

REVIEW ARTICLE OPEN ACCESS

Proctorship in Chronic Total Occlusion Percutaneous Coronary Intervention in Low- and Middle-Income Countries: Challenges, Ethics, and Safety Implications—A Perspective From High-Volume CTO PCI Proctors in Latin America

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Received: 27 January 2026 | **Revised:** 4 May 2026 | **Accepted:** 21 May 2026

Academic Editor: Irfan Ahmad

Keywords: chronic total occlusion | ethics | health systems | Latin America | low- and middle-income countries | patient safety | percutaneous coronary intervention | proctorship | training and education

ABSTRACT

Chronic total occlusion percutaneous coronary intervention (CTO PCI) has evolved into a safe and effective revascularization strategy when performed by experienced operators in adequately resourced centers. Proctorship has accelerated learning curves, improved procedural success, and reinforced safety during early program development. However, available evidence derives predominantly from high-income countries with relatively uniform infrastructure, device availability, and team expertise.

In low- and middle-income countries (LMICs), particularly Latin America, CTO PCI proctorship operates within a markedly heterogeneous landscape characterized by variable institutional infrastructure, inconsistent access to safety devices, limited hemodynamic support, and wide disparities in operator experience. Under these conditions, the proctor's role extends beyond technical mentorship to encompass real-time safety oversight, active procedural participation, ethical stewardship, and mitigation of system-level vulnerabilities.

This perspective explores the contemporary role of CTO PCI proctorship in LMICs, focusing on structural constraints, operator heterogeneity, recurrent procedural pitfalls, human factors, and ethical considerations. We propose a regionalized, center-focused model as a more sustainable strategy for capacity building, patient safety, and long-term program development. Although grounded in Latin American experience, the structural challenges and proposed solutions are broadly applicable to any setting where procedural complexity outpaces institutional readiness.

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1 | Introduction

Chronic total occlusion percutaneous coronary intervention (CTO PCI) is among the most technically demanding procedures in interventional cardiology. When performed by experienced operators within adequately resourced institutions, CTO PCI achieves high technical success with acceptable safety profiles, reflecting advances in guidewire technology, microcatheter design, re-entry techniques, intravascular imaging, and standardized procedural algorithms [1–3].

The dissemination of these outcomes has been supported by structured training pathways and proctorship, traditionally conceived as a mechanism for skill transfer and procedural supervision [1, 4, 5]. Evidence demonstrates that CTO PCI outcomes are strongly associated with operator experience and institutional case volume, with structured proctoring shown to shorten the learning curve and facilitate safe adoption of advanced strategies [6–9].

However, this conventional understanding derives largely from high-income healthcare systems, where institutional infrastructure, device availability, bailout readiness, and team experience are relatively stable [1, 3]. In these settings, proctorship primarily functions as an educational accelerator within a mature safety ecosystem.

In low- and middle-income countries (LMICs), particularly Latin America, assumptions regarding infrastructure frequently do not hold. CTO PCI programs are implemented within heterogeneous systems characterized by variable infrastructure, inconsistent access to essential safety devices, limited hemodynamic support availability, and wide disparities in operator experience [10]. Under these conditions, proctorship undergoes a fundamental transformation: rather than functioning solely as an educational adjunct, it operates as an adaptive, patient-level safety intervention designed to mitigate structural and experiential gaps that would, otherwise, expose patients to disproportionate procedural risk [1, 4, 5].

Importantly, these challenges are not exclusive to Latin America; any environment where procedural complexity outpaces institutional readiness faces analogous vulnerabilities. Latin America serves as a representative case study encompassing the full spectrum of infrastructure heterogeneity within a single region with documented outcomes [4, 5, 10].

This perspective is informed by the authors' collective clinical experience and expert opinion. Where evidence from prospective studies or registries supports our observations, we cite it explicitly; where recommendations derive primarily from accumulated field experience, we acknowledge this distinction to delineate evidence-based assertions from experience-derived expert opinion throughout the manuscript.

2 | Evidence Supporting Proctorship in CTO PCI

Observational studies and registry data consistently demonstrate that structured proctorship is associated with increased procedural success and safer management of complex lesions without a concomitant rise in major complications [4–7]. Proctorship facilitates adoption of the hybrid algorithm, advanced antegrade and retrograde techniques, and optimized bailout approaches, while promoting procedural discipline and adherence to standardized decision-making [1, 3, 4].

