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Obesity and C-Reactive Protein, Immunoglobulins, and Lipids

AMAL ABDULAZIZ ALSUFYANI

Department of Biochemistry, Faculty of Sciences, King Abdulaziz University
Jeddah, Saudi Arabia

King Saud bin Abdulaziz University for Health Sciences
Jeddah, Saudi Arabia

Department of Chemistry and Biochemistry, George Mason University
Fairfax, VA

Obesity has been increasing in rich oil producing countries, such as Saudi Arabia, for the last few decades. Weight above the healthy level is suggested to interfere with normal immune function, affecting both innate and acquired immune responses. This study aimed to determine the relationship between increased weight and serum concentrations of C-reactive protein (CRP), Immunoglobulin (Ig)G, IgM, IgA, and the lipid profile. One hundred and nineteen randomly chosen Saudi female college students were assessed for their weight status using the body mass index (BMI) and the waist-to-hip ratio (WHR). Findings show that as the BMI and WHR increase, the CRP levels increase highly significantly compared to the controls. IgA levels also increase significantly as the BMI and WHR increase. Conversely, both IgG and IgM levels are not affected by the BMI or WHR. As for the lipid profile, cholesterol concentrations rise highly significantly as the WHR increases, but it is not affected by the BMI. Triacylglycerols and LDL levels increase highly significantly, while HDL decreases highly significantly in association with BMI and WHR increase. Multiple comparisons between the BMI and WHR groups were also investigated. In conclusion, increasing weight and obesity is correlated with an increase in CRP concentration, suggesting the presence of a state of harmful unspecific inflammation. The observed increase in IgA with the increase of weight and obesity agrees with findings by other researchers of increased respiratory infections in obese individuals. Finally, it is also concluded that overweight and

obesity are associated with an unfavorable lipid profile, which is known to be detrimental to health and the immune system.

Obesity and C-Reactive Protein, Immunoglobulins, and Lipids

An increasing percentage of the population in rich oil-exporting countries, such as Saudi Arabia and Kuwait, are overweight or obese. This trend has been observed in both sexes and in all age groups for the last few decades (Al-Nuaim, Bamgboye, & Al-Herbish, 1996; El-Hazmi & Warsy, 1997; Al-Nuaim, 1997; Popkin & Doak, 1998; Madani, 2000; Al-Nozha et al., 2005). Obesity predisposes an individual to many medical risks and serious diseases (van den Elzen et al., 2005; Gonzalez-Quintela et al., 2008), and adversely affects general health and homeostasis of the body, including the immune system (AlSufyani & Mahassni, 2011). Systems in the body must interact in order to function properly, thus a malfunction in the immune system leads to a malfunction in other systems of the body, and vice versa (Gonzalez-Quintela et al., 2007; Staines, Brostoff, & James, 1994). Some diseases and conditions may cause the non-specific activation of the immune response, even in the absence of a specific pathogen, leading to, among other effects, inflammation and its subsequent grave consequences (Davidson & Diamond, 2001; Irwin & Miller, 2007). One such condition is excess weight and, to a greater extent, obesity and morbid obesity (Das, 2001; Davì et al., 2002; Ferrante, 2007; Heilbronn & Clifton, 2002; Kelley, 2001).

Properly assessing body weight and fat distribution using more than one method is important, to be able to determine their effects on the health status of the body. The waist-to-hip ratio (WHR) defines the exact location of fat to differentiate between abdominal (android or male pattern) obesity and lower body (gynoid or female pattern) obesity (Champe, Harvey, & Ferrier, 2005; Rolfes, Pinna, & Whitney, 2006). Android obesity may lead to serious metabolic consequences and increased morbidity and mortality, whereas gynoid obesity carries a better prognosis for health risks and morbidity and mortality (Geissler & Powers, 2005). The body mass index (BMI) is a measure of body weight status, and although it is considered one of the most accurate methods (Deurenberg & Yap, 1999; Rolfes et al., 2006), it does not indicate location of fat and body shape.

