The present study was undertaken to know the association of visceral adiposity and cardiovascular reactivity to treadmill exercise test in 18-19 years of Indian adolescents. The secondary objective of the study was to compare the effects of visceral and total adiposity on cardiovascular response to exercise stress in Indian adolescents.

Rising trends of overweight and obesity are seen in developing countries such as India due to Industrialization\textsuperscript{15,16,139}. Overweight and obesity have become pandemic in last few decades and they have been considered as an independent risk factor for hypertension in all age groups. Changes in lifestyle due to concept of new modern society such as intake of high calorie diet, high fat and low fiber diet (Western Diet), low vitamins, minerals, micronutrients rich food and sedentary life style, spending more time on television, mobile, video games and lesser time for outdoor games has increased prevalence of obesity worldwide\textsuperscript{6,16,17,18}. The prevalence of obesity has escalating during the late adolescent phase, which is recognized as “Emerging Adulthood”\textsuperscript{144}.

Kelly RK et al. (2015) recently stated that 32% of adolescents across the globe are overweight and obese. In addition, typically among the age group of 10-19 years i.e. during adolescence phase, increased body weight is the root cause of all types of morbidity and mortality in adulthood. Overweight in them is associated with comorbidities such as hypertension, diabetes type II, dyslipidemia, nonalcoholic steatohepatitis, obstructive sleep apnea etc. Out of these, hypertension is the main culprit found in overweight adolescents, which leads to mortality in adulthood and
globally it is responsible for almost 12.8% deaths\textsuperscript{145}. Framingham Heart Study reported that extra body weight lead to 26% and 28% of hypertension in male and female respectively, further tentatively 23% and 15% had CAD in 44 years of follow up study\textsuperscript{144}.

Increased body fat causes an increase in cardiac output, left ventricular mass, blood volume and finally increased in the arterial resistance which elevates the blood pressure in overweight and obese\textsuperscript{106,146}. Kelly RK et al. (2015) stated in his review article that in adolescents, every 1mmHg rise in SBP causes 0.5gm increase in left ventricular mass\textsuperscript{145}. Hyperinsulinemia and insulin resistance in overweight and obese persons lead to metabolic syndrome. It is also associated with an increased secretion of leptin and angiotensinogen from the adipocytes which have a role in developing obesity and hypertension\textsuperscript{106,144-146}.

Abdominal obesity is a major risk factor because it is more prone for lipolysis and is nearer to major blood vessels. Overall risk of developing hypertension was 170% higher in person with higher abdominal obesity, with specification of gender difference being 197% higher in girls and 147% in boys\textsuperscript{57}.

In our study, we found that the resting SBP and DBP were more in high VF group in both the genders as compared to normal VF adolescents. Our study depicted that there was significant increase in basal SBP (p <0.05), DBP(p<0.001) and MAP(p<0.01) of male adolescents with high VF group than with normal VF group (Table 5,6 and 8). Female adolescents with high VF group have higher basal SBP(p<0.001), DBP(p<0.01), MAP (p<0.001) and RPP (p<0.001) than the normal VF group (Table 11,12,14 and 15).
Stephen R et al. (1999)\textsuperscript{147} and Daniel SR et al. (2000)\textsuperscript{148} concluded that there is a positive relationship between central fat and hypertension in adolescents and children. In children and adolescents for development of CVD, regional distribution of body fat plays a crucial role. Accumulation of excess visceral fat is allied with metabolic syndrome in them. More deposition of visceral fat in South Asian is documented than Caucasian children and adolescents and they are prone for development of type 2 diabetes and hypertension in future.

Hiuge-Shimizu A et al. (2012)\textsuperscript{149} stated that raised blood pressure is seen in Japanese with more visceral fat area. Further, Tatsumi Y et al. (2017)\textsuperscript{150} recently stated that even in normal weight Japanese who have normal BMI but high visceral fat, the risk for developing metabolic syndrome was considerably high.

Sironi AM et al. (2004)\textsuperscript{147} reported that in hypertensive men there is more amount of fat over abdominal visceral compartment than normotensive men. Studies have shown that there is association between high blood pressure and obesity\textsuperscript{46,106,107,114,145}. Moreover, studies have depicted that there is relationship between rise in PP, MAP and aortic stiffness in overweight and obese than normal weighted adolescents\textsuperscript{111,112}.