A multicenter analysis reported increased CTO PCI success from 62.1% to 77.5% following the implementation of structured proctoring, with the most pronounced improvements in lesions with J-CTO scores ≥ 2 [5].

Given the inherently dynamic nature of CTO PCI, where procedural direction must frequently be adjusted in response to tactile feedback and evolving risk–benefit considerations, an experienced proctor acts as a critical intraprocedural safety mechanism, enabling immediate strategy reassessment and timely procedure termination when the risk–benefit balance becomes unfavorable [1, 4, 5].

These attributes are particularly relevant in centers where institutional experience with CTO PCI is still maturing and structural safeguards may be incomplete. In this context, the proctor operates not only as an educator but also as a real-time cognitive partner, integrating procedural feedback that may exceed the pattern-recognition capacity of less experienced operators [1, 4, 5].

3 | Structural and Infrastructure Challenges in LMICs

A hallmark of CTO PCI programs across many LMICs is striking heterogeneity in institutional infrastructure. While a minority of centers operate comparably to high-volume international programs, the majority face critical limitations that directly impact procedural safety and reproducibility [1, 3]. Notably, Latin American centers have reported technical success rates of 82.5%–86%, consistent with leading global registries [8, 10]. These achievements, however, reflect the capacity of experienced operators and proctors to adapt techniques to available resources rather than evidence of equivalent structural support.

Common infrastructural challenges include limited access to covered stents, microcoils, and pericardiocentesis kits [1, 3]. In some institutions, basic components of a standardized CTO setup, including dual-manifold systems, are unavailable and must be assembled ad hoc by visiting proctors. The absence of point-of-care ACT monitoring systems remains an often overlooked limitation, impairing anticoagulation management during prolonged procedures [1, 9]. Intravascular imaging is more readily available in the private sector where most proctorship cases occur [3, 10]; however, imaging access alone cannot compensate for the absence of critical bailout tools in complex or hemodynamically unstable scenarios [1, 11].

A particularly limiting factor is the lack of advanced mechanical circulatory support (MCS) devices such as Impella or ECMO, routinely used in high-risk CTO PCI across Europe and North America [12] but largely inaccessible in Latin America. Consequently, the case mix tends to exclude the most hemodynamically precarious scenarios, inherently limiting external comparability of regional registries.

4 | A Conceptual Framework for CTO PCI Proctorship in LMICs

At the core of CTO PCI proctorship in LMICs lies a structural asymmetry between procedural ambition, operator experience, and institutional safety capacity. The learning curve is prolonged and highly sensitive to operator experience [4, 6]. In high-income

settings, this process unfolds within environments with reliable bailout devices, standardized monitoring, intravascular imaging, and MCS. In many LMICs, the same learning curve occurs where these safeguards are variably available or absent.

Procedural risk during the learning curve is thus amplified not solely by technical complexity but by structural vulnerability. Within this framework, the proctor functions as a real-time risk moderator, identifying when procedural escalation exceeds institutional safety margins, prompting early strategy changes, or directly intervening to prevent irreversible complications [1, 4, 9]. Active procedural involvement by the proctor, including assumption of first-operator responsibilities when necessary, should be interpreted not as a failure of training but as an adaptive response to system-level constraints aimed at preserving patient safety [4, 5, 7]. A summary of this conceptual reframing is presented in Table 1.

5 | Operator Heterogeneity and the Expanded Role of the Proctor

A major challenge in CTO PCI proctorship across LMICs is marked heterogeneity in operator experience, ranging from operators with solid foundational knowledge to others with minimal prior exposure to complex occlusion cases [4, 6]. The conventional role of the proctor as a passive observer often proves insufficient; ensuring procedural safety frequently requires direct involvement during critical procedure segments or acting as a primary operator [1, 4, 5].

Core components of CTO PCI, particularly advanced guidewire manipulation, depend on tactile feedback, spatial perception, and visual-tactile pattern recognition developed through repeated procedural exposure [4, 6]. Short-term or episodic proctoring encounters are rarely sufficient for durable skill transfer. These constraints help explain why procedure-based training models may be inadequate for lasting competence in complex CTO PCI, particularly where institutional support systems remain incomplete [4, 5, 7].

