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Incidence and In-Hospital Outcomes of Single-Vessel Coronary Chronic Total Occlusion Treated with Percutaneous Coronary Intervention

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Abstract

Background—Coronary chronic total occlusion (CTO) using percutaneous coronary intervention (PCI) presents a distinct challenge in the field of cardiology owing to multiple reasons including the increased risk of peri-procedural complications. We sought to explore rates of hospitalization, outcomes, use of mechanical circulatory support devices, and economic burden associated with single-vessel coronary CTO undergoing PCI for stable coronary artery disease (CAD).

Methods—The National Inpatient Sample spanning from 2008 through 2014 was queried to identify hospitalizations associated with single-vessel coronary CTO-PCI for stable CAD by

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“This author takes responsibility for all aspects of the reliability and freedom from bias of the data presented and their discussed interpretation”

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excluding hospitalizations with ST-elevation and non-ST elevation myocardial infarction. Survey-Specific logistic regression was used to analyze adjusted incidence of in-hospital mortality and acute renal failure.

Results—A total of 109,094 hospitalizations were identified as having single-vessel coronary CTO-PCI for stable CAD from 2008–2014. An increasing number of coronary CTO-PCI hospitalizations (2,465 to 2,688 per 100,000 PCI procedures, $P_{\text{trend}} < 0.001$) with an overall in-hospital mortality of 0.5% was observed. The rate of in-hospital mortality remained unchanged ($P_{\text{trend}} = 0.13$), but an increasing rate of acute renal failure was observed in the multivariate-adjusted analysis ($P_{\text{trend}} < 0.001$). Furthermore, a rise in the utilization of intraaortic balloon pumps and percutaneous left ventricular assist devices during single-vessel coronary CTO-PCI was noted. Taken together, these may account for increasing costs of hospitalization for single-vessel coronary CTO-PCI (\$13,909 in 2008 to \$17,729 in 2014, $P_{\text{trend}} < 0.001$).

Conclusion—In a large retrospective study, slightly increased rates of single-vessel coronary CTO-PCI for stable CAD were observed. This is accompanied by a rise in morbidity and growing healthcare costs.

Keywords

Chronic total occlusion; Coronary artery disease; Epidemiology; Percutaneous coronary intervention

Introduction

Chronic Total Occlusion (CTO) of a coronary artery is a complex coronary lesion, the treatment of which is highly challenging.[1] By definition, CTO of a coronary artery is 100% occlusion (true or functional) of the coronary lumen for more than 3 months that results in either a Thrombolysis in Myocardial Infarction (TIMI) grade 0 flow (true occlusion) or a TIMI grade 1 flow (functional occlusion).[2, 3] Approximately 15% of patients with CTO of a coronary artery present with unstable angina, while others experience chronic stable angina or are asymptomatic making it difficult to assess the true population prevalence of CTO.[4] Although there has been limited randomized trial data,[5, 6, 7] the increase in CTO-percutaneous coronary interventions (PCIs) was seen which has primarily been driven by observational evidence suggesting an improvement in cardiac function from revascularization of these lesions.[8, 9] Despite numerous advances in the era of PCI in terms of newer atherectomy devices, microcatheters, dedicated guide wires, retrograde approach, and dissection based crossing strategies, coronary CTO treatment continues to be a challenging issue owing to associated variable success and peri-procedural complications. [10, 11, 12, 13]

We analyzed rates of hospitalization, in hospital mortality, and acute renal failure as primary outcome measures in single-vessel coronary CTO-PCI with stable coronary artery disease (CAD) from the nation's largest publically available database. Additionally, we analyzed recent rates of utilization of mechanical circulatory support devices and costs for single-vessel coronary CTO-PCI hospitalizations.

Methods

Data Source

Our study cohorts were derived from the National Inpatient Sample (NIS) database from 2008 to 2014.[14, 15] A brief description on the NIS has been published previously.[16, 17] Briefly, we used the NIS, sponsored by Health Care Cost and Utilization Project (H-CUP), which allowed us to study a large number of hospitalizations for single-vessel coronary CTO-PCI for stable CAD. The study protocol conforms to the ethical guidelines of the 1975 Declaration of Helsinki, and as the NIS is a publically available deidentified national dataset, it was exempt from the formal review by institutional review board.