According to Casonatto J et al. (2011)\textsuperscript{57}, out of many proposed hypothesis, one of the possibility that seem to be associated with central obesity and hypertension is reduced sensitivity to insulin which leads to compensatory hyperinsulinemia. Increased insulin secretion seen in obese adolescents is thought to be associated with accumulation of visceral fat. The primary cause of hypertension in obese adolescents is mainly the amalgamation of various elements that causes increased sympathetic vascular resistance. Some of the elements which leads to increased vascular tone are: insulin resistance, vascular dysfunction and activation of SNS. Previous studies have shown
that activation of SNS is the main culprit behind the association between obesity and hypertension\textsuperscript{58,145}.

Esler M et al. (2006)\textsuperscript{146} stated that the abnormal feeding behavior has been linked with overweight/obesity which causes sympathetic excitation. Leptin is secreted by the adipocytes, which is prime determinant for the commencement of puberty. It is manufactured in proportion to the body fat mass. Rise in leptin level will have contrary effects on the cardiovascular system like hypertension and atherosclerosis\textsuperscript{46}. Leptin and Ghrelin play a vital part in controlling the balance between appetite and energy expenditure\textsuperscript{140}. Leptin suppress appetite and raises energy expenditure\textsuperscript{46,140,146}, while ghrelin has the reverse properties. Resistance of Leptin and Ghrelin and sympathetic hyper activation are connected with abnormal feeding behavior and constellations of this triad is seen in overweight and obese individuals\textsuperscript{140}.

It is estimated that exercise-induced stress can reveal a latent tendency toward hypertension and can unmask underlying cardio-vascular pathology. Blood pressure reactivity to exercise stress test is different normotensive persons\textsuperscript{49,109,124,143}. The drop in BP or failure to increase during exercise is unanimously accepted sign of severe cardiac ischemia. Physiologically during exercise, SBP increases and DBP remains unaffected or decrease depending on the type of exercise. Exaggerated exercise induced blood pressure responses in normotensive is an early warning sign of CVD, LVH and potent predictor of future hypertension\textsuperscript{152}.

During submaximal treadmill exercise test, exaggerated blood pressure response should be determined from SBP and DBP\textsuperscript{49,51,121}. Submaximal exercise test is a very
useful test in terms of exercise duration, less fatigue, low anxiety, cooperation of subjects and exercise load. During everyday life, one can reach physical activity up to the level of submaximal exercise test or probably less than submaximal exercise level, but it is tough to reach at maximal exercise level\textsuperscript{151}.

In our study, as per Table 1, the mean age of male and female adolescents were 18.16±0.37 years and 18.56±0.49 years respectively, males were younger in age than females which is statistically significant. Further, it is universally known that boys are physically more active than girls\textsuperscript{152}. However, it is documented that physically less active adolescents will become sedentary adults. In our study, overall all adolescents were having low to moderate physical activity by NASA scale\textsuperscript{140} and males were more physically active than female adolescents, it was statistically highly significant too(p<0.001), (Table 1). Further, as per Table 1, male adolescents were able to execute treadmill test for longer time (11.75±2.68 min) than female adolescents (9.74±2.68min), which was statistically highly significant (p<0.001). Further, as per Table 2 and Table 3 male and female adolescents with high VF group were able to perform exercise for lesser duration than with normal VF male and female adolescents, it was also found highly statistically significant(p<0.001). Watts K et al. (2005)\textsuperscript{153} and De Sousa G et al. (2009)\textsuperscript{154} stated that obesity leads to reduced exercise capacity and limits an individual to reach the level of exercise tolerance.

The primary objective of our study was to check the association of visceral adiposity and clinical significance of blood pressure reactivity to treadmill testing and these findings are considered as an early marker of developing future hypertension.
In our study, BP during exercise was high in high visceral fat adolescents. But, it may be due to their high resting BP. As such there was no abnormal or exaggerated reactivity in study group. The findings of our study was supported by Dipla K et al. (2012)\textsuperscript{58}.

According to Dipla K et al. (2012)\textsuperscript{58}, during acute dynamic exercise, an exaggerated BP response is defined as rise in SBP more than 10 mmHg by MET from rest or more than 10 mmHg rise in DBP at any stage of exercise. So, our study population did not show such exponential rise in BP parameters.

Conversely, Chiacchio Sieira M et al. (2010)\textsuperscript{121} documented that DBP may remain unchanged or somewhat decline during acute dynamic exercise. In our study also, DBP remained same in male adolescents with normal and high VF group.

