CYP450- and COMT-Derived Estradiol Metabolites Inhibit Activity of Human Coronary Artery SMCs


Abstract—The purpose of this study is to test the hypothesis that the inhibitory effects of estradiol in human coronary vascular smooth muscle cells are mediated via local conversion to methoxyestradiols via specific cytochrome P450s (CYP450s) and catechol-O-methyltransferase (COMT). The inhibitory effects of estradiol on serum-induced cell activity (DNA synthesis, cell number, collagen synthesis, and cell migration) were enhanced by 3-methylcholanthrene, phenobarbital (broad-spectrum CYP450 inducers), and β-naphthoflavone (CYP1A1/1A2 inducer) and were blocked by 1-aminobenzotriazole (broad-spectrum CYP450 inhibitor), Ellipticine, α-naphthoflavone (selective CYP1A1 inhibitors), and pyrene (selective CYP1B1 inhibitor), but not ketoconazole (selective CYP3A4 inhibitor) or furafylline (selective CYP1A2 inhibitor), abrogated the inhibitory effects of estradiol on cell activity, a profile consistent with a CYP1A1/CYP1B1-mediated mechanism. The inhibitory effects of estradiol were blocked by the COMT inhibitors OR486 and quercetin. The estrogen receptor antagonist ICI 182,780 blocked the inhibitory effects of estradiol, but only at concentrations that also blocked the metabolism of estradiol to hydroxysteradiols (precursors of methoxyestradiols). Western blot analysis revealed that coronary smooth muscle cells expressed CYP1A1 and CYP1B1. Moreover, these cells metabolized estradiol to hydroxyestradiols and methoxyestradiols, and the conversion of 2-hydroxyestradiol to 2-methoxyestradiol was blocked by OR486 and quercetin. These findings provide evidence that the inhibitory effects of estradiol on coronary smooth muscle cells are largely mediated via CYP1A1- and CYP1B1-derived hydroxysteradiols that are converted to methoxyestradiols by COMT. (Hypertension. 2003;41[part 2]:807-813.)

Key Words: hormones ■ menopause ■ estrogen ■ metabolism ■ coronary artery disease ■ remodeling ■ cardiovascular diseases

Estradiol protects the blood vessels against vasoocclusive disorders. In this regard, physiological concentrations of estradiol attenuate the development of atherosclerosis,1 decrease balloon injury–induced and allograft-induced vascular lesions1 and inhibit the proliferation of vascular smooth muscle cells (SMCs),2 a process that contributes to vascular pathology after vascular injury.1 Because the biological effects of estrogens are mediated by estrogen receptors (ERs), and arteries express both ERα and ERβ,1,3 the antivasoocclusive actions of estradiol are thought to be ER mediated. However, the recent findings that estradiol inhibits injury-induced lesion formation in arteries of mice lacking either ERα or ERβ,3 and inhibits injury-induced SMC proliferation in double knockout mice lacking both ERα and ERβ,6 challenge this concept. Thus, other mechanisms that do not involve ERs may participate in the vasculoprotective actions of estradiol.

We have recently shown that catecholestradiols and methoxyestradiols, endogenous metabolites of estradiol with little or no affinity for ERs, are potent inhibitors of SMC growth.5 Moreover, production of estradiol metabolites plays a key role in regulating growth of cancer cells.7 Therefore, it is possible that the vasculoprotective actions of estradiol are mediated in part by local (vascular) conversion of estradiol to metabolites that inhibit vascular lesion formation independently of ERs by exerting inhibitory effects on SMC migration, growth, and extracellular matrix production.

The metabolism of estradiol to catecholestradiols and methoxyestradiols is catalyzed by the sequential actions of cytochrome P450s (CYP450s)8 and catechol-O-methyltransferase (COMT).9 Multiple isoforms of CYP450 that are capable of metabolizing estradiol to hydroxysteradiols have been identified;7,8 however, it is not known which CYP450s mediate the ER-independent inhibitory effects of locally applied estradiol. In the present study, we investigated the enzymes involved in mediating the inhibitory effects of estradiol on human coronary artery SMCs.
Methods