Study Population

The International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) maintenance and coordination committee implemented a separate diagnostic code for CTO (i.e. 414.2) on October 1, 2007.[18] Therefore, our study cohort was derived using the NIS database starting from 2008 onwards. The following steps were implemented to identify hospitalizations with single-vessel CTO-PCI (Figure 1) for stable CAD: 1) using validated ICD-9-CM procedure codes (i.e., 00.66, 36.06, and 36.07),[19] hospitalizations for PCI among adults were identified; 2) hospitalizations with “single-vessel” PCI were recognized using ICD-9-CM procedure code 00.40 (n=2,995,446); 3) Hospitalizations below 18 years of age were excluded from the analysis (n=2,252); 4) single-vessel PCI hospitalizations with ST-elevation and non-ST elevation myocardial infarction were excluded (n=1,623,693) (ICD-9-CM diagnosis codes 410.xx), [20] and finally, 5) single-vessel PCI with stable CAD with presence of a concomitant diagnosis code of “chronic total occlusion” was used to ascertain our final study cohort. Those hospitalizations having codes for both, PCI and coronary artery bypass grafting (CABG), were assumed to have been treated with CABG post-PCI. In summary, a careful selection of study cohort was done to ensure that all CTO hospitalizations included in our study reflect the rates and outcomes of the intervention i.e. single-vessel “PCI” of the chronically occluded coronary artery (Figure 1).

The Elixhauser comorbidities were utilized in this study to identify baseline conditions, as described earlier.[21] Mechanical circulatory support devices such as Intra-Aortic Balloon Pump (IABP), and Percutaneous Left Ventricular Assist Device (pLVAD) were identified using appropriate ICD-9-CM codes (Supplemental Table 1). Additional information of the ICD-9-CM codes which were used in our study demonstrated in Supplemental Table 1.

Outcomes

All the outcomes were identified in an a priori manner. Primary outcomes were the rates of hospitalization, and adjusted rates of in-hospital mortality and acute renal failure for single-vessel coronary CTO-PCI with stable CAD. Secondary outcomes were the rate in the use of mechanical circulatory support devices, and costs associated with single-vessel coronary CTO-PCI hospitalizations.

Statistical Analysis

The statistical software SAS 9.4 (SAS institute Inc., Cary, NC) and STATA 14.2 were used to analyze the NIS dataset. All analyses were performed using hospital-level discharge weights provided by the sponsor and followed the recommendations of H-CUP.[22, 23] Categorical data was presented as weighted frequency in percentages, and continuous data was presented as mean $\pm$ standard deviation. Incidence of single-vessel coronary CTO-PCI for stable CAD were calculated using the number of single-vessel coronary CTO-PCI procedures divided by 100,000 PCI procedures in a given year. Rates of in-hospital mortality were assessed using the hierarchical, survey-specific, mixed-effect logistic regression model (SURVEYLOGISTIC) accounting for hospital level clustering. Using 2008 CTO-PCI hospitalizations as reference, the rates of in-hospital mortality adjusted for age, sex, race, Elixhauser comorbidities, insurance status, and hospital-level characteristics were analyzed. Data were presented as odds ratio (OR) with 95% confidence interval. Similarly, adjusted odds in rates of acute renal failure using the aforementioned model was generated.

The rates of IABP and pLVAD use was calculated as the number of these devices implanted per 100 single-vessel coronary CTO-PCIs in the given year. The associated cost was calculated by merging cost-to-charge dataset with the NIS dataset, provided by the sponsor (H-CUP). The cost of each in-patient hospitalization was estimated by multiplying the total hospital charge with cost-to-charge ratio, after adjusting for inflation as per H-CUP's recommendation.[24] To outline the cost of hospitalization over the period of study duration, the median cost of hospitalization per year was used. The Jonckheere-Terpstra test was used to analyze the trend in aforementioned rates. P value less than 0.05 was considered as statistically significant.

Sensitivity analysis to assess the impact of hospital volume of CTO-PCI on outcomes

The relationship between institutional volume of coronary CTO-PCI and in-hospital outcomes were analyzed from 2008 to 2011, as the study sponsor (AHRQ) recommends against performing hospital-level analyses from 2012 onwards (due to changes in the sampling strategy). [25, 26] A scattered plot was developed to visualize the impact of hospital volume on in-hospital mortality (albeit in unadjusted manner). Furthermore, the number of admissions per hospital were categorized and analyzed by dividing the study cohort into two groups: 1) <50 hospitalizations (low-volume centers) and 2) $\geq$ 50 hospitalizations (high-volume centers) for single-vessel coronary CTO-PCI.[27] A unique identification number for each hospital (HOSP_NIS) was used to calculate total number of procedures performed in each hospital. Adjusted in-hospital outcomes such as mortality and acute renal failure were compared using similar methods as described above. All the analyses were in accordance with the best research practices summarized in a recent consensus statement for conducting research using the NIS database.[22]

Results

A total of 109,094 hospitalizations for single-vessel coronary CTO-PCI were identified from 2008 through 2014 (Figure 1). The mean age was 67 ± 11.2 years, and a greater percentage of males had single-vessel coronary CTO-PCI for stable CAD compared to females (73.6% vs.

