Sex Differences in Cardiovascular Risk Factors for Dementia

Mi-Young Kim1,†, Kyeongjin Kim1,†, Chang Hyung Hong2,3, Sang Yoon Lee4 and Yi-Sook Jung1,5,*

1College of Pharmacy, Ajou University, Suwon 16499,
2Department of Psychiatry, Ajou University School of Medicine, Suwon 16499,
3Institute on Aging, Ajou University Medical Center, Suwon 16499,
4Department of Biomedical Sciences, Chronic Inflammatory Disease Research Center, Ajou University School of Medicine, Suwon 16499,
5Research Institute of Pharmaceutical Sciences and Technology, Ajou University, Suwon 16499, Republic of Korea

Abstract

Dementia, characterized by a progressive cognitive decline and a cumulative inability to behave independently, is highly associated with other diseases. Various cardiovascular disorders, such as coronary artery disease and atrial fibrillation, are well-known risk factors for dementia. Currently, increasing evidence suggests that sex factors may play an important role in the pathogenesis of diseases, including cardiovascular disease and dementia. Recent studies show that nearly two-thirds of patients diagnosed with Alzheimer’s disease are women; however, the incidence difference between men and women remains vague. Therefore, studies are needed to investigate sex-specific differences, which can help understand the pathophysiology of dementia and identify potential therapeutic targets for both sexes. In the present review, we summarize sex differences in the prevalence and incidence of dementia by subtypes. This review also describes sex differences in the risk factors of dementia and examines the impact of risk factors on the incidence of dementia in both sexes.

Key Words: Sex difference, Dementia incidence, Dementia prevalence, Cardiovascular risk factors

INTRODUCTION

Dementia is a chronic, progressive, and multifactorial neurodegenerative disorder characterized by cognitive decline. It has been a major public health problem, with 36 million people worldwide estimated to have dementia, and the global prevalence of dementia is expected to increase to more than 80 million by 2040 (Ferri et al., 2005). In addition to the substantial burden on patients and their families, dementia also affects the healthcare system worldwide. As a result, the high demand for medical care and treatment need for cumulative cognitive decline will have significant socioeconomic impacts.

Dementia has been demonstrated to be highly related to various risk factors, including age and many diseases. For example, various cardiovascular disorders (CVD), such as atrial fibrillation (AF) (Ott et al., 1997), heart failure (HF) (Qiu et al., 2006), and hypertension (HTN) (Kivipelto et al., 2001), are well-known risk factors for dementia; therefore, prevention of these diseases can help reduce the burden of dementia on people and the healthcare system (Wu et al., 2016). In fact, several cardiovascular (CV) drugs have been reported to reduce the risk of dementia (Kim et al., 2016; Mangmool et al., 2017; Xiao et al., 2017).

Increasing evidence indicates that sex factors can play an important role in the pathogenesis of diseases, including CVD and dementia. According to recent reports, almost two-thirds of patients with Alzheimer’s disease (AD), the most common type of dementia, are women (Hebert et al., 2013). However, the incidence studies suggest that sex differences in AD are still controversial. The Cache County Study in the United States (US) indicates a greater incidence of AD in men than in women before age 78, after which men have a lower incidence than women (Lethbridge et al., 2013). Notably, sex differences in the incidence of AD are not observed in most studies conducted in the US (Kukull et al., 2002). Therefore, it is critical to understand sex-related differences in the incidence of dementia, and the results would help to delineate the pathophysiology of dementia and suggest potential therapeutic strategies for men and women.

In this review, we discuss sex differences in the prevalence...
and/or incidence of different subtypes of dementia. Sex differences in various CVDs, well-known risk factors for dementia, are also summarized. In addition, we review the impact of risk factors on the incidence of dementia in men and women.

DEMENTIA IN MEN AND WOMEN

Incidence and prevalence are common terms used to describe disease epidemiology. In medicine, the incidence is generally the case for newly identified diseases and the frequency of disease is the actual number of cases alive. Thus, to explain the etiology of disease, incidence is more usually used than prevalence. The prevalence of AD has been shown to be significantly higher in women than in men (Mielke et al., 2014). The Italian Cohort study on dementia indicates that women account for more than 70% in a total of 213 consecutive dementia patients (Musicco, 2009). However, this clinical observation cannot be simply interpreted as a high dementia risk in women because the prevalence is determined by both the incidence of disease and the post-onset survival duration (Hebert et al., 2003). Despite the well-known great prevalence of AD in women, epidemiologic studies examining the incidence of AD suggest a different result of sex differences. Sex differences in the incidence of dementia seem to be complicated because many diseases can cause dementia (Muscioc, 2009). Thus, although some subtypes of dementia may occur more frequently in women, the sex differences may not always apply to AD. In addition, the prevalence can increase as a function of disease duration. Indeed, AD is a long-lasting disease, and many patients die from other causes during illness. Because the average life expectancy is longer in women than in men, more women, especially at the older ages, survive with AD. Therefore, sex-specific risks of dementia should be considered from the studies that focus on incidence but not on prevalence.