SMC Cultures and Growth Studies
Human female coronary artery SMCs were purchased from Clonetics and cultured under standard tissue culture conditions as described previously. Studies were conducted using phenol red-free culture medium. Subconfluent SMCs were growth-arrested for 48 hours in the presence or absence of 10 μmol/L 3-methylcholantherene (3-MC), phenobarbital, or β-naphthoflavone. For H-thymidine incorporation, growth was initiated by treating growth-arrested cells for 20 hours with Dulbecco’s modified Eagle’s medium supplemented with steroid-free fetal calf serum (FCS; 2.5%) and containing or lacking fresh 3-MC, phenobarbital, or β-naphthoflavone in the presence or absence of various treatments or vehicle. After 20 hours of incubation, treatments were repeated with freshly prepared solutions but supplemented with H-thymidine (1 μCi/mL) for an additional 4 hours. Incorporation of H-thymidine in the acid-insoluble fraction was subsequently measured on a scintillation counter by our previously described method.

To measure cell number, SMCs were plated (5×10⁵ cells/well) and allowed to attach overnight. Cells were growth-arrested for 48 hours and subsequently treated every 24 hours for 4 days. On day 5, cells were dislodged by trypsinization and counted on a Coulter counter. In some experiments, cells were treated every 48 hours with estradiol, and then cells were dislodged and counted on days 4, 8, 12, and 16.

For H-proline incorporation, confluent monolayers of SMCs were growth-arrested for 48 hours in the presence or absence of 10 μmol/L 3-MC or phenobarbital. Collagen synthesis was stimulated by treating cells for 48 hours with 2.5% FCS in the presence of H-thymidine (1 μCi/mL) and 3-MC, phenobarbital, or β-naphthoflavone and with various other treatments. Incorporation of H-proline in the acid-insoluble fraction was subsequently measured on a scintillation counter by our previously described method. Moreover, confluent monolayers of SMCs were used to preclude the influence of changes in cell number.

Modified Boyden chambers were used to evaluate the effects of various treatments on 2.5% FCS-induced SMC migration, as previously described. To investigate the effects of CYP450 and COMT modulators, SMCs were pretreated with the respective modulators as described above under DNA synthesis.

Metabolism Studies
To assess whether SMCs can metabolize estradiol, SMCs grown to confluence in 75-cm² flasks and pretreated for 24 hours with or without 3-MC (10 μmol/L) or phenobarbital (10 μmol/L) were incubated with Dulbecco’s modified Eagle’s medium/F12 containing 1 μmol/L estradiol for 24 hours. After incubation, the medium and the cells were collected, and the samples were treated with acetone containing 1 mmol/L ascorbic acid. Subsequently, 2-fluoroestradiol (50 μmol/10 mL; internal standard) was added to each sample, and the metabolites, together with the internal standard, were extracted with dichloromethane. The dichloromethane was evaporated, and the residue was derivatized with trifluoroacetyl anhydride and analyzed by negative-ion gas chromatography–mass spectrometry (GC-MS).

Standards of the metabolites were extracted similarly along with the internal standards and were used to generate a standard curve.

To assess metabolism of catecholestradiols to methoxyestradiols, confluent monolayers of SMCs were incubated with 2-hydroxyestradiol for 4 hours, internal standard (16α-hydroxyestradiol) was added, samples were extracted with methylene chloride, extracts were dried under vacuum, residues were reconstituted in mobile phase, and samples were analyzed by high-performance liquid chromatography with UV detection using gradient elution.

CYP1A1 and CYP1B1 Expression Studies
To investigate whether the human coronary vascular SMCs express CYP1A1 and CYP1B1, cell lysates from cultured SMCs were analyzed by Western blotting and probed with antibodies to CYP1A1 (rabbit antihuman polyclonal antibodies; Chemicon International Inc) and CYP1B1 (rabbit antihuman polyclonal antibodies; Gentest Corp).

Statistics
Statistical significance (P<0.05) was assessed with ANOVA, Student t test, or Fisher least significant difference test.

Results
Trypan blue exclusion tests and MTT assay indicated no loss in viability of cells treated with various agents. Treatment of growth-arrested SMCs with 2.5% FCS induced DNA synthesis (H-thymidine incorporation), collagen synthesis (H-proline incorporation), proliferation (cell number), and cell migration.

Estradiol, 2-hydroxyestradiol, and 2-methoxyestradiol inhibited FCS-induced DNA synthesis (H-thymidine incorporation), collagen synthesis (H-proline incorporation), proliferation (cell number), and cell migration.

