

Association of Testosterone Therapy With Mortality, Myocardial Infarction, and Stroke in Men With Low Testosterone Levels

FREE

Rebecca Vigen, MD, MSCS¹; Colin I. O'Donnell, MS^{2,3}; Anna E. Barón, PhD^{2,3}; Gary K. Grunwald, PhD^{2,3}; Thomas M. Maddox, MD, MSc^{2,3,4}; Steven M. Bradley, MD, MPH^{2,3,4}; Al Barqawi, MD³; Glenn Woning, MD³; Margaret E. Wierman, MD^{2,3}; Mary E. Plomondon, PhD^{2,3,4}; John S. Rumsfeld, MD, PhD^{2,3,4}; P. Michael Ho, MD, PhD^{2,3,4}

[\[+\] Author Affiliations](#)

JAMA. 2013;310(17):1829-1836. doi:10.1001/jama.2013.280386. **This article was corrected** | [View correction](#)

Text Size: **A** **A** **A**

[Article](#) | [Figures](#) | [Tables](#) | [Supplemental Content](#) | [References](#)

ABSTRACT

[ABSTRACT](#) | [METHODS](#) | [RESULTS](#) | [DISCUSSION](#) | [CONCLUSION](#) | [ARTICLE INFORMATION](#) | [REFERENCES](#)

Importance Rates of testosterone therapy are increasing and the effects of testosterone therapy on cardiovascular outcomes and mortality are unknown. A recent randomized clinical trial of testosterone therapy in men with a high prevalence of cardiovascular diseases was stopped prematurely due to adverse cardiovascular events raising concerns about testosterone therapy safety.

Objectives To assess the association between testosterone therapy and all-cause mortality, myocardial infarction (MI), or stroke among male veterans and to determine whether this association is modified by underlying coronary artery disease.

Design, Setting, and Patients A retrospective national cohort study of men with low testosterone levels (<300 ng/dL) who underwent coronary angiography in the Veterans Affairs (VA) system between 2005 and 2011.

Main Outcomes and Measures Primary outcome was a composite of all-cause mortality, MI, and ischemic stroke.

Results Of the 8709 men with a total testosterone level lower than 300 ng/dL, 1223 patients started testosterone therapy after a median of 531 days following coronary angiography. Of the 1710 outcome events, 748 men died, 443 had MIs, and 519 had strokes. Of 7486 patients not receiving testosterone therapy, 681 died, 420 had MIs, and 486 had strokes. Among 1223 patients receiving testosterone therapy, 67 died, 23 had MIs, and 33 had strokes. At 3 years after coronary angiography, the Kaplan-Meier estimated cumulative percentages with events were 19.9% in the no testosterone therapy group vs 25.7% in the testosterone therapy group, with an absolute risk difference of 5.8% (95% CI, -1.4% to 13.1%). In Cox proportional hazards models adjusting for the presence of coronary artery disease, testosterone therapy use as a time-varying covariate was associated with increased risk of adverse outcomes (hazard ratio, 1.29; 95% CI, 1.04 to 1.58). There was no significant difference in the effect size of

testosterone therapy among those with and without coronary artery disease (test for interaction, $P = .41$).

Conclusions and Relevance Among a cohort of men in the VA health care system who underwent coronary angiography and had a low serum testosterone level, the use of testosterone therapy was associated with increased risk of adverse outcomes. These findings may inform the discussion about the potential risks of testosterone therapy.

Rates of testosterone therapy prescription have increased markedly in the United States over the past decade. Annual prescriptions for testosterone increased by more than 5-fold from 2000¹ to 2011, reaching 5.3 million prescriptions and a market of \$1.6 billion in 2011.^{2,3} Professional society guidelines recommend testosterone therapy for patients with symptomatic testosterone deficiency.⁴ In addition to improving sexual function⁵⁻⁷ and bone mineral density^{8,9} and increasing free-fat mass^{8,9} and strength,¹⁰ treatment with testosterone has been shown to improve lipid profiles¹¹⁻¹³ and insulin resistance^{11,12} and increase the time to ST depression during stress testing.^{14,15}

The effects of testosterone therapy on cardiovascular outcomes and mortality are unknown. Prior clinical studies of testosterone therapy have not detected adverse cardiac events, but these trials were generally focused on intermediate end points, of short duration, and not powered for clinical end points. A recent trial, the Testosterone in Older Men with Mobility Limitations (TOM) trial,¹⁶ conducted in older frail men with a high prevalence of cardiovascular diseases was stopped prematurely due to increased cardiovascular events in the treatment group. The premature termination of the TOM trial and the limitations of the prior studies highlight uncertainty regarding the safety of testosterone therapy in older men with cardiovascular diseases.

To address this gap in knowledge, we evaluated the association between the use of testosterone therapy and all-cause mortality, myocardial infarction (MI), and stroke among male veterans and whether this association was modified by underlying coronary artery disease (CAD).

