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New insights into ischemic heart disease in women

■ ABSTRACT

Coronary artery disease is different in women than in men in its pathogenesis, symptoms, and prognosis. Needed is a strategy for detecting and assessing coronary disease specifically in women. This review highlights recent evidence on sex differences in coronary artery disease.

■ KEY POINTS

Coronary artery disease is the leading cause of death in women, and more women than men die of it.

The prognosis after an acute myocardial infarction is worse in women than in men, possibly because women receive less aggressive treatment owing to atypical presentations.

Different risk factors and mechanisms of disease may be at work in women. When women with acute coronary syndromes undergo angiography, about half do not have any flow-limiting stenosis visible. Endothelial dysfunction and microvascular disease may account for ischemia in this situation.

Exercise stress electrocardiography does not appear to be as accurate in women as in men, but stress echocardiography and single-photon-emission computed tomography (SPECT) may be.

Research is needed to clarify how best to identify women at risk of coronary events and to assess those with suspected disease. Possible strategies involve measuring serum estrogen and testosterone concentrations, coronary calcium and atherosclerotic burden, vascular reactivity, and functional capacity.

ISCHEMIC HEART DISEASE appears to be substantially different in women than in men, and it is time to devise sex-specific strategies for detecting and assessing it. Compared with men, women have:

- As great a prevalence of coronary disease, at least in their older years
- A higher death rate from coronary disease
- Worse outcomes after acute coronary events
- Different pathophysiologic mechanisms of coronary disease
- Different presentations and risk factors.

Herein we summarize the current understanding of ischemic heart disease in women and challenges in detecting it.

■ THE LEADING CAUSE OF DEATH IN WOMEN

Coronary artery disease is the leading cause of death and disability in women in Western countries, responsible for nearly 250,000 deaths in women annually in the United States.¹ The US Centers for Disease Control and Prevention attributes 38% of deaths in women to coronary artery disease, compared with only 22% to cancer.²

The onset of disease is about 10 years later in women than in men. However, the preva-

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More women than men die of cardiovascular disease

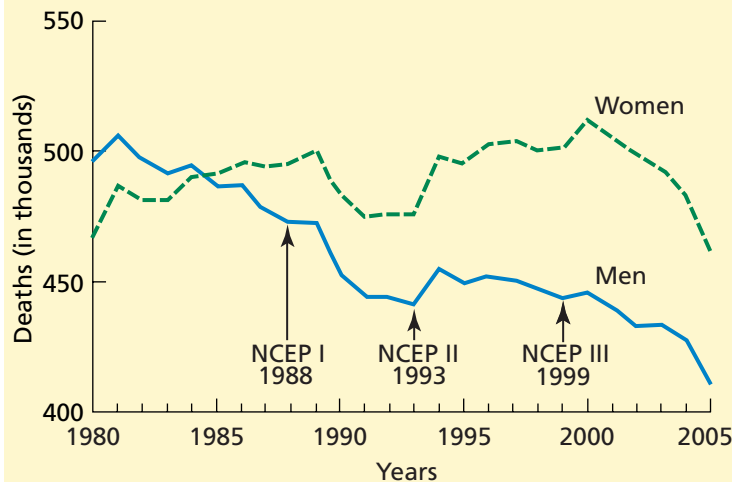


FIGURE 1. Cardiovascular disease deaths in the United States from 1979 through 2005 in women and men, highlighted by the introduction of new guidelines for cholesterol lowering from the National Cholesterol Education Panel (NCEP) I, II, and III.

FROM ROSAMOND W, FLEGAL K, FRIDAY G, ET AL. HEART DISEASE AND STROKE STATISTICS—2007 UPDATE. A REPORT FROM THE AMERICAN HEART ASSOCIATION STATISTICS COMMITTEE AND STROKE STATISTICS SUBCOMMITTEE. CIRCULATION 2007; 115:E69–E171. COPYRIGHT LIPPINCOTT WILLIAMS AND WILKINS, 2006.

lence in women increases rapidly after menopause and approaches that of men in the seventh decade of life.^{3–5}

■ WOMEN HAVE A WORSE PROGNOSIS

Advances in the diagnosis and treatment of coronary artery disease have reduced the cardiovascular death rate by 35% to 50% over the past decades, but the reduction among women has not matched that among men (FIGURE 1).^{6,7} Furthermore, although women have a lower incidence of acute coronary syndromes, they have a worse prognosis after an acute myocardial infarction than do men,^{8–10} with a mortality rate about twice as high (hazard ratio = 2.1; 95% confidence interval [CI] 1.1–3.9).¹⁰

■ WOMEN ARE TREATED DIFFERENTLY

One possible explanation for the poor cardiovascular prognosis among women is gender bias in the use of medical and interventional therapies.

