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The effects of obesity on venous thromboembolism: A review*

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Abstract

Obesity has emerged as a global health issue that is associated with wide spectrum of disorders, including coronary artery disease, diabetes mellitus, hypertension, stroke, and venous thromboembolism (VTE). VTE is one of the most common vascular disorders in the United States and Europe and is associated with significant mortality. Although the association between obesity and VTE appears to be moderate, obesity can interact with other environmental or genetic factors and pose a significantly greater risk of VTE among individuals who are obese and who are exposed simultaneously to several other risk factors for VTE. Therefore, identification of potential interactions between obesity and certain VTE risk factors might offer some critical points for VTE interventions and thus minimize VTE morbidity and mortality among patients who are obese. However, current obesity measurements have limitations and can introduce contradictory results in the outcome of obesity. To overcome these limitations, this review proposes several future directions and suggests some avenues for prevention of VTE associated with obesity as well.

Keywords

Obesity; Comorbidity; Deep Vein Thrombosis; Pulmonary Embolism; Venous Thromboembolism; Risk Factor; Prevention

1. INTRODUCTION

Venous thromboembolism (VTE) is the third most common cardiovascular disorder after ischemic heart attack and stroke [1,2]. It is estimated that VTE occurs among 1 to 2 per 1000 persons annually in the United States [3–5]. VTE imposes a substantial burden on the US health care system. The initial clinical management, recurrence, and long-term complications of VTE including post-thrombotic syndrome (PTS) and other VTE-associated comorbid conditions compromise quality of life and cost about $2 billion to 10 billion annually to the health care system in the United States [6,7].

Obesity is a major public health problem not only in the United States, but also rapidly is becoming a global threat [8]. While obesity can serve as a risk factor for some diseases, it

*Disclaim: The findings and conclusions in this paper are those of the authors and do not necessarily represent the views of the Centers for Disease Control and Prevention.

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also can affect preexisting diseases or lead to an array of comorbid conditions, including coronary artery disease (CAD), type 2 diabetes mellitus, hypertension, stroke, heart failure, obstructive sleep apnea syndrome, gastrointestinal disorders, depression, malignancies, and VTE [9,10]. In this review, we focus on the association between obesity and VTE, explore possible interactions between obesity and several other risk factors for VTE, discuss limitations of current obesity measurement, identify possible research gaps, and suggest some avenues for prevention of VTE associated with obesity. Although medical interventions are important, the clinical management of VTE is not in the scope of this review.

2. CLINICAL EPIDEMIOLOGY OF VTE

VTE encompasses two distinct clinical entities: deep vein thrombosis (DVT) and pulmonary embolism (PE). DVT begins with formation of a blood clot in the deep veins of the body, usually in the legs or pelvis. PE occurs if the clot becomes detached and travels to the pulmonary arteries, and can result in death. Development of PTS is a common medical complication of DVT [11], while chronic thromboembolic pulmonary hypertension (CTEPH) can occur following a PE [12]. CTEPH is initiated by the obstruction of pulmonary arteries with thrombi that can lead to cardiac failure and death if left untreated [13]. PTS clinically manifests as persistent or intermittent pain, swelling, ulceration, or cramping in the limb affected [6]. In one longitudinal study, the cumulative incidence of PTS was reported to be 17% and 23% at 1-year and 2-year follow-up post-DVT, respectively, and increased gradually to 29% over a period of 8 years [6]. In addition, approximately 30% of patients experienced recurrent VTE (DVT or PE) within 10 years of an initial VTE event [14]. Consequently, VTE can be considered a chronic rather than an acute disease.