Estradiol, 2-hydroxyestradiol, and 2-methoxyestradiol inhibited FCS-induced DNA synthesis (Figure 1A), proliferation (Figure 1B), collagen synthesis (Figure 1C), and cell migration (Figure 1D) in the following order of potency (from most to least): 2-methoxyestradiol, 2-hydroxyestradiol, and estradiol. Physiological concentrations (1 nmol/L) of estradiol significantly inhibited FCS-induced increases in cell number. The inhibitory effects of estradiol increased with time of exposure. Treatment of SMCs with 1 nmol/L of estradiol for 4, 8, 12, and 16 days inhibited FCS-induced cell proliferation by 17%, 31%, 45%, and 68%, respectively.

To investigate whether the local metabolism of estradiol to metabolites by CYP450s is responsible for the growth inhibitory effects of estradiol, we studied the effects of estradiol in the presence and absence of modulators of CYP450s. Exposure of SMCs for 48 hours to CYP450 inducers (10 μmol/L 3-MC, 10 μmol/L phenobarbital, or 10 μmol/L β-naphthoflavone) and to a CYP450 inhibitor (0.1 to 10 μmol/L 1-aminobenzotriazole; ABT) did not influence FCS-induced DNA synthesis, cell proliferation, or collagen synthesis. However, the concentration-dependent effects of estradiol (1 to 100 nmol/L) on cell proliferation were significantly enhanced by 3-MC, phenobarbital (CYP450 inducers), and β-naphthoflavone (selective CYP1A1/
IA2 inducer). For example, the inhibitory effect of estradiol (1 nmol/L) on FCS-induced proliferation of SMCs on day 8 of the growth curve was enhanced from 29% to 51%, 56%, and 41% by the CYP450 inducers 3-MC, phenobarbital, and β-naphthoflavone, respectively (Figure 2). In contrast, the broad-spectrum CYP450 inhibitor ABT blocked the inhibitory effects of estradiol on cell proliferation, DNA synthesis, collagen synthesis, and cell migration (Figure 2).

Similar to ABT, the growth inhibitory effects of estradiol on DNA synthesis, cell proliferation, collagen synthesis, and cell migration were blocked in presence of ellipticine (selective CYP1A1 inhibitor, 10 μmol/L), pyrene (selective CYP1B1 inhibitor, 5 nmol/L), and α-naphthoflavone (selective CYP1A1 inhibitor, 10 μmol/L), but not ketoconazole (selective CYP3A4 inhibitor, 10 μmol/L) or furafylline (selective CYP1A2 inhibitor, 10 μmol/L) (Figure 3). Ellipticine, pyrene, and α-naphthoflavone abrogated the inhibitory effects of 100 nmol/L of estradiol on cell proliferation from 49% to 14%, 9%, and 19%, respectively.

To test further the hypothesis that metabolism of estradiol by CYP1A1 and CYP1B1 is responsible for mediating the inhibitory effects of estradiol in SMCs, we assayed the expression of CYP1A1 and CYP1B1. Human coronary artery SMCs expressed both CYP1A1 and CYP1B1 (Figure 4). Moreover, SMCs metabolized estradiol to 2- and 4-hydroxyestradiol and to 2- and 4-methoxyestradiol (Figure 4). Compared with SMCs grown in medium containing FCS alone, the expression of both CYP1A1 and CYP1B1 was increased in SMCs treated with 10 μmol/L of 3-MC and phenobarbital. Based on the densitometric analysis of the gels, the expression of CYP1A1 and CYP1B1 in response to 3-MC and phenobarbital was increased from 23 arbitrary units (AU) in controls to 34 AU (48% increase) and 35 AU (52% increase), respectively, for CYP1A1; and from 11 to 16.5 AU (50% increase) and 17 AU (54.5% increase), respectively, for CYP1B1. In SMCs pretreated with 3-MC and phenobarbital, the formation of 2- and 4-hydroxyestradiol and 2-and 4-methoxyestradiol was significantly induced.

Compared with SMCs treated with phenobarbital, the formation of 2-methoxyestradiol was significantly higher in SMCs stimulated with 3-MC. Moreover, compared with 4-methoxyestradiol, the conversion of estradiol to 2-methoxyestradiol was significantly greater in presence of both 3-MC and phenobarbital.