Further, DBP was found to increase as exercise progresses in female adolescents with high VF compared to normal VF female adolescents. Miyai N et al. (2002)\textsuperscript{51}, stated that in normal subjects, a marked increase in DBP is indicative of impaired ability for exercise-induced vasodilatation and elevated basal peripheral resistance. Thus, this theory can be elucidated by an exaggerated activity of the sympathetic nerves, elevated vascular reaction to sympathetic stimulation or by a thickening of arteriolar wall that modifies its ability to react to vasoconstrictor stimuli. In subjects with this type of vascular features and hemodynamic pattern, the increased cardiac output will cause rise in both, SBP and DBP which is a characteristic of known case of hypertensive patient. Therefore, both SBP and DBP are key determinant for checking abnormal cardiovascular reactivity to physical stress.
During dynamic physical exercise, oxygen requirement of the tissues increase significantly and these demands are delivered by increasing the cardiac output, due to which there is increase in systolic blood pressure\textsuperscript{51}, which is the most common physiological response along with the rise in heart rate in untrained participants as seen in our study participants.

Tanaka H et al. (1996)\textsuperscript{10} reported that, higher SBP reactivity is seen during maximal exercise in endurance-trained persons as compared to untrained subjects, although they are at less susceptible for developing hypertension.

In our study, all normotensive adolescents were free from diabetes and other chronic diseases. High basal blood pressure is considered as one of the independent risk for the development of future hypertension. In our study, resting blood pressure was high in high VF groups and statistically significant as compared to normal VF group. Hence, BP was shoot up more during exercise. Tzemos N et al. (2002)\textsuperscript{11} also supported this as he stated that resting BP should be taken into consideration because participants with high exercise BP also tended to demonstrate higher resting cardiovascular parameters. Moreover, Spartano NL (2016)\textsuperscript{12} stated that elevated basal SBP is commonly related with exaggerated SBP response during exercise.

Sustenance of physical activity for long time depends on cardiovascular endurance. In our study VO\textsubscript{2max} was considerably less in high visceral fat adolescents compared to normal visceral fat adolescents. High visceral fat is associated with reduced aerobic fitness. LaFortuna CL et al. (2008)\textsuperscript{13} reported that female with high fat mass showed decreased mechanical efficiency probably due to more energy required to ease concerned body movement. Anton Kuchly BR et al. (1984)\textsuperscript{14} stated that obese male

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and female showed high energy expenditure during submaximal exercise than lean individual, may be due to extra energy required with muscular postural activity or during movement of lower limb.

It is not unknown that significant relation exists between VO$_{2\text{max}}$ and obesity. Chatterjee S et al. (2005)$^{129}$, Kamyabnia M et al. (2011)$^{159}$, Cc L et al. (2014)$^{160}$ and Shah H et al. (2016)$^{61}$ found association between body mass and VO$_{2\text{max}}$. They have used BMI as an outcome parameter. Though, BMI is most acceptable marker to reveal overall fitness, it is well established that BMI cannot differentiate body fat mass from lean mass and fail to reflect distribution of body fat$^{96,101}$.

De Souza e Silva CG et al. (2016)$^{161}$ recently studied on impact of central obesity in estimating VO$_{2\text{max}}$ and concluded that central obesity reduces aerobic fitness. However, they have used WHtR which is a measure of central obesity than visceral fatness. Even in subjects with normal body mass, fat mass, fat free mass and visceral fat mass are different.

Exercise performing capacity is expressively diminished in persons with central or peripheral fatness. Oxygen supply to the working muscles is lessened in overweight/obese individuals due to fatness$^{63,64,129,161}$. Physical inactivity/sedentary lifestyle is the vital issue for collection of fat around abdominal area and if appropriate attention is not given it leads to visceral or central obesity. Regular physical activity prevents CVD as well all-cause mortality. Stevens J et al. (2002)$^{65}$ stated interrelation of fitness and body mass with cardiovascular mortality. Reduction of visceral fatness by performing regular physical exercise is highly effective strategy.
for prevention of non-communicable diseases and for good aerobic fitness.

In our study, adolescents with high visceral fat also have high exercise RPP. Excess visceral fat plays a remarkable role in high exercise RPP as compared to normal VF. In untrained adolescents HR shoot up to supply oxygen to exercising muscles. During Exercise Stress Test, high VF adolescents were not able to sustain exercise for long duration or not able to cross more numbers of stages due to high visceral fat.

Sembulingam P. et al. (2015) depicted that low resting RPP is heart friendly. They reported that low RPP is related with increased vagal tone\textsuperscript{119}. In our study low resting RPP was seen in normal VF adolescents compared to high VF adolescents which gave shield against anxiety induced cardiovascular disturbances. Proportionate rise in HR and SBP with exercise moreover reflects appropriate functioning of autonomic nervous system. During maximal and submaximal exercises, RPP rises as per the exercise duration and intensity by rising HR and SBP. SBP and HR are the separate component of RPP which play a key role in determining oxygen supply to the heart and managing ischemic heart disease particularly during stressful condition\textsuperscript{162}. In our study, both the groups showed increase in HR along with SBP after submaximal exercise which was sufficient to withstand cardiovascular stress without any discomfort.