In Latin America, a common and underappreciated barrier is the persistently low annual CTO PCI volume of most local operators (< 25 cases/year, based on the authors' collective experience). Although many interventionalists actively participate in congresses, hands-on training courses, and proctoring visits, such low procedural volumes make it difficult to develop and sustain the experiential learning curve required for safe and independent CTO PCI practice. Consequently, proctorship often evolves into an ongoing compensatory intervention rather than a temporary educational bridge.

These realities underscore the need for structured, longitudinal proctoring models emphasizing progressive skill acquisition, repeated exposure to complexity, and consistent mentorship across multiple stages of operator development [1, 4, 8].

6 | Recurrent Real-World Procedural Pitfalls

Real-world CTO PCI proctorship consistently reveals recurrent procedural behaviors posing substantial safety risks regardless of geographic setting. These patterns reflect gaps in experiential learning, situational awareness, and intraprocedural cognition that are inherent to the learning curve and difficult to correct

through formal training alone [1, 4, 6]. While these pitfalls occur across all practice environments, their consequences are amplified in settings where bailout resources and institutional safety nets are incomplete. Key pitfalls are summarized in Figure 1 and include the following:

- (1) Loss of distal wire position after successful crossing, often from inadvertent wire retraction or inadequate micro-catheter support, can negate hours of procedural effort and expose patients to additional risk during recrossing attempts.
- (2) Failure to recognize guidewire exit from the true vessel architecture is among the most frequently observed pitfalls. Less experienced operators may misinterpret sub-intimal or extravascular wire paths as side branches without systematic confirmation using orthogonal projections or contralateral injections, increasing perforation and tamponade risk [1, 9, 13].
- (3) Underutilization of roadmap imaging and contralateral injection, despite widespread availability, deprives operators of spatial orientation required for safe wire escalation. The LATAM CTO Registry documented contralateral injection use in fewer than 60% of the cases [10].
- (4) Neglect of systemic warning signs, including progressive hypotension, declining patient responsiveness, or operator fatigue during prolonged procedures. The proctor's role as global safety observer becomes critical, including authority to abort when risk-benefit deteriorates [9, 14].
- (5) Excessive contrast administration in the context of sub-intimal hematoma or distal true lumen compression promotes hydraulic dissection and increases both renal and procedural risk [3, 14].
- (6) Resistance to timely strategy modification, particularly reluctance to pivot from an initial crossing approach despite stagnation or escalating risk, results in prolonged procedures and cumulative hazard until active proctor intervention occurs [1, 4, 6].

These pitfalls align with Reason's Swiss Cheese Model of system failure, in which multiple latent vulnerabilities can align to produce major adverse events when not actively mitigated [9]. In any CTO PCI program, proctorship serves as a critical barrier layer, intercepting human and system-level failures before they translate into irreversible harm. In LMICs, where fewer institutional safety layers exist, the proctor's role as the final defense becomes proportionally more consequential.

7 | Human Factors, Fatigue, and Cognitive Load

The human cost of proctorship remains an underappreciated determinant of procedural safety across all practice settings. Fatigue, circadian misalignment, and cognitive overload are well-established contributors to medical error, yet proctors are universally expected to perform demanding procedures under suboptimal physiological conditions. These risks are compounded in geographically vast countries such as Brazil, where proctors routinely contend with extensive travel logistics, limited flight availability, overnight itineraries, and high-stakes procedures concentrated into a single day.

TABLE 1 | From educational tool to system-level safety intervention: conceptual reframing of CTO PCI proctorship in low- and middle-income countries.

Traditional view	LMIC reality	Conceptual reframing
Skill transfer	Structural risk mitigation	Proctorship as adaptive safety layer
Learning curve acceleration	Learning curve + infrastructure gap	Proctor as risk moderator
Passive supervision	Active participation	Procedural co-operator
Short-term case success	System-level volume fragmentation	Risk of false autonomy
Device education	Ethical stewardship required	Neutrality and transparency
On-site episodic visits	Need for longitudinal mentorship	Regionalized training hubs

Each row reads left to right: the traditional high-income-country assumption (left column) is contrasted with the observed LMIC reality (center column), leading to the proposed conceptual reframing (right column).

