# Development of a Novel Score to Predict Urgent Mechanical Circulatory Support in Chronic Total Occlusion Percutaneous Coronary Intervention

Judit Karacsonyi, MD, PhD[a], Larissa Stanberry, PhD[a], Bahadir Simsek, MD[a], Spyridon Kostantinis, MD[a], Salman S. Allana, MD[a], Athanasios Rempakos, MD[a], Brynn Okeson, MS[a], Khaldoon Alaswad, MD[b], Mir B. Basir, DO[b], Farouc Jaffer, MD, PhD[c], Paul Poommipanit, MD[d], Jaikirshan Khatri, MD[e], Mitul Patel, MD[f], Ehtisham Mahmud, MD[f], Abdul Sheikh, MD[g], Jason R. Wollmuth, MD[h], Robert W. Yeh, MD[i], Raj H. Chandwaney, MD[j], Ahmed M. ElGuindy, MD[k], Nidal Abi Rafeh, MD[l], Daniel R. Schimmel, MD[m], Keith Benzuly, MD[m], M. Nicholas Burke, MD[a], Bavana V. Rangan, BDS, MPH[a], Olga C. Mastrodemos, BA[a], Yader Sandoval, MD[a], Imre Ungi, MD, PhD[n], and Emmanouil S. Brilakis, MD, PhD[a,*]

**Estimating the likelihood of urgent mechanical circulatory support (MCS) can facilitate procedural planning and clinical decision-making in chronic total occlusion (CTO) percutaneous coronary intervention (PCI). We analyzed 2,784 CTO PCIs performed between 2012 and 2021 at 12 centers. The variable importance was estimated by a bootstrap applying a random forest algorithm to a propensity-matched sample (a ratio of 1:5 matching cases with controls on center). The identified variables were used to predict the risk of urgent MCS. The performance of the risk model was assessed in-sample and on 2,411 out-of-sample procedures that did not require urgent MCS. Urgent MCS was used in 62 (2.2%) of cases. Patients who required urgent MCS were older (70 [63 to 77] vs 66 [58 to 73] years, p = 0.003) compared with those who did not require urgent MCS. Technical (68% vs 87%, p <0.001) and procedural success (40% vs 85%, p <0.001) was lower in the urgent MCS group compared with cases that did not require urgent MCS. The risk model for urgent MCS use included retrograde crossing strategy, left ventricular ejection fraction, and lesion length. The resulting model demonstrated good calibration and discriminatory capacity with the area under the curve (95% confidence interval) of 0.79 (0.73 to 0.86) and specificity and sensitivity of 86% and 52%, respectively. In the out-of-sample set, the specificity of the model was 87%. The Prospective Global Registry for the Study of Chronic Total Occlusion Intervention CTO MCS score can help estimate the risk of urgent MCS use during CTO PCI.**  **(Am J Cardiol 2023;202:111−118)**

Chronic total occlusion (CTO) percutaneous coronary interventions (PCIs) can be complex procedures with approximately 85% to 90% technical success rates at experienced centers but also relatively high incidence of major adverse cardiac events (MACEs) (1% to 3%).[1−4] Urgent mechanical circulatory support (MCS) might be necessary in some complication cases. The use of mechanical circulatory devices to support high-risk elective PCI has become more common in part because an increasing number of patients is considered inoperable or at high risk for surgical revascularization.[5] Estimating the need for urgent MCS could facilitate clinical decision-making and procedural planning in CTO PCI. We developed a score to identify patients at increased risk of requiring urgent MCS.

[a]Center for Coronary Artery Disease, Minneapolis Heart Institute and Minneapolis Heart Institute Foundation, Abbott Northwestern Hospital, Minneapolis, Minnesota; [b]Department of Cardiology, Henry Ford Hospital, Detroit, Michigan; [c]Department of Cardiology, Massachusetts General Hospital, Boston, Massachusetts; [d]Department of Cardiology, University Hospitals, Case Western Reserve University, Cleveland, Ohio; [e]Department of Cardiovascular Medicine, Cleveland Clinic, Cleveland, Ohio; [f]Cardiovascular Institute, VA San Diego Healthcare System and University of California San Diego, La Jolla, California; [g]Interventional Cardiology Department, WellStar Health System, Marietta, Georgia; [h]Interventional Cardiology, Providence Heart Institute, Portland, Oregon; [i]Division of Cardiology, Beth Israel Deaconess Medical Center, Boston, Massachusetts; [j]Interventional Cardiology, Oklahoma Heart Institute, Tulsa, Oklahoma; [k]Department of Cardiology, Aswan Heart Centre, Magdi Yacoub Foundation, Aswan, Egypt; [l]Department of Cardiology, North Oaks Health System, Hammond, Louisiana; [m]Cardiovascular Care, Feinberg School of Medicine, Northwestern University, Chicago, Illinois; and [n]Division of Invasive Cardiology, Department of Internal Medicine and Cardiology Center, University of Szeged, Szeged, Hungary. Manuscript received February 7, 2023; revised manuscript received and accepted June 5, 2023.

Funding: The authors are grateful for the generosity of our many philanthropy partners, including our anonymous donors, Drs. Mary Ann and Donald A. Sens, Ms. Dianne and Dr. Cline Hickok, Ms. Charlotte and Mr. Jerry Golinvaux Family Fund, the Roehl Family Foundation, and the Joseph Durda Foundation, Ms. Wilma and Mr. Dale Johnson, for making this work possible at the Minneapolis Heart Institute Foundation's Science Center for Coronary Artery Disease (CCAD).

See page 117 for Declaration of Competing Interest.

*Corresponding author: Tel: 612-863-3900; fax: 612-863-6441.
*E-mail address:* esbrilakis@gmail.com (E.S. Brilakis).

0002-9149/
https://doi.org/10.1016/j.amjcard.2023.06.051

## Methods

We analyzed 2,784 CTO PCIs performed between 2012 and 2021 at 12 centers in the PROGRESS (Prospective Global Registry for the Study of Chronic Total Occlusion Intervention)-CTO Registry (*Clinicaltrials.gov* identifier: NCT02061436); only data from centers with at least 40 PCIs and those with urgent MCS were used. Study data were collected and managed using REDCap (Research Electronic Data Capture) electronic data capture tools hosted at the Minneapolis Heart Institute Foundation.[6,7] The study was approved by the institutional review board of each site.