METHODS

ABSTRACT | **METHODS** | RESULTS | DISCUSSION | CONCLUSION | ARTICLE
INFORMATION | REFERENCES

The VA Clinical
Assessment

Reporting and Tracking (CART) Program uses a customized software application that collects patient and procedural data at the point-of-care for all procedures performed in the 76 VA cardiac catheterization laboratories nationwide.^{17,18} It is designed to simultaneously allow for data entry by clinicians during routine clinical workflow, integrate into the VA's electronic medical record system, and collect individual and aggregate data to support quality management and improvement initiatives for cardiovascular procedures. CART was initially implemented in 2005 and was actively used in all VA catheterization laboratories by 2009. The methods of its implementation have been previously described.¹⁷ This study was approved by the Colorado Multiple Institutional Review Board.

Patient Population

This was a retrospective cohort study of all male veterans who underwent coronary angiography between 2005 and 2011 and who had a total testosterone level checked. Patients who started testosterone therapy prior to coronary angiography were excluded because we could not ascertain the effect of testosterone therapy treatment on underlying burden of coronary disease. Additionally, patients who started testosterone therapy prior to having a testosterone level checked in the VA were excluded because we did not know if the patient had low testosterone levels prior to treatment. Patients with missing coronary anatomy data and those who were prescribed testosterone therapy after an MI were excluded. Patients with a hematocrit of more than 50% and a prostate-specific antigen (PSA) level of 4.0 ng/mL or higher were excluded because these are contraindications to testosterone therapy per guidelines.⁴ The final cohort was limited to patients who had a total testosterone level less than 300 ng/dL (to

convert to nanomoles per liter, multiply by 0.0347) because this is a generally agreed threshold for biochemical hypogonadism per the Endocrine Society Clinical Practice Guidelines.⁴

Covariates

Patient characteristics and presence of CAD were obtained via CART and VA administrative data.¹⁸ Patient characteristics are entered into CART at the time of coronary angiography by physicians performing the procedure in the cardiac catheterization laboratory. Covariates not present in CART were obtained from VA administrative data, the majority of which were derived from Elixhauser codes. Total testosterone levels were obtained from VA laboratory files, and the level closest in timing to the procedure date was included in this analysis. Coronary artery disease was present if there was 20% or more stenosis in any epicardial vessel as recorded in CART by the physician performing the procedure. No evidence of CAD was defined as less than 20% stenosis in all epicardial vessels on angiography. These definitions were chosen based on standardized definitions of flow-limiting stenosis.^{19,20}

Primary Exposure Variable

Patients were categorized as initiating testosterone therapy if they filled a prescription for testosterone gel, patch, or injections following coronary angiography based on pharmacy-dispensing data (VHA Decision Support System). Once initiated, a patient was assumed to have continued treatment until an outcome event occurred or the end of follow-up. Testosterone therapy is generally prescribed long-term with recommendations for assessment of response and adverse effects at 3 months following initiation and then annually thereafter.⁴

Outcome Variable

The primary end point was a combined end point of time to all-cause mortality or to hospitalization for MI or ischemic stroke. All-cause mortality was assessed via the VA vital status file. The file has 98.3% sensitivity and 97.6% exact agreement with the National Death Index.^{21,22} Myocardial infarction and ischemic stroke were assessed via *International Classification of Diseases, Ninth Revision (ICD-9)* codes (410.x0 and 410.x1) and (433.x or 444.x), respectively, from VA inpatient treatment files. The last day of follow-up was January 23, 2012.

Statistical Methods

Because patients were not randomized to receive testosterone therapy, we used stabilized inverse probability of treatment weighting to adjust for any unmeasured confounders that may have affected when and if patients were prescribed testosterone therapy. Variables used to create these weights included demographic characteristics (age, race), comorbidities (prior MI, congestive heart failure, diabetes, renal failure, depression, posttraumatic stress disorder, hyperlipidemia, peripheral vascular disease, chronic pulmonary disease, chronic obstructive pulmonary disease, obstructive sleep apnea, hypertension, cerebrovascular disease, overweight, dialysis, ever smoker, alcohol, anemia, blood loss anemia, coagulation disorder, complicated diabetes, uncomplicated diabetes, drug abuse, fluid electrolyte disorder, human immunodeficiency syndrome or AIDS, hypothyroidism, liver disease, lymphoma, metastatic cancer, neurological disorder, paralysis, peptic ulcer disease, psychoses, pulmonary circulatory disorder, renal failure, rheumatoid arthritis, nonmetastatic tumor, and weight loss), and procedures (prior revascularization, prior catheterization, prior percutaneous coronary intervention [PCI], prior coronary artery bypass graft surgery, cardiac transplant, prior stress test, prior cardiac blood pool imaging, cardiac magnetic resonance imaging, cardiac computed tomography [CT], CT coronary angiography, prior myocardial perfusion imaging, prior transthoracic echocardiogram, and prior transesophageal echocardiogram).