Many incidence studies carried out in Europe and the US are available in the scientific literature. Most of these studies have analyzed small populations, and the findings of sex differences show considerable variability. One large meta-analysis demonstrates that the risk of AD increases 1.6-fold in women (Gao et al., 1998), but the results have not been confirmed in recent US studies, which indicate the same incidence in both sexes. Fig. 1 shows the age- and sex-specific dementia incidence rates in studies in the US, Europe, and Asia. The incidence of dementia is higher in women especially aged more than 90 years in Europe and Japan. However, studies in the US and Canada show a little difference in the incidence between men and women. These results, although not well explained by methodological differences, suggest that some types of premorbid exposures, causally related to AD, and different patterns in various regions in the world may play different roles in both sexes.

Sex differences in prevalence also depend on dementia subtypes, such as AD, Lewy body dementia (LBD), vascular dementia (VD), and Parkinson’s dementia (PD). For example, women have a higher risk of developing AD, and men have a higher risk of developing VD (Podcasy and Epperson, 2016). Table 1 summarizes the sex differences in prevalence/incidence of different subtypes of dementia. AD is shown to be the most common form of dementia, accounting for up to 60-80% of dementia cases. Progression of AD may be more rapid among elderly women, but studies from the US and the United Kingdom (UK) demonstrate that women with AD have a longer lifespan (Kua et al., 2014). Women are frequently diagnosed earlier with AD than men, which can determine their
postdiagnosis longevity. It is becoming increasingly important to consider sex together with other risk factors (such as apo-
lipoprotein E genotype and depression) for dementia. The
development of AD in women at a later age has been associ-
ated with a longer lifetime exposure to estrogens (Lin et al.,
2011). However, women show a marked decrease in estradiol
levels in the second half of menopause, while age-matched
men retain either a lifelong gonadal steroid level or a relatively
slower decline in testosterone synthesis (Mielke et al.,
2014). VD is reported to account for 10-20% of dementia cases
and results from hemorrhagic or ischemic insults in some regions
of the brain, which is critical for cognitive functions (Gorelick et al.,
2011). Studies conducted worldwide indicate that the
prevalence of stroke, either ischemic or hemorrhagic stroke, is 44%
higher in men than in women. However, other studies demonstrate
that women have a greater risk for stroke possi-
bly because of their longer life span and increased risk of
thrombosis and stroke with AF (Cheng and Kong, 2016). LBD
is clinically distinguished from Parkinson’s dementia because
the onset of dementia precedes the onset of parkinsonism.
The pathology of LBD is known as an abnormal deposition of α-synuclein, known as Lewy body. Autopsy analysis of patients
who died with dementia reveals that Lewy bodies are shown
almost three times more often in men than in women, regard-
less of age, smoking, or education (Nelson et al., 2010). PD is
a movement disorder characterized by tremor at rest, rigidity,
and difficulty with speech, and loss of midbrain dopaminergic
neurons in the substantia nigra is known to be the main cause of dis-
ease. The prevalence of PD is known to be between 0.3% and
3% of the population worldwide and is 2 times higher in men
than in women at any given age (Elbaz et al., 2002). Among
individuals who are treated in the early stages of PD, women
are better in cognitive functioning than men (Augustine et al.,
2015). Dementia from multiple causes (mixed dementia) is re-
ferred as cognitive impairment due to multiple central nervous
system pathologies, which are most often a combination of AD
pathology, β-amyloid deposits, and vascular damage, such as
multiple microbleeds or infarcts (Jellinger, 2013). According to
autopsy reports, vascular damage occurs in up to 28% of AD
cases (Gearing et al., 1995). Creutzfeldt-Jakob disease (CJD)
primarily occurs in individuals aged more than 60 years world-
wide. Although little is known about the pathophysiology of the
disease, researchers believe that the disease is caused by
prions or misfolded proteins, which aggregate in the brain and
lead to neuronal death and progressive dementia. The cases
of CJD do not vary by sex, and no differences in the survival
time after diagnosis are observed between men and women
(Gubbels et al., 2012).