Coronary CTOs were defined as coronary lesions with thrombolysis in myocardial infarction (MI) grade 0 flow of at least 3-month duration. Estimation of the duration of occlusion was clinical, based on the first onset of angina, previous history of MI in the target vessel territory, or comparison with a previous angiogram. Calcification was assessed by angiography as mild (spots), moderate (involving ≤50% of the reference lesion diameter), or severe

Table 1
Baseline clinical characteristics of study patients with and without urgent mechanical support

| Variable | No UMCS used* (n= 2,722) | UMCS used* (n= 62) | P value† |
|---|---|---|---|
| Age (years) | 66 (58, 73) | 70 (63, 77) | 0.003 |
| BMI (kg/m$^2$) | 30 (27, 34) | 30 (25, 33) | 0.354 |
| Man (%) | 2,137 (79%) | 50 (81%) | 0.685 |
| Diabetes Mellitus | 1,178 (44%) | 24 (41%) | 0.647 |
| Hypertension | 2,455 (91%) | 54 (89%) | 0.552 |
| Dyslipidemia | 2,620 (97%) | 59 (95%) | 0.481 |
| LVEF (%) | 55 (43, 60) | 45 (33, 55) | <0.001 |
| Family History of CAD | 780 (31%) | 21 (40%) | 0.144 |
| Prior PAD | 409 (15%) | 17 (27%) | 0.007 |
| Congestive Heart Failure | 762 (28%) | 21 (34%) | 0.287 |
| Prior Myocardial Infarction | 1,095 (41%) | 31 (53%) | 0.075 |
| Prior CABG | 894 (33%) | 27 (44%) | 0.080 |
| Prior CVD | 247 (9.1%) | 9 (15%) | 0.145 |
| Baseline creatinine (mg/dL) | 1.00 (0.86, 1.21) | 1.11 (0.94, 1.42) | 0.011 |
| Target vessel | | | |
| LAD | 683 (26%) | 11 (18%) | 0.284 |
| RCA | 1,333 (51%) | 35 (58%) | |
| LCX | 532 (21%) | 12 (20%) | |
| Left Main | 11 (0.4%) | 1 (1.7%) | |
| SVG | 3 (0.1%) | 0 (0%) | |
| Other | 31 (1.2%) | 1 (1.7%) | |
| PROGRESS-CTO score | 1.00 (1.00, 2.00) | 2.00 (1.00, 2.50) | 0.014 |
| PROGRESS MACE score | 4.00 (3.00, 5.00) | 4.50 (4.00, 5.00) | <0.001 |
| Japan CTO score | 3.00 (2.00, 3.00) | 3.00 (3.00, 4.00) | <0.001 |
| Moderate/severe calcification | 1,419 (52%) | 43 (69%) | 0.007 |
| Moderate/severe tortuosity | 841 (31%) | 29 (47%) | 0.008 |
| Proximal cap ambiguity | 947 (37%) | 32 (55%) | 0.006 |
| In-stent restenosis | 443 (17%) | 10 (18%) | 0.981 |
| Side branch at proximal cap | 1,310 (52%) | 32 (57%) | 0.427 |
| Blunt/no stump | 1,512 (56%) | 47 (76%) | 0.001 |
| Vessel diameter (mm) | 3.00 (2.50, 3.00) | 3.00 (2.50, 3.50) | 0.025 |
| Lesion length (mm) | 25 (15, 40) | 25 (15, 40) | <0.001 |
| Number of stents | 2.00 (2.00, 3.00) | 3.00 (2.50, 4.00) | <0.001 |
| First crossing strategy | | | |
| Antegrade wiring | 2,285 (84%) | 32 (52%) | <0.001 |
| Retrograde | 341 (13%) | 25 (40%) | |
| Antegrade dissection and re-entry | 92 (3.4%) | 5 (8.1%) | |
| Successful crossing strategy | | | |
| Antegrade wiring | 1,473 (54%) | 13 (21%) | <0.001 |
| Retrograde | 613 (23%) | 29 (47%) | |
| Antegrade dissection and re-entry | 327 (12%) | 11 (18%) | |
| None | 307 (11%) | 9 (15%) | |
| Retrograde crossing strategy used | 971 (36%) | 48 (77%) | <0.001 |

BMI= body mass index; CABG = coronary artery bypass grafting; CAD = coronary artery disease; CTO = chronic total occlusion; CVD = cerebrovascular disease; LVEF = left ventricular ejection fraction; PAD = peripheral arterial disease; PROGRESS = Prospective Global Registry for the Study of Chronic Total Occlusion Intervention; UMCS = Urgent Mechanical Circulatory Support.

* n (%); Median (IQR).

† Fisher's exact test; Pearson's Chi-squared test; Wilcoxon rank sum test.

(involving >50% of the reference lesion diameter). Moderate proximal vessel tortuosity was defined as the presence of at least 2 bends >70° or 1 bend >90° and severe tortuosity as 2 bends >90° or 1 bend >120° in the CTO vessel. A retrograde procedure was an attempt to cross the lesion through a collateral vessel or bypass graft supplying the target vessel distal to the lesion; otherwise, the intervention was classified as an anterograde-only procedure. Antegrade dissection/re-entry was defined as anterograde PCI during which a guidewire was intentionally introduced into the extraplaque space proximal to the lesion, or re-entry into the distal true lumen was attempted after intentional or inadvertent extraplaque guidewire crossing. Technical success was defined as successful CTO revascularization with achievement of <30% residual diameter stenosis within the treated segment and restoration of thrombolysis in MI grade 3 anterograde flow.[8] Procedural success was defined as achievement of technical success without any in-hospital MACE, that was defined as any of the following events before hospital discharge: death, MI, recurrent symptoms requiring urgent repeat target-vessel revascularization with PCI or coronary artery bypass graft surgery, tamponade requiring either pericardiocentesis or surgery, and stroke. MI was defined using the Third Universal Definition of Myocardial Infarction (type 4a MI).[9] The PROGRESS CTO score as described by Christopoulos et al,[10] PROGRESS MACE score was described by Simsek et al[11] and the Japanese CTO (J-CTO) score was calculated as described by Morino et al.[12] Urgent MCS was defined as use of MCS after the procedure started and not in a planned fashion.