The incidence of VTE varies widely across different racial populations and increases with age and hospitalization. Analysis of the California Patient Discharge Data Set showed that the total annual VTE incidence rate per 100,000 adults was 141 for Blacks or African Americans, 104 for Whites, 55 for Hispanics, and 21 for Asians [5]. Blacks or African Americans not only appeared to have the highest overall VTE incidence rate, but also were found to have a significantly greater PE case-fatality rate [5,15,16]. The incidences of PE and DVT also increase sharply with age [3,17]. Stein *et al.* investigated the database of the National Hospital Discharge Survey, which consists of data obtained during the period 1979 through 1999 from patients of over 400 nonfederal short-stay hospitals in all 50 states and the District of Columbia [17]. They found that the frequency of PE among patients 70 years of age or older was more than 4-times that among patients younger than 50 years of age [17]. Also, hospitalized patients and recently discharged patients were seen to have a remarkably increased risk for VTE [18]. Different from idiopathic or spontaneous VTE that occurs in the absence of known precipitating factors, VTE associated with hospitalization likely is provoked by multiple risk factors for VTE, including immobilization; surgery; trauma; childbirth; stroke; or the patient's comorbid medical conditions, such as infection, inflamematory bowel disease, or cancer [19].

3. DEFINITION OF OBESITY—MEASUREMENT TOOLS

The most frequently used indicator of obesity is the body mass index (BMI) [10], with a normal range of 18.5 – 24.9 kilograms per square meter (kg/m^2) among adults 20 years of age or older. Someone with a BMI of 25 – 29.9 kg/m^2 is considered overweight, and someone having a BMI ≥ 30 kg/m^2 is considered to be obese. According to World Health Organization (WHO) criteria established in 1997 [10], obesity among adults is further classified into three categories: Class I obesity is a BMI of 30 – 34.9 kg/m^2; Class II obesity is a BMI of 35 – 39.9 kg/m^2; and Class III obesity, or morbid obesity, is a BMI ≥ 40 kg/m^2. Childhood obesity is defined as a BMI greater than or equal to the 95th percentile of BMI-for-age for children and adolescents of the same sex (2 through 19 years of age) [20]. Wang *et al.* proposed that severe obesity among the pediatric population (2 through 19 years of age) be defined as BMI-for-age greater than or equal to 120% of the 95th percentile of the Centers for Disease Control and Prevention growth charts [21].

Alternative anthropometric measures that reflect the distribution of body fat have been suggested as being superior to BMI in predicting certain diseases [22,23]. For example, waist circumference (WC), waist-to-hip ratio (WHR), and waist-to-height ratio (W/Hr) that define central obesity appear to be associated more closely with cardiovascular disease (CVD) than BMI [22,24]. WHO reference cutoff points for obesity were introduced in 2008 as a WHR (WC) > 0.9 (102 centimeters (cm)) for males and >0.85 (88 cm) for females [25].

Body fat percentage (BF%) directly calculates an individual's body composition. It can be measured accurately when using magnetic resonance imaging (MRI) [26] or dual-energy X-ray absorptiometry [27]. In the HERITAGE Family Study, Jackson *et al.* found that the BF % of females was 10.4% higher than that of males with the same BMI [28]. The American Council on Exercise recommended that cutoff value for obesity was a BF% > 25% for men and >32% for women [29]. In addition, BF% also is subject to change depending on age and race [28,30]. Asian populations generally have a higher BF% and appear to be more sensitive to the metabolic consequences of obesity than Whites of the same age, sex, and BMI [25]. Body fat generally increases and fat-free mass decreases with increasing age [28]. Consequently, older individuals usually have a higher percentage of body fat than younger individuals of the same BMI [30].

4. ASSOCIATION OF OBESITY WITH VTE

4.1. Obesity and First Occurrence of VTE

Obesity appears to be associated with an increased risk for VTE. A meta-analysis of 1 cohort and 8 case-control studies involving a total of 8125 patients with VTE and 23,272 control patients indicated that likelihood of first spontaneous VTE among people who were obese was more than twice that of individuals with a normal BMI (odds ratio (OR) = 2.33; 95% confidence interval (CI), 1.68 – 3.24) [31]. However, the OR reduced to 1.84 (95% CI, 1.55 – 2.18) after excluding three studies that had no adequate controls or BMI measurements [31]. In the Tromso study, Borch *et al.* found abdominal obesity as defined by WC was the only risk factor for VTE (PE or DVT) (OR = 2.03; 95% CI, 1.47 – 2.75) in a multivariable analysis that included hypertension, impaired glucose metabolism, a low level

of high-density lipoprotein cholesterol (HDL-c), and hypertriglyceridemia [32]. Similarly, Steffen *et al.* found abdominal obesity was associated with idiopathic VTE among men (OR = 2.31; 95% CI, 1.48 – 3.62) and women (OR = 1.84; 95% CI, 1.19–2.84) after adjusting for age, race, education, smoking, triglycerides, HDL-c, glucose, and systolic blood pressure [33].

