22.7
Diameter stenosis (%), mean \pm SD	92.07 \pm 6.8

* = Many vessels have disease in more than one segment, ACC = American College of Cardiology, AHA = American Heart Association, SCAI= Society of Cardiovascular Angiography and Interventions.

GE was used only when other measures were unsuccessful.

The procedures were completed in a median time of 31 (12-131) minutes using the device, with an overall procedural success rate of 100%. Complications occurred in 1.78% of the cases and included hypotension (n=1), transient bradycardia with hypotension (n=1), both of which resolved intra-procedurally, and non-flow-limiting dissections at or proximal to the lesion (n=2), which were managed with stenting. No cases of GE-related flow-limiting dissection, perforation, plaque rupture, abrupt vessel closure, stent deformation/dislodgement, persistent hemodynamic instability or arrhythmias were observed.

Four patients experienced GE unrelated coronary perforations. Two patients required coil embolization, and one patient required covered stents. These perforations did not occur at the

after partial or complete failure of conventional GE insertion methods. In all remaining cases,

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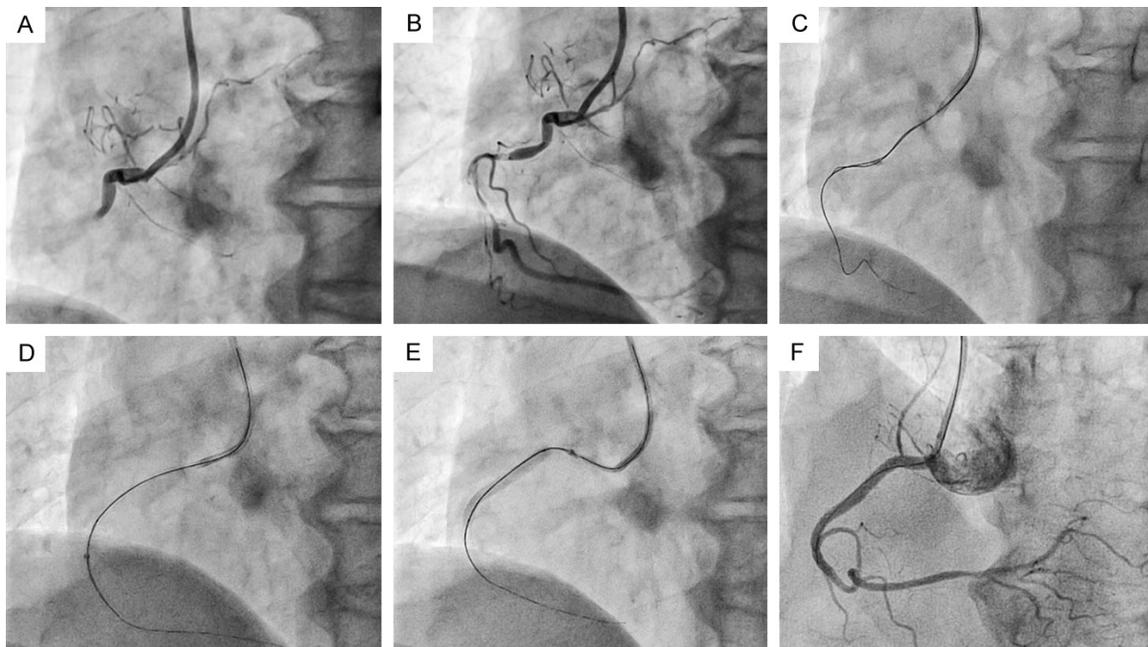


Figure 4. Angioplasty of a tortuous right coronary artery (RCA) with chronic total occlusion. A: Occlusion of an extremely tortuous RCA. B: RCA after pre-dilatation. C: Angioplasty attempted using a buddy-wire. D: Guide-extension advanced using the traction balloon technique. E: Stent deployment. F: Final post-stenting angiogram.