Categorical variables were expressed as counts (%) and compared using Pearson's chi-square test or Fisher's exact test, as appropriate. Continuous variables in the study were skewed and were summarized by medians (interquartile ranges); the variables were compared between urgent MCS and nonurgent MCS patients using Wilcoxon rank sum test.

To develop a prediction model to identify procedures that may require urgent MCS, first, risk factors were selected, then 3 competing models were built and their performances were compared. Given the small number of urgent MCS cases and sample imbalance, we used a random forest algorithm with a bootstrap (B = 1,000) data to identify risk factors to include in the model. For that, based on clinical reasoning and existing literature, the following factors plausibly associated with the risk of urgent MCS were identified: age, gender, body mass index (BMI), left ventricular ejection fraction (LVEF), creatinine levels at baseline (log scale), retrograde approach, previous MI, previous coronary artery bypass graft, previous heart failure, previous peripheral arterial disease, cerebrovascular disease, diabetes mellitus, vessel diameter, proximal cap ambiguity, lesion length, side branch at proximal cap, and blunt stump. The importance of each risk factor was estimated by applying a random forest algorithm to a propensity-matched bootstrap sample (n = 373, with a ratio of 1:5 matching urgent MCS with nonurgent MCS patients on center only). The prediction error and the node impurity were estimated for these variables on each of the bootstrap samples using accuracy and the Gini index, accordingly. The variables were ranked by their index medians and the top 5 factors for each of the 2 importance measures were selected: retrograde approach, LVEF, proximal cap ambiguity, lesion length, and creatinine were the most important based on model accuracy and age, BMI, LVEF, creatinine, and lesion length were the top for the Gini index of node impurities.

With risk factors identified, an independent matched sample (n = 373) was drawn using the same criteria as previously mentioned and 2 predictive models were built using a logistic regression approach for the 2 sets of variables; these models are referred to as $M_1$ and $M_2$ (for Gini and accuracy). A third joint model, $M_3$, was built by applying a logistic regression with a backward elimination to a joint factor set across the first 2 models, that is, retrograde

Table 2
Procedural characteristics and outcomes of study patients with and without urgent mechanical circulatory support (UMCS)

| Variable | No UMCS used* (n= 2,722) | UMCS used* (n= 62) | P value† |
|---|---|---|---|
| Technical Success | 2,373 (87%) | 42 (68%) | <0.001 |
| Procedural Success | 2,316 (85%) | 25 (40%) | <0.001 |
| Procedural time (min) | 140 (98, 196) | 256 (193, 328) | <0.001 |
| Fluoroscopy time (min) | 51 (31, 79) | 93 (60, 121) | <0.001 |
| Air kerma radiation dose (Gray) | 1.99 (1.14, 3.30) | 3.39 (2.09,4.81) | <0.001 |
| MACE | 57 (2.1%) | 19 (31%) | <0.001 |
| Death | 5 (0.2%) | 8 (13%) | <0.001 |
| Acute MI | 17 (0.6%) | 7 (11%) | <0.001 |
| Re-PCI | 7 (0.3%) | 2 (3.2%) | 0.016 |
| Stroke | 6 (0.2%) | 0 (0%) | >0.999 |
| Emergency CABG | 2 (<0.1%) | 1 (1.6%) | 0.065 |
| Pericardiocentesis | 28 (1.0%) | 7 (11%) | <0.001 |
| Perforation | 139 (5.1%) | 22 (35%) | <0.001 |
| Tamponade | 20 (0.7%) | 5 (8.1%) | <0.001 |
| Dissection/Thrombus of Donor Artery | 22 (0.8%) | 8 (13%) | <0.001 |
| Vascular access site complication | 41 (1.5%) | 4 (6.5%) | 0.017 |

CABG = coronary artery bypass grafting; MACE = major adverse cardiac events; MI = myocardial infarction; PCI = percutaneous coronary intervention; UMCS = urgent mechanical circulatory support.

* n (%); Median (IQR).

† Pearson's Chi-squared test; Fisher's exact test, Wilcoxon rank sum test.

approach, LVEF, proximal cap ambiguity, lesion length, creatinine, age, and BMI. The 3 risk models were validated using a bootstrap resampling; the estimated shrinkage parameters and bias-corrected performance indexes are reported. The indexes were based on the receiver operating characteristic curves including area under the curve (AUC), specificity, and sensitivity. The performance of the models was also assessed on the remaining sample of patients with no urgent MCS (n = 2,411). Further details of the statistical methods can be found in Supplementary Material and Supplementary Figure 1.

The statistical analysis was performed in R 4.1.2 (R Core Team) in RStudio 2022/7/1 environment (The R Foundation for Statistical Computing, Vienna, Austria).

## Results

Urgent MCS was used in 62 of 2,722 CTO PCIs (2.2%). The baseline clinical characteristics of the study patients classified according to urgent MCS use and their angiographic characteristics are listed in Table 1. Urgent MCS patients were older (70 [63 to 77] vs 66 [58 to 73] years,

Table 3
Baseline clinical and angiographic characteristics of study patients included in the model with and without urgent mechanical support