Daly et al¹⁰ recently reported that women with stable angina were less likely than men to undergo exercise electrocardiography (odds ratio = 0.81; 95% CI 0.69–0.95) or coronary angiography (odds ratio = 0.59; 95% CI 0.48–0.72). Similarly, medical therapy (antiplatelet agents and statins) and revascularization procedures were used significantly less in women than in men, both at the time of the initial visit and 1 year later. Thus, only the most severely affected women underwent aggressive diagnostic testing and were treated.

■ CORONARY DISEASE IS DIFFERENT IN WOMEN

Compared with men, more women with coronary artery disease have atypical manifestations, and fewer of them have flow-limiting coronary stenosis at angiography.^{11–13}

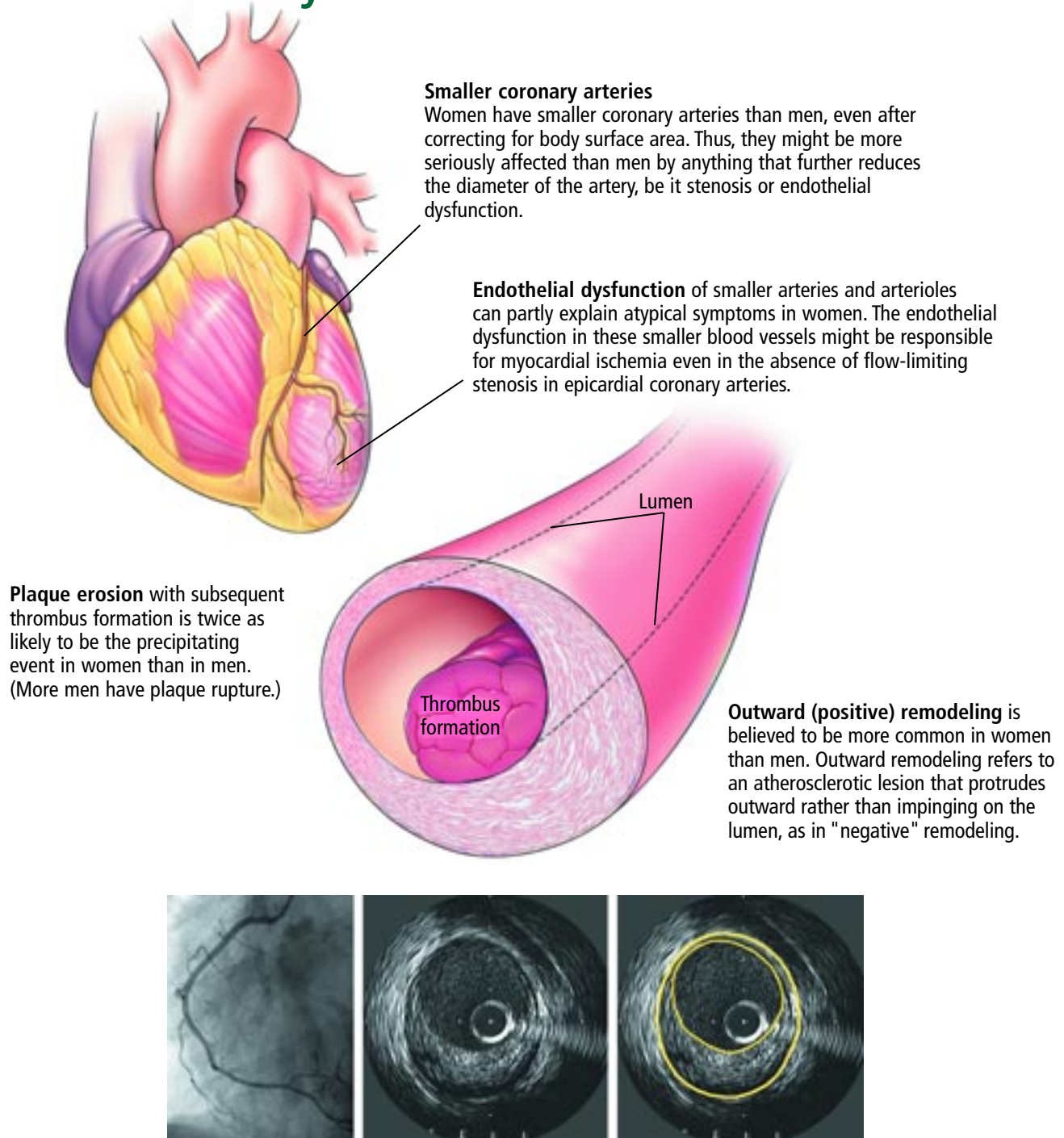
Less flow-limiting stenosis

Although donor hearts for cardiac transplantation show a similar prevalence of atherosclerotic lesions no matter if they come from male or female donors,¹⁴ numerous angiographic studies have shown less obstructive epicardial coronary artery disease in women than in their male counterparts.^{11–13} These differences were first reported several decades ago in the Coronary Artery Surgery Study registry and have persisted in current angiographic series.^{15,16}

In the Women's Ischemia Syndrome Evaluation (WISE) study,¹⁷ nearly 60% of women who underwent angiography to evaluate chest pain or an abnormal stress test result did not have a flow-limiting stenosis (defined as 50% or greater stenosis in more than one major epicardial coronary artery).¹³ Nevertheless, even without luminal narrowing, their symptoms persisted or worsened, and they suffered a worse outcome during the ensuing 4 to 5 years when compared with expected event rates in similarly aged women in the general population.¹³ Most of them also had stress test abnormalities, suggesting that their myocardial ischemia might be the result of microvascular disease or endothelial dysfunction, or both.¹⁸

Of 375,886 patients (45% women) who underwent coronary angiography in the American College of Cardiology's National Cardiovascular Registry, 12% to 35% of women