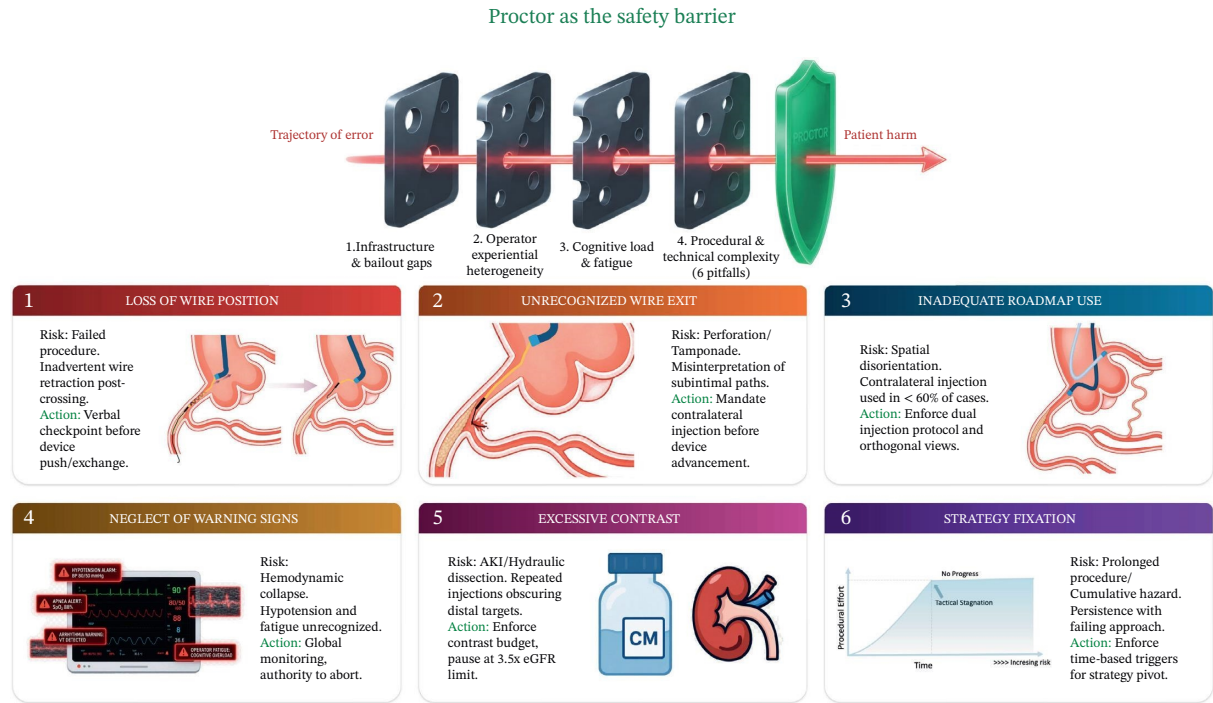


FIGURE 1 | Recurrent procedural pitfalls observed during CTO PCI proctorship in low- and middle-income countries. Key safety-critical behaviors identified through accumulated proctoring experience, highlighting patterns that are difficult to correct through formal training alone and require real-time proctor intervention. AKI = acute kidney injury; CM = contrast media; eGFR = estimated glomerular filtration rate.

Based on our collective experience across hundreds of proctored CTO PCI cases, we propose the following operational safeguards to mitigate fatigue-related risk, acknowledging that these recommendations represent expert opinion derived from accumulated field experience rather than prospective evidence:

- (1) A minimum 8-h rest interval between arrival and the first procedure, particularly after transcontinental travel.
- (2) A maximum of two CTO PCI cases per proctoring day, with mandatory reassessment before a second procedure.
- (3) Prospective case stratification using complexity scores (J-CTO, PROGRESS-CTO) to sequence lower-complexity cases first.
- (4) Shared procedural responsibility structures allowing the proctor to delegate noncritical segments, preserving cognitive reserve for high-stakes decision points.

To provide a quantitative illustration, we present a documented subset of 409 consecutive proctored CTO PCI procedures performed by a single high-volume operator within

our group across multiple Latin American centers (2023–2025). The collective proctoring experience of the authors substantially exceeds this number; only this subset has been systematically documented. Cases reflected real-world heterogeneity (J-CTO ≥ 2 in 67%), with inherent selection bias toward greater complexity, as operators typically reserve their most challenging lesions for proctored sessions. Key outcomes and procedural characteristics are summarized in Figure 2 alongside international benchmarks (PROGRESS-CTO, OPEN-CTO, EURO-CTO, J-CTO Japan, and LATAM CTO Registry), demonstrating that structured proctorship can achieve results at or above international standards even in resource-constrained environments [10, 15–18]. This single-operator, multicenter, hypothesis-generating experience provides a descriptive observational basis for the strategies described herein. Prospective, multicenter validation is warranted to establish evidence-based operational standards for CTO PCI proctorship programs.