| Variable | No UMCS used* (n= 311) | UMCS used* (n= 62) | P value† |
|---|---|---|---|
| Age (years) | 65 (58, 74) | 70 (63, 77) | 0.007 |
| BMI (kg/m$^2$) | 30 (26, 35) | 30 (25, 33) | 0.300 |
| Man (%) | 249 (80%) | 50 (81%) | 0.917 |
| Diabetes Mellitus | 137 (44%) | 24 (41%) | 0.618 |
| Hypertension | 281 (91%) | 54 (89%) | 0.609 |
| Dyslipidemia | 2,620 (97%) | 59 (95%) | 0.481 |
| LVEF (%) | 55 (43, 60) | 45 (33, 55) | <0.001 |
| Family History of CAD | 92 (31%) | 21 (40%) | 0.203 |
| Prior PAD | 0 (0%) | 0 (0%) | 0.005 |
| Congestive Heart Failure | 89 (29%) | 21 (34%) | 0.380 |
| Prior Myocardial Infarction | 131 (43%) | 31 (53%) | 0.188 |
| Prior CABG | 101 (33%) | 27 (44%) | 0.097 |
| Prior CVD | 28 (9.0%) | 9 (15%) | 0.185 |
| Baseline creatinine (mg/dL) | 1.02 (0.88, 1.24) | 1.11 (0.94, 1.42) | 0.040 |
| Target vessel | | | |
| LAD | 67 (23%) | 11 (18%) | 0.633 |
| RCA | 167 (57%) | 35 (58%) | |
| LCX | 54 (18%) | 12 (20%) | |
| Left Main | 2 (0.7%) | 1 (1.7%) | |
| SVG | 0 (0%) | 0 (0%) | |
| Other | 3 (1.0%) | 1 (1.7%) | |
| PROGRESS-CTO score | 1.00 (1.00, 2.00) | 2.00 (1.00, 2.50) | 0.012 |
| PROGRESS MACE score | 4.00 (3.00, 5.00) | 4.50 (4.00, 5.00) | <0.001 |
| Japan CTO score | 3.00 (2.00, 3.00) | 3.00 (3.00, 4.00) | <0.001 |
| Moderate/severe calcification | 153 (49%) | 43 (69%) | 0.004 |
| Moderate/severe tortuosity | 87 (28%) | 29 (47%) | 0.003 |
| Proximal cap ambiguity | 111 (39%) | 32 (55%) | 0.020 |
| In-stent restenosis | 45 (16%) | 10 (18%) | 0.710 |
| Side branch at proximal cap | 163 (56%) | 32 (57%) | 0.918 |
| Blunt/no stump | 179 (58%) | 47 (76%) | 0.007 |
| Vessel diameter (mm) | 3.00 (2.50, 3.00) | 3.00 (2.50, 3.50) | 0.102 |
| Lesion length (mm) | 25 (15, 40) | 30 (25, 60) | <0.001 |
| Number of stents | 2.00 (2.00, 3.00) | 3.00 (2.50, 4.00) | <0.001 |
| First crossing strategy | | | |
| Antegrade wiring | 262 (84%) | 32 (52%) | <0.001 |
| Retrograde | 40 (13%) | 25 (40%) | |
| Antegrade dissection and re-entry | 9 (2.9%) | 5 (8.1%) | |
| Successful crossing strategy | | | |
| Antegrade wiring | 165 (53%) | 13 (21%) | <0.001 |
| Retrograde | 79 (25%) | 29 (47%) | |
| Antegrade dissection and re-entry | 44 (14%) | 11 (18%) | |
| None | 23 (7.4%) | 9 (15%) | |
| Retrograde crossing strategy used | 117 (38%) | 48 (77%) | <0.001 |

BMI = body mass index; CABG = coronary artery bypass grafting; CAD = coronary artery disease; CTO = chronic total occlusion; CVD = cerebrovascular disease; LVEF = left ventricular ejection fraction; MACE = major adverse cardiac events; PAD = peripheral arterial disease; PROGRESS = Prospective Global Registry for the Study of Chronic Total Occlusion Intervention; UMCS = urgent mechanical circulatory support.

* n (%); Median (IQR)

† Pearson's Chi-squared test; Fisher's exact test, Wilcoxon rank sum test.

p = 0.003) compared with patients who did not receive urgent MCS. Previous heart failure (34% vs 28%, p = 0.287) and previous MI (53% vs 41%, p = 0.075) were similar between the 2 groups. LVEF was lower in the urgent MCS group (45% [33 to 55] vs 55% [43 to 60], p <0.001). The CTO lesions in the urgent MCS group were more complex with higher prevalence of moderate/severe calcification (69% vs 52%, p = 0.007), moderate/severe tortuosity (47% vs 31%, p = 0.008) proximal cap ambiguity (55% vs 37%, p = 0.006), higher PROGRESS CTO scores (2.00 [1.00 to 2.50] vs 1.00 [1.00 to 2.00], p = 0.014) and J-CTO scores (3.00 [3.00 to 4.00] vs 3.00 [2.00 to 3.00], p <0.001). Use of the retrograde approach (77% vs 36%, p <0.001) was also more common in the urgent MCS group.

Procedural outcomes classified according to urgent MCS use are listed in Table 2. Technical (68% vs 87%, p <0.001) and procedural success (40% vs 85%, p <0.001) were lower and MACE was higher (31% vs 2.1%, p <0.001) in the urgent MCS group. Urgent MCS was associated with longer procedural (256 [193 to 328] minutes vs 140 [98 to 196] minutes, p <0.001) and fluoroscopy time 93 [60 to 121] minutes vs 51 [31 to 79] minutes, p <0.001) and higher air kerma radiation dose 3.39 [2.09 to 4.81] Gray vs 1.99 [1.14 to 3.30] Gray, p <0.001) compared with no urgent MCS cases.

The baseline clinical and angiographic characteristics of the study patients included in the prediction model are listed in Table 3. The outcomes of the procedures included in the model are listed in Table 4.

The final joint model, M3, included retrograde approach, LVEF, and lesion length. The 3 models M1-M3 demonstrated reasonable calibration and discriminatory capacity (Figure 1). The estimated AUC (95% CI) for these models were 0.77 (0.70 to 0.84), 0.78 (0.72 to 0.85), and 0.79 (0.73 to 0.86) with the shrinkage factors of 0.85, 0.90, and 0.93, respectively. Adjusting for optimism, the corrected AUC were 0.75, 0.76, and 0.79.

For the joint model, a threshold of 0.27 corresponded to accuracy (95% CI) of 80.6% (76.0 to 84.6) with specificity of 85.8% and sensitivity of 51.9%. In the out-of-sample set of patients with no urgent MCS (n = 2,411), the estimated specificity of the joint model was 86.8%, consistent with the in-sample validation. The baseline characteristics and outcomes of the validation dataset are listed in Supplementary Tables 1 and 2. Estimated class probabilities of the PROGRESS CTO MCS scores with Gini, Accuracy, and Joint models of the patients with and without urgent MCS are listed in Supplementary Table 3. For the validation sample of controls the estimate is 0.08 (0.04 to 0.17).

Based on the joint model, a nomogram in Figure 2 gives a simple bedside tool to estimate the risk of urgent MCS.

## Discussion

We developed a novel score for estimating the risk of urgent MCS during CTO PCI. The score may be a useful aid to assist in procedure planning.