■ How coronary disease is different in women



Although many women with chest pain seem to have no obstructive stenosis on coronary angiography (left), intravascular ultrasonography reveals that lesions are indeed present but do not impinge on the lumen (middle and right images).

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FIGURE 2

TABLE 1

Effect of menopause on risk factors for cardiovascular disease

Lipid levels worsen

Total cholesterol levels increase
High-density lipoprotein cholesterol levels decrease

Prevalence increases

Hypertension
Metabolic syndrome

Outcome risk increases

Triglycerides
Diabetes mellitus
Obesity (body mass index ≥ 30)
Abdominal obesity (waist circumference > 35 inches)

ADAPTED FROM SHAW LJ, BAIREY MERZ CN, PEPINE CJ, ET AL. INSIGHTS FROM THE NHLBI-SPONSORED WOMEN'S ISCHEMIA SYNDROME EVALUATION (WISE) STUDY: PART I: GENDER DIFFERENCES IN TRADITIONAL AND NOVEL RISK FACTORS, SYMPTOM EVALUATION, AND GENDER-OPTIMIZED DIAGNOSTIC STRATEGIES. J AM COLL CARDIOL 2006; 47:S4-S20

and 32% to 65% of men ages 50 to 80 years presented with a flow-limiting stenosis ($P < .0001$). Similarly, flow-limiting stenoses are found in only about half of women undergoing cardiac catheterization for acute coronary artery syndromes.¹³

In contrast, rates of obstructive disease are similar for elderly women and men.¹⁹

Smaller coronary arteries

Women have smaller coronary arteries than men, even after correcting for body surface area.^{20,21} Thus, they might be more seriously affected than men by anything that further reduces the diameter of the artery, be it stenosis or endothelial dysfunction.

More outward remodeling

Although men and women have a similar amount of coronary plaque and calcification,²² pathology studies and intravascular ultrasonography reveal that outward ("positive") remodeling is more common in women than in men.²³ (Outward remodeling refers to atherosclerotic lesions that protrude outward (FIGURE 2) rather than impinging on the lumen, as in "negative" remodeling.)