Similar to the CYP450 inhibitors, the inhibitory effects of estradiol on DNA synthesis, cell proliferation, collagen synthesis, and cell migration were blocked by the COMT inhibitors quercetin and OR486 (Figure 5). The CYP450 inhibitor ABT and the COMT inhibitors quercetin and OR486 also blocked the enhanced inhibitory effects of estradiol observed in the presence of CYP450 inducers, 3-MC and phenobarbital, on DNA synthesis, cell proliferation, and collagen synthesis (data not shown). ICI 182,780, an ER antagonist, blocked the inhibitory effects of estradiol on DNA synthesis in a concentration-dependent manner (Figure 5). The lowest concentration of ICI 182,780 that significantly attenuated the inhibitory effects of 1 μmol/L estradiol was 10
μmol/L, and at a concentration of 50 μmol/L, ICI 182,780 completely blocked the inhibitory effects of 1 μmol/L estradiol (Figure 5). Compared with ICI 182,780, ABT, quercetin, and OR486 were more potent in antagonizing the inhibitory effects of estradiol (Figure 5). Quercetin and OR486 also blocked the inhibitory effects of estradiol on collagen synthesis, cell number, and cell migration (Figure 5).

The inhibitory effects of 2-hydroxyestradiol, but not 2-methoxyestradiol, on SMC proliferation, DNA synthesis, collagen synthesis, and cell migration (Figure 6) were completely prevented by quercetin and OR486, competitive inhibitors of COMT.3,9 In contrast to quercetin and OR486, ICI 182,780 (50 μmol/L) did not block the growth inhibitory effects of either 2-hydroxyestradiol or 2-methoxyestradiol (Figure 6).

Human coronary artery SMCs metabolized 2-hydroxyestradiol to 2-methoxyestradiol, and this metabolism was blocked by quercetin and OR486, but not ICI 182,780 (Figure 7A). Concentrations of ICI 182,780 greater than 1 μmol/L ICI 182,780 inhibited the metabolism of estradiol to 2- and 4-hydroxyestradiol by human lymphoblastoid cells expressing CYP1A1 and by supersomes expressing human CYP1B1 (Figure 7B). Compared with quercetin, OR486, ABT, or pyrene, much higher concentrations (>10 μmol/L) of ICI 182,780 were required to block the inhibitory effects of estradiol on SMC growth (Figure 5). Moreover, 1 μmol/L ICI 182,780 was unable to block the inhibitory effects of 1 nmol/L estradiol; yet, 50 μmol/L ICI 182,780 was able to block the inhibitory effects of 50 nmol/L estradiol, even though the estradiol-to-ICI 182,780 ratio was 1:1000 in both cases (Figure 7C).

**Discussion**

The purpose of the present study was to test the hypothesis that in human coronary artery SMCs, sequential conversion of estradiol to methoxyestradiols by CYP450s and COMT, respectively, mediates in part the inhibitory effects of estradiol on human coronary SMC activity (DNA synthesis, cell number, collagen synthesis, and cell migration). In support of this hypothesis, we observed that (1) 2-methoxyestradiol and its precursor, 2- hydroxyestradiol, are more potent than estradiol in inhibiting SMC activity; (2) the inhibitory effects of estradiol on SMC activity are enhanced by CYP450
hydroxylated by CYP3A4 and CYP1A2; therefore, it is
pressed CYP1A1 and CYP1B1.

The metabolism of 2-hydroxyestradiol (5/H9262
OR486 (OR; 10^mol/L) to
2-methoxyestradiol (2-ME) by coronary artery SMCs. Values are 
mean±SEM from 3 separate cultures. B, Concentration-
dependent inhibitory effects of ICI 182,780 on the metabolism of 
estradiol to 2- and 4-hydroxyestradiol by human lymphoblas-
toma cells expressing CYP1A1 and by insect supersomes 
expressing human CYP1B1. C, Antagonistic effects of concen-
trations of ICI 182,780 (ICl) that inhibit estradiol (βE) metabolism 
(50 μmol/L) and do not inhibit estradiol metabolism (1 μmol/L) 
on the inhibitory effects of 1 and 50 nmol/L estradiol, respec-
tively, on FCS-induced proliferation of SMCs. The ratio of estradi-
ol and ICI 182,780 was 1:1000 under both treatment condi-
tions. The data are presented as percentage of control, where 100%
 is defined as the increase in cell number in response to 
FCS alone. *P<0.05 vs SMCs treated with FCS alone; §P<0.05, 
reversal of the inhibitory effects of estradiol. inducers; (3) the inhibitory effects of estradiol are abolished by 
a broad-spectrum CYP450 inhibitor; (4) the inhibitory 
effects of estradiol are blocked by selective inhibitors of 
CYP1A1 and CYP1B1, enzymes that metabolize estradiol to hydroxyestradiols; and (5) cultured SMCs metabolized estradiol to hydroxyestradiols and methoxyestradiols.