The 2021 American College of Cardiology/American Heart Association/Society for Cardiovascular Angiography and Interventions Guideline for Coronary Artery Revascularization guidelines support elective insertion of appropriate MCS in selected high-risk patients, as an adjunct to PCI to prevent hemodynamic compromise during PCI with class IIB, level of evidence B recommendation.[13] CTO PCI carries increased risk of complications compared with non-CTO PCI because of complex coronary anatomy (calcification, tortuosity, multivessel disease), difficulties with CTO crossing, and co-morbidities (left ventricular dysfunction, particularly in the donor vessel being instrumented during retrograde procedures).[1,14–16] How can we identify patients who are more likely to need MCS? We recently developed

Table 4
Procedural characteristics and outcomes of the cases included in the model with and without urgent mechanical support

| Variable | No UMCS used* (n= 311) | UMCS used* (n= 62) | P value† |
|---|---|---|---|
| Technical Success | 285 (92%) | 42 (68%) | <0.001 |
| Procedural Success | 283 (91%) | 25 (40%) | <0.001 |
| Procedural time (min) | 140 (98, 196) | 256 (193, 328) | <0.001 |
| Fluoroscopy time (min) | 51 (31, 79) | 93 (60, 121) | <0.001 |
| Air kerma radiation dose (Gray) | 1.99 (1.14, 3.30) | 3.39 (2.09,4.81) | <0.001 |
| MACE | 4 (1.3%) | 19 (31%) | <0.001 |
| Death | 0 (0%) | 8 (13%) | <0.001 |
| Acute MI | 2 (0.6%) | 7 (11%) | <0.001 |
| Re-PCI | 0 (0%) | 2 (3.2%) | 0.027 |
| Stroke | 0 (0%) | 0 (0%) | >0.999 |
| Emergency CABG | 0 (0%) | 1 (1.6%) | 0.166 |
| Pericardiocentesis | 2 (0.6%) | 7 (11%) | <0.001 |
| Perforation | 16 (5.1%) | 22 (35%) | <0.001 |
| Tamponade | 2 (0.6%) | 5 (8.1%) | 0.002 |
| Dissection/Thrombus of Donor Artery | 2 (0.6%) | 8 (13%) | <0.001 |
| Vascular access site complication | 6 (1.9%) | 4 (6.5%) | 0.066 |

CABG = coronary artery bypass grafting; MACE = major adverse cardiac events; MI = myocardial infarction; PCI = percutaneous coronary intervention; UMCS = urgent mechanical circulatory support.

* n (%), Median (IQR).

† Pearson's Chi-squared test; Fisher's exact test, Wilcoxon rank sum test.

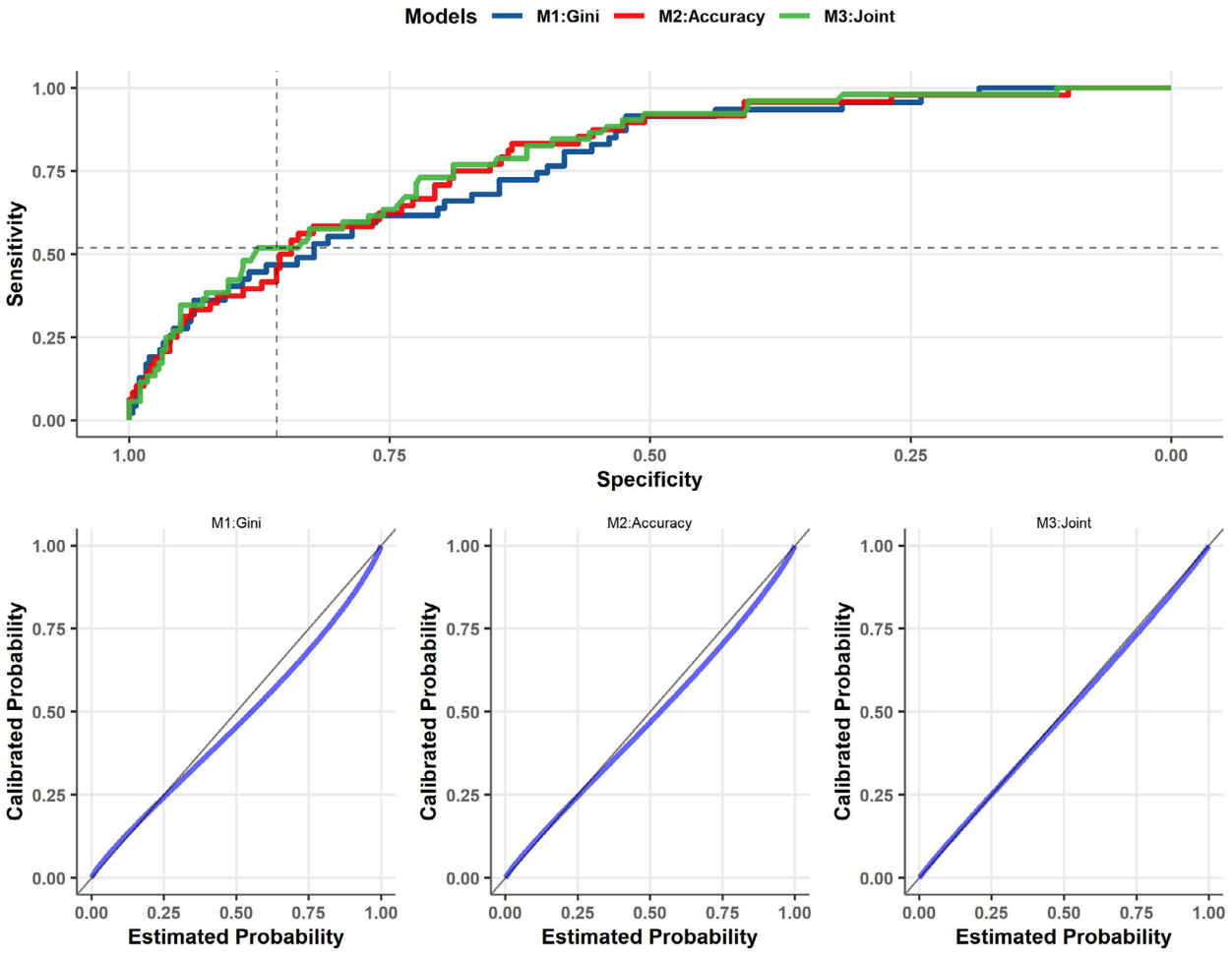


Figure 1. (*A*) Urgent MCS use and receiver operator characteristics analysis of the PROGRESS CTO MCS score for models based on Gini index (M1), classification accuracy (M2), and using a joint set of M1/M2 variables (M3) (*B*) Calibration plots for M1 to M3 models.

risk scores for estimating the risk of periprocedural in-hospital MACE, mortality, pericardiocentesis, and acute MI in patients who underwent CTO PCI,[11] but there are currently no risk scores for assessing the need for urgent MCS in CTO PCI.