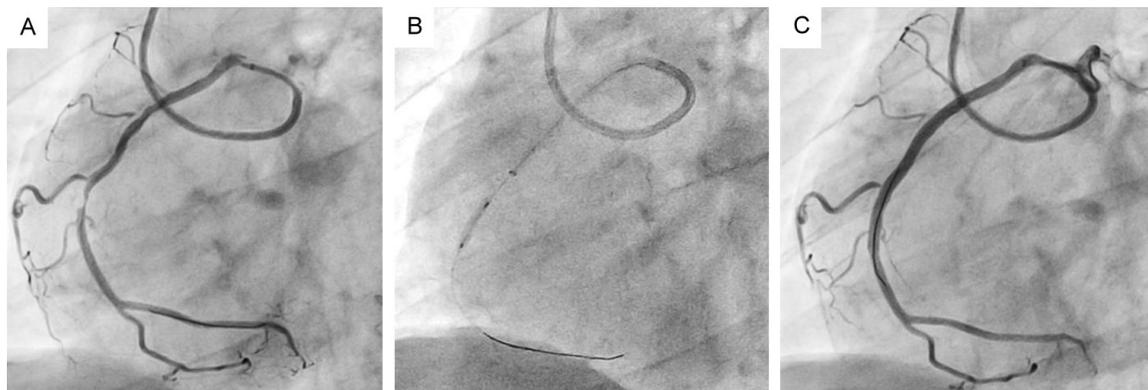


Figure 5. Coronary angioplasty of an anomalous right coronary artery (RCA) originating from the left coronary cusp. A: Obstructive lesions in the anomalous RCA. B: Advancement of the guide extension using the traction balloon technique. C: Final post-stenting angiogram.

site of balloon inflation or GE positioning. No in-hospital or 30-day myocardial infarction or repeat revascularization were observed. The event-free survival rate at 30 day was 98.6%.

At a median follow-up of 22 (1-58) months, all patients were asymptomatic except for three deaths: two due to sepsis (one had gastrointestinal infection and the other had respiratory infection) and one due to scar-related ventricular fibrillation. Only one patient required surgi-

cal revascularization for in-stent restenosis at the 16-month follow-up.

Discussion

PCIs in complex anatomies, such as anomalous origins, tortuous vessels, heavy calcification, long lesions, and distal lesions, are time consuming and typically require multiple adjunctive techniques [11]. Unsuccessful stent delivery across such complexities is frequently

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Table 3. Procedural details (n=225)

Route		
Radial		193 (85.78%)
Ulnar		1 (0.44%)
Femoral		31 (13.78%)
Lesion preparation methods*, n (%)		
Semi-compliant balloon		117 (52.00%)
Non-compliant balloon		108 (48.00%)
Cutting/Scoring balloon		30 (13.33%)
Ultrahigh-Pressure balloon		4 (1.78%)
Rotational Atherectomy		4 (1.78%)
Orbital Atherectomy		1 (0.44%)
IntraVascular Lithotripsy		1 (0.44%)
Thrombosuction		9 (4.00%)
Other Methods for Device negotiation*, n (%)		
Supportive-Guide		165 (73.33%)
Deep intubation		45 (20.00%)
Super-stiff Wire (GrandSlam)		2 (0.89%)
Buddy-Wire		65 (28.89%)
Buddy-Balloon		3 (1.33%)
Anchor-Wire		27 (12.00%)
Anchor-Balloon		2 (0.89%)
Stents		
Total No.		351
Size (mm), mean \pm SD		2.89 \pm 0.5 X 34.52 \pm 11.5

* = Multiple methods were used in some cases.

Table 4. Procedural details related to GE (n=225)

Size of GE (French), n (%)		
5.5		211 (93.78%)
6		14 (6.22%)
Other methods of GE insertion attempted*, n (%)		
Direct		123 (54.66%)
Balloon Assisted Tracking		106 (47.11%)
Anchor Balloon Technique		185 (82.22%)
Inch-worming		137 (60.89%)
Anchor-balloon, n (%)		
Type		
Semi-compliant		117 (52.00%),
Non-compliant		108 (48.00%)
Size (mm), mean \pm SD		2.48 \pm 0.35 X 12.40 \pm 3.6
Balloon: Artery diameter, mean \pm SD		0.91 \pm 0.1
GE insertion		
Maximum depth of intubation (mm), mean \pm SD		55.32 \pm 17.9
No. of times, GE inserted/Vessel, median (range)		2 (1-6)

* = Multiple options were used in some cases, GE = guide extension.

related to inadequate guide-catheter support [11]. Maneuvers such as a stable coaxial guide

hardware crowding or entanglement. Other risks include vessel perforation, abrupt vessel

position, using an extra back-up or larger guide-catheter, employing deep intubation, improved lesion preparation or straightening the vessel with a buddy-wire, buddy-balloon, super-stiff guide wire; anchor-wire or anchor-balloon can improve support and facilitate stent delivery in such lesions [3, 6-8, 16, 21-25].