Increasing BMI above normal value has been reported to be associated with a rising risk of VTE [34–36]. A prospective cohort study of 87,226 women in the Nurses' Health Study (NHS) showed that the relative risk of unprovoked PE that was not associated with prior surgery, trauma, or cancer raised by about 8% per 1 kg/m^2 increase in BMI and approached a nearly sixfold greater risk among individuals with a BMI ≥ 35 kg/m^2 ($p < 0.001$) [34]. In a prospective Danish study that enrolled 29,340 women and 26,674 men [36], Severinsen *et al.* found the OR of VTE was 1.45(0.98), 1.81(1.32), and 2.82(1.72) among women (men) with BMIs of 23.7 – 26.3 (24.4 – 26.8), 26.3 – 29.9 (26.8 – 29.4), and >29.9 (>29.4), respectively, after adjusting for age, physical activity, smoking, height, cholesterol, hypertension, diabetes mellitus, and use of hormone replacement therapy. The data have suggested the risk of VTE increases with a rising BMI among the individuals who are overweight or obese. Given about a 33% increase in obesity prevalence and a 130% increase in severe obesity prevalence through 2030 predicted by Finkelstein *et al.* [37], this positive association between increasing BMI and escalating risk of VTE might herald a parallel climbing of VTE incidence with the rising rates of obesity.

4.2. Obesity and Recurrent VTE

Several studies have addressed the relationship between obesity and recurrent VTE. Eichinger *et al.* followed 1107 patients for an average of 46 months after termination of anticoagulation therapy for a first spontaneous VTE. They found the frequency of recurrent VTE was 9.3% (95% CI, 6.0% – 12.7%) among patients with a normal BMI and 17.5% (95% CI, 13.0% – 22.0%) among patients who were obese [35]. In a prospective cohort study that followed 583 patients with a first idiopathic VTE for 28 months, Olie *et al.* found obesity was related to an increased risk of recurrent VTE (OR = 2.8; 95% CI 1.3 – 6.0) [32]. Similarly, Garcia-Fuster *et al.* also reported obesity was a risk factor for recurrent VTE (OR = 2.27; 95% CI 1.00 – 5.15) in a long-term prospective study of incidence of recurrent VTE that followed 98 patients and for 117 months after an initial episode of spontaneous VTE [38]. In contrast, Linnemann *et al.* showed no association between obesity and a risk of recurrent VTE in their cohort study that consisted of 1006 patients with history of VTE with an average follow-up time of 40 months after discontinuation of anticoagulation therapy [39]. It is worth noting that both spontaneous VTE and provoked VTE were included in Linnemann's study that investigated the effects of established cardiovascular risk factors on the risk of recurrent VTE [35]. The potential VTE-provoking factors—such as thrombophilia, cancer, inflammation, hormone therapy, and surgery—in Linnemann's study might have masked the effect of obesity on recurrent VTE.

4.3. Obesity and VTE Mortality

PE is responsible for almost all mortality from VTE, but the association between obesity and PE case mortality has yet to be explained. Although obesity is associated with adverse