### SEX DIFFERENCES IN CARDIOVASCULAR RISK FACTORS FOR DEMENTIA

Various CV disorders, such as coronary artery disease (CAD), AF, myocardial infarction (MI), HF, and HTN are known
risk factors for dementia. Table 2 presents sex differences in
the prevalence and incidence of these CV disorders. In addi-
tion, as shown in Table 3, the sex differences in the impact
of CV disorders on the incidence of dementia are discussed here.

### Coronary artery disease

CAD usually results from atherosclerosis and causes chest
pain, shortness of breath during exercise, and heart attack.
According to data from National Health and Nutrition Exami-
nation Survey (NHANES) 2011 to 2014 (National Center for

---

Table 1. Effects of sex on prevalence/incidence of dementia subtypes

<table>
<thead>
<tr>
<th>Subtypes of dementia</th>
<th>Sex differences in prevalence/incidence</th>
<th>References</th>
</tr>
</thead>
</table>
| Alzheimer disease (AD) | • Accounts for 60%-80% of dementia cases  
  • Lifetime risk of AD in women is almost twice that of men  
  • Men with AD have a shorter lifespan, regardless of age at diagnosis | Seshadri et al., 1997  
  Kua et al., 2014 |
| Vascular dementia (VD) | • Accounts for 10%-20% of dementia cases  
  • Risk factors for vascular or multi-infarct dementia  
  • More common in males than in females; greater severity of impact in females than in males | Appelros et al., 2009  
  Pendlebury and Rothwell, 2009 |
| Lewy body dementia (LBD) | • Extensive overlap with Parkinson disease dementia  
  • Greater incidence in males than in females (4.8 vs 2.2)  
  • More rapid cognitive decline in males than in females | Nelson et al., 2010  
  Savica et al., 2013 |
| Parkinson disease dementia (PD) | • Higher prevalence in males than in females  
  • Earlier onset of Parkinson disease dementia in males  
  • Greater severity of cognitive decline in males | Elbaz et al., 2002  
  Gillies et al., 2014  
  Augustine et al., 2015 |
| Due to multiple causes (mixed dementia) | • Prevalence differs greatly depending upon age and study but is 1.3% according to a recent systematic review  
  • Almost twice as common in men as in women aged > 60, although other studies suggest equal frequency in males and females | Martin-Laeez et al., 2016  
  Siraj, 2011 |
| Creutzfeldt-Jakob disease (CJD) | • Rare: 1.26 cases/million people.  
  • Sex differences in prevalence and clinical course have not been reported | Gubbels et al., 2012  
  Skillback et al., 2014 |

Modified from Podcasy and Epperson (2016).
Table 2. Sex differences in prevalence/incidence of cardiovascular diseases which are known as dementia risk factor

<table>
<thead>
<tr>
<th>CV Risk factors</th>
<th>Sex differences in prevalence/incidence/prognosis</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coronary artery</td>
<td>• Higher prevalence in males than in females for all ages</td>
<td>Bairey Merz et al., 2006</td>
</tr>
<tr>
<td>disease (CAD)</td>
<td>• CAD first presents approximately 10 years later in women than in men, most commonly after menopause</td>
<td>Shaw et al., 2006</td>
</tr>
<tr>
<td></td>
<td>• More annual incidence of all coronary events in men than in women aged &lt;65 years</td>
<td>Lerner and Kannel, 1986</td>
</tr>
<tr>
<td></td>
<td>• Women with CAD have worse outcomes than their male counterparts</td>
<td>Davis et al., 2015</td>
</tr>
<tr>
<td>Atrial fibrillation</td>
<td>• The age-adjusted prevalence of AF is reported to be higher in men</td>
<td>Chugh et al., 2014</td>
</tr>
<tr>
<td>(AF)</td>
<td>• Higher incidence rates in males than in females.</td>
<td>Heeringa et al., 2006</td>
</tr>
<tr>
<td></td>
<td>• Lifetime risk of developing AF is slightly lower in women than in men</td>
<td>Svensberg et al., 2015</td>
</tr>
<tr>
<td></td>
<td>• Mortality associated with AF is higher in females overall</td>
<td>Piccini et al., 2012</td>
</tr>
<tr>
<td>Myocardial infarction</td>
<td>• Lower incidence rate in women than in men, except among very old people ≥69 years</td>
<td>Albrektsen et al., 2016</td>
</tr>
<tr>
<td>(MI)</td>
<td>• By age groups, males have a higher prevalence of MI than females</td>
<td>de Torbal et al., 2006</td>
</tr>
<tr>
<td></td>
<td>• Men have roughly twice the risk of MI compared with women</td>
<td>Benjamin et al., 2018</td>
</tr>
<tr>
<td></td>
<td>• Women have been found to have worse short-term prognosis than men</td>
<td>Malafrida et al., 1998</td>
</tr>
<tr>
<td>Heart failure (HF)</td>
<td>• Prevalence is higher in men than in women</td>
<td>Bleumink et al., 2004</td>
</tr>
<tr>
<td></td>
<td>• Incidence rates are on average approximately two times higher in men than in women in each age category</td>
<td>Adams et al., 1996</td>
</tr>
<tr>
<td></td>
<td>• Women are found to have a lower mortality than men</td>
<td>Burns et al., 1997</td>
</tr>
<tr>
<td>Hypertension (HTN)</td>
<td>• HTN prevalence tends to be higher in women</td>
<td>Roger et al., 2011</td>
</tr>
<tr>
<td></td>
<td>• During early adulthood, women have lower systolic BP than men, but after the age of 60 years, the opposite is the case</td>
<td>Ostchega et al., 2008</td>
</tr>
<tr>
<td></td>
<td>• Even though BP control improves with time in women and men, fewer women than men have controlled BP levels despite treatment</td>
<td>Lloyd-Jones et al., 2005</td>
</tr>
</tbody>
</table>