Plaque erosion as the precipitating event

Another important sex difference is the mechanism of plaque disruption as the inciting

event in acute coronary syndromes. Arbustini et al²⁴ found that the precipitating event in women was twice as likely as in men to be plaque erosion with subsequent thrombus formation (37% for women vs 18% for men). In contrast, more men presented with plaque rupture (82% for men vs 63% for women).²⁴

More endothelial dysfunction

The atypical symptoms and worse prognosis for women with symptoms might be partly explained by endothelial dysfunction—inability of the arteries and arterioles to dilate, due to inability of the endothelium to produce nitric oxide, a relaxant of vascular smooth muscle. Dysfunctional endothelium within smaller arteries and arterioles might be responsible for myocardial ischemia even in the absence of flow-limiting stenosis in an epicardial coronary artery.^{25–28} The WISE group has recently reviewed this topic in detail.¹⁸

Several studies demonstrated that impaired endothelium-dependent vasomotor function of the coronary and brachial arteries is associated with long-term risk of cardiovascular events in women.^{25–28}

These preliminary findings require substantial validation as well as models to define a causal pathway between vascular dysfunction and cardiac symptom provocation.

CORONARY DISEASE IS DIFFICULT TO EVALUATE IN WOMEN

Evaluation of coronary artery disease in women is complicated by a greater burden of symptoms in stable chest pain syndromes, more functional disability,^{2,19} and a more frequent atypical presentation than in men.¹⁹ Furthermore, traditional tests for obstructive coronary artery disease are less sensitive and specific in female patients.^{12,29,30}

Women may have atypical or no prodromal symptoms

Although typical anginal symptoms appear to be equally accurate in identifying underlying coronary artery disease in men and women with acute coronary syndromes, prodromal symptoms in women are often atypical and

A reason for the poor prognosis in women may be gender bias in treatment

nonspecific and include fatigue, sleep disturbance, and dyspnea.³¹

Women with more frequent chest pain symptoms, including those associated with stressful circumstances and those occurring during activities of daily living or household tasks, should receive more intensive evaluation. Symptoms occurring at rest are also classified as more unstable. Additionally, women may accommodate their physical activity level to avert symptom provocation. Thus, clinicians should inquire about changes in activities of daily living when discussing a woman's symptom burden.

A recent National Heart, Lung, and Blood Institute consensus conference reported that 65% of women with coronary artery disease did not have typical angina.¹³ Additionally, up to 50% of the women presenting with an acute myocardial infarction report no prior chest pain.³² Similarly, more women than men with sudden cardiac death had no symptoms beforehand.¹

Symptoms at presentation are more similar for older women and men.³³

Traditional risk factors differ

Multivariable predictive models have revealed that traditional risk factors account for up to 70% of the variance in estimating cardiovascular events,³⁴ but this explanatory variation is less in women than in men.³⁵ In fact, substantial sex differences exist in the prevalence of traditional cardiovascular risk factors and in the clinical outcomes associated with them. For example:

- Smoking and hypertension are more prevalent among men.¹ When present, these factors generally pose the same degree of risk in women and men.
- Elevated triglyceride levels and low levels of high-density lipoprotein (HDL) cholesterol are more prominent and more potent independent risk factors for ischemic heart disease in women.^{5,36} (Elevated levels of total cholesterol and low-density lipoprotein cholesterol pose a similar relative risk in women and men.^{2,5})
- Cardiovascular mortality rates are nearly three times higher in diabetic women than in diabetic men.^{37–39}

Not your father's heart attack

Sex hormones

Estrogen loss
Hyperandrogenism
Polycystic ovarian syndrome



Cardiovascular risk factors

Risk factor clustering
(eg, metabolic syndrome)
Chronic inflammation



Risk markers for subclinical disease

Atherosclerotic plaque burden
Positive remodeling
(microvascular and macrovascular)



New-onset cardiac symptoms

Endothelial dysfunction
Impaired flow reserve
Regional hypoperfusion
(epicardial or subendocardial)



Progressive disease

Negative remodeling

FIGURE 3. Theoretical model of risk factors, subclinical disease risk markers, symptoms, and progressive disease states in women.

Cardiovascular mortality rates are nearly 3 times higher in diabetic women than in diabetic men

Novel risk factors

Several novel and evolving cardiovascular risk factors suggest that more women are at risk than are currently identified by routine clinical practice.

Abdominal obesity. Women with an androidal shape (ie, waist circumference greater than hip circumference, as opposed to the common “pear” shape of women) have an increased risk of coronary artery disease. In women, metabolically active abdominal fat⁴⁰ leads more frequently to insulin resistance^{40,41} and to higher levels of C-reactive protein, a generalized measure of inflammation^{2,11,42} than in nonobese women.