Advancing large-diameter guide catheters is often challenging in presence of obstructive proximal lesions, tortuous coronary segments, or jailed target-branch ostia, vein-grafts or anomalous coronary vessels [1, 7]. In fact, 23% of complications were attributed to difficulty in advancing the catheter, which further complicated stent delivery in one study [1]. Large guides or deep intubation may cause trauma to the coronary ostium, proximal vessel, or aortic root, due mainly to the primary curve of the guide-catheter [3, 15, 25]. Coronary artery dissection and perforation occurred in 14% and 3% of cases respectively in prior reports [26].

Buddy- or anchor-wire techniques are easy to perform. However, they provide relatively weak support [27]. Wire entanglement may necessitate rewiring. Buddy-balloon and anchor-balloon techniques offer relatively better support. However, these may lead to difficult tracking of subsequent devices due to

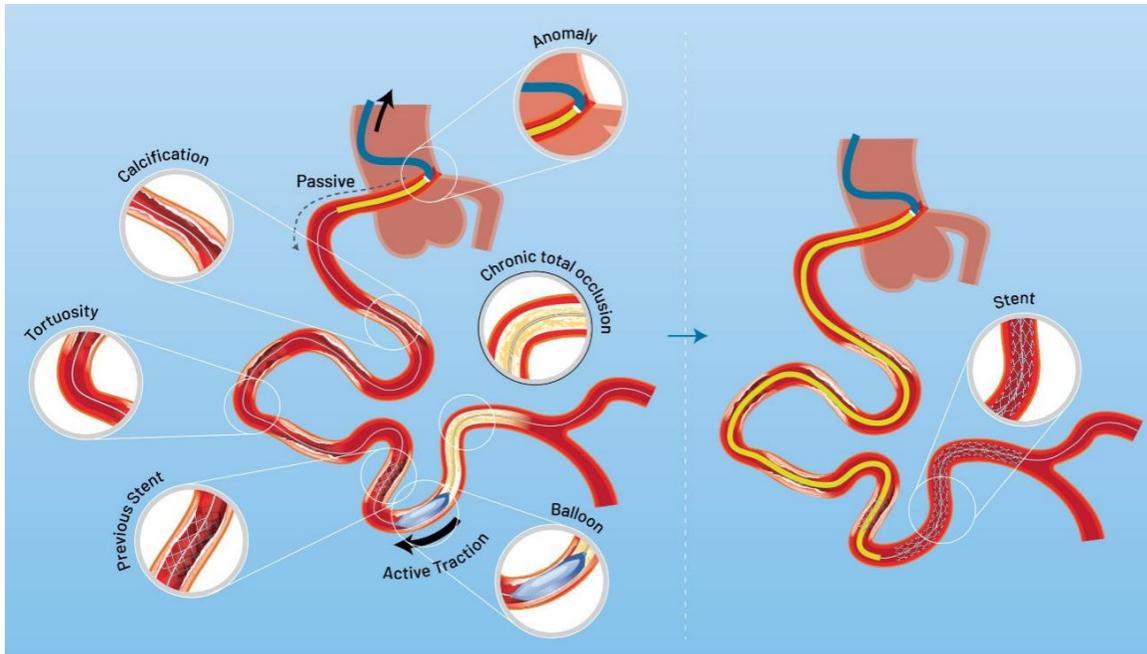


Figure 6. Central illustration.

closure, increased radiation or contrast load, stent damage or deformation and potential procedural failure - all of which may lead to morbidity or mortality [11].