HRR or rate of decline in HR after a graded exercise test is a stronger predictor of CVD and all-cause mortality in normal adults and subjects with either DM, CVD or risk factors for CVD. HRR is primarily due to function of parasympathetic nervous system. HRR is inversely related with abdominal obesity, BMI, Low HDL in geriatric population\textsuperscript{61,70,71}. 
In our study, post-exercise recovery parameters were taken after the 2nd, 4th, and 6th minutes of exercise. Post exercise HRR was same in both the genders with normal and high VF adolescents, but not recovered at 6th minutes and it was remained on the higher side in high VF groups but was not statistically significant.

Post exercise recovery of SBP did not come to resting level in high VF groups at 6th minutes. However, it was statistically significant (p<0.01) for female adolescents between normal and a high VF group at 2nd, 4th and 6th minutes (Table 11) while it was statistically not significant between normal and high VF group of male adolescents (Table 5). Post-exercise SBP recovery has been reflected as potent and independent forecaster of cardiovascular mortality and morbidity\(^\text{72}\). It is a manifestation of level of SBP drop after peak exercise and is recognized as a sign of how cardiovascular system and Autonomic Nervous System (ANS) reacts to physical exertion. It is well documented that delayed SBP recovery is an indicator of ANS dysfunction and vascular activity pathology and is linked with high risk of hypertension, acute myocardial infarction, CVD and stroke\(^\text{163}\).

The immediate post-exercise cardiovascular adaptation is linked with coordinated rapid rise in parasympathetic and a progressive decline in sympathetic activity. Consequently, it is predominantly due to withdrawal of sympathetic discharge during post-exercise period. So, these ANS alterations rely on the basal autonomic status and the adaptive heart-rate alterations to exercise-induced stress reflects this steady state autonomic condition. It is well recognized that during the exercise, there is reciprocity between sympathetic over-activity and parasympathetic suppression in the modulation of HR. The sympathetic activity remains high during the 1st minutes of post-exercise
period and gradual returns to the baseline level. In trained athletes, HRR is seen during 1st minute of recovery\textsuperscript{72,164}. Dimkpa et al. (2010)\textsuperscript{163} stated that overweight/obese male and female had blunted SBP recovery than their control groups respectively. Faster SBP recovery is linked with high aerobic capacity and fitness. Further, weight reduction causes faster SBP recovery.

Our Regression analysis concluded that visceral fat level is the main culprit for change in systolic blood pressure and diastolic blood pressure during exercise than total body fat. With one VFL rise, there was expected rise of 1.38mmHg in SBP, which was statistically highly significant (p<0.001), (Table 58). Further, with one VFL rise, there was expected rise of 0.66mmHg in DBP, which was statistically highly significant too (p<0.001), (Table 61).

So our study is in agreement with many studies\textsuperscript{2,4,5,6,11,44} which stated that central obesity plays a key role in the development of metabolic syndrome in adolescents than peripheral fat. Metabolic Syndrome is an amalgamation of hypertension, obesity, DM, dyslipidemia which are risk factors for establishment of CVD and chronic kidney disease. National Cholesterol Education Program’s Adult Treatment Panel III report found six components of metabolic syndrome which is linked with CVD i.e. central obesity, elevated BP, atherogenic dyslipidemia, insulin resistance/glucose intolerance, prothrombotic and proinflammatory state\textsuperscript{33,165}. Canale MP et al. (2013)\textsuperscript{165} specified that visceral obesity is an autonomous risk factor for CVD and metabolic syndrome. Subcutaneous fat is described by insulin sensitive adipocytes, whereas visceral adipocytes are insulin resistant cells.
Another hypothesis that why visceral fat promotes the risk of hypertension has its key role for insulin resistance. Framingham Offspring study found the high levels of plasminogen activator inhibitor-1, a major circulating inhibitor of thrombolysis which is positively linked with SBP and DBP. While other reported plausible mechanism may be visceral fat produce more number of this peptide comparison to subcutaneous fat. So, plasminogen activator inhibitor-1 plays a crucial role for connecting visceral fat to the risk of developing hypertension\textsuperscript{26,35,36}.

Fortunately, adolescence is the prime period for halting everlasting cardiovascular impairment as it is early enough to reverse pathological changes. Hence, prevention/reduction of visceral obesity by integrating increase in physical activity, regular exercise and dietary interventions are welcome steps to combat consequences of comorbidities associated with it. Visceral obesity intervention program may have positive effect on hemodynamic and metabolic alteration, body composition, cardiovascular fitness, vascular function and thus, improvement of overall cardiovascular health in these younger generation.