Metabolic syndrome. A growing body of evidence reveals that metabolic dysfunction plays a key role in placing a woman at risk for coronary artery disease and cardiac events.

The WISE study revealed that women with the metabolic syndrome had a higher risk of death and major cardiovascular events than those without metabolic syndrome or with normal metabolic status, and that this risk was independent of body mass index.⁴³

Low estrogen levels would logically seem to be a risk factor in women, in view of the greater prevalence of heart disease in women after menopause.^{2,3} Furthermore, certain traditional risk factors worsen or become prognostically more important after menopause (TABLE 1). However, estrogen replacement therapy does not seem to reduce cardiovascular risk in postmenopausal women with^{44,45} or without⁴⁶ existing coronary artery disease.

Elevated testosterone levels and polycystic ovary syndrome (PCOS). There is a strong link between PCOS and diabetes and the metabolic syndrome; however, the link between altered metabolism and increased coronary artery disease is less well defined.

Elevated C-reactive protein. As women have higher levels of inflammatory markers (eg, C-reactive protein) than men after the approximate age of 12 years, this milieu combined with a clustering of risk factors appears to be more atherogenic and may result in greater deposition of atherosclerotic plaque.⁴⁷

Recently, a global risk score was devised that includes the C-reactive protein level.⁴⁸ This risk score is similar to the Framingham Risk Score but adds C-reactive protein to the equation to estimate 10-year risk of cardiac death or myocardial infarction. This score, called the Reynolds Risk Score, resulted in substantial improvements in detecting risk in women, far better than the Framingham Risk Score alone.

Toward a new model of heart disease in women

Taken together, these findings emphasize the need for a better understanding of the sex-specific pathophysiology of coronary artery disease. We would like to propose a model of heart disease in women (FIGURE 3), emphasizing that it is a hypothesis that requires validation and that must be viewed within the limited scope and depth of current evidence. In our view, altered levels of sex hormones exacerbate or lead to other cardiovascular

risk factors in women. Atherosclerosis develops, but often with a pattern of outward remodeling. Acute coronary events may be due to endothelial dysfunction or to erosion and thrombosis of atherosclerotic plaques.

NEEDED: A BETTER WAY TO DETECT SUBCLINICAL DISEASE

Newer tests for atherosclerosis (eg, coronary artery calcium screening) and testing of endothelial function have some advantages over traditional risk assessment algorithms in women.

Coronary calcium screening. In 4,191 women and 6,186 men without symptoms who underwent electron beam computed tomography, coronary calcification was associated with a higher risk of death in women than in men at each level of calcification. At 5 ± 3.5 years of follow-up, 98.4% of women without coronary artery calcification were still alive, compared with 80% of women with extensive coronary calcification (ie, a score $> 1,000$, $P < .001$). Of note, calcium screening added incremental prognostic information over and above traditional risk factors for death from any cause in both women and men.⁴⁹

Endothelial function is assessed invasively or noninvasively.

Invasive assessment of endothelial function is determined by injecting acetylcholine into the coronary or brachial arteries. This testing has a demonstrated value in coronary artery disease assessment. An impaired response to an acetylcholine challenge has been shown to add independently to the prediction of death even after adjustment for confounders in women with and without epicardial coronary artery disease.

Noninvasive detection of endothelial dysfunction is measured using brachial artery reactivity testing.

Impaired coronary or brachial endothelial function is associated with reduced cardiovascular event-free survival.^{25–28} Bairey Merz et al¹⁹ summarized 15 studies of coronary and peripheral testing for endothelial dysfunction. The risk of cardiovascular events was 10 times higher (95% CI 7.8–12.8) if the test results were abnormal.

Half of women with acute MI have no prior chest pain symptoms

Furthermore, restoration of endothelial function is associated with improved outcomes. In a study of 400 hypertensive postmenopausal women, those who had an improvement in brachial flow-mediated vasodilatation of more than 10% in response to antihypertensive treatment had a rate of cardiovascular events that was one seventh that of women who had no response to treatment.²⁷

These findings are important, given that few therapies are available for women with vascular dysfunction. Additional research is needed to devise targeted treatment strategies for women.