An important aspect of the current study is elucidation of 
the CYP450 isozymes involved in converting estradiol to 
inhibitory metabolites. Hydroxylation of estradiol is mediated 
mostly by CYP1A1 and CYP1B1 and contributes to >50% of 
the all the metabolites formed.7,8 Although our data with ABT 
are consistent with the involvement of CYP1A1 and CYP1B1 
in the conversion of estradiol to inhibitory metabolites, 
studies with ABT cannot preclude the contribution of other 
isoenzymes because ABT is a broad-spectrum CYP450 inhibi-
tor. However, our findings that the inhibitory effects of 
estradiol are blocked by ellipicine and pyrene, selective 
inhibitors of CYP1A1 and CYP1B1, respectively,11 together 
with the fact that CYP1A1 and CYP1B1 metabolize estradiol 
to 2- and 4-hydroxyestradiol (which are both inhibitory 
estradiol metabolites), provides strong evidence that the 
inhibitory effects of estradiol are mediated primarily by 
CYP1A1 and CYP1B1. This contention is further supported 
by the findings that the inhibitory effects of estradiol are 
enhanced by exposure to β-naphthoflavone, a selective 
ducer of CYP1A1,8 and that human coronary SMCs ex-
pressed CYP1A1 and CYP1B1.

In addition to CYP1A1 and CYP1B1, estradiol can also be 
hydroxylated by CYP3A4 and CYP1A2;1,7,8 therefore, it is 
possible that these CYP450 isozymes also contribute to 
conversion of estradiol to inhibitory metabolites. However, 
our finding that the inhibitory effects of estradiol are not 
blocked by ketoconazole, a CYP3A4 inhibitor, or by furafyll-
line, a CYP1A2 inhibitor, suggests that these isozymes do not 
play a major role in mediating the inhibitory effects of 
estradiol.

The hypothesis that conversion of estradiol to meth-
oxyestradiols mediates in part the inhibitory effects of 
estradiol on SMC growth is also supported by the observation 
that the inhibitory actions of 2-hydroxyestradiol, but not 
2-methoxyestradiol, on SMCs are attenuated by the COMT 
inhibitors quercetin and OR486.3,9 drugs that have no binding 
affinity for ERs.1 In this regard, both quercetin and OR486 
also decrease the inhibitory effects of estradiol on human 
coronary SMCs. On the other hand, even high concentrations 
of the ER antagonist ICI 182,780 do not block the inhibitory 
effects of either 2-hydroxyestradiol or 2-methoxyestradiol. 
This is strong evidence that the metabolism by COMT of 
2-hydroxyestradiol to 2-methoxyestradiol mediates the inhib-
itory effects of 2-hydroxyestradiol. Moreover, these results 
indicate that the inhibitory effects of 2-hydroxyestradiol and 
2-methoxyestradiol are ER-independent, as would be anticip-
ted because of the low affinity of hydroxyestradiols and 
methoxyestradiols for ERs. The hypothesis that the inhibitory 
effects of estradiol are due to its conversion to methoxyesta-
diols is further supported by our observation that human 
coronary SMCs metabolize 2-hydroxyestradiol to 
2-methoxyestradiol, and this metabolic step is blocked by 
quercetin and by OR486. Equally importantly, human vascu-
lar SMCs metabolize estradiol to 2- and 4-methoxyestradiol, 
and the formation of these metabolites is enhanced by 
CYP450 inducers 3-MC and phenobarbital.