comorbidities such as hypertension and stroke [10], some studies have indicated that mortality among patients with PE appeared to be paradoxically lower among patients who were obese than those who were not [40,41]. However, it still remains obscure whether this phenomenon—the so-called “obesity paradox” [42]—is attributable to a real protective role of increased body fat because the lower mortality was seen mostly among old people who were obese, but not among young adults and children who were obese [40, 41]. The observed lower PE mortality among old people who were obese might have been due in part to a number of factors. First, some obesity-related adverse effects take years to manifest. Therefore, those who become obese in old age might have lower mortality risk compared with those who were obese at midlife but were not obese in old age [43]. Next, being underweight is a strong predictor of mortality in the elderly [44]. Normal BMI due to unintentional weight loss caused by a wasting disease or unrecognized systemic illness can lead to an overestimation of the mortality among older adults with these “healthy” BMI, thereby making the elderly who are obese seem protected by obesity. Finally, an age-related decline in body height among the elderly [45] that might have introduced a false BMI increase and registered the individuals with merely an overweight BMI as being obese. Accordingly, PE mortality among the old population who are considered to be obese as defined by BMI might represent partially PE mortality among people who are not obese. Indeed, the studies that reported an obesity paradox used BMI to assess obesity [46,47]. After controlling for BMI, however, obesity as defined by WC or WHR in the same studies actually was associated positively with mortality [48].

5. INTERPLAY OF OBESITY WITH THE RISK FACTORS FOR VTE

VTE results from the complex interactions of genetic and environmental factors that influence the coagulant, inflammatory procoagulant, anticoagulant, and fibrinolytic system, leading to hypercoagulability or hypofibrinolysis, or both. In other words, VTE is a multifactorial chronic disease that most often involves two or more risk factors. Although obesity appears to be a moderate risk factor for VTE [32,49], it can interact with other risk factors in VTE development and recurrence. Here, we have summarized the relationship of obesity with some common weak-to-moderate risk factors for VTE, including genetic factors, use of sex steroid hormones, inflammation, and insulin resistance [50,51].

5.1. In Relation to Genetic Factors

Identification of a positive family history of VTE as a risk factor for VTE suggests a contribution of genetic factors to VTE [52]. Common genetic factors reported to be associated with a greater risk of VTE include factor V Leiden (FVL), factor II (FII) G20210A, non-O blood group, sickle cell trait, and thalassemia intermedia (HbSC and HbS/β^{+}) [53]. Among these inherited risk factors, FVL and FII G20210A are the most frequent prothrombotic mutations [54]. However, the incidence rate of VTE among individuals with FVL and FII G20210A is highly variable, suggesting other factors might be involved in shaping the effects of these genetic factors. In a prospective case-control study consisting of 732 patients with unprovoked VTE and 732 individuals without VTE who were matched to the cases by age, sex, risk factor for VTE—surgery, plaster cast, pregnancy, childbirth in the past 3 months, and active cancer [55], Delluc *et al.* reported an

OR for VTE among patients with the FII G20210A mutation who were obese was 12.03 compared with the matched controls with the FII G20210A mutation who were obese. In contrast, the OR for VTE among patients with the FII G20210A mutation who had a BMI < 25 kg/m^2 was only 1.67 compared with the matched controls with the FII G20210A mutation who had a BMI < 25 kg/m^2 [55]. The data suggest FII G20210A mutation interacts with obesity to increase risk of VTE. However, the association between FVL and increasing BMI lacked statistical significance [55]. Similar findings have been reported by Severinsen *et al.*, who analyzed the effects of the FVL and FII G20210A mutations on the risk of VTE among a subcohort of 1803 individuals randomly selected from the Danish Diet, Cancer, and Health Study [56]. The ORs for VTE were 5.27 and 2.63 for patients with FVL who were obese and of normal BMI, respectively compared with the patients without FVL who had normal BMI [56]. This approximate twofold increase in the risk of VTE was essentially equivalent to the risk of VTE associated with obesity alone (OR = 2.34; 95% CI, 1.73 – 3.16) [56], suggesting there was no interaction between obesity and FVL. In contrast, the risk of VTE was nearly fivefold higher among patients carrying the FII G20210A mutation who were obese than among those with the mutation who were of normal weight [56]. These findings are in line with those of Delluc *et al.* that suggested obesity might interact with FII G20210A—but not with FVL—in modifying the risk of VTE [55,56].