26.4%) (Supplemental Table 2). Caucasians (70.9%) were predominantly undergoing single-vessel coronary CTO-PCI procedures compared to the other races (Supplemental Table 2). Hypertension (78.9%) and diabetes (36.9%) were most frequently associated comorbidities for hospitalizations with single-vessel coronary CTO-PCI. Most common primary payer among these hospitalizations was Medicare (61.9%) followed by private insurance (26.8%). Majority of single-vessel coronary CTO-PCI hospitalizations were at large bedded hospitals (67.6%), and in urban teaching facilities (56.5%) (Supplemental Table 2). Overall, unadjusted rate of in-hospital mortality was 0.5%, and acute renal failure was 4.8% in single-vessel coronary CTO-PCI hospitalizations for stable CAD (Supplemental Table 2).

The incidence of single-vessel coronary CTO-PCI with stable CAD increased from 2,465 per 100,000 PCI procedures in 2008 to 2,688 per 100,000 PCI procedures in 2014 (relative increase 9%) ($P_{\text{trend}} < 0.001$) (Figure 2). In an analysis adjusted for age, sex, race, Elixhauser comorbidities, insurance status, and hospital-level characteristics, in-hospital mortality for single-vessel coronary CTO-PCI hospitalizations for stable CAD remained stable during the study period (OR: 1.80, 95% CI: 0.89–3.64, $P_{\text{trend}} = 0.13$) (Figure 3, **Panel A**). However, risk of acute renal failure in a multivariable adjusted analysis for above-mentioned variables, was noted to be significantly increased in CTO-PCI hospitalizations from 2008 to 2014 (OR: 2.66, 95% CI: 2.03–3.49, $P_{\text{trend}} < 0.001$) (Figure 3, **Panel B**).

Increasing utilization of IABP was noted during the CTO-PCI hospitalizations (0.7% in 2008 to 1.6% in 2014, $P_{\text{trend}} < 0.001$). The use of newer support devices such as pLVAD demonstrated an increase (0.1% in 2009 to 0.6% in 2014, $P_{\text{trend}} < 0.001$) as well (Figure 4, **Panel A**). Overall, median cost of hospitalization increased significantly during the study period (\$13,909 in 2008 to \$17,729 in 2014, $P_{\text{trend}} < 0.001$) (Figure 4, **Panel B**). The conversion rate of CTO-PCI to CABG remained steady during the study period (0.7% in 2008 to 1.2% in 2014, $P_{\text{trend}} = 0.07$).

Impact of PCI volumes on single-vessel coronary CTO-PCI

A total of 65,789 hospitalizations were identified between 2008 and 2011 for single-vessel coronary CTO-PCI for stable CAD (Supplemental Table 3). Among these hospitalizations, 37,541 were in low-volume centers and 28,248 were in high-volume centers. The mean age of hospitalizations for single-vessel coronary CTO-PCI for stable CAD were similar between low- and high-volume centers (66.9 vs. 66.7 years, $p = 0.61$) (Supplemental Table 3). The Northeast region of the United States had a higher proportion of high-volume centers where single-vessel coronary CTO-PCI for stable CAD were performed (Supplemental Table 3). The Supplemental Figure represents the relationship between in-hospital mortality and annual hospital volume of single-vessel coronary CTO-PCI procedures. We observed that high-volume centers (hospitals performing ≥ 50 coronary CTO-PCI per year) were associated with significantly lower rate of in-hospital mortality compared with low-volume centers (< 50 coronary CTO-PCIs per year) (multivariable adjusted OR: 0.76, 95% CI: 0.60–0.97, $P = 0.03$) between 2008 and 2011 (Supplemental Table 4). Additionally, we observed a lower incidence of acute renal failure in high-volume centers in a multivariable-adjusted analysis (OR: 0.64, 95% CI: 0.58–0.71, $P < 0.001$) (Supplemental Table 4).