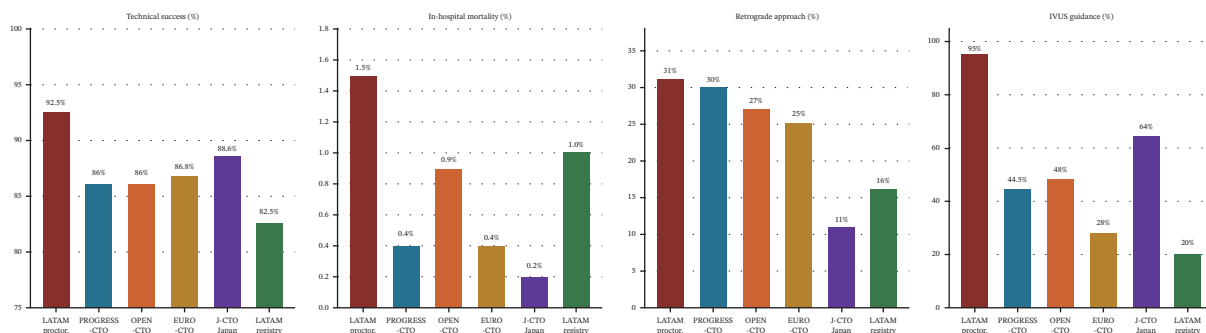


FIGURE 2 | Procedural characteristics and outcomes from a single-operator, multicenter proctored CTO PCI experience across Latin America (2023–2025, $n = 409$) compared with international CTO PCI registries: PROGRESS-CTO (Brilakis 2012–2022, $n = 10,249$), OPEN-CTO (Sapontis 2017, $n = 1000$), EURO-CTO (Galassi 2019, $n = 1253$), J-CTO Japan (Morino 2011, $n = 494$), and LATAM CTO Registry (Quadros 2020, $n = 1040$; IVUS data from Hernandez-Suarez 2022, $n = 1662$). Bars represent rates of technical success, in-hospital mortality, retrograde approach use, and intravascular ultrasound guidance. All LATAM Proctorship procedures were performed under active proctorship in heterogeneous institutional settings. Data are descriptive and hypothesis-generating. IVUS data were not systematically reported in all registries. CTO = chronic total occlusion; PCI = percutaneous coronary intervention; IVUS = intravascular ultrasound.

Specific patient subgroups such as those with prior CABG are consistently associated with higher complexity and lower success (technical success 78.8% vs. 86.6% in non-CABG patients, $p = 0.002$) [19], requiring dedicated proctor support and individualized strategies [10]. In this documented case series, post-CABG cases represented 22% of the procedures (90/409), with a technical success rate of 88%, approximately 4.5% points below the overall cohort average, consistent with the expected anatomical complexity of this subgroup.

8 | Unintended System-Level Effects and the Case for Regionalized Training

While proctorship benefits are well established, its broader system-level effects remain underexplored. On-site proctor availability may inadvertently lower the threshold for accepting complex cases by operators without sustained programmatic commitment, particularly in systems where referral networks are less formalized and procedural credentialing oversight is limited.

This may fragment procedural volume and weaken referral networks, counteracting the established volume–outcome relationship [20] and fostering false autonomy where short-term technical success does not translate into durable procedural independence.

This reflects a structural misalignment between proctoring program design and broader goals of system-level safety and expertise consolidation.

A conceptual comparison between diffuse, episodic proctorship, and a regionalized, center-focused strategy is illustrated in Figure 3.

9 | A Regionalized and Center-Focused Proctorship Strategy

An alternative involves deliberate regionalization, concentrating proctoring within selected reference centers staffed by dedicated operators, allowing natural volume accumulation, team development, and reinforcement of institutional memory.