Some researchers have shown that the immune response is compromised and affected by increased weight above the average healthy weight, although there is no consensus on the type of effect that results (Visser, Bouter, McQuillan, Wener, & Harris, 1999; Das, 2001; Marti, Marcos,

& Martinez, 2001; Samartin & Chandra, 2001; Davì et al., 2002; Park H., Park J., & Yu, 2005; Matsuda, Okamatsu, Tani, Kimura, & Matsuishi, 2007; AlSufyani & Mahassni, 2011). However, other researchers do not concur that immune function is influenced or reduced in the obese and overweight compared to healthy weight individuals (Nieman et al., 1996; Samartin & Chandra, 2001). Nieman et al. (1996), for example, found no significant difference in the immune functions of the obese and non-obese healthy, normoglycemic, or premenopausal females. However, studies showing that obesity reduces immunity explain the changes in the unspecific and specific immune responses in obese subjects by humoral and cell-mediated mechanisms (e.g., Samartin & Chandra, 2001).

C-reactive protein (CRP), an acute phase protein, is important in immunity as it increases rapidly in the case of trauma, inflammation, and infection, as well as decreases rapidly upon cessation of the abnormal conditions. Thus, CRP is valuable as an inflammation marker to assess and follow inflammatory states (Das, 2001). Although there is some debate, it is generally believed that increased weight leads to a non-specific inflammatory reaction, which is partially due to the many associated health problems (Stienstra, Duval, Müller, & Kersten, 2006; Ferrante, 2007). Researchers have shown that the level of CRP increases significantly as the BMI and WHR increase in both men and women (Visser et al., 1999; Das, 2001; Park et al., 2005; Heilbronn & Clifton, 2002), especially in women with android obesity (Davì et al., 2002). An inflammatory state, which is associated with abdominal adiposity, leads to platelets activation through enhanced lipid peroxidation. This explains the high prevalence of cardiovascular diseases in overweight and obese people through platelets and vascular abnormalities, which is triggered by inflammatory conditions (Davì et al., 2002).

A study by Matsuda and colleagues (2007) found an effect of the body weight on the Immunoglobulin (Ig) levels where the levels of IgG, IgA and IgE antibodies increased and IgM levels decreased in the overweight subjects. Another study showed lower production of antibodies after vaccination in obese individuals compared to non-obese individuals (Marti et al., 2001). Alternatively, according to McMurray, Beskitt, and Newmark (1982) there is no significant effect of obesity, which is not associated with any health complications, on serum immunoglobulins IgG, IgA, IgM, IgD and on IgA found in tears. Thus, the relationship between obesity and levels of serum antibodies is not well understood and warrants further investigation.

Another pathway by which obesity affects the immune system is through the serum lipid levels. Studies carried out on animals (Gunstone & Padley, 1997; Watkins, German, Shoenfeld, & Gershwin, 2001) and humans (Calder, 1998; Kelley, 2001; Ray et al., 1997) showed that the immune system may be affected by dietary lipids and the lipid profile in different ways. Serum levels of fats reflect the amount and type of consumed dietary lipids. In addition, body fat composition reflects the dietary intake of fat, and therefore excess body fat and obesity are highly correlated (Jeor, 1997). Thus, obesity may be associated with a state of decreased levels of high-density lipoprotein (HDL) cholesterol, and increased levels of low-density lipoprotein (LDL) cholesterol, which is recognized as an unhealthy lipid profile (Pi-Sunyer, 1983). Another correlation between blood lipoproteins and the immune system appears in the stages of plaque development caused by injuries (Rolfes et al., 2006), where the immune response at the site of injury leads to accumulation of cholesterol. Therefore, dietary lipids, body lipids, and serum lipids all play a major role in immunity. This correlation may be due to the effect of obesity on the levels of serum lipids, which may thereby affect the immune system.