5.2. In Relation to Use of Sex Steroid Hormones in Women

Steroid hormone applications, mainly estrogen derived compounds, appear to be associated with a risk of VTE [57,58]. At least 10 million women in the United States and 100 million women worldwide use oral contraceptive pills (OCPs) [59]. In spite of a sustained decline in hormone replacement therapy (HRT) due to adverse health risks reported by Ettinger *et al.* from the Women's Health Initiative (WHI) study [60], HRT still is prescribed widely for women who are postmenopausal to prevent osteoporosis or other medical conditions [61,62].

The combination of oral steroid usage and obesity has been associated with higher risk of VTE than use of oral steroids or obesity alone [57,63]. In the WHI estrogen plus progestin clinical trial, Cushman *et al.* found that the risk of VTE further increased among women who were overweight or obese and who were taking oral steroids compared with women who were normal weight and were taking a placebo [58]. Analysis of the data from the EStrogen and THromboEmbolism Risk (ESTHER) study by Canonico *et al.* also indicated that obesity alone or oral estrogen use by itself each increased the risk of VTE by 4.0- and 5.6-fold, respectively; however, the OR approached more than 20-fold when these two risk factors were combined among women who were obese and were taking oral estrogen [63], suggesting an interaction between obesity and oral estrogen use. However, transdermal delivery of estrogen did not impose an additional risk of VTE on women who were overweight or obese [57,63]. Transdermal hormone delivery bypasses hepatic metabolism and, hence, might have less pronounced effects on the hepatic synthesis of coagulation and anticoagulation factors [64]. However, little is known about the molecular mechanism underlying the disparity in the risk of VTE between oral and transdermal steroid administration.

Thrombin generation that enhances overall coagulation potential has been shown to be elevated among patients who are obese and is reduced following weight loss after bariatric surgery [65]. Oral estrogen can shift hemostasis balance toward a prothrombotic state by increasing resistance to activated protein C [66,67] and upregulating plasma concentration of coagulation factors (II, VII, VIII, and X) [68] and prothrombin activation peptide (F1 + 2) [69], while decreasing the antigen level and activity of protein S [70] and antithrombin [71]. Therefore, obesity is considered as a prothrombotic state that can be enhanced further by the use of oral steroids, especially among elderly women who are obese and who have been reported to attain higher concentrations of estrogen than women with a normal BMI who received an oral HRT [72].

5.3. In Relation to Inflammation and Insulin Resistance

Excessive visceral adipose tissue causes hypoxia and increases delivery of inflammatory adipocytokines and free fatty acids (FFA) to the liver, where coagulation factors are synthesized abundantly [73,74]. FFA can induce mitochondrial production of reactive oxygen species (ROS) [75]. Alone or in combination with inflammatory adipocytokines, ROS is able to activate endothelial cells and can initiate systemic coagulation [76].

Overactivation of the rennin-angiotensin system (RAS) and an elevated level of circulating free fatty acids (FFAs) among those who are obese, especially among those with visceral obesity, has been postulated to cause insulin resistance by interfering with insulin-mediated glucose uptake in its target tissues [9,77]. The subsequent hyperglycemia can lead to ROS generation and oxidative stress [77], which can trigger systemic inflammation and mediate further FFA production [9]. This process ultimately leads to a prothrombotic tendency by enhancing coagulation while inhibiting fibrinolysis [78,79], which in some cases can contribute to the pathogenesis of VTE associated with abdominal obesity [32]. Indeed, insulin resistance has been reported to increase the risk of VTE in a BMI-dependent manner [80].

6. PREVENTION OF VTE ASSOCIATED WITH OBESITY

With the high prevalence of obesity [21,81] and potential interplay of obesity with other risk factors for VTE discussed previously, implementation of effective, safe, and practical prevention strategies is critical in reducing the incidence of VTE associated with obesity and minimizing recurrence of VTE.