By strengthening rather than diluting referral pathways, such a strategy aligns proctorship with patient safety, equity, and efficiency principles. The likelihood that proctoring results in true procedural independence is substantially higher when operators are exposed to repeated, longitudinal mentorship within a stable team framework, as opposed to isolated encounters across multiple low-volume centers [1, 4, 8].

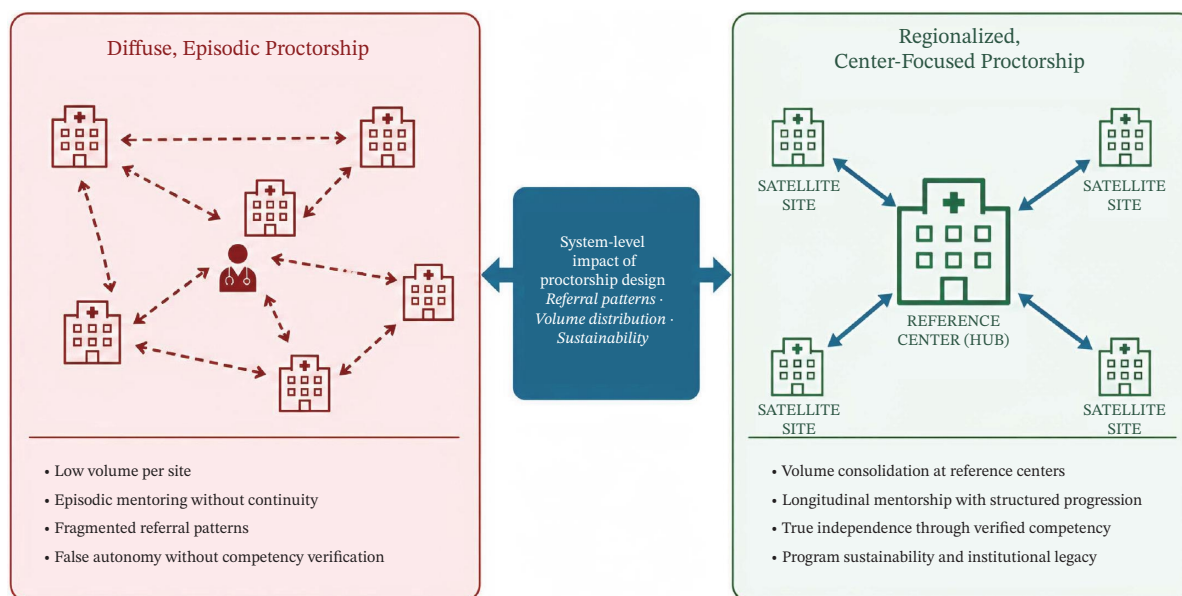
Within this framework, proctorship may be complementarily integrated with structured training pathways at high-volume educational centers, including short-term observerships, immersive hands-on training, or focused fellowships that accelerate skill acquisition more effectively than on-site supervision alone while preserving appropriate referral dynamics.

Importantly, this observation extends beyond the domain of CTO PCI. Similar dynamics may apply to other complex interventional subspecialties, including structural heart interventions such as transcatheter aortic valve implantation and mitral repair, where procedural risk, resource utilization, and the learning curve are equally demanding. The principles of volume consolidation, longitudinal mentorship, and center-focused capacity building are likely generalizable across these domains.

10 | Ethical Considerations and Industry-Sponsored Proctorship

Industry-sponsored proctorship has played a pivotal role in disseminating CTO PCI expertise, particularly in regions where formal training pathways are scarce [1, 5, 7]. In many LMICs, access to high-level mentorship would be largely unfeasible without industry-supported logistics and educational initiatives.

However, this model raises important ethical considerations. Educational objectives, patient safety, and clinical judgment must remain fully independent of commercial interests. Proctorship should not serve as a surrogate for inadequate training pathways or as a mechanism to accelerate market penetration at the expense of procedural safety [1, 9]. Device neutrality is paramount: clinical decision-making must remain patient-centered and uninfluenced by commercial affiliations, with



Applicable to CTO PCI and other complex interventional domains (e.g., structural heart interventions).

FIGURE 3 | System-level impact of proctorship design in complex interventional cardiology. Diffuse, episodic proctorship across multiple low-volume centers may fragment procedural volume and weaken regional referral networks. In contrast, a regionalized, center-focused model promotes volume consolidation, longitudinal mentorship, team maturation, and sustainable procedural independence.

proctors retaining full autonomy to recommend non-sponsored devices when clinically appropriate.