IR: incident rate, BP: blood pressure.

Health statistics in the US, the prevalence of CAD is higher in men than in women for all ages, 7.4% for men and 5.3% for women (Kivipelto et al., 2001). However, women with CAD show worse outcomes than men do when no adjustments are made for other characteristics and comorbidities. Women tend to present with CAD in life, and even in the young ages, they tend to have less evidence-based treatment for CAD than men do (Davis et al., 2015). CAD first presents approximately 10 years later in women than in men possibly because of the protective effect of estrogen. Upon reaching menopause, the incidence of CAD in women catches up with that in men (Yu-suf et al., 2001).

The differences in CAD between women and men have been explained particularly by focusing on estrogen (Lawton, 2011). Estrogen is thought to be beneficial through vasodilation and the protective effects against atherosclerotic plaque, oxidative stress, and inflammation (Mendelsohn and Karas, 2005). Animal models have suggested that benefits conferred to females are due to estrogen (Patten et al., 2004). However, the cardiovascular advantages of exogenous estrogen have not been demonstrated clinically. Large randomized studies have reported that the estrogen treatment in postmenopausal women is not beneficial and even potentially harmful (Grady et al., 2002). Another reason for the greater incidence of CAD in men is the fact that men have an increased burden of atheroma than women. A study suggests that rupture of atheroma plaque in patients with sudden death is more often in men than in women (Patten et al., 2004). Men have more severe structural and functional abnormalities in the epicardial coronary arteries than women. In addition to physiological differences, other factors may be contributable to the clinical differences between women and men with CAD.

A strong association has been reported between CAD and dementia. The incidence of dementia is higher in those with prevalent CAD in the Cardiovascular Health Study cohort in the US (Newman et al., 2005), and several studies have confirmed that CAD is associated with cognitive impairment (Roberts et al., 2010) and hippocampal damage (Koschack and Ike, 2005). Recent studies have shown that CAD is observed more frequently in VD patients (Graban et al., 2009) and that the damaged region of the brain is strongly related to the atherosclerotic burden. Microvascular lesions in the brain are considered an important pathophysiological mechanism by which CAD acts as a risk factor for dementia (Rosano et al., 2005). Microvascular lesions in the brain disturb cerebral blood flow (CBF) regulation and perfusion, reduce cerebral circulation through blood-brain barrier disruption, and finally lead to brain tissue damage (Kovacic et al., 2011). In addition, several recent studies have found that the failure to clear excess Aβ (produced in cortical neurons) in the blood-brain barrier network contributes to cerebral hemorrhaging and AD pathology (Bell and Zlokovic, 2009). These aforementioned studies indicate a correlation between the CAD history and low cognitive scores and suggest that the longer the CAD period, the lower the cognitive scores. In men, those who had the first CAD event 10 years ago are more likely to have poor...
cognition. Therefore, future studies should be carried out to examine the correlation between the CAD history and cognition not only in men but also in postmenopausal women.