We applied stabilized weights for each patient in the cohort at each time that an event was observed.²³ Treating testosterone therapy as a time-varying covariate, Cox proportional hazards models with stabilized inverse probability of treatment weighting were used to assess the association between testosterone therapy and the primary outcome of death, MI, or stroke. Next, we adjusted for the presence of CAD and then tested for an interaction between CAD status and testosterone therapy. We wanted to determine whether the association of

testosterone therapy with adverse outcomes was modified by the presence of CAD given the uncertainty regarding the safety of testosterone therapy in older men with comorbidities such as CAD.

We compared select baseline characteristics between patients receiving testosterone therapy (based on whether testosterone was given at any point during follow-up) and patients not receiving testosterone therapy using *t* tests for continuous variables and Fisher exact tests for dichotomous variables. We also compared the covariate balance of patients prescribed testosterone therapy vs no testosterone therapy based on the cohorts created by the stabilized inverse probability of treatment weighting at 180, 365, and 540 days during follow-up after coronary angiography.²³ *P* values were obtained for the comparison between the testosterone therapy and no testosterone therapy groups to assess covariate balance.

We applied the stabilized inverse probability of treatment weighting to obtain Kaplan-Meier survival curves with testosterone therapy use treated as a time-varying covariate.²⁴ To further assess the association between testosterone therapy and outcomes, we separated the exposure by type of testosterone prescribed (injections, patch, and gel) and used linear contrasts to evaluate for differences in risk of outcomes across the testosterone preparations.

Next, we performed a series of sensitivity analyses to further assess the robustness of our findings. First, we assessed whether the differences in outcomes could be attributed to differential treatment of cardiovascular risk factors or use of secondary prevention medications between the testosterone therapy vs no testosterone therapy groups. Using stabilized inverse probability of treatment weighting based on the same covariates used in the primary model, we compared low-density lipoprotein (LDL) and blood pressure levels at 1 and 2 years following coronary angiography between patients receiving vs not receiving testosterone therapy at those times using *t* tests. We also compared the proportion of patients filling statins and β -blocker prescriptions at 1 and 2 years following coronary angiography between the testosterone therapy vs no testosterone therapy groups using χ^2 tests with stabilized inverse probability of treatment weighting. Second, we included subsequent coronary revascularization, including PCI and CABG surgery as additional outcomes and assessed the association between testosterone therapy and outcomes (death, stroke, MI, PCI, and CABG surgery). Third, we assessed the dose prescribed and the duration of testosterone treatment based on the dates of testosterone refill as well as the number of refills obtained. Finally, we evaluated the testosterone levels among patients with repeat testosterone levels following initiation of therapy.

R version 2.15.2 (The R Foundation for Statistical Computing, <http://www.R-project.org>) was used for data preparation and for descriptive and graphical analysis. The Cox regression models for this article were fit using SAS/STAT software, version 9.3 of the SAS System for Windows 2002-2010 (SAS Institute Inc). Hypothesis tests were 2-sided and performed at a .05 significance level.

RESULTS

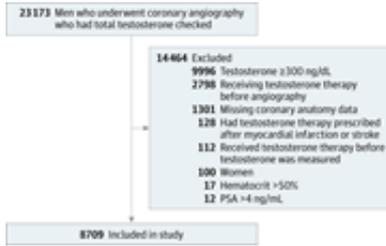
ABSTRACT | METHODS | **RESULTS** | DISCUSSION | CONCLUSION | ARTICLE
INFORMATION | REFERENCES

The primary cohort consisted of 23 173 men who underwent coronary angiography between 2005 and 2011 and who had had a total testosterone level checked (Figure 1). We excluded the following patients from this cohort: 2798 patients who had initiated testosterone prior to coronary angiography; 1301 patients who had missing coronary anatomy data or whose coronary anatomy was categorized as other; 128 patients who had testosterone prescribed after MI because treatment decisions after an event were likely to be different and because coronary anatomy data to assess coronary disease severity was not uniformly available; 112 patients who had started testosterone prior to having a testosterone level checked; 100 patients who were women; 17 patients with hematocrit levels higher than 50%; 12 patients with PSA levels of 4.0 ng/mL or higher; and 9996 patients who had total testosterone levels of 300 ng/dL or higher.

Figure 1.

Study Cohort

To convert testosterone from ng/dL to nmol/L, multiply by 0.0347. PSA indicates prostate-specific antigen.



[View Large](#) | [Save Figure](#) | [Download Slide \(.ppt\)](#)

In the cohort of 8709 veterans with a total testosterone level less than 300 ng/dL who underwent coronary angiography, there was a high burden of comorbidities. Approximately 20% had a prior history of MI, 50% had diabetes, and more than 80% had CAD. Of the 8709 patients, 1223 (14.0%) initiated testosterone therapy after a median of 531 days (interquartile range [IQR], 229-894 days) following angiography. Patients who initiated testosterone therapy tended to be younger and have lower rates of comorbidities (eg, congestive heart failure and renal failure; [Table 1](#)).