A GE catheter functioning as a “mother-and-child” system, allows deep intubation. It provides a selective visualization of target segments, improved coaxial alignment, enhanced stability, significantly increased back-up support, and deep engagement [2]. By effectively shortening the distance required for interventional devices and stents to access the target-site and by increasing the reach of traditional guide system; GE improves deliverability of devices and stents, an imaging device, and helps stent protection, thrombectomy, and foreign body removal [1, 2]. All these factors result in high procedural success with minimal major complications [3]. GE also minimizes stent-strut deformation. The more distally a GE can be advanced, the easier the procedure becomes [4].

All GE-insertion techniques aim for coaxial introduction to minimize complications. However, existing methods rely on active insertion of the GE- whether supported by a partially inflated balloon at its tip in BAT, a static distally inflated anchor balloon in the ABT or a deflating balloon in inch-worming [1, 25]. When

encountering severe tortuosity, calcification, anomalous origins or vein-grafts; the active pushing force generates non-coaxial vectors dissipating the linear force tangentially rather than translating into forward coaxial movement. This not only limits advancement but may also damage the outer curvature of the vessel. For direct GE insertion without balloon support, success is limited to favourable anatomy only. The sharp GE tip creates significant dissection risk in calcified or severely tortuous segments. BAT may fail in such an anatomy, because the unsupported GE-balloon assembly cannot always be pushed efficiently [4]. In addition, inflating a balloon in the proximal vessel carries a small but significant risk of vessel injury. In contrast, TBT provides an alternative. In conventional ABT, the anchor balloon remains static, while the GE is actively inserted. TBT fundamentally differs in that, it allows passive GE advancement as a counteraction to active traction applied to a distally inflated large anchor balloon. The GE thus advances over both a wire and a balloon shaft-similar to ABT- but without active forward force from the operator [11, 28]. In inch-worming, the GE is actively inserted on a deflating balloon that is static or pulled. Whereas in TBT, the balloon remains inflated and is gently pulled, allowing the GE to track passively (Figure 6).

We hypothesized that, TBT relying on “passive coaxial tracking” with active traction on a distally positioned inflated balloon, provides more coaxial force vectors and considerable safety profile, than active pushing across complex anatomy. Applying the basic principles of physics and mechanics, passive advancement is more aligned with the vessel’s natural axis and is therefore less likely to cause injury to the outer curvature of the vessel and optimize device delivery in challenging anatomy. In addition, passive tracking reduces frictional resistance compared to active insertion against resistance. The GE-inflated balloon assembly forms a closed system that snugly fits the vessel. This mechanism results in the outward traction force applied to the balloon to be effectively translated into an inward driving force that advances the GE catheter [29]. Meanwhile, opening the Y-adaptor converts the anchor balloon-mother guide interface into an open system. This open system and continuous outward traction on the guide catheter prevent inadvertent deep guide engagement and reduces the risk of proximal vessel trauma. Compared with active pushing techniques, unintentional guide disengagement is less common with TBT. The concept of “Sequential-TBT” is introduced for extremely tortuous vessels where distal balloon positioning is initially impossible. This modification, including advancement of the GE progressively through multiple balloon repositioning-inflation-traction cycles and using partially inserted GE as intermediate support for distal balloon advancement, further permits stepwise GE insertion when negotiating a large anchor balloon distally is difficult. Conceptually, this technique serves as the TBT analogue of the previously described stepwise ABT [27].

In our cohort, 90 out of 225 (40.0%) lesions were heavily calcified, and 170 out of 225 (75.56%) vessels were extremely tortuous. Chan et al. reported lower prevalence of such lesions (nine and seven percent respectively) [28]. Such differences likely reflect variations in lesion definitions, patient selection, and the complexity of cases included. We treated ten patients for in-stent restenosis, whereas Ali et al. included none [11]. Boukhris et al. [24] and Kassimis et al. [30] have also treated patients with in-stent restenosis in vein grafts and right coronary ostium with GE-assisted PCI. The

mother-daughter approach using the GE has been effective in chronic total occlusions and vein-graft PCI as well with higher procedural success, and similar incidence of adverse outcomes [7, 31, 32]. Three of our patients (1.4%) had vein-graft lesions, like 15% reported by Chan et al. [28]. We used GE to deliver distal stents beyond proximal stents in 29 (12.89%) cases, similar to the 15% reported by Chan et al. [28]. The GE was supportive and safe in assisting PCI to chronically occluded arteries when passing a small balloon was unsuccessful and in anomalous coronary arteries with difficult alignment [7, 28, 33]. Chronic total occlusions accounted for 17 (7.56%) of our cases, compared with 38% in a study by Chan et al. [28].