High concentrations of the ER antagonist ICI 182,780 
block the inhibitory effects of estradiol on SMCs. This result 
is at odds with our hypothesis that methoxyestradiols mediate 
the growth inhibitory actions of estradiol. However, because 
the molecular structure of ICI 182,780 resembles estradiol, it 
is likely that ICI 182,780 competes with estradiol for 
CYP450s and blocks the metabolism of estradiol. This 
contention is supported by our finding that in human lympho-
blastoid cells expressing CYP1A1, ICI 182,780 inhibited 
the metabolism of estradiol to catecholestradiols. Thus, 
the inhibitory effects of ICI 182,780 may be mediated either via 
antagonism of ERs or by inhibition of estradiol metabolism. 
In this regard, it is important to note that the blockade of 
estradiol-induced inhibition by ICI 182,780 is independent of 
the estradiol-to-ICI 182,780 ratio, but rather is dependent on 
whether the concentration of ICI 182,780 inhibits estradiol 
metabolism. The potential that ICI 182,780 may block the 
inhibitory effects of estradiol by inhibiting COMT can also be 
ruled out, as it blocked the inhibitory effects of estradiol, but 
not 2-hydroxyestradiol or 2-methoxyestradiol. Moreover, in 
contrast to quercetin and OR486, ICI 182,780 failed to inhibit 
the conversion of 2-hydroxyestradiol to 2-methoxyestradiol. 
These findings support the conclusion that ICI 182,780 
blocks the inhibitory effects of estradiol on coronary artery 
SMCs by preventing the metabolism of estradiol to catecho-
lestradiols, the precursors of methoxyestradiols.
Although our findings provide evidence that the inhibitory effects of estradiol are mediated by methoxyestradiols, the relative role of 2- and 4-methoxyestradiols in mediating these effects still remains unresolved. CYP1A1 largely converts estradiol to 2-hydroxyestradiol, and CYP1B1 largely metabolizes estradiol to 4-hydroxyestradiol. Thus, the inhibitory effects of estradiol are likely mediated via both 2- and 4-methoxyestradiol. However, the finding that the conversion of estradiol to 2-methoxyestradiol was significantly greater than its conversion to 4-hydroxyestradiol suggests that the antimitogenic effects of estradiol are largely 2-methoxyestradiol-mediated. This contention is further supported by our previous finding that 2-methoxyestradiol is more potent than 4-methoxyestradiol in inhibiting SMC growth and by the finding that estradiol is metabolized endogenously to 2-methoxyestradiol, whereas the levels of 4-methoxyestradiol are low. It is unclear why the inhibitory effects of estradiol are enhanced to similar extent by 3-MC and phenobarbital, even though the formation of 2-methoxyestradiol is far greater in SMCs treated with 3-MC compared with phenobarbital. In this regard, it is possible that maximal inhibition of SMC growth is achieved at concentrations of 2-methoxyestradiol attained in response to phenobarbital; therefore, any increase beyond such levels by 3-MC cannot further enhance the effects of estradiol. Alternatively, 3-MC may inhibit the catabolism of 2-methoxyestradiol, which may result in a greater accumulation of 2-methoxyestradiol by 3-MC compared with phenobarbital. It is also plausible that 4-methoxyestradiol, which is induced to a similar extent by 3-MC and phenobarbital, is the important metabolite that mediates the antimitogenic effects of estradiol. Finally, differences in the experimental conditions (cell number, cell density, time of treatment, concentration of estradiol, presence or absence of serum) for the metabolism of estradiol and that individual differences, both genetic and acquired, in the local vascular metabolism of estradiol could determine a particular woman’s risk of coronary artery disease. Moreover, genetic or acquired differences in estradiol metabolism may determine the cardiovascular benefits a woman receives from estradiol replacement therapy in the postmenopausal state. Finally, our results also imply that nonfeminizing estradiol metabolites may afford cardiovascular protection regardless of gender.

Perspectives

The present study provides evidence that estradiol inhibits the activity of human coronary artery SMCs via the local metabolism of estradiol to methoxyestradiols by CYP1A1/CYP1B1 and COMT. Our results suggest that estradiol metabolism within the coronary artery may be an important determinant of the cardiovascular protective effects of circulating estradiol and that individual differences, both genetic and acquired, in the local vascular metabolism of estradiol could determine a particular woman’s risk of coronary artery disease. Moreover, genetic or acquired differences in estradiol metabolism may determine the cardiovascular benefits a woman receives from estradiol replacement therapy in the postmenopausal state. Finally, our results also imply that nonfeminizing estradiol metabolites may afford cardiovascular protection regardless of gender.

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References

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