Discussion

In this retrospective observational study, we highlight recent rates in the incidence, in-hospital outcomes, and costs for single-vessel coronary CTO-PCI hospitalizations for stable CAD from 2008 to 2014. Using the NIS, we observed marginally increasing number of hospitalization for single-vessel coronary CTO-PCI for stable CAD. In-hospital mortality for single-vessel coronary CTO-PCI did not change during the study period. However, CTOPCIs were associated with significantly higher (~166% greater) odds of acute renal failure. Furthermore, an increase in the utilization of IABP and pLVAD with the single-vessel coronary CTO-PCIs was observed. Higher complication rates and device utilization may have translated into increasing median costs for the single-vessel coronary CTO-PCI hospitalization for stable CAD. Lastly, we observed significantly lower odds of in-hospital mortality and acute renal failure in hospitals performing ≥ 50 CTO-PCI per year as compared to the low-volume centers. To the best of our knowledge, ours is the largest retrospective study reporting aforementioned rates, outcomes, and costs of single-vessel coronary CTOPCI for stable CAD.

Coronary CTO-PCI carries a Class IIa indication in the AHA/ACC PCI guidelines since there is an ongoing controversy on the safety and efficacy of CTO-PCI with somewhat conflicting results from the limited randomized controlled trials (RCTs).[28] Recently, null results from a trial comparing DES implantation versus optimal medical treatment in patients with CTO (DECISION-CTO) were reported,[5] with a notable absence of improvement in angina in the PCI arm.[5] On the contrary, the Randomized Multicenter Trial to Evaluate the Utilization of Revascularization or Optimal Medical Therapy for the Treatment of Chronic Total Coronary Occlusions (EURO-CTO) trial demonstrated an improvement in quality of life after CTOPCI.[7] The Randomized Multicenter Trial to Evaluate the Utilization of Revascularization or Optimal Medical Therapy for the Treatment of Chronic Total Coronary Occlusions (EXPLORE) trial demonstrated that concurrent treatment of CTO with ST-elevation myocardial infarction is not beneficial in terms of improving cardiac function.[6] Notwithstanding the RCT data, two large observational studies demonstrated benefits in terms of lower cardiovascular death and major adverse cardiac events in patients who undergo coronary CTO-PCI as compared to medical therapy.[29, 30] In agreement with the results from the above mentioned RCTs and AHA/ACC guidelines, overall incidence of coronary CTO-PCI rates were noted to be low (2.5%) throughout the study period. This finding is in concordance with previous registry data reporting that CTO-PCI is infrequently performed (3.8%) for stable CAD.[31]

We demonstrated steady rates of in-hospital mortality during our study period with overall mortality at 0.5%, similar compared to the previously published articles for CTO-PCI.[31, 32] An observational study by Sapontis *et al* demonstrated in-hospital mortality rates to be 0.9% in a study performed by eleven highly trained operators.[33] Correspondingly, our sensitivity analyses demonstrated lower in-hospital mortality (0.3%) and acute renal failure (2.5%) at hospitals with higher CTO-PCI volume (≥ 50 CTO-PCIs/year). Additionally, previous studies have likewise demonstrated higher success rates and lower complications rates at higher volume centers.[1, 3] Our study specifically adds to the literature by describing the mortality rates for “single-vessel” coronary CTO-PCI as compared to

previous studies which had patients with “multi-vessel” disease.[34] Furthermore, increasing use of IABP and pLVAD devices in our study demonstrates adaptation of new technologies with time. We observed increasing rates of acute renal failure which is independently associated with increased morbidity.[35] Possibly, longer procedure time, and higher contrast use may have contributed to higher acute renal failure rates observed in our study. [36]

Lastly, the overall median cost of index hospitalization for single-vessel coronary CTO-PCI was noted to be steadily increasing during the study period. This signifies the economic burden of an intervention, “CTO-PCI” which has no proven benefits on hard outcomes, and unclear efficacy in improvement of angina. Use of newer techniques combined with higher morbidity may have contributed to the increasing overall median cost of CTO-PCI hospitalization in our study cohort.

With our study results, we hope to inform clinicians that single-vessel coronary CTO-PCI for stable CAD is associated with a considerable risk of acute renal failure (~5%) even in the contemporary era where there has been a marked improvement in tools and techniques to perform such procedures. With RCT data showing lack of benefit of coronary CTO-PCI over medical therapy,[5] individualized decisions should be made and patients should be well informed of the risks associated with coronary CTO-PCI procedures. Furthermore, results from sensitivity analyses reaffirms the conclusion that coronary CTO-PCI requires highly skilled operators who are committed to developing and maintaining CTO-PCI programs.[31] If a decision has been made to perform coronary CTO-PCI on a patient on maximal anti-anginal therapy, referral to centers of excellence may improve success rates and lower the complication rates. Finally, strategies for prevention of acute renal failure should be employed which may include limiting the use of contrast, risk assessment prior to the procedure,[37] withdrawing nephrotoxins, nephrology consultation in case of high risk clinical factors (e.g. patients with pre-existing renal dysfunction), use of micro-catheters for retrograde approach, and avoidance of antegrade injections.