Access-site patterns varied across studies: Ali et al. reported femoral access in 37% of patients, and radial-to-femoral conversion in two patients [11]. Chan et al. [28], reported the femoral approach in the majority of patients (71%). In contrast, we have predominantly used the upper-limb access (86.22%), with no need of radial-to-femoral crossover. This suggests that, TBT enables deeper GE advancement than conventional methods and provides enhanced support for device delivery, which sufficiently compensates for relatively lesser inherent support of radial access.

While Ali et al. [11] used of semi-compliant balloons, we also used non-compliant balloons in 108 out of 225 (48.0%) cases. A non-compliant balloon provides a stronger anchor for traction. In addition, we placed greater emphasis on balloon size and type than previous studies. The depth of intracoronary GE insertion achieved with TBT was 55.32 ± 17.9 mm-greater than the 33 ± 21 mm [3] and 45 ± 24 mm [11] reported previously. This is very important as, with even five mm of extension, bench testing has shown that the GE significantly increases back-up support of a standard six French guide catheter and provides improved deliverability [7].

We used six French guide catheters in most cases (222/225, 98.67%), compared with seven French guides in 42% of the cases reported by Chan et al. [28]. This demonstrates that TBT provides adequate support even with smaller guides. This is especially helpful with

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radial access when there is inability to use large guides [7].

GE device failure was seven percent in de Man et al. [3]. Procedural success rates were 88% for Ali et al. [11], 98.7% for Sharma et al. [34], and 90% with seven French guides from femoral route in Luna et al. [25]. A retrospective study by Waterbury et al. reported 80% success rate in more than 300 cases of GE-facilitated PCI [35]. In comparison, our procedural success rate was 100%.

Potential GE related complications include GE-induced dissection, thrombosis, balloon damage at the metallic collar, stent damage, proximal stent-edge distortion, stent dislodgement, longitudinal stent deformation (while GE crosses proximal stents), dislodgement of cylinder portion of GE, pressure dampening, inadequate vessel opacification, hemodynamic instability and air embolism [2, 4, 7, 9, 11, 25, 28]. Complication rates of 5.9% and 1.6% were reported by Ali et al. [11] and Sharma et al. [34] respectively. Dissection remains a major concern, with an incidence ranging from one to five percent [7]. Luna et al. [25] observed major flow-limiting dissection. However, no such major dissection occurred with TBT.

Mamas et al. [12] reported a high success rate in a series of 13 complex cases using the 'five-in-six French' GE system via radial access. However, stent damage occurred in two of 32 stents while advancing stents across the metallic collar [12]. In our study, no such damage occurred because GuideLiner V3 lacks a metal transition zone.

No immediate GE-related complications were reported by Chan et al. [28]. With TBT, a large balloon requires only small traction movements of an inflated balloon within the vessel per unit advancement of the GE as per Newton's third law of motion [29]. Therefore, the large balloons, are associated with less vessel injury. Flow-limiting dissections, perforations and abrupt vessel closures, were not observed with TBT, likely due to its inherently coaxial passive GE insertion mechanism.

Limitations

This is a single-center case series. Therefore, a multicenter prospective study would be nec-

essary to generate more robust evidence regarding the feasibility and safety of TBT in complex PCI settings. In this study, we used GuideLiner V3 in all the cases. However, the use of different GE catheters may provide additional insight into the generalizability and overall feasibility of TBT.

Conclusion

The TBT for GE insertion enables passive, coaxial, and progressively deep advancement of the GE. It is particularly useful, in procedures involving multiple anatomical and procedural complexities. By facilitating controlled force transmission and stable catheter alignment, TBT may reduce vascular injury and device-related complications, thereby contributing to improved procedural safety and success in complex PCI.

Disclosure of conflict of interest

Abhishek P Raval has filed an Indian provisional patent related to the Traction Balloon Technique described in this manuscript. This has no influence on the study design, data or reporting.

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