The aim of this study is to determine the effects of obesity, measured by the BMI and WHR, on the levels of CRP, IgG, IgM, IgA, and the lipid profile in Saudi Arabian female university students. As a result, this study helps in comparing these effects with other populations and helps with setting local dietary guidelines and recommendations.

Materials and Methods

Subjects, Blood Collection, and Categories

This study included 119 randomly chosen Saudi female students (17–26 years old) at King Abdulaziz University, Jeddah, Saudi Arabia. This same group had been previously studied for other immune parameters (AlSufyani & Mahassni, 2011). None of the subjects were taking any type of medications, other than birth control pills for some subjects. Also, none suffered from any immune allergic disease or any health problems related to lipids or heart disease.

The Body Mass Index (BMI) was used to divide the sample into 5 groups with a total of 20–25 subjects per each BMI category. The underweight group had a BMI below 18.9, the average weight group had a BMI of 18.9–24.9, the overweight group had a BMI of 25–29.9, the obese group had a BMI of 30–40, and the highly obese group had a BMI above 40 (Rolfes et al., 2006). The waist to hip ratio was also used to assess the subjects and assign them into one of 3

groups: low risk (0.80 or below), moderate risk (0.81 to 0.85), and high risk (0.85+) (Rolfes et al., 2006).

Whole blood was collected from each subject into plain vacutainer tubes. Clear serum was carefully separated, transferred into micro-centrifuge tubes, and stored at -20 ^{o}C up to the time of analysis. At the time of blood collection, each subject was weighed using household scales, and the height, waist (at the naval), and hips (at the fullest point) measurements were taken using a measuring tape. All parametric analyses were carried out at King Abdulaziz University Hospital, Jeddah, Saudi Arabia.

IgG, IgA, and IgM Antibody Concentrations

Serum concentrations of IgG, IgA and IgM antibodies were measured using the *in vitro* diagnostic reagents N antisera to human IgG, IgA and IgM immunoglobulins (Siemens, Germany), according to the manufacturers' instructions. Results were read using a Siemens nephelometer II (BN II-system, Germany).

CRP Concentrations

The CRP concentrations were determined using the high sensitivity C-reactive protein assay (hsCRP; Siemens, Germany). The results were read on a Siemens nephelometer II (BN II-System, Germany). A nephelometry calibration procedure and a control run were performed before running the samples.

Complete Lipid Profile

Triacylglycerols (TAGs), cholesterol, high-density lipoprotein-cholesterol (HDL-C), and low-density lipoprotein-cholesterol (LDL-C) concentrations were measured on a Dimension Vista instrument (Siemens, Germany) using the Flex reagent cartridges (Siemens, USA) specific for each measured substance, as described by the manufacturer.

Statistical Analysis

Descriptive and analytical statistics were calculated using the statistical program SPSS (Version 12.0). The mean, standard deviation, standard error of the mean, and range were calculated for all parameters. A one-way ANOVA was used to test the significance of the correlations between BMI and WHR categories, individually, with each measured parameter. In the case that the ANOVA resulted in a significant difference, post hoc tests were used for multi-comparisons. The Tukey test was used for the homogeneous parameters (where equal variance is

not assumed), and Tamhane's T2 test was used for the non-homogeneous parameters (where equal variance is assumed).

Results

Subjects and Categories

The 119 female Saudi students included in the study, with an age range of 17–26 years (M = 21.680, SD = 1.895), have a BMI range of 13.77–55.26 kg/m^2 (M = *28*.2480, SD = 9.5515), which falls in the overweight category of the well-established BMI categories. Subjects were divided into 5 BMI groups, or categories, with a total of 20–26 subjects per each BMI category. Thus, based on the BMI, 20.2% (n = 24) of the subjects are underweight (BMI below 18.9), 21.8% (n = 26) are healthy or average weight (BMI between 18.9 and 24.9), 19.3% (n = 23) are overweight (BMI between 25 and 29.9), 21.0% (n = 25) are obese (BMI between 30 and 40), and 17.6% (n = 21) are highly obese subjects (BMI above 40).