Table 1. Characteristics of Patients at Study Entry Who Did and Did Not Receive Testosterone Therapy

Characteristic	No. Testosterone Therapy	No. No Testosterone Therapy	P Value
Age (mean [SD], y)	61.2 (10.5)	63.1 (10.5)	<.001
Testosterone level (mean [SD], ng/dL)	206 (117.0)	174 (80.3)	<.001
Comorbidities			
Hypertension	960 (77.8)	107 (76.0)	<.001
Dyslipidemia	2000 (163.8)	206 (149.0)	.001
Diabetes	400 (32.6)	410 (296.0)	.001
Heart failure	400 (32.6)	410 (296.0)	.001
Stroke	400 (32.6)	410 (296.0)	.001
COPD	400 (32.6)	410 (296.0)	.001
Current smoker	400 (32.6)	410 (296.0)	.001
Previous smoker	400 (32.6)	410 (296.0)	.001
No smoking	400 (32.6)	410 (296.0)	.001
Alcohol use	400 (32.6)	410 (296.0)	.001
Current	400 (32.6)	410 (296.0)	.001
Previous	400 (32.6)	410 (296.0)	.001
None	400 (32.6)	410 (296.0)	.001
Medication use	400 (32.6)	410 (296.0)	.001
Beta-blockers	400 (32.6)	410 (296.0)	.001
Calcium channel blockers	400 (32.6)	410 (296.0)	.001
Diuretics	400 (32.6)	410 (296.0)	.001
Nitroglycerin	400 (32.6)	410 (296.0)	.001
Statins	400 (32.6)	410 (296.0)	.001
Aspirin	400 (32.6)	410 (296.0)	.001
Clopidogrel	400 (32.6)	410 (296.0)	.001
Other antiplatelet agents	400 (32.6)	410 (296.0)	.001
Insulin	400 (32.6)	410 (296.0)	.001
Oral hypoglycemics	400 (32.6)	410 (296.0)	.001
Testosterone therapy	1223 (97.6)	0 (0.0)	<.001
Time to testosterone therapy (median [IQR], days)	531 (229-894)		

[View Large](#) | [Save Table](#) | [Download Slide \(.ppt\)](#)

The average follow-up was approximately 840 days or 27.5 months. Of the 1710 total number of events in the entire cohort, 748 died; 443 had MIs; and 519 had strokes. Of the 7486 patients not receiving testosterone therapy, 681 died, 420 had MIs, and 486 had strokes. Of the 1223 patients receiving testosterone therapy, 67 died, 23 had MIs, and 33 had strokes. The Kaplan-Meier estimated cumulative percentages with events among the no testosterone therapy group vs the testosterone therapy group at 1 year after coronary angiography were 10.1% vs 11.3%; at 2 years, 15.4% vs 18.5%; and at 3 years, 19.9% vs 25.7%. The absolute risk differences were 1.3% (95% CI, -7.1% to 9.7%) at 1 year, 3.1% (95% CI, -4.9% to 11.0%) at 2 years, and 5.8% (95% CI, -1.4% to 13.1%) at 3 years.

Following application of the standardized weights, there were no statistically significant differences in the comorbidities between the groups at 180, 365, and 540 days of follow-up except for a history of cerebrovascular disease ([Table 2](#)). Kaplan-Meier survival curves demonstrated that testosterone use was associated with increased risk of death, MI, or stroke ([Figure 2](#)). The prevalence of the weighted co-morbidities at 180, 365 and 540 days among those using and not using testosterone therapy during those time points are presented in the eTable in the [Supplement](#). In analysis with standardized weights and testosterone therapy as a time-varying covariate, testosterone use was associated with increased risk of adverse outcomes including all-cause mortality, MI, and ischemic stroke (hazard ratio [HR], 1.29; 95% CI, 1.05-1.58; *P* = .02). The findings remained unchanged after adjusting for the presence of CAD (HR, 1.29; 95% CI, 1.04-1.58). There was no significant difference in the effect size of testosterone therapy between those with and without CAD (test of interaction, *P* = .41). Furthermore, the association between testosterone therapy and adverse outcomes adjusting for the presence of CAD remained unchanged when revascularization procedures were included as additional outcomes (HR, 1.37; 95% CI, 1.21-1.56).

prescription, the mean number of days from first fill to the last fill of testosterone therapy was 376 days. Furthermore, the mean numbers of refills by testosterone formulation were 9.8 for gel, 11.2 for injections, and 6 for patches. Of the patients prescribed testosterone therapy, 734 patients (60.0%) had another testosterone value checked after starting treatment. These patients had a mean of 3.3 measurements. Among these patients, the baseline testosterone level was 175.5 ng/dL and increased to 332.2 ng/dL for the first repeat testosterone measurement.