There is limited data regarding MCS in CTO PCI. In a previous publication of the PROGRESS CTO registry, MCS was used electively in 69 procedures (4%) and urgently in 22 procedures (1%).[17] In a retrospective cohort, elective MCS support with the Impella 2.5 or CP was used in 57 CTO PCIs (2%). Technical (87.7%) and procedural (75.4%) success were high, but so was the risk of periprocedural complications occurred: vascular injury (5.3%), all-cause death (5.3%), major bleeding (3.5%), stroke (1.8%), and coronary perforation resulting in tamponade (1.8%).[18] An analysis of the National Inpatient Sample between 2008 and 2014 found that MCS was utilized in 2% of hospitalizations with CTO PCI (n = 93,109). MCS utilization, both elective and urgent, increased during the study period. Although overall in-hospital mortality was 2%, it was 25.9% in patients requiring MCS compared with 1.6% in patients who did not need MCS (p <0.0001). Patients requiring MCS have more co-morbidities and are more likely to be in cardiogenic shock, limiting their tolerance of procedural complications. An additional explanation could be the development of acute kidney injury during MCS hospitalizations, which was higher in patients who received MCS.[19] Azzalini et al[20] evaluated the early and 1-year outcomes of 250 Impella-supported (Impella 2.5 or CP)

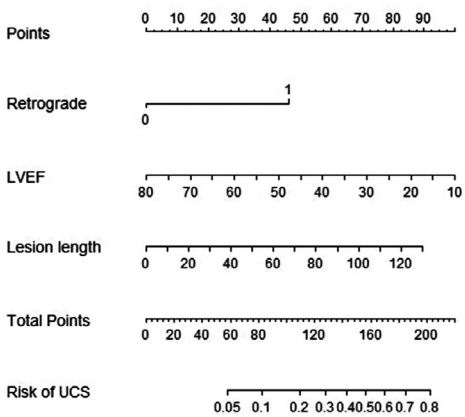


Figure 2. A nomogram of the PROGRESS CTO MCS score. Example patient: use of retrograde crossing strategy (45 points), LVEF <30% (70 points), lesion length >60 mm (40 points), this means a total of 155 points which translates to 0.5 (50%) risk of using UCS. UCS = urgent MCS.

high-risk nonemergent PCIs in a single-center retrospective study (15% of the lesion were CTOs). After propensity matching the incidence of MACE was higher in the MCS group (26.8% vs 13.2%, p <0.001), as was the incidence of periprocedural MI (14.0% vs 6.4%, p = 0.005), major bleeding (6.8% vs 2.8%, p = 0.04), and need for blood transfusion (11.2% vs 4.8%, p = 0.008). In addition, in-hospital mortality trended numerically higher in the Impella-supported group (3.2% vs 1.2%, p = 0.13). There were no differences in the incidence of MACE (31.2% vs 27.4%, p = 0.78) or any of its individual components between Impella-supported patients and controls at 1-year follow-up. A retrospective, observational, multicenter (10 hospitals) registry included 157 patients who underwent high-risk PCI with Impella support (14% CTOs). During 180-day follow-up, MACE occurred in 34 patients (23%), 27 patients (18%) died, 9 patients (6%) sustained an ST-elevation MI, and 4 patients (3%) suffered a stroke.[21]

In a single-center study of 13 prophylactic TandemHeart-supported (Cardiac Assist, Inc., Pittsburgh, Pennsylvania) CTO PCIs, the most common reason for hemodynamic support was use of the retrograde approach in the setting of left ventricular dysfunction (38%). Technical success was high (92%) despite high lesion complexity. Procedural success was 77%, there were no major bleeding complications, but one patient developed an arteriovenous fistula at the arterial cannula insertion site, one patient had a coronary perforation with hemodynamic compromise requiring pericardiocentesis, and one patient died of cardiogenic shock, secondary to right ventricular wall hematoma.[22]

Use of the PROGRESS CTO urgent MCS score may facilitate patient selection for prophylactic hemodynamic support optimizing the risk-benefit ratio of the procedure.

The primary limitation of this study is the relatively small number of procedures requiring urgent MCS. These are rare events and given limited available data, we tackled this issue using a bootstrap resampling to develop the least complex-most informative model. Furthermore, the out-of-sample validation was limited to CTO PCIs not requiring urgent MCS, so only model specificity could be estimated. Other limitations of our study include its observational design, lack of clinical event adjudication and core laboratory analyses, and using data from high-volume, experienced PCI centers with a record of performing urgent MCS, which limits the generalizability of our findings. The criteria for use of MCS were not predefined but based on operator decision. The score performance will need to be re-evaluated as more data become available.

In conclusion, use of the PROGRESS CTO urgent MCS score may facilitate patient selection for prophylactic MCS and optimize the risk-benefit ratio of CTO PCI.

## Declaration of Competing Interest

Dr. Alaswad: consultant and speaker for Boston Scientific, Abbott Cardiovascular, Teleflex, and CSI Dr. Jaffer: sponsored research from Canon U.S.A., Siemens, Shockwave, Teleflex; Institutional grants: Abbott vascular, Boston Scientific, CSI, Philips, Asahi Intecc, and Biotronik; Consultant for Boston Scientific, Siemens, Biotronik, Magenta Medical, IMDS, and Asahi Intecc; Equity interest, Intravascular Imaging Inc.; DurVena; Massachusetts General Hospital has a patent licensing arrangement with Terumo, Canon U.S.A., and Spectrawave; FAJ has the right to receive royalties. Dr. Poommipanit: Asahi Intecc, Inc., Abbott, Vascular-Consultant. Dr. Khatri: received honoraria from Asahi Intecc; and is a speaker and proctor for Abbott Vascular. Dr. Patel: member of the Speakers Bureau for AstraZeneca. Dr. Yeh: grants and personal fees from Abbott Vascular, AstraZeneca, Medtronic, and Boston Scientific. Dr. ElGuindy: received consultancy and proctorship fees from Medtronic, Asahi Intecc, Boston Scientific, and Terumo. Dr. Abi-Rafeh: proctor and speaker honoraria from Boston Scientific and Abbott Vascular. Dr. Brilakis: consulting/speaker honoraria from Abbott Vascular, American Heart Association (associate editor Circulation), Amgen, Asahi Intecc, Biotronik, Boston Scientific, Cardiovascular Innovations Foundation (Board of Directors), CSI, Elsevier, GE Healthcare, IMDS, Medicure, Medtronic, Siemens, and Teleflex; research support: Boston Scientific, GE Healthcare; owner, Hippocrates LLC; shareholder: MHI Ventures, Cleerly Health, Stallion Medical. All other authors: Nothing to disclose.