The WHR was used to assess the subjects' weight distribution and assign subjects into one of three risk groups for health problems. For females, a low risk WHR is 0.8 or lower, a moderate risk WHR is between 0.81 and 0.85, and a high risk WHR is above 0.85 (Cozamanis, 2006). The percent of subjects in the low risk group is 68.9% (n = 82), the moderate risk is 9.2% (n = 11), and the high risk group is 21.8% (n = 26) of the subjects.

Parameters and BMI Analysis

Antibody concentrations. The concentrations of IgM, IgG, and IgA for all subjects are shown in Table A1, along with the minimum and maximum values and the descriptive statistics for each category. The one-way ANOVA shows the IgM and IgG concentrations for all BMI groups are not significantly different from the healthy (control) group. As for the IgA concentrations, the concentration means increase significantly as the BMIs increase from the healthy to the highly obese. The one-way ANOVA shows a significant difference in the IgA serum concentration for the BMI groups compared to the healthy (p = .049). As the IgA data are non-homogenous at the 95% confidence level, the following non-homogenous post hoc tests were used: the Tamhane, Dunnett T3, Games-Howell. However, it did not show multiple comparison differences between groups. Using the Tukey Post Hoc test, only the highly obese group showed a difference, an increase of the mean levels of IgA compared to those of the control group (Supplementary Materials, Table S1).

CRP concentrations. CRP concentrations means for the subjects are shown in Table A2, with the minimum and maximum values provided for each category. The one-way ANOVA shows the mean serum CRP levels increase is highly significant as the BMI increases ($p < .001$). Thus, the mean CRP levels for all groups, except for the underweight group, are higher than the healthy group.

The Tamhane Post Hoc multiple comparisons test was used to compare the serum CRP concentration mean of each BMI group with that of the control (Supplementary Materials, Table S2). There is a highly significant difference in the CRP levels in the obese and highly obese groups in comparison to the healthy group, which has a lower CRP. However, the underweight and overweight categories has no significant difference from the healthy category.

Complete lipid profile concentrations. The means of the cholesterol concentrations (Table A3) for each category are similar and no significant differences exist between the healthy weight and the four other weight categories. Thus, there is no significant effect of the BMI on the total serum cholesterol.

Based on the one-way ANOVA, the observed increase of TAGs concentration means for all BMIs compared to the healthy BMI is highly significant ($p = .001$), and, thus, there is a highly significant effect of the BMI on serum TAGs concentrations (Table A3). The Tamhane Post Hoc multiple comparisons test was used because the equal variance is not assumed due to the non-homogeneity of the population. The test results indicate that, in comparison with the healthy weight group, the concentration of TAGs have significantly higher mean in the overweight, obese, and highly obese groups, whereas for the underweight group there is no significant difference.

The means of the LDL-C concentrations increase as the BMI increases from underweight to obese (Table A3). The one-way ANOVA shows that the effect of the BMI on the serum LDL-cholesterol concentrations is highly significant ($p < .001$). For the multiple comparisons between groups, the Tukey Post Hoc test (Supplementary Materials, Table S3) shows that the mean LDL-C level of the highly obese was significantly higher compared to the healthy (control) weight, whereas the other groups showed no significant differences.

The HDL-C concentrations means for the BMI groups are all lower than that of the healthy BMI (Table A3). Using the one-way ANOVA, the mean HDL-C levels of all BMI categories is highly significantly different as compared to the healthy weight BMI group ($p <$

.001). For the multiple comparisons between groups for HDL-C, the Tukey Post Hoc test (Table S3) shows that the mean HDL-C level of the underweight BMI is significantly lower, while the levels for the overweight, obese, and highly obese BMI groups are highly significantly lower than that of the control.