DISCUSSION

ABSTRACT | METHODS | RESULTS | **DISCUSSION** | CONCLUSION | ARTICLE
INFORMATION | REFERENCES

The objective of this study was to

assess the association between testosterone therapy and all-cause mortality, MI, or ischemic stroke. The use of testosterone therapy was significantly associated with adverse outcomes despite the lower prevalence of baseline comorbidities in the testosterone therapy group. The association was consistent among patients with and without CAD. The increased risk of adverse outcomes associated with testosterone therapy use was not related to differences in risk factor control or rates of secondary prevention medication use because patients in both groups had similar blood pressure, LDL levels, and use of secondary prevention medications. These findings raise concerns about the potential safety of testosterone therapy.

Clinical trials have demonstrated that testosterone therapy improves a number of intermediate outcomes and cardiac risk factors. Aside from the TOM trial,¹⁶ these trials and subsequent meta-analyses²⁵⁻²⁷ did not demonstrate adverse cardiovascular outcomes. However, most of the studies were small, enrolled patients of different ages, and were of variable duration. A clinical trial evaluating the effect of testosterone therapy on cardiovascular outcomes including mortality, MI, and stroke has not been conducted to our knowledge. The TOM study,¹⁶ which enrolled an older cohort of men with a high prevalence of comorbidities, was halted after enrolling 209 of the planned 252 patients over a 3-year period because 23 patients in the treatment group vs 5 in the placebo had adverse cardiovascular events. Because the long-term safety of testosterone therapy has not been studied, the results of this retrospective study of male veterans add to our understanding of the potential risks of testosterone therapy.

The association between testosterone therapy use and adverse outcomes observed in this study differs from the association observed in a prior retrospective VA study. These discrepant results may be due to differences in the patient populations and methods used to control for confounding. In the study by Shores et al,²⁸ investigators noted a 39% reduction in mortality risk among patients treated with testosterone therapy. The patients in that cohort had a lower incidence of heart disease (~20%) defined by angina, MI, CAD, coronary artery bypass graft surgery, percutaneous transluminal coronary angioplasty, or heart failure. This contrasts with our cohort in which more than 20% had a prior history of MI and heart failure, and more than 50% had confirmed obstructive CAD on angiography. Additionally, the Shores study adjusted for confounders using proportional hazards regression and then used propensity matching in a secondary analysis. This matching method does not account for differences in time from study cohort entry to testosterone initiation, which might not account appropriately for either time-varying treatment-selection bias, immortal time bias, or both.²⁹ In contrast, the stabilized weights method used in this analysis adjusts for confounders dynamically throughout the study period to overcome these biases.

There are several potential mechanisms by which testosterone therapy may increase cardiovascular risk. First, in a study of healthy men, intramuscular testosterone was associated with an increase in platelet thromboxane A₂ receptor density and platelet aggregation.³⁰ It is known that platelets play a role in coronary plaque formation, beginning with platelet adhesion and eventual thrombus formation with plaque rupture resulting in acute coronary syndrome.³¹ Second, laboratory studies have demonstrated that dihydrotestosterone, a testosterone metabolite, increases smooth muscle proliferation and expression of vascular cell adhesion molecule 1, which enhances monocyte activation in the endothelium.^{32,33} Monocytes promote atherosclerosis through their effects on inflammatory cytokines and matrix metalloproteinases and are implicated in the pathogenesis of acute coronary

syndromes.³⁴ Testosterone administration has been shown to worsen sleep disordered breathing among patients with severe obstructive sleep apnea,³⁵ which is a risk factor for atherosclerosis.³⁶ Therefore, there are several potential mechanisms by which testosterone therapy could confer increased risk of adverse cardiovascular outcomes, so further study of these mechanisms is needed.

This study is the first observational study, to our knowledge, to suggest that testosterone therapy is associated with adverse cardiovascular outcomes. Our findings raise some uncertainty regarding the potential safety of testosterone use in men. Although physicians should continue to discuss the symptomatic benefits of testosterone therapy with patients, it is also important to inform patients that long-term risks are unknown and there is a possibility that testosterone therapy might be harmful. Randomized clinical trials and observational studies in other populations are needed to help inform whether long-term testosterone therapy use is safe or if it is associated with adverse cardiovascular events.

Potential limitations of this study should be noted. First, given that this was an observational study, unmeasured confounding or hidden bias might exist. However, to minimize residual confounding, we used a nonparsimonious model to obtain stabilized weights in order to balance the covariates among patients receiving and not receiving treatment over the course of the study. Furthermore, we performed several ancillary analyses that showed that no differences existed in risk factor control or use of secondary prevention medications among groups, suggesting that these factors are unlikely to explain the higher event rates in the testosterone therapy group.