Intentional weight loss through diet control and physical activity may modulate risk factors for VTE among the population with obesity. Regular physical activity may reduce risk of VTE through a reduction of the activity of plasminogen activator inhibitor-1 (PAI-1) that was accompanied with body-weight loss [82] and an increase in endothelial release of tissue-type plasminogen activator (t-PA) upon bradykinin stimulation among the individuals who were obese [83]. Lutsey *et al*. reported that moderate to high intensity physical exercise was associated with reduced risk of VTE compared with low level of physical activity [84]. However, others did not find a significant impact of regular physical exercise on the risk of VTE [85–87]. It is not clear whether increasing intensity and frequency of exercises, or whether exercises in conjunction with diet control to an extent that can result in weight loss

may decrease risk of VTE among individuals who are obese. In the NHS and Health Professionals Follow-Up Study (HPFS), Varraso *et al.* found that a diet intake rich in vitamins E and B6 and fiber was associated with a decreased risk for VTE [88]. These results were corroborated by findings from the WHI study (n = 39,876) [89] and the Longitudinal Investigation of Thromboembolism Etiology (LITE) study (n = 14,962) [90]. However, Lutsey *et al.* observed no significant association between VTE and food nutrients, including vitamins E and B6 and whole grains, in the Iowa Women's Health Study (IWHS) [91]. A noticeable difference among these studies was the age of their participants. Lutsey *et al.* pointed out in the IWHS that the mean age of their study participants at the midpoint of follow-up was 72 years compared a mean age of 60 years among participants in the LITE study [91]. The nurses were 30 through 55 years of age in both the NHS/HPFS and more than 90% of the participants in WHI were younger than 64 years of age [88,89]. A general decline in food-nutrient digestion, absorption, and metabolization among old adults in the IWHS might have contributed in part to the less significant effect of diet on VTE than among younger people in the NHS/HPFS and WHI and LITE studies. Nevertheless, Lutsey *et al.* found alcohol intake was inversely related to risk of VTE in the IWHS [91]. Moderate wine consumption modulated expression of fibrinolytic proteins, including PAI-1 and t-PA [92,93] and the effects appeared to be alcohol dependent [94]. Although some studies have suggested that alcohol intake conferred a reduced risk of VTE [91,95], the effects have not been confirmed by others [85,96,97]. Given these inconsistent findings about alcohol and VTE, extensive epidemiological investigations are warranted to determine if alcohol consumption might be beneficial in reducing the risk for VTE among individuals who are obese.

Effective DVT prophylaxis (mechanical and pharmacological) can reduce the morbidity and mortality of VTE among hospitalized patients [98], but studies examining thromboprophylaxis of patients who are obese are limited [99]. The American College of Chest Physicians (ACCP) guidelines do not recommend using mechanical prophylaxis alone for VTE prevention among patients with morbid obesity unless a high bleeding risk precludes the use of pharmacological prophylaxis; however, the ACCP guidelines do suggest weight-based dosing for certain anticoagulation medications for VTE prophylaxis [100]. Several studies have demonstrated the necessity of adjusting the anticoagulant loading dose and dosing interval to achieve optimal anticoagulation among patients who are morbidly obese [99,101]. Suboptimal adherence to prophylaxis schemes or inappropriate prophylaxis (underprophylaxis of patients who are severely obese or overprophylaxis of patients who are of normal weight or who are underweight) has been reported [98, 99,102]. Moreover, both the ACCP and the National Institute for Health and Clinical Excellence underscore the importance of individualized prophylaxis according to the estimated risk of VTE [103]. Therefore, education of at-risk individuals (e.g., people who are obese), VTE patients, and health care providers to improve clinical awareness and knowledge of VTE is essential to ensure proper and timely thromboprophylaxis [99].

7. LIMITATIONS AND GAPS

The WHO-defined BMI cutoff points for obesity classification have been accepted generally and used widely. However, BMI does not account for the wide variation in body fat

distribution and, hence, might not be appropriate for use in all populations to predict accurately disease development as a risk factor. For example, in a cohort study of Italian children recruited from 15 national clinical centers (n = 1479, 5 – 15 years of age), Maffeis *et al*. reported that children with a normal BMI but with an increased W/Hr were at high risk for metabolic disorders and CVD compared with those with a lower W/Hr (OR > 7, $p < 0.001$) [24].