Parameters and WHR Analysis

Antibody concentrations. Means, minimum, and maximum concentrations of IgG, IgM, and IgA antibodies for each WHR category are shown in Table A4. The one-way ANOVA test shows that the IgG and IgM concentration means for the moderate and high risk groups are not significantly different from the respective low risk (control) group. On the other hand, the IgA concentration means for the moderate and high risk groups are significantly above the low risk (control) group mean (p = .020).

The IgA results were non-homogeneous, therefore equal variance was not assumed. The Tamhane, Dunnett T3, and Games-Howell post hoc tests are suitable for multiple comparisons, but analysis did not yield such comparisons, as shown in Supplementary Materials, Table S4. Thus, the Least Significant Difference (LSD) test was used because it compares the differences between groups. The LSD test shows that the IgA concentrations means of both the moderate and high risk groups are significantly higher than that of the control (low risk) group (Supplementary Materials, Table S4).

CRP concentrations. The concentrations means of serum CRP for all subjects and the minimum and maximum concentrations for each WHR category are shown in Table A5. Using a one-way ANOVA, the CRP concentration means in both the moderate and high risk groups show a highly significant increase when compared to the control group (p = .001).

The Tamhane Post Hoc multiple comparisons test was used to analyze the CRP results because the results were not homogeneous (results are included in Supplementary Materials, Table S5). The difference between the mean CRP concentrations for the low and moderate risk groups is not significant, whereas the high risk group level is significantly higher than that for the low risk group.

Complete lipid profile concentrations. The means, minimum, and maximum values of the concentrations of serum cholesterol, TAGs, LDL-C, and HDL-C for each WHR group are shown in Table A6. The one-way ANOVA shows a significant correlation between the WHR

and the mean serum cholesterol levels ($p = .011$), and a highly significant correlations between serum TAGs ($p < .001$), LDL-C ($p < .001$), and HDL-C concentrations ($p = .010$).

For the multiple comparisons testing (Supplementary Materials, Table S6), the Tukey Post Hoc multiple comparisons test for homogeneous data was used for the cholesterol, LDL-C, and HDL-C concentrations means. For the cholesterol levels, the high risk group means concentration is highly significantly higher than the low risk (control) group, while there is no significant difference between the moderate and low risk groups. For the LDL-C concentrations means, the Tukey test shows a significant increase of the moderate risk group mean compared to the low risk group (control), and a highly significant increase for the high risk group mean compared to the control. As for the HDL-C concentrations, the moderate risk group is significantly lower than the low risk group, whereas there is no significant difference between the high and low risk groups. The Tamhane Post Hoc multiple comparisons test was used for the TAGs data and it shows that the higher level of HDL-C is highly significant for the high risk group compared to the control, whereas the moderate risk group shows no difference.

Discussion

There is a lack of sufficient information on the effects of body weight on the immune system and general health, especially for Middle Eastern populations. The data from this study show that obesity is associated with increasing serum IgA levels. This increase is significantly associated with the increase of BMI ($p = .049$) and WHR ($p = .020$). The highly obese BMI group is the only group that shows a significant increase ($M = 2.9152$, $SD = 1.27287$) compared to the healthy (control) BMI group ($M = 2.1196$, $SD = 0.91463$). The significant association between the WHR and IgA shows that the increase in the IgA levels is significant in both the moderate risk ($M = 2.8764$, $SD = 1.15809$) and the high risk ($M = 2.6281$, $SD = 1.37759$) groups, in comparison with the control (low risk) group ($M = 2.1804$, $SD = 0.74345$). The lowest IgA concentrations means are seen in the healthy BMI group, and the low risk group.

Furthermore, the highly significant correlation between IgA serum concentrations and the WHR may indicates that the fat distribution in obese subjects, not obesity per se, may have a more significant effect on the immunological status of the obese by affecting IgA concentrations. The finding of increased IgA values in the obese and highly obese subjects may explain the

increased respiratory inflammation observed in obese individuals, which could also be related to the high incidence of asthma (Pallaro et al., 2002; Poulain et al., 2006).