There were several limitations associated with this study inherent to any retrospective, observational study. Because of the nature of the database, our study does not include information about CTO-PCI procedures that were performed on outpatients, including failure rates and deaths that occurred in outpatient setting. Further, success rates for coronary CTO-PCI procedures in our study cohort cannot be ascertained for inpatient hospitalizations as well. Severity of the CTO lesion as measured by SYNTAX or J-CTO scoring system, both of which are good predictors of procedural success,[38] could not be determined in our study cohort. Finally, the NIS data are available for in-hospital stay only; as such differences in long term outcomes for patients undergoing single-vessel coronary CTO-PCI for stable CAD could not be assessed. The selection of the study cohort required the presence of concomitant diagnosis codes of single-vessel PCI and CTO after excluding acute coronary syndrome (STEMI and NSTEMI). Due to the lack of information on vessel type (e.g., left anterior descending vs. right coronary) in the NIS database, we may have captured single-vessel PCI performed for stable CAD in the non-CTO vessel among individuals with multi-vessel obstructive CAD. However, we believe that this may be unlikely considering current clinical practice favoring CABG over PCI in such settings.[39] Finally, the NIS data are

available for in-hospital stay only; as such differences in long term outcomes for patients undergoing single-vessel coronary CTO-PCI for stable CAD could not be assessed.

Conclusions

In summary, our results demonstrate that frequency of single-vessel coronary CTO-PCI procedure in US for stable CAD is low but has somewhat increased for the past several years. Increasing rates of acute renal failure were observed during the study period which is worrisome. Furthermore, single-vessel coronary CTO-PCI procedures were associated with increasing use of mechanical circulatory support devices. Taken together, these observations suggest that the treatment decisions for single-vessel coronary CTO for stable CAD should be critically weighed keeping in mind uncertain clinical benefits and increasing risks of complications. Likewise, these results highlight the importance of dedicated CTO-PCI training for interventionalists. Moreover, we recommend that these procedures are performed only at high-volume centers of excellence where we can offer this treatment option to carefully selected patients for symptom relief.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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References

- [1]. Moliterno DJ. CTO-Chronic Total Occlusions and Continuous Training Opportunity. JACC Cardiovasc Interv. 2017;10:2231–2.10.1016/j.jcin.2017.10.001. [PubMed: 29122138]
- [2]. Stone GW, Reifart NJ, Moussa I, Hoyer A, Cox DA, Colombo A, et al. Percutaneous recanalization of chronically occluded coronary arteries: a consensus document: part II. Circulation. 2005;112:2530–7.10.1161/CIRCULATIONAHA.105.583716. [PubMed: 16230504]
- [3]. Tajti P, Brilakis ES. Chronic Total Occlusion Percutaneous Coronary Intervention: Evidence and Controversies. J Am Heart Assoc. 2018;7:10.1161/JAHA.117.006732.
- [4]. Bagnall A, Spyridopoulos I. The evidence base for revascularisation of chronic total occlusions. Curr Cardiol Rev. 2014;10:88–98 [PubMed: 24694105]
- [5]. Park S-J. ACC 2017 Optimal Medical Therapy With or Without Stenting For Coronary Chronic Total Occlusion: DECISION-CTO. http://www.clinicaltrialresults.org/Slides/ACC2017/DECISIONCTO_Park.pdf. Assessed on October 13, 2017.
- [6]. Henriques JP, Hoebers LP, Ramunddal T, Laanmets P, Eriksen E, Bax M, et al. Percutaneous Intervention for Concurrent Chronic Total Occlusions in Patients With STEMI: The EXPLORE Trial. Journal of the American College of Cardiology. 2016;68:1622–32.10.1016/j.jacc.2016.07.744. [PubMed: 27712774]
- [7]. Werner GS, Martin-Yuste V, Hildick-Smith D, Boudou N, Sianos G, Gelev V, et al. A randomized multicentre trial to compare revascularization with optimal medical therapy for the treatment of chronic total coronary occlusions. European heart journal. 201810.1093/eurheartj/ehy220.