## Acknowledgment

Study data were collected and managed using Research Electronic Data Capture (REDCap) electronic data capture tools hosted at the Minneapolis Heart Institute Foundation, Minneapolis, Minnesota. REDCap is a secure, web-based application designed to support data capture for research studies, providing: (1) an intuitive interface for validated data entry; (2) audit trails for tracking data manipulation and export procedures; (3) automated export procedures for seamless data downloads to common statistical packages; and (4) procedures for importing data from external sources.

## Supplementary materials

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.amjcard.2023.06.051.

1. Kostantinis S, Simsek B, Karacsonyi J, Alaswad K, Krestyaninov O, Khelimskii D, Karmpaliotis D, Jaffer FA, Khatri JJ, Poommipanit P, Choi JW, Jaber WA, Rinfret S, Nicholson W, Patel MP, Mahmud E, Dattilo P, Gorgulu S, Koutouzis M, Tsiafoutis I, Elbarouni B, Sheikh AM, Uretsky BF, ElGuindy AM, Jefferson BK, Patel TN, Wollmuth J, Riley RF, Benton SM, Jr Davies RE, Chandwaney RH, Toma C, Yeh RW, Schimmel DR, Abi Rafeh N, Goktekin O, Kerrigan JL, Mastrodemos OC, Rangan BV, Garcia S, Sandoval Y, Burke MN, Brilakis E. In-hospital outcomes and temporal trends of percutaneous coronary interventions for chronic total occlusion. *EuroIntervention* 2022;18:e929–e932.
2. Suzuki Y, Tsuchikane E, Katoh O, Muramatsu T, Muto M, Kishi K, Hamazaki Y, Oikawa Y, Kawasaki T, Okamura A. Outcomes of percutaneous coronary interventions for chronic total occlusion performed by highly experienced Japanese specialists: the first report from the Japanese CTO-PCI expert registry. *JACC Cardiovasc Interv* 2017;10:2144–2154.
3. Konstantinidis NV, Werner GS, Deftereos S, C Di Mario, Galassi AR, Buettner JH, Avran A, Reifart N, Goktekin O, Garbo R, Bufe A, Mashayekhi K, Boudou N, Meyer-Geßner M, Lauer B, Elhadad S, Christiansen EH, Escaned J, Hildick-Smith D, Carlino M, Louvard Y,