Atrial fibrillation

AF is the most common persistent cardiac arrhythmia and is recognized as one of the major public health problems (Naccarelli et al., 2009). Its prevalence is known to increase steadily with age, and the number of patients aged ≥65 is expected to reach 1.3 billion by 2040 worldwide (Dublin et al., 2011). The age-adjusted prevalence of AF is reported to be higher in men (10.3%) than in women (7.4%) in the US Medicare recipients (Piccini et al., 2012). Consistently, the incidence rates of AF are also shown to be higher in men than in women. Current evidence indicates that age and sex are the two most powerful predictors for the incidence of AF. In fact, the incidence of AF has been reported to be as high as 32.9 per 1,000 men and 30.4 per 1,000 women by age 85-89 years (Wilke et al., 2013). The lifetime risk of AF incidence has been slightly higher in men than in women (23.8% vs. 22.2% at 55 years of age in the Rotterdam study and 25.8% vs. 23.4% at 60 years of age in the Framingham study) (Lloyd-Jones et al., 2004). In addition, data from California administrative databases were analyzed for racial variation in the incidence of AF. After adjustment for AF risk factors, lower incidence rates have been found in blacks (Hazard Ratio (HR), 0.84; 95% Confidence Interval (CI), 0.82-0.85; p<0.001), Asians (HR, 0.78; 95% CI, 0.77-0.79; p<0.001), and Hispanics (HR, 0.78; 95% CI, 0.77-0.79; p<0.001) than in their white counterparts (Dewland et al., 2016). However, despite the high prevalence, incidence, and risk for AF in men, the count of women with AF is greater than that of men with AF due to the differences in life expectancy. In addition, the relative mortality rate of AF patients has been higher in women than in men. Although the findings in individual studies are still controversial, a meta-analysis study has demonstrated that the pooled ratio of relative risks for AF-associated all-cause mortality is 12% higher in women than in men (HR 1.12; 95% CI, 1.07-1.17) (Emdin et al., 2016).

The precise mechanisms that cause sex-related differences in AF are poorly explained, but several suggestions have been proposed. First, anthropomorphic differences (especially in lean body weight) between men and women cause a larger size and volume of left atrium in men than in women, and the changes could promote AF-maintenance, independently of the increase in AF incidence (Liu et al., 2004). Second, women with AF have a relatively greater burden of atrial fibrillation, and the changes could promote AF-maintenance, independently of the increase in AF incidence (Liu et al., 2004). Second, women with AF have a relatively greater burden of atrial fibrillation (Cochet et al., 2015). Third, variations in the X-linked genes may account for some sex differences in AF (Ravn et al., 2010). Further basic and clinical research are needed to clarify the pathophysiological aspect of sex differences in AF. In fact, the contribution of sex hormones has been examined in several studies. Testosterone deficiency has been shown to increase arrhythmogenicity possibly through increased calcium release from the sarcoplasmic reticulum, and this abnormality is reversed by testosterone therapy in an animal study using mice (Tsuneda et al., 2009). Clinically, it is observed that an increased risk of AF is associated with decreased testosterone levels in men (Magnani et al., 2014).

Recently, increasing evidence suggests that patients with AF have been associated with not only high rates of CAD and...
HF but also an increased risk of cognitive decline (Dublin et al., 2011). A meta-analysis study of eight studies including 77,668 patients has demonstrated that AF significantly increases the risk of dementia incidence by 42% (Santangeli et al., 2012). In addition, AF possibly causes modifiable ischemic stroke and leads to considerable physical and cognitive disability and dementia (Aloino and Arenas de Larriva, 2016). The relationship between AF and dementia in the absence of stroke is still uncertain (Kwok et al., 2011), but it is clear that AF can cause the onset of dementia (Barba et al., 2000; Rastas et al., 2007). Moreover, growing evidence supports AF as a risk factor for dementia without stroke (O’Connell et al., 1998). In fact, several studies have shown that AF is associated with brain abnormalities, more specifically, a small hippocampal volume and left ventricular hypertrophy (Wozakowska-Kaplon et al., 2009). Individuals suffering from AF also show poor learning, memory, attention, and performance (Knecht et al., 2008), as well as decreased scores on cognition tests (Schrader, 2004; Kermode-Scott, 2012).