Second, we were unable to determine the time of day in which the total testosterone levels were drawn. If some patients had their blood drawn after the morning hours when testosterone levels peak, their levels would be underestimated.³⁷ There may be small differences in the testosterone assays used by the different VA hospitals that could possibly contribute to error in our assessment of patient's total testosterone levels.

Third, because of the retrospective nature of this study, outcomes were determined using *ICD-9* codes and not validated by chart review. However, *ICD-9* codes have been shown to be valid in determining outcomes including stroke and MI in VA cohorts.³⁸⁻⁴⁰

Fourth, there was a relatively small group of patients with extended follow-up time (267 patients at 2000 days after coronary angiography) so that our estimates of the risk of testosterone therapy are less reliable at these extremes of follow-up; however, this is a potential limitation of any study that follows up patients for extended periods.

Fifth, this was a select group of patients who were undergoing angiography in the VA system. Although this limits generalizability, we were able to better assess the burden of CAD and evaluate whether the association between testosterone therapy and adverse outcomes was modified by the presence of CAD in response to concerns of a prior randomized clinical trial of testosterone therapy.¹⁶

CONCLUSION

ABSTRACT | METHODS | RESULTS | DISCUSSION | **CONCLUSION** | ARTICLE
INFORMATION | REFERENCES

Use of
testosterone

therapy in this cohort of veterans with significant medical comorbidities was associated with increased risk of mortality, MI, or ischemic stroke. These findings were not modified by the presence of CAD. Future studies including randomized controlled trials are needed to properly characterize the potential risks of testosterone therapy in men with comorbidities.

ARTICLE INFORMATION

ABSTRACT | METHODS | RESULTS | DISCUSSION | CONCLUSION | **ARTICLE**
INFORMATION | REFERENCES

Corresponding Author: P. Michael Ho, MD, PhD, VA Eastern Colorado Health Care System, 1055 Clermont St, Research (A151), Denver, CO 80220 (Michael.Ho@va.gov).

Author Contributions: Drs Vigen and Ho had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

Study concept and design: Vigen, O'Donnell, Bradley, Barqawi, Ho.

Acquisition of data: O'Donnell, Plomondon, Rumsfeld, Ho.

Analysis and interpretation of data: Vigen, O'Donnell, Barón, Grunwald, Maddox, Bradley, Barqawi, Woning, Wierman, Plomondon, Ho.

Drafting of the manuscript: Vigen, O'Donnell, Woning, Ho.

Critical revision of the manuscript for important intellectual content: O'Donnell, Barón, Grunwald, Maddox, Bradley, Barqawi, Woning, Wierman, Plomondon, Rumsfeld.

Statistical analysis: Vigen, O'Donnell, Barón, Grunwald.

Administrative, technical, or material support: Woning, Plomondon, Rumsfeld, Ho.

Study supervision: Barqawi.

Conflict of Interest Disclosures: All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest and none were reported.

Funding/Support: Dr Vigen was supported by a Cardiovascular Outcomes Research Fellowship through a Department of Veterans Affairs Graduate Medical Education Enhancement Grant. Drs Maddox and Bradley were supported by a Department of Veterans Affairs Health Services Research and Development Service Career Development Awards.

Role of the Sponsor: The Department of Veteran Affairs had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

Disclaimer: The views expressed in this article are those of the authors and do not necessarily reflect the position or policy of the Department of Veterans Affairs or the US government.

Correction: This article was corrected November 11, 2013, and on February 4, 2014, to enumerate excluded patients in the text and in Figure 1.

REFERENCES

ABSTRACT | METHODS | RESULTS | DISCUSSION | CONCLUSION | ARTICLE
INFORMATION | **REFERENCES**

1 US
Depar
of
Food
and
Drug
Admi
Repro
Health
Drugs
Advis

-
- 2** US Securities and Exchange Commission. Annual report of Auxilium Pharmaceuticals Inc, Form 10-K. <http://services.corporate-ir.net/SEC.Enhanced/SecCapsule.aspx?c=142125&fid=8040442>. Accessed May 3, 2013.
-
- 3** Spitzer M, Huang G, Basaria S, Travison TG, Bhasin S. Risks and benefits of testosterone therapy in older men. *Nat Rev Endocrinol*. 2013;9(7):414-424.
[PubMed](#) | [Link to Article](#)
-
- 4** Bhasin S, Cunningham GR, Hayes FJ, et al; Task Force, Endocrine Society. Testosterone therapy in men with androgen deficiency syndromes: an Endocrine Society clinical practice guideline. *J Clin Endocrinol Metab*. 2010;95(6):2536-2559.
[PubMed](#) | [Link to Article](#)
-
- 5** Wang C, Swerdloff RS, Iranmanesh A, et al; Testosterone Gel Study Group. Transdermal testosterone gel improves sexual function, mood, muscle strength, and body composition parameters in hypogonadal men. *J Clin Endocrinol Metab*. 2000;85(8):2839-2853.
[PubMed](#)
-
- 6** Boloña ER, Uruga MV, Haddad RM, et al. Testosterone use in men with sexual dysfunction: a systematic review and meta-analysis of randomized placebo-controlled trials. *Mayo Clin Proc*. 2007;82(1):20-28.
[PubMed](#)
-
- 7** Isidori AM, Giannetta E, Gianfrilli D, et al. Effects of testosterone on sexual function in men: results of a meta-analysis. *Clin Endocrinol (Oxf)*. 2005;63(4):381-394.
[PubMed](#) | [Link to Article](#)
-
- 8** Isidori AM, Giannetta E, Greco EA, et al. Effects of testosterone on body composition, bone metabolism and serum lipid profile in middle-aged men: a meta-analysis. *Clin Endocrinol (Oxf)*. 2005;63(3):280-293.
[PubMed](#) | [Link to Article](#)
-
- 9** Snyder PJ, Peachey H, Berlin JA, et al. Effects of testosterone replacement in hypogonadal men. *J Clin Endocrinol Metab*. 2000;85(8):2670-2677.
[PubMed](#)