- [8]. Cheng AS, Selvanayagam JB, Jerosch-Herold M, van Gaal WJ, Karamitsos TD, Neubauer S, et al. Percutaneous treatment of chronic total coronary occlusions improves regional hyperemic myocardial blood flow and contractility: insights from quantitative cardiovascular magnetic resonance imaging. *JACC Cardiovasc Interv.* 2008;1:44–53.10.1016/j.jcin.2007.11.003. [PubMed: 19393143]
- [9]. Chung CM, Nakamura S, Tanaka K, Tanigawa J, Kitano K, Akiyama T, et al. Effect of recanalization of chronic total occlusions on global and regional left ventricular function in patients with or without previous myocardial infarction. *Catheter Cardiovasc Interv.* 2003;60:368–74.10.1002/ccd.10641. [PubMed: 14571489]
- [10]. Christofferson RD, Lehmann KG, Martin GV, Every N, Caldwell JH, Kapadia SR. Effect of chronic total coronary occlusion on treatment strategy. *The American journal of cardiology.* 2005;95:1088–91.10.1016/j.amjcard.2004.12.065. [PubMed: 15842978]
- [11]. Al-Lamee R, Ielasi A, Latib A, Godino C, Ferraro M, Mussardo M, et al. Incidence, predictors, management, immediate and long-term outcomes following grade III coronary perforation. *JACC Cardiovasc Interv.* 2011;4:87–95.10.1016/j.jcin.2010.08.026. [PubMed: 21251634]
- [12]. El Sabbagh A, Patel VG, Jeroudi OM, Michael TT, Alomar ME, Mogabgab O, et al. Angiographic success and procedural complications in patients undergoing retrograde percutaneous coronary chronic total occlusion interventions: a weighted meta-analysis of 3,482 patients from 26 studies. *Int J Cardiol.* 2014;174:243–8.10.1016/j.ijcard.2014.04.004. [PubMed: 24768461]
- [13]. Danek BA, Karatasakis A, Tajti P, Sandoval Y, Karmaliotis D, Alaswad K, et al. Incidence, Treatment, and Outcomes of Coronary Perforation During Chronic Total Occlusion Percutaneous Coronary Intervention. *The American journal of cardiology.* 2017;10.1016/j.amjcard.2017.07.010.
- [14]. Doshi R, Rao G, Shlofmitz E, Donnelly J, Meraj P. Comparison of In-Hospital Outcomes After Percutaneous Revascularization for Peripheral Arterial Disease in Patients With a Body Mass Index of >30 kg/m² Versus ≤30 kg/m² (from the National Inpatient Sample). *The American journal of cardiology.* 2017;120:1648–52.10.1016/j.amjcard.2017.07.065. [PubMed: 28842147]
- [15]. Healthcare Cost and Utilization Project, Agency for Healthcare Research and Quality. NIS database documentation archive. Rockville, MD; 6 2016www.hcupus.ahrq.gov/db/nation/nis/nisarchive.jsp. Accessed December 6, 2017.
- [16]. Patel N, Kalra R, Doshi R, Arora H, Bajaj NS, Arora G, et al. Hospitalization Rates, Prevalence of Cardiovascular Manifestations, and Outcomes Associated With Sarcoidosis in the United States. *J Am Heart Assoc.* 2018;7:e007844.10.1161/JAHA.117.007844. [PubMed: 29358190]
- [17]. Patel N, Kalra R, Doshi R, Bajaj NS, Arora G, Arora P. Trends and Cost of Heart Transplantation and Left Ventricular Assist Devices: Impact of Proposed Federal Cuts. *JACC Heart Fail.* 2018;6:424–32.10.1016/j.jchf.2018.03.005. [PubMed: 29724365]
- [18]. New Diagnosis Codes Effective on October 1, 2007. Centers for Medicare & Medicaid Services Website. https://www.cms.gov/Medicare/Coding/ICD9ProviderDiagnosticCodes/downloads/new_diagnosis_codes_2007.pdf Accessed on January 18, 2018.
- [19]. Epstein AJ, Polsky D, Yang F, Yang L, Groeneveld PW. Coronary Revascularization Trends in the United States: 2001–2008. *JAMA : the journal of the American Medical Association.* 2011;305:1769–76.10.1001/jama.2011.551. [PubMed: 21540420]
- [20]. Yeh RW, Sidney S, Chandra M, Sorel M, Selby JV, Go AS. Population trends in the incidence and outcomes of acute myocardial infarction. *The New England journal of medicine.* 2010;362:2155–65.10.1056/NEJMoa0908610. [PubMed: 20558366]
- [21]. Elixhauser A, Steiner C, Harris DR, Coffey RM. Comorbidity measures for use with administrative data. *Med Care.* 1998;36:8–27 [PubMed: 9431328]
- [22]. Khera R, Angraal S, Couch T, Welsh JW, Nallamothu BK, Girotra S, et al. Adherence to Methodological Standards in Research Using the National Inpatient Sample. *Jama.* 2017;318:2011–8.10.1001/jama.2017.17653. [PubMed: 29183077]
- [23]. HCUP. Rockville, MD: Agency for Healthcare Research and Quality; Sep, 2014. HCUP. Rockville, MD: Agency for Healthcare Research and Quality; 9, 2014 <https://www.hcup-us.ahrq.gov/db/nation/nis/trendwghts.jsp>. Accessed on December 11, 2017.