■ ASSESSING ISCHEMIC DISEASE: WHAT WORKS, WHAT DOESN'T?

Stress electrocardiography may be less useful in women

Several studies found that exercise stress electrocardiography is of limited value in assessing inducible ischemia and risk in women.^{12,29,30} The reason often cited is that women cannot exercise as long as men and are therefore more likely to have an inconclusive study. However, guidelines still support its use as a diagnostic test for women with a normal resting 12-lead electrocardiogram who can perform maximal exercise.⁵⁰

A randomized trial is currently comparing exercise electrocardiography and exercise single-photon emission computed tomography (SPECT) for risk prediction.

Decreased functional capacity may predict bad outcomes

Recent evidence suggests that postmenopausal women have a greater decline in their ability to perform physical activity than men do,⁵¹ leading to a greater functional severity of ischemic heart disease in women upon presentation. Reduced functional capacity may predict bad outcomes.

The WISE investigators used a simple 12-item questionnaire called the Duke Activity Status Index (DASI) to estimate functional capacity.⁵² Women whose responses indicated they could not achieve 4.7 metabolic equivalents (METs) of work in activities of daily living had a risk of death or nonfatal myocardial infarction 3.7 times higher than that of women

Subendocardial perfusion is diminished in metabolic syndrome

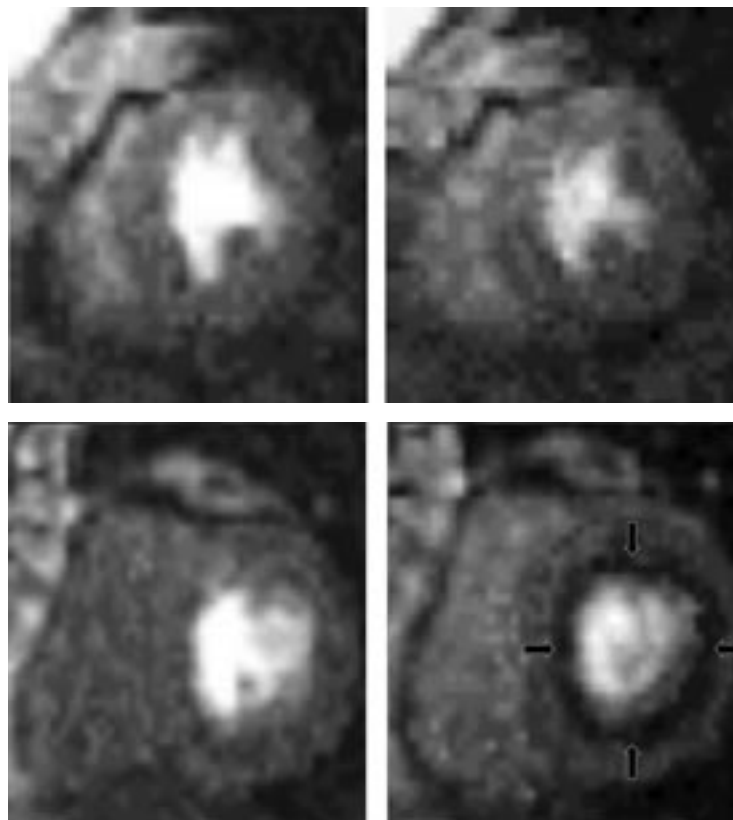


FIGURE 4. Top, cardiovascular magnetic resonance imaging in a control subject at rest (left) and during stress (right). Bottom, images in a patient with syndrome X at rest (left) and during stress (right)

FROM PANTING JR, GATEHOUSE PD, YANG GZ, ET AL. ABNORMAL SUBENDOCARDIAL PERFUSION IN CARDIAC SYNDROME X DETECTED BY CARDIOVASCULAR MAGNETIC RESONANCE IMAGING. N ENGL J MED 2002; 346:1948–1953. COPYRIGHT© 2002, MASSACHUSETTS MEDICAL SOCIETY.

reporting a better functional capacity.⁵² Almost two thirds of the cardiovascular events in the WISE cohort occurred in women who had an estimated capacity of less than 4.7 METs, and for every 1-MET increase in the DASI, the risk of major cardiovascular events decreased by 8% (hazard ratio = 0.92; 95% CI 0.85–0.99; $P = .02$). Low DASI scores correlated with impaired coronary flow reserve, perhaps due to a sedentary lifestyle in these women.⁵³

Stress echocardiography and SPECT may be good options in women

Large studies, including some that included more than 1,000 patients, indicate that stress echocardiography and SPECT imaging are as

accurate in women as in men,^{49,54-56} and a recent statement from the American Heart Association includes recommendations for cardiac imaging in women.⁵⁰

Shaw et al⁵⁴ performed a meta-analysis and estimated that women who had high-risk results on stress echocardiography or SPECT had a nearly 10-fold higher risk of cardiovascular death or myocardial infarction compared with women who had a low-risk or negative scan.