-
- 10** Sih R, Morley JE, Kaiser FE, Perry HM III, Patrick P, Ross C. Testosterone replacement in older hypogonadal men: a 12-month randomized controlled trial. *J Clin Endocrinol Metab.* 1997;82(6):1661-1667.
[PubMed](#) | [Link to Article](#)
-
- 11** Jones TH, Arver S, Behre HM, et al; TIMES2 Investigators. Testosterone replacement in hypogonadal men with type 2 diabetes and/or metabolic syndrome (the TIMES2 study). *Diabetes Care.* 2011;34(4):828-837.
[PubMed](#) | [Link to Article](#)
-
- 12** Jones TH, Saad F. The effects of testosterone on risk factors for, and the mediators of, the atherosclerotic process. *Atherosclerosis.* 2009;207(2):318-327.
[PubMed](#) | [Link to Article](#)
-
- 13** Mårin P, Holmång S, Gustafsson C, et al. Androgen treatment of abdominally obese men. *Obes Res.* 1993;1(4):245-251.
[PubMed](#) | [Link to Article](#)
-
- 14** Mathur A, Malkin C, Saeed B, Muthusamy R, Jones TH, Channer K. Long-term benefits of testosterone replacement therapy on angina threshold and atheroma in men. *Eur J Endocrinol.* 2009;161(3):443-449.
[PubMed](#) | [Link to Article](#)
-
- 15** Malkin CJ, Pugh PJ, Morris PD, et al. Testosterone replacement in hypogonadal men with angina improves ischaemic threshold and quality of life. *Heart.* 2004;90(8):871-876.
[PubMed](#) | [Link to Article](#)
-
- 16** Basaria S, Coviello AD, Travison TG, et al. Adverse events associated with testosterone administration. *N Engl J Med.* 2010;363(2):109-122.
[PubMed](#) | [Link to Article](#)
-
- 17** Box TL, McDonell M, Helfrich CD, Jesse RL, Fihn SD, Rumsfeld JS. Strategies from a nationwide health information technology implementation: the VA CART story. *J Gen Intern Med.* 2010;25(suppl 1):72-76.
[PubMed](#) | [Link to Article](#)
-
- 18** Byrd JB, Vigen R, Plomondon ME, et al. Data quality of an electronic health record tool to support VA cardiac catheterization laboratory quality improvement: the VA Clinical Assessment, Reporting, and Tracking System for Cath Labs (CART) program. *Am Heart J.* 2013;165(3):434-440.
[PubMed](#) | [Link to Article](#)
-
- 19** Wilson RF, Marcus ML, White CW. Prediction of the physiologic significance of coronary arterial lesions by quantitative lesion geometry in patients with limited coronary artery disease. *Circulation.* 1987;75(4):723-732.

[PubMed](#) | [Link to Article](#)

- 20** Smith SC Jr, Feldman TE, Hirshfeld JW Jr, et al; American College of Cardiology/American Heart Association Task Force on Practice Guidelines; American College of Cardiology/American Heart Association/Society for Cardiovascular Angiography and Interventions Writing Committee to Update the 2001 Guidelines for Percutaneous Coronary Intervention. ACC/AHA/SCAI 2005 Guideline Update for Percutaneous Coronary Intervention—summary article: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (ACC/AHA/SCAI Writing Committee to Update the 2001 Guidelines for Percutaneous Coronary Intervention). *Circulation*. 2006;113(1):156-175.

[PubMed](#) | [Link to Article](#)

- 21** Cowper DC, Kubal JD, Maynard C, Hynes DM. A primer and comparative review of major US mortality databases. *Ann Epidemiol*. 2002;12(7):462-468.

[PubMed](#) | [Link to Article](#)

- 22** Sohn M-W, Arnold N, Maynard C, Hynes DM. Accuracy and completeness of mortality data in the Department of Veterans Affairs. *Popul Health Metr*. 2006;4(1):2.