Several mechanisms have been suggested to link AF and dementia. In AF patients, irregular rapid ventricular rates may cause a reduced cerebral perfusion because of low cardiac release (Petersen et al., 1989; Duron and Hanon, 2010). Another suggested mechanism is the increased risk of coagulable state, which may give rise to subclinical cerebral embolism (Choudhury and Lip, 2003; Barber et al., 2004). Furthermore, cerebrovascular disease may precipitate neurodegenerative changes, manifesting as white matter hyperintensities on MRI (Kalari, 2000). A recent study of sex differences in the relationship between AF and dementia suggests that age-adjusted rates of dementia are not different between men and women with AF (Miyasaka et al., 2007). Another sex-stratified analysis indicates that the risk of dementia associated with AF in women is comparable with that in men (p=0.96 for interaction by sex) (Chen et al., 2018). Therefore, further studies should focus on the sex differences in the relationship between AF and dementia.

**Myocardial infarction**

MI is defined as cardiomyocyte necrosis because of the sustained ischemia/hypoxia. It is frequently, but not always, an acute manifestation of atherosclerosis-related CAD (Mendis et al., 2011). Based on a UK national survey of self-reported MI, the prevalence of MI is approximately 4.1% in men and 1.7% in women in 2006, and the prevalence is age-dependent, extending from 1% in men aged <45 years to 17% in those aged ≥75 years. Similarly, the overall prevalence of MI is 3.0% in US adults aged ≥20 years according to data from NHANES 2011 to 2014. Men have a higher prevalence of MI than women in all age groups except those of 20 to 39 years (3.8% for men and 2.3% for women), and more women than men have MI in the highest age group because of women’s longevity (Benjamin et al., 2018). The sex difference in the risk of MI persists throughout life; the relative risk of MI diminishes with age, but the absolute sex differences increase (Albrektsen et al., 2016). The lower risk in women at premenopausal ages may be associated with a beneficial effect of female hormones on vascular function, lipid profile, or other cardioprotective molecules (Chou and Saw, 2014). Despite a positive role of female hormones on CV risk factors, a few previous studies have reported no or even an adverse effect of hormone treatment on the risk of MI (Coutinho, 2014). Actually, it is not easy to distinguish between effects of age and menopause (Gierach et al., 2006), but the age-incidence relationship with hormone-dependent diseases may be affected by hormone changes (Kalin and Zumoff, 1990). However, once a woman has MI, she loses the advantage and may become no better or worse than a man with MI at the same age (Rosengren et al., 2001). It is still controversial about the prognosis of women with MI. Several studies (Greenland et al., 1991; Maynard et al., 1992) indicate that women have a worse short-term prognosis than men; however, in general, the findings have been partly attributed to differences in age and prior diseases, mainly diabetes.

It is a growing interest to define the mechanism underlying the sex-related differences in MI-associated damage, but conflicting results have been found. Ischemic insults in the heart reduce blood flow and trigger apoptotic death, and loss of cardiac cells results in tissue damage. A primary clinical strategy is to restore blood flow, although the restored blood flow may further increase tissue damage because of myocardial ischemia/reperfusion (I/R) injury. An animal study has found that regional myocardial IR in the heart produces a significantly larger size of infarct in male rats than in female rats (Le et al., 2014). Aggravated reperfusion injury correlates with increased apoptosis in the area at risk, and consistent with the smaller infarct size, significantly less apoptosis is observed in the female heart. In fact, testosterone has been shown to inversely affect myocardial remodeling after MI (Kanasashiro-Takeuchi et al., 2009). Testosterone is known to activate nuclear factor-kB, which contributes to inflammatory mechanisms and the downregulation of fatty acid oxidation (Gardner et al., 2002). Only a limited number of studies have examined the relationship between MI and dementia. Patients with MI have been shown to share a genetic background, including abnormal cholesterol metabolism and upregulated inflammation, with those with AD. Some studies have revealed a high risk of cognitive impairment after MI because of brain hypoperfusion (Zuccala et al., 2001), and a cross-sectional evaluation in the Rotterdam study reveals a positive relationship between MI and cognitive impairment (Breteler et al., 1994). In addition, the Bronx Aging Study suggests that women with a history of MI have a 5-fold increase in the risk of dementia (Aronson et al., 1990). Another study indicates that the incidence of dementia is remarkably higher in women with than without a history of MI, but the results are not found in men (Aronson et al., 1990). The significant findings suggest that women with MI may be particularly susceptible for dementia (Aronson et al., 1990). However, the impact of MI on dementia remains controversial; for example, the Honolulu-Asia Aging Study has not demonstrated a link between later cognitive impairment and MI (Petrovitch et al., 1998). Therefore, further studies remain to improve understanding of the effect of MI on dementia.