Metz et al⁵⁵ compared the rates of cardiac death or myocardial infarction in women and men with negative test results. Among patients with no inducible wall-motion abnormalities on exercise echocardiography, annual rates of cardiac events were 0.8% in women and 1.2% in men. Among patients with normal perfusion scans on exercise SPECT imaging, annual rates of cardiac events were 0.3% in women and 0.8% in men.

Therefore, both echocardiography and SPECT are highly accurate in predicting risk, with rates of cardiovascular events of less than 1% in patients with normal studies, increasing by as much as 10 times with a markedly abnormal study. Given this high rate of events, most clinical guidelines recommend referring patients for coronary angiography if they have a markedly abnormal scan. However, physicians should carefully exclude technical artifacts, especially in obese women, in whom the image quality may be impaired in both echocardiography and SPECT.

Which women should get an imaging test?

Previous guidelines recommended exercise electrocardiography in women with suspected ischemic heart disease, to be followed by selective cardiac imaging if the results are indeterminate or abnormal. Now, the American Heart Association⁵⁰ has revised these recommendations to identify women at risk who would benefit from initial testing with a cardiac imaging test. It now recommends the use of echocardiography or SPECT as an initial test for evaluation of suspected ischemic heart disease in women with symptoms and any of the following:

- Diabetes
- Functional impairment (ie, who cannot achieve at least 5 METs of exercise on a treadmill or stationary bicycle)

- Abnormal resting electrocardiogram.

Other women to receive an imaging test include those who present for evaluation of chest pain symptoms or their equivalents and who are at intermediate risk of coronary disease. This latter group would largely consist of women older than 55 years and those with multiple cardiac risk factors.

Intravascular ultrasonography, coronary reactivity, magnetic resonance imaging

If a woman experiences ischemic symptoms but has no flow-limiting stenoses on standard angiography, intravascular ultrasonography may document atherosclerosis within the arterial wall (FIGURE 2).

Additionally, with significant positive remodeling, impaired coronary flow reserve or endothelial dysfunction may occur more frequently and be the cause of a woman's symptoms. Testing for endothelial function in women without obstructive coronary artery disease at angiography is not routine.

Recently, in a small series, Panting et al⁵⁷ noted that women with symptoms and no obstructive coronary artery disease may be manifesting subendocardial ischemia (the initial manifestation of ischemia) as detected by cardiovascular magnetic resonance imaging (FIGURE 4). Thus, clinicians should verify that "true" ischemia may be occurring in women presenting with symptoms, even for those without obstructive coronary disease. True ischemia or symptoms may be the result of increased demand and impaired coronary flow reserve resulting in subendocardial ischemia.

We hope that additional clinical research will be undertaken to more clearly define the role of intravascular ultrasonography, magnetic resonance imaging, and testing of vascular function in risk detection in women and as a preamble to devising sex-specific targeted therapeutic strategies.

■ WHAT SHOULD DOCTORS DO NOW?

As strategies evolve over the next few years, physicians should consider the symptom burden in women as well as their functional abilities and quality of life as markers of the global burden of risk in females. Strategies aimed at diagnosing and treating a woman's athero-

Outward remodeling could hide extensive atherosclerosis in coronary arteries

sclerotic disease burden, with or without obstructive coronary artery disease, will be the aim of future diagnostic and therapeutic strategies aimed at risk reduction for women.

While we await this evidence, physicians should treat all women to optimal goals for risk factors and should not ignore cardiac symp-

toms, given credible evidence of ischemia, vascular dysfunction, or some other marker of atherosclerosis. Although treatment strategies are ill-defined for these women, at a minimum, focused risk-factor modification should be a short-term goal for women with nonobstructive coronary artery disease. ■

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