[PubMed](#) | [Link to Article](#)

- 23** Xu S, Shetterly S, Powers D, et al. Extension of Kaplan-Meier methods in observational studies with time-varying treatment. *Value Health*. 2012;15(1):167-174.

[PubMed](#) | [Link to Article](#)

- 24** Snapinn S, Jiang QI, Iglewicz B. Illustrating the impact of a time-varying covariate with an extended Kaplan-Meier estimator. *Am Stat*. 2005;59(4):301-307.

[Link to Article](#)

- 25** Haddad RM, Kennedy CC, Caples SM, et al. Testosterone and cardiovascular risk in men: a systematic review and meta-analysis of randomized placebo-controlled trials. *Mayo Clin Proc*. 2007;82(1):29-39.

[PubMed](#)

- 26** Fernández-Balsells MM, Murad MH, Lane M, et al. Adverse effects of testosterone therapy in adult men: a systematic review and meta-analysis. *J Clin Endocrinol Metab*. 2010;95(6):2560-2575.

[PubMed](#) | [Link to Article](#)

- 27** Calof OM, Singh AB, Lee ML, et al. Adverse events associated with testosterone replacement in middle-aged and older men: a meta-analysis of randomized, placebo-controlled trials. *J Gerontol A Biol Sci Med Sci*. 2005;60(11):1451-1457.

[PubMed](#) | [Link to Article](#)

- 28** Shores MM, Smith NL, Forsberg CW, Anawalt BD, Matsumoto AM. Testosterone treatment and mortality in men with low testosterone levels. *J Clin Endocrinol Metab*. 2012;97(6):2050-2058.

[PubMed](#) | [Link to Article](#)

-
- 29** Suissa S. Immortal time bias in pharmaco-epidemiology. *Am J Epidemiol*. 2008;167(4):492-499.
[PubMed](#) | [Link to Article](#)
-
- 30** Ajayi AA, Mathur R, Halushka PV. Testosterone increases human platelet thromboxane A₂receptor density and aggregation responses. *Circulation*. 1995;91(11):2742-2747.
[PubMed](#) | [Link to Article](#)
-
- 31** Abbate R, Cioni G, Ricci I, Miranda M, Gori AM. Thrombosis and acute coronary syndrome. *Thromb Res*. 2012;129(3):235-240.
[PubMed](#) | [Link to Article](#)
-
- 32** Death AK, McGrath KC, Sader MA, et al. Dihydrotestosterone promotes vascular cell adhesion molecule-1 expression in male human endothelial cells via a nuclear factor-kappaB-dependent pathway. *Endocrinology*. 2004;145(4):1889-1897.
[PubMed](#) | [Link to Article](#)
-
- 33** McCrohon JA, Jessup W, Handelsman DJ, Celermajer DS. Androgen exposure increases human monocyte adhesion to vascular endothelium and endothelial cell expression of vascular cell adhesion molecule-1. *Circulation*. 1999;99(17):2317-2322.
[PubMed](#) | [Link to Article](#)
-
- 34** Pamukcu B, Lip GY, Devitt A, Griffiths H, Shantsila E. The role of monocytes in atherosclerotic coronary artery disease. *Ann Med*. 2010;42(6):394-403.
[PubMed](#) | [Link to Article](#)
-
- 35** Hoyos CM, Killick R, Yee BJ, Grunstein RR, Liu PY. Effects of testosterone therapy on sleep and breathing in obese men with severe obstructive sleep apnea: a randomized placebo-controlled trial. *Clin Endocrinol (Oxf)*. 2012;77(4):599-607.
[PubMed](#) | [Link to Article](#)
-
- 36** Drager LF, Polotsky VY, Lorenzi-Filho G. Obstructive sleep apnea: an emerging risk factor for atherosclerosis. *Chest*. 2011;140(2):534-542.
[PubMed](#) | [Link to Article](#)
-
- 37** Brambilla DJ, Matsumoto AM, Araujo AB, McKinlay JB. The effect of diurnal variation on clinical measurement of serum testosterone and other sex hormone levels in men. *J Clin Endocrinol Metab*. 2009;94(3):907-913.
[PubMed](#) | [Link to Article](#)
-
- 38** Petersen LA, Wright S, Normand SL, Daley J. Positive predictive value of the diagnosis of acute myocardial infarction in an administrative database. *J Gen Intern Med*. 1999;14(9):555-558.
[PubMed](#) | [Link to Article](#)
-
- 39** Niesner K, Murff HJ, Griffin MR, et al. Validation of VA administrative data algorithms for

identifying cardiovascular disease hospitalization. *Epidemiology*. 2013;24(2):334-335.

[PubMed](#) | [Link to Article](#)

40 Reker DM, Hamilton BB, Duncan PW, Yeh SC, Rosen A. Stroke: who's counting what? *J Rehabil Res Dev*. 2001;38(2):281-289.

[PubMed](#)