Lefèvre T, Angelis L, Giannopoulos G, Sianos G, Euro CTO Club. Temporal trends in chronic total occlusion interventions in Europe. *Circ Cardiovasc Interv* 2018;11:e006229.
4. Quadros A, Belli KC, de Paula JET, de Magalhães Campos CAH, da Silva ACB, Santiago R, Ribeiro MH, de Oliveira PP, Lamelas P, Abelin AP, Bezerra CG, Filho EM, Fuchs FC, de Los Santos FD, de Andrade PB, Quesada FLH, Araya M, Perez LA, Côrtes LA, Zukowski CN, Alcantara M, Muniz AJ, Martinelli GC, de Carvalho Cantarelli MJ, Brito FS, Baradel S, de Alencar Araripe Falcão B, Mangione JA, Medeiros CR, Degrazia RC, Lecaro JAN, Gioppato S, Ybarra LF, Weilenmann D, Gottschall CAM, Lemke V, Padilla L. Chronic total occlusion percutaneous coronary intervention in Latin America. *Catheter Cardiovasc Interv* 2020;96:1046–1055.
5. Kunkel KJ, Dabbagh MF, Zaidan M, Alaswad K. Mechanical circulatory support in high-risk percutaneous coronary intervention. *Interv Cardiol Clin* 2021;10:207–219.
6. Harris PA, Taylor R, Minor BL, Elliott V, Fernandez M, O'Neal L, McLeod L, Delacqua G, Delacqua F, Kirby J, Duda SN, REDCap Consortium. The REDCap consortium: building an international community of software platform partners. *J Biomed Inform* 2019; 95:103208.
7. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research Electronic Data Capture (REDCap)—a metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform* 2009;42:377–381.
8. Ybarra LF, Rinfret S, Brilakis ES, Karmpaliotis D, Azzalini L, Grantham JA, Kandzari DE, Mashayekhi K, Spratt JC, Wijeysundera HC, Ali ZA, Buller CE, Carlino M, Cohen DJ, Cutlip DE, De Martini T, Di Mario C, Farb A, Finn AV, Galassi AR, Gibson CM, Hanratty C, Hill JM, Jaffer FA, Krucoff MW, Lombardi WL, Maehara A, Magee PFA, Mehran R, Moses JW, Nicholson WJ, Onuma Y, Sianos G, Sumitsuji S, Tsuchikane E, Virmani R, Walsh SJ, Werner GS, Yamane M, Stone GW, Rinfret S, Stone GW, Chronic Total Occlusion Academic Research Consortium. Definitions and clinical trial design principles for coronary artery chronic total occlusion therapies: CTO-ARC consensus recommendations. *Circulation* 2021;143:479–500.
9. Thygesen K, Alpert JS, Jaffe AS, Simoons ML, Chaitman BR, White HD, Joint ESC/ACCF/AHA/WHF Task Force for the Universal Definition of Myocardial Infarction, Katus HA, Lindahl B, Morrow DA, Clemmensen PM, Johanson P, Hod H, Underwood R, Bax JJ, Bonow RO, Pinto F, Gibbons RJ, Fox KA, Atar D, Newby LK, Galvani M, Hamm CW, Uretsky BF, Steg PG, Wijns W, Bassand JP, Menasché P, Ravkilde J, Ohman EM, Antman EM, Wallentin LC, Armstrong PW, Simoons ML, Januzzi JL, Nieminen MS, Gheorghiade M, Filippatos G, Luepker RV, Fortmann SP, Rosamond WD, Levy D, Wood D, Smith SC, Hu D, Lopez-Sendon JL, Robertson RM, Weaver D, Tendera M, Bove AA, Parkhomenko AN, Vasilieva EJ, Mendis S. Third universal definition of myocardial infarction. *Circulation* 2012;126:2020–2035.
10. Christopoulos G, Kandzari DE, Yeh RW, Jaffer FA, Karmpaliotis D, Wyman MR, Alaswad K, Lombardi W, Grantham JA, Moses J, Christakopoulos G, Tarar MNJ, Rangan BV, Lembo N, Garcia S, Cipher D, Thompson CA, Banerjee S, Brilakis ES. Development and validation of a novel scoring system for predicting technical success of chronic total occlusion percutaneous coronary interventions: the PROGRESS CTO (prospective global registry for the study of chronic total occlusion intervention) score. *JACC Cardiovasc Interv* 2016;9:1–9.
11. Simsek B, Kostantinis S, Karacsonyi J, Alaswad K, Krestyaninov O, Khelimskii D, Davies R, Rier J, Goktekin O, Gorgulu S, ElGuindy A, Chandwaney RH, Patel M, Abi Rafeh N, Karmpaliotis D, Masoumi A, Khatri JJ, Jaffer FA, Doshi D, Poommipanit PB, Rangan BV, Sanvodal Y, Choi JW, Elbarouni B, Nicholson W, Jaber WA, Rinfret S, Koutouzis M, Tsiafoutis I, Yeh RW, Burke MN, Allana S, Mastrodemos OC, Brilakis ES. Predicting periprocedural complications in chronic total occlusion percutaneous coronary intervention: the PROGRESS CTO complication scores. *JACC Cardiovasc Interv* 2022;15:1413–1422.
12. Morino Y, Abe M, Morimoto T, Kimura T, Hayashi Y, Muramatsu T, Ochiai M, Noguchi Y, Kato K, Shibata Y, Hiasa Y, Doi O, Yamashita T, Hinohara T, Tanaka H, Mitsudo K, J-CTO Registry Investigators. Predicting successful guidewire crossing through chronic total occlusion of native coronary lesions within 30 minutes: The J-CTO (Multicenter CTO Registry in Japan) score as a difficulty grading and time assessment tool. *JACC Cardiovasc Interv* 2011;4:213–221.
13. Lawton JS, Tamis-Holland JE, Bangalore S, Bates ER, Beckie TM, Bischoff JM, Bittl JA, Cohen MG, DiMaio JM, Don CW, Fremes SE, Gaudino MF, Goldberger ZD, Grant MC, Jaswal JB, Kurlansky PA, Mehran R, Metkus TS Jr, Nnacheta LC, Rao SV, Sellke FW, Sharma G, Yong CM, Zwischenberger BA. 2021 ACC/AHA/SCAI guideline for coronary artery revascularization: executive summary: a report of the American College of Cardiology/American Heart Association joint committee on clinical practice guidelines. *Circulation* 2021;145:e4–e17.
14. Karacsonyi J, Vemmou E, Nikolakopoulos I, Ungi I, Abi Rafeh N, ElGuindy A, Azzalini L, Burke MN, Brilakis ES. Current challenges and prevention strategies for chronic total occlusion (CTO) complications. *Expert Rev Cardiovasc Ther* 2021;19:337–347.
15. Brilakis ES. *Manual of Chronic Total Occlusion Interventions: A Step-by-Step Approach*. London: Elsevier; 2023.
16. Davila CD, Sharma S, Krishnamoorthy P, Rengifo-Moreno P, Palacios IF, O'Neill W, Kapur NK, Witzke CF. Prevalence and clinical correlates of extended mechanical support in patients undergoing high-risk percutaneous coronary intervention in current clinical practice: insights from the cVAD registry. *Cardiovasc Revasc Med* 2020; 21:342–347.
17. Danek BA, Basir MB, O'Neill WW, Alqarqaz M, Karatasakis A, Karmpaliotis D, Jaffer FA, Yeh RW, Wyman M, Lombardi WL, Kandzari D, Lembo N, Doing A, Patel M, Mahmud E, Choi JW, Toma C, Moses JW, Kirtane A, Parikh M, Ali ZA, Garcia S, Karacsonyi J, Rangan BV, Thompson CA, Banerjee S, Brilakis ES, Alaswad K. Mechanical circulatory support in chronic total occlusion percutaneous coronary intervention: insights from a multicenter U.S. registry. *J Invasive Cardiol* 2018;30:81–87.
18. Riley RF, McCabe JM, Kalra S, Lazkani M, Pershad A, Doshi D, Kirtane AJ, Nicholson W, Kearney K, Demartini T, Aaron Grantham J, Moses J, Lombardi W, Karmpaliotis D. Impella-assisted chronic total occlusion percutaneous coronary interventions: a multicenter retrospective analysis. *Catheter Cardiovasc Interv* 2018;92:1261–1267.
19. Patel K, Doshi R, Decter D, Shah J, Meraj P. Trends in the utilization and in-hospital outcomes when using mechanical circulatory support devices for stable chronic total occlusion treated with percutaneous coronary intervention. *Eur J Intern Med* 2019;59:e11–e13.
20. Azzalini L, Johal GS, Baber U, Bander J, Moreno PR, Bazi L, Kapur V, Barman N, Kini AS, Sharma SK. Outcomes of Impella-supported high-risk nonemergent percutaneous coronary intervention in a large single-center registry. *Catheter Cardiovasc Interv* 2021;97:E26–E33.
21. Baumann S, Werner N, Al-Rashid F, Schäfer A, Bauer T, Sotoudeh R, Bojara W, Shamekhi J, Sinning JM, Becher T, Eder F, Akin I. Six months follow-up of protected high-risk percutaneous coronary intervention with the microaxial Impella pump: results from the German Impella registry. *Coron Artery Dis* 2020;31:237–242.
22. Neupane S, Basir M, Alqarqaz M, O'Neill W, Alaswad K. High-risk chronic total occlusion percutaneous coronary interventions assisted with TandemHeart. *J Invasive Cardiol* 2020;32:94–97.