**Heart failure**

HF is defined as “a complex clinical syndrome that can result from structural or functional heart injury that reduces the ability of the ventricle to pump blood” (Hunt et al., 2005). Because HF is a syndrome rather than a disease, the diagnosis can depend on a clinical test. The incidence of HF has been reported to be 14.4/1000 person-years (95% CI, 13.4-15.5) and is significantly higher in men (17.8/1000 man-years; 95% CI, 15.8-19.5) than in women (12.5/1000 woman-years; 95%
Ventricular hypertrophy even in the absence of heart disease (Redfield et al., 2002). The relationships between hormones and the renin-angiotensin system are modified by sex, and women are less likely to respond to pressure overload conditions, such as hypertension. The ventricular systolic dysfunction but less often due to ischemic heart disease than men. In addition to these effects, a pathophysiological specificity for sex is also observed. Left ventricular responses to pressure overload conditions, such as hypertension, can be modified by sex, and women are less likely to have increased stiffness of vessel walls compared to men (Ceia et al., 2002). However, in the UK, the overall HF incidence rate per year is 4.4 cases per 1,000 people in men and 3.9 cases per 1,000 people in women and doubles every 5 years after the age of 55 years (Johansson et al., 2001).

HF seems to have different characteristics in men and women. Some of the differences are associated to age, ventricular function, and causes of HF. Women have a higher onset age of HF and have HF more often without left ventricular systolic dysfunction but less often due to ischemic heart disease. Therefore, they have a lower threshold for perceiving and expressing their symptoms. In contrast, women have increased stiffness of vessel walls and ventricle even in the absence of heart disease (Redfield et al., 2005), and the combined ventricular–vascular stiffening may contribute to the increased prevalence of HF in women. Furthermore, women also tend to be more depressed than men do. Therefore, they have a lower threshold for perceiving and expressing their symptoms. In addition, social integration, another psychosocial factor, affects C-reactive protein concentration, a measure of inflammatory activation, in men but not in women (Ford et al., 2006). Thus, men tend to develop silent biological responses to such stimuli, and the responses may indirectly affect the cardiovascular risk. Therefore, clinical trials in women or at least with enough women are needed to guide management of HF.

The Heart-Mind Study suggests that participants with HF experience declines in cognitive function (Almeida et al., 2012). In addition, other studies demonstrate that HF is associated with both cognitive impairment and dementia (Trojano et al., 2003). A recent pilot case-control study indicates that HF patients have lower scores in cognitive functions, including visuospatial and executive function, visual memory, and verbal learning tasks (Beer et al., 2009). Investigation for pathophysiological mechanisms underlying the relationship between HF and dementia are still ongoing. Reduced CBF appears to worsen cognitive impairment related with HF, and those with heart transplantation have restored CBF and improved cognitive performance (Gruhn et al., 2001; Alves et al., 2005). In HF, low cardiac output combined with impaired cerebral autoregulatory systems may lead to reduced CBF and increased cognitive impairment and dementia (Jefferson et al., 2007, 2010). HF is also a risk factor for multiple cerebral emboli, which could cause cognitive impairment (Pullicino and Hart, 2001). HF is demonstrated to be a remarkable risk factor for dementia incidence in men (HR=2.58, 95% CI=1.11-5.99) but not in women (Noale et al., 2013). However, another study suggests that HF is a risk factor for dementia in both men and women, and slightly greater HR is found in men (HR=1.31; 95% CI, 1.26-1.36) than in women (HR=1.15; 95% CI, 1.11-1.18) (Adelborg et al., 2017). Although causes and outcomes of HF can differ between men and women (Taylor, 2015), the basis of the sex differences in the dementia risk is still unclear.