When complex CTO PCI is performed in environments with incomplete safety infrastructure, the distribution of procedural risk during the learning curve becomes an ethical concern rather than a purely technical one. Proctorship functions as a mechanism to rebalance risk by introducing external expertise that compensates for local structural limitations [1, 9].

Emerging technologies, such as remote proctoring via mixed-reality platforms [21], offer potential to partially decouple proctorship logistics from direct industry dependence while preserving real-time procedural support across geographic boundaries.

Ethical proctorship in CTO PCI ultimately requires transparency, clearly defined roles, and explicit safeguards to prevent conflicts of interest. Educational goals must align with patient safety and system-level responsibility, ensuring that proctorship serves as a mechanism for sustainable capacity building rather than a driver of premature procedural expansion [1, 9, 10].

11 | Proctor Qualification and Trainee Background

An often underdiscussed challenge, applicable to CTO PCI programs worldwide, relates to the qualification of both proctor and trainee. Effective proctorship presupposes that the proctor is technically proficient and continuously immersed in high-volume clinical practice, routinely managing the full spectrum of CTO complexity. Sustained exposure is essential for mature clinical judgment, situational awareness, and real-time decision-making guidance in complex scenarios.

Equally important is the trainee's baseline experience. CTO recanalization represents the apex of coronary interventional complexity and should not be approached as an isolated technical skill. Successful and safe CTO PCI requires prior mastery of advanced

guide catheter support, systematic intracoronary imaging use (IVUS and OCT), and proficiency with adjunctive technologies including rotational and orbital atherectomy, intravascular lithotripsy, and hemodynamic support devices. Without this foundational experience, proctorship risks devolving into procedural substitution rather than true skills transfer.

12 | Future Directions

Future proctorship models in LMICs should move beyond isolated, case-based interventions and adopt strategies aimed at preserving regional referral networks. Key recommendations include (1) structured, longitudinal proctorship programs supporting progressive skill acquisition; (2) minimum procedural safety infrastructure requirements for centers hosting proctorship cases, including bailout devices, CTO-specific equipment, and intravascular imaging; (3) adoption of remote and hybrid proctoring technologies to reduce travel burden while preserving expert oversight; (4) formal integration of human factors, including fatigue management and cognitive load, into operational design; and (5) transparent ethical frameworks governing industry partnerships, device neutrality, and conflict-of-interest disclosure.

Collectively, these future directions aim to transform proctorship from an opportunistic educational encounter into a sustainable, ethically grounded, system-integrated process capable of scaling CTO PCI expertise across resource-constrained environments while preserving system-level efficiency and long-term sustainability [4–6].

13 | Conclusions

CTO PCI proctorship is essential for safe dissemination of complex revascularization techniques across all practice environments. In LMICs, where structural asymmetry, operator

heterogeneity, and limited bailout capacity converge, proctorship transcends its conventional educational role and functions as a patient-level safety intervention.

Episodic, volume-dispersed proctorship may offer short-term feasibility but risks perpetuating structural fragility and premature autonomy. In contrast, regionalized, center-focused models prioritize safety, longitudinal mentorship, and institutional maturation, providing a more sustainable pathway for capacity building [10].

Aligning procedural ambition with institutional readiness is a universal imperative applicable wherever CTO PCI programs are being developed or expanded.

Future research should prospectively evaluate regionalized proctorship models incorporating metrics of skill transfer durability, institutional capacity, and patient-centered endpoints to build the evidence base for guideline-level recommendations.

Author Contributions

Conceptualization: E.M.F., B.A.A.F. Writing—original draft: E.M.F. Writing—review and editing: A.C.B.S., J.E.T.P., N.M.-V., F.H.Q., R.S., M.E.-P., and B.A.A.F. Supervision: B.A.A.F.

Funding

No specific funding was received for this work.

Disclosure

All authors have reviewed and approved the final version of the manuscript.

Conflicts of Interest

E.M.F., A.C.B.S., J.E.T.P., N.M.-V., F.H.Q., R.S., M.E.-P., and B.A.A.F. have received speaker, consulting, and proctoring fees from Boston Scientific.

Data Availability Statement

The procedural data described in this manuscript are derived from an unpublished, single-operator registry. Data are available from the corresponding author upon reasonable request.

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