Although growing evidence has suggested an association between obesity and VTE, several questions remain to be answered. For instance:

1. Does the interplay between obesity and other risk factors for VTE additively or synergistically intensify the clinical severity of VTE (besides the frequency of VTE)?
2. Will the frequency or severity, or both, of VTE differ between those who are obese in their early life and those who gain weight and become obese at midlife or in old age?
3. Is there any dose-dependent effect between interacting risk factors for VTE? As discussed previously, the association between the risk of VTE and alcohol consumption is inconsistent. Could this controversy be attributable to the difference in amount of alcohol intake? Light to moderate alcohol consumption has been seen to reduce risk of VTE [95,96], but frequent binge drinkers have been subjected to an increased risk of VTE compared with those with restrained alcohol intake [95, 104], suggesting alcohol might have a dose-dependent effect on VTE occurrence. Nevertheless, it remains unclear if a given amount of alcohol might have a differential effect on patients depending on their level of obesity.

8. FUTURE DIRECTIONS

As discussed previously, epidemiological studies have suggested that obesity is associated with a significantly higher frequency of VTE in the context of multiple risk factors than obesity by itself. Dire future efforts should be directed to:

1. **D**evelop thromboprophylaxis schemes and other prevention strategies suitable for patients of different obesity categories (*i.e.*, Class I obesity, Class II obesity, and morbid obesity). A fixed dose of FDA-approved anticoagulant regimens might not provide optimal VTE prophylaxis among patients who are severely obese. For example, subcutaneous injection of 40 mg of enoxaparin twice daily generated an anti-Xa concentration of 0.14 internation units per milliliter (IU/mL) among patients who were overweight, but only 0.06 IU/mL among patients who were morbidly obese [101].
2. **I**dentify novel interactions among risk factors for VTE among the population with obesity. For example, observations that body height was an independent risk factor for VTE among men [105–107] warrant further studies to understand the sex-specific influence of body height on VTE occurrence and take this parameter into consideration when assessing risk of VTE among people who are obese.

3. **R**esearch molecular and pathogenic mechanisms responsible for VTE onset, development, and recurrence among patients who are obese, which might help us to better understand the differential effects between oral and transdermal administration of HRT on the risk of VTE among women who are obese [57,63].

4. **E**xamine the dose-dependent effect on the interactions between obesity and other risk factors for VTE. For instance, low amounts of alcohol might enhance thrombolysis through regulation of the expression and activity of t-PA and PAI-1 among individuals who are obese and have elevated levels of circulating PAI-1 [92, 93,108], whereas consistently high levels of alcohol can cause liver diseases such as cirrhosis [109] that might predispose the individuals to the risk of VTE [110].

In future studies, a combination of two or more methods should be considered in obesity measurement [48]. Some individuals with a normal BMI might have excessive adiposity as determined by more sensitive methods, such as BF% [27]. This so-called “normal weight obesity” suggests that exclusively relying on a single measurement for obesity might be of limited value and might result in inconsistent findings regarding excessive body fat as a risk factor for disease. Given WC (positively) and BMI (negatively) were differently associated with mortality [48], the “obesity paradox” phenomenon among patients with PE [31,32] might be reconciled by using WC or WHR in combination with BMI for obesity assessment.

9. CONCLUSION

People who are obese are at an increased risk for VTE compared with individuals who are of normal weight. The extent of the effects of obesity on VTE depends not only on total body fat, but also on the distribution of adipose tissue (e.g., central obesity) and the interplay among risk factors for VTE, such as genetic mutations, hospitalizations, and OCP use. The dimension and strength of possible interactions between obesity and these VTE risk factors may vary across different racial populations and can differ by age and sex as well. Therefore, consideration of other proper anthropometric measurements (not relying on BMI solely) for accurate identification of obesity may be needed to understand the etiology of VTE and to assess the need for and effectiveness of interventions to reduce the risk of VTE among individuals of different races who are obese. With the high prevalence of obesity in the United States [21,81,111], it is likely that the incidence of VTE also will increase with time. Commensurate attention is needed to develop effective VTE prevention strategies aimed at the large population who are obese.

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