Hypertension

HTN is defined as a systolic blood pressure (BP) of 140 mmHg or a diastolic BP of 90 mmHg, and it has been reported that approximately 80 million US adults more than 20 years old have HTN (i.e., 32.6% prevalence) (Mozaffarian et al., 2016). HTN prevalence is shown to be the highest in non-Hispanic Blacks (33.5%), and it increases with age (65.4% among those aged ≥60 years) and tends to be higher in women than in men. The numbers of patients treated for HTN increase with time in both women and men and are more in women than in men. Although BP control has improved over time in women and men, fewer women than men have been able to control BP despite treatment, especially in the elderly. HTN is also more prevalent in women among the elderly (Roger et al., 2011), and about 80% of women aged over 70 years suffer from HTN (Roger et al., 2011). Women have a lower systolic blood pressure than men in early adulthood, but this trend is reversed after age 60 (Lloyd-Jones et al., 2005). Decreased survival in old hypertensive men can account for the higher prevalence of HTN in old women. Diastolic BP is slightly lower in women than in men, regardless of age. The prevalence of hypertension is significantly higher in men than in women (34% and 22%, respectively) (Ostchega et al., 2008). Previous NHANES data reveal a minimal difference in HTN incidence between women and men at all ages, but the incidence of HTN in black is almost twice that of white for almost all age- and sex-matched groups (Cornoni-Huntley et al., 1989). In the subgroup of adults under age 60, women (87%) are more likely to recognize and seek treatment for HTN than men (63%) (Ostchega et al., 2008). No differences in perception of HTN are found between hypertensive men (84%) and women (81%) over 60 years of age. Among HTN patients aged 18-59 years, men (47%) are less likely to be treated than women (74%), but no differences in treatment are observed between hypertensive men (78%) and women (75%) aged 60 years and older (Engberding and Wenger, 2012).

High BP is a well-known risk factor for cerebrovascular disorders, including cerebral infarct, stroke, and dementia (Vermeer et al., 2003; Celle et al., 2012). However, whether HTN is an independent risk factor for dementia is unknown. The association between HTN and the risk of dementia is prominent, and few studies have failed to show this relationship (Johnson et al., 2008). The high prevalence of HTN at the age of between 30 and 50 years indicates that understanding the relationship between HTN and dementia is important for the potential prevention of dementia. In fact, the Cache County study by Mielke et al. also indicates that systolic BP of 160 mmHg is related with greater rates of cognitive decline in the elderly than low systolic BP. Other studies have further shown that HTN is associated with not only VD but also AD (Staessen et al., 2007). In particular, elderly people with HTN rather than young people with HTN are shown to have an increased risk of VD (Yamada et al., 2003). The relationship between HTN...
and risk of AD has been also suggested by a recent study, which demonstrates a significant interaction between diastolic BP and plasma Aβ1 levels (Shah et al., 2012). In addition, mid-adulthood HTN is associated with increased dementia risk in women but not in men. It is predicted that women with onset HTN in the mid-adulthood have a 73% higher dementia risk than stable normotensive women (Gilsanz et al., 2012). In addition, mid-adulthood HTN is associated with increased dementia risk in men. In fact, it has been recently demonstrated that HTN is strongly associated with BD in both men and women similarly (Kimm et al., 2011). HTN has also been shown to be associated with AD, especially in men younger than 65 years. However, the association of HTN with AD is not observed in men or women over 65 years.

CONCLUSION

With aging of the population, the prevalence of dementia including AD is expected to reach an epidemic size worldwide. However, currently no cure is available for this devastating disease, and because currently approved medications are just symptomatic, they do not modify the underlying disease pathology. Although lots of preclinical studies and clinical trials for candidate medications to reduce amyloid and other targets for AD are ongoing, studies clarifying the factors related with the risk and progression of AD are needed to identify potential novel therapeutic targets. As described in this review, the prevalence/incidence of dementia and CV risk factors for dementia is quite different by sex. Because women live longer than men in most countries, the adverse impact of the risk factors may affect women in particular. In that context, drugs may have efficacy in only one sex or have different efficacy between men and women. Actually, both male and female patients were included in many studies, but most studies did not consider the issue of sex separately. Therefore, future clinical trials for new AD therapeutics should consider a deliberate stratification by sex, and an adequate sample size is needed to test the therapeutic efficacy in men and women separately. In addition, further studies are needed to understand sex-specific effects of the CV risk factors on dementia incidence and to examine the mechanisms underlying the sex differences. The resulting information may help to establish a new strategy for the development of individualized therapeutics and preventive medications for dementia.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

ACKNOWLEDGMENTS

This research was supported by a grant of the Korea Health Technology R&D Project through the Korea Health Industry Development Institute (KHIDI), funded by the Ministry of Health & Welfare, Republic of Korea (grant number: HI18C0920); the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-2016R1A6A3A11935320 and 2018R1D1A1B07048729), Republic of Korea; and the Support Program for Women in Science, Engineering and Technology through the NRF funded by the Ministry of Science and ICT (No. 2016H1C3A1930220).

REFERENCES


exposure is associated with longer telomeres in postmenopausal women at risk for cognitive decline. *Brain Res.* 1379, 224-231.


M. et al. *Sex Differences in Dementia Risk Factors*