- [24]. National Trends in Inpatient Stays. HCUP Fast Stats Frequently Asked Questions. HCUP website. https://www.hcup-us.ahrq.gov/faststats/faq_faststats.jsp. Accessed on December 6, 2017.
- [25]. Houchens RL RD, Elixhauser A, Jiang J. Nationwide Inpatient Sample Redesign: Final Report. 4 4, 2014 <https://www.hcupus.ahrq.gov/db/nation/nis/reports/NISRedesignFinalReport040914.pdf>. Accessed on December 10, 2017.
- [26]. Khera R, Cram P, Lu X, Vyas A, Gerke A, Rosenthal GE, et al. Trends in the use of percutaneous ventricular assist devices: analysis of national inpatient sample data, 2007 through 2012. *JAMA Intern Med*. 2015;175:941–50.10.1001/jamainternmed.2014.7856. [PubMed: 25822170]
- [27]. Harold JG, Bass TA, Bashore TM, Brindiss RG, Brush JE, Jr., Burke JA, et al. ACCF/AHA/SCAI 2013 Update of the Clinical Competence Statement on Coronary Artery Interventional Procedures: a Report of the American College of Cardiology Foundation/American Heart Association/American College of Physicians Task Force on Clinical Competence and Training (Writing Committee to Revise the 2007 Clinical Competence Statement on Cardiac Interventional Procedures). *Catheter Cardiovasc Interv*. 2013;82:E69–111.10.1002/ccd.24985. [PubMed: 23653399]
- [28]. Levine GN, Bates ER, Blankenship JC, Bailey SR, Bittl JA, Cercek B, et al. 2011 ACCF/AHA/SCAI Guideline for Percutaneous Coronary Intervention. A report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines and the Society for Cardiovascular Angiography and Interventions. *Journal of the American College of Cardiology*. 2011;58:e44–122.10.1016/j.jacc.2011.08.007. [PubMed: 22070834]
- [29]. Tomasello SD, Boukhris M, Giubilato S, Marza F, Garbo R, Contegiacomo G, et al. Management strategies in patients affected by chronic total occlusions: results from the Italian Registry of Chronic Total Occlusions. *European heart journal*. 2015;36:3189–98.10.1093/eurheartj/ehv450. [PubMed: 26333367]
- [30]. Jang WJ, Yang JH, Choi SH, Song YB, Hahn JY, Choi JH, et al. Long-term survival benefit of revascularization compared with medical therapy in patients with coronary chronic total occlusion and well-developed collateral circulation. *JACC Cardiovasc Interv*. 2015;8:271–9.10.1016/j.jcin.2014.10.010. [PubMed: 25700750]
- [31]. Brilakis ES, Banerjee S, Karpaliotis D, Lombardi WL, Tsai TT, Shunk KA, et al. Procedural outcomes of chronic total occlusion percutaneous coronary intervention: a report from the NCDR (National Cardiovascular Data Registry). *JACC Cardiovasc Interv*. 2015;8:245–53.10.1016/j.jcin.2014.08.014. [PubMed: 25700746]
- [32]. Patel VG, Brayton KM, Tamayo A, Mogabgab O, Michael TT, Lo N, et al. Angiographic success and procedural complications in patients undergoing percutaneous coronary chronic total occlusion interventions: a weighted meta-analysis of 18,061 patients from 65 studies. *JACC Cardiovasc Interv*. 2013;6:128–36.10.1016/j.jcin.2012.10.011. [PubMed: 23352817]
- [33]. Sapontis J, Salisbury AC, Yeh RW, Cohen DJ, Hirai T, Lombardi W, et al. Early Procedural and Health Status Outcomes After Chronic Total Occlusion Angioplasty: A Report From the OPEN-CTO Registry (Outcomes, Patient Health Status, and Efficiency in Chronic Total Occlusion Hybrid Procedures). *JACC Cardiovasc Interv*. 2017;10:1523–34.10.1016/j.jcin.2017.05.065. [PubMed: 28797429]
- [34]. Christakopoulos GE, Christopoulos G, Carlino M, Jeroudi OM, Roesle M, Rangan BV, et al. Meta-analysis of clinical outcomes of patients who underwent percutaneous coronary interventions for chronic total occlusions. *The American journal of cardiology*. 2015;115:1367–75.10.1016/j.amjcard.2015.02.038. [PubMed: 25784515]
- [35]. Zhang QB, Chen LM, Li M, Cui YQ, Zhao CY, Cui LQ. Influence of chronic kidney disease on the outcome of patients with chronic total occlusion. *Am J Transl Res*. 2016;8:196–208 [PubMed: 27069553]
- [36]. Michael TT, Karpaliotis D, Brilakis ES, Alomar M, Abdullah SM, Kirkland BL, et al. Temporal trends of fluoroscopy time and contrast utilization in coronary chronic total occlusion revascularization: insights from a multicenter United States registry. *Catheter Cardiovasc Interv*. 2015;85:393–9.10.1002/ccd.25359. [PubMed: 24407867]
- [37]. Mehran R, Aymong ED, Nikolsky E, Lasic Z, Iakovou I, Fahy M, et al. A simple risk score for prediction of contrast-induced nephropathy after percutaneous coronary intervention:

development and initial validation. Journal of the American College of Cardiology. 2004;44:1393–9.10.1016/j.jacc.2004.06.068. [PubMed: 15464318]

- [38]. Fujino A, Otsuji S, Hasegawa K, Arita T, Takiuchi S, Fujii K, et al. Accuracy of JCTO Score Derived From Computed Tomography Versus Angiography to Predict Successful Percutaneous Coronary Intervention. JACC Cardiovasc Imaging. 2018;11:209–17.10.1016/j.jcmg.2017.01.028. [PubMed: 28624404]
- [39]. Weintraub WS, Garratt KN. Should Chronic Total Occlusion Be Treated With Coronary Artery Bypass Grafting? Chronic Total Occlusion Should Not Routinely Be Treated With Coronary Artery Bypass Grafting. Circulation. 2016;133:1818–25.10.1161/CIRCULATIONAHA.115.017798. [PubMed: 27143549]

Highlights

- Randomized trial data suggest an unclear benefit of CTO-PCI in patients with stable CAD.
- Hospitalizations for single-vessel CTO-PCI has marginally increased from 2008–2014.
- Hospital deaths are stable at ~0.5%, however risk of acute renal failure has risen with CTO-PCI.
- Economic burden associated with single-vessel CTO-PCI for stable CAD has increased.
- High-volume centers (≥ 50 CTO-PCIs) have improved outcomes compared to low-volume centers.

Figure 1: Patient selection flow chart

ICD 9 CM- International Classification of Disease, Ninth Revision, Clinical Modification,
PCI- Percutaneous Coronary Intervention

* represents procedure codes 00.40, 00.66, 36.06 and 36.07, and # represents Diagnosis code 410.x

Figure 2: Incidence of single-vessel coronary CTO-PCI for stable CAD

Figure shows proportion of hospitalizations with single-vessel chronic total occlusion of a coronary artery with stable coronary artery disease treated with percutaneous coronary intervention (PCI) per 100,000 PCI procedures.

Trend p value is <0.001 by Jonckheere-Terpstra test.

CAD- Coronary artery disease, CTO- Chronic Total Occlusion, PCI- Percutaneous Coronary Intervention

Figure 3: Rates of in-hospital mortality (Panel A) and acute renal failure (Panel B) stratified by year for single-vessel coronary CTO-PCI for stable CAD (Multivariable adjusted analysis)
 Year 2008 was taken as a reference. Trend p value for in-hospital mortality is 0.13 by Jonckheere-Terpstra test (Panel A). Trend p value for acute renal failure is <0.001 by Jonckheere-Terpstra test (Panel B). Blue dots represent adjusted odds ratio and black lines represent 95% confidence interval.
 CAD- Coronary artery disease, CTO- Chronic Total Occlusion, PCI- Percutaneous Coronary Intervention

Figure 4: Rates of utilization of mechanical circulatory support devices (Panel A) and median cost of hospitalization (Panel B) for the treatment of single-vessel coronary CTO-PCI.

Figure shows utilization of IABP, and pLVAD per 100 single-vessel CTO-PCIs in the given year. Trend p value for the use of IABP and pLVAD is <0.001 by Jonckheere-Terpstra test (Panel A). Trend p value for median hospitalization cost is <0.001 by Jonckheere-Terpstra test (Panel B).

CAD- Coronary artery disease, CTO- Chronic Total Occlusion, IABP- Intra-Aortic Balloon Pump, PCI- Percutaneous Coronary Intervention, pLVAD- Percutaneous Left Ventricular Assist Device.