This study shows no significant effects of obesity on IgM and IgG concentrations, either when obesity is assessed by BMI or by WHR. This confirms the findings of McMurray and colleagues (1982) that there is no effect of obesity on IgM or IgG concentrations. Therefore, for obese young Saudi females with no other health problems, obesity does not seem to affect immune functions mediated by IgG or IgM, although it does affect those mediated by IgA.

The results also show that increased BMI and obesity are highly significantly associated with the CRP serum concentrations ($p < .001$). The CRP levels increase as the BMI and WHR increase. For the BMI assessment of obesity, the CRP levels are highly significantly greater in both obese ($M = 5.8836$, $SD = 5.91259$) and highly obese subjects ($M = 11.2467$, $SD = 11.40476$) when compared to healthy weight subjects ($M = 0.8062$, $SD = 1.41780$). As for the WHR ratio assessment of obesity, only the high risk group ($M = 7.7181$, $SD = 9.06482$) has a significant increase in the CRP level above the control ($M = 2.6401$, $SD = 6.46560$). This result suggests that the CRP concentration level does not show a significant difference among groups with lower BMI and WHR. Similar correlations have been observed in other populations (Visser et al., 1999; Das, 2001; Park et al., 2005).

The increase in the CRP concentrations as both the WHR and BMI increase, and the remarkably high level of the CRP in the high risk group (WHR above 0.85, male-like shape) support the hypothesis that the location of fat is important for the assessment of body weight and its health effects (Rolfes et al., 2006). The increase of the adipose tissue mass could be related to its increasing content of interleukin-6 (IL-6), which is related to and could explain the elevated levels of CRP in females with high WHR ratios or BMIs (Das, 2001). Also, the finding of a significant association between CRP and both the BMI and WHR ratio may explain the high prevalence of inflammation in the obese, especially females, and supports the classification of obesity as an inflammatory disease (Das, 2001; Davì et al., 2002; Ferrante, 2007; Heilbronn & Clifton, 2002; Kelley, 2001). The increase of the CRP levels in obese and highly obese individuals is dangerous because of the strong correlation between heart disease and elevated levels of CRP (Das, 2001).

In this study, subjects' serum cholesterol concentrations did not show an association with obesity measured by the BMI ($p = .185$), but they show a significant association with obesity

measured by the WHR ratio (p = .011). The association between the serum cholesterol concentration and WHR ratio shows a highly significant increase in the high risk group only (M = 4.7485, SD = 0.61772) when compared with the control group (M = 4.2898, SD = 0.67724). This leads to the conclusion that body shape, or fat distribution, is an indicator of cholesterol levels, whereas total weight or body fat is not. The results are in agreement with previous research, which found that fat distribution is a strong indicator for body weight and its relation to health (Visscher et al., 2001; Marti et al., 2001).

Both LDL and HDL cholesterol levels are highly significantly correlated to obesity measured by the BMI (p < .001 for both LDL and HDL) and WHR ratio (p < .001 and p = .010, respectively). The LDL cholesterol levels increase as the BMI and WHR increase. This increase is significant in the moderate risk group (M = 3.0682, SD = 0.60959) and highly significant in the high risk group (M = 3.2062, SD = 0.59472) compared with the control group (M = 2.6020, SD = 0.51369). The LDL levels increase significantly in the highly obese subjects (M = 3.1024, SD = 0.50877) compared with the healthy weight subjects (M = 2.600, SD = 0.59271). All other groups do not show significant differences.

The opposite occurs with HDL: HDL levels are lower for all BMI categories and WHR risk groups. This decrease is significant for the moderate risk group (M = 1.4409, SD = 0.16022) compared to the low risk (control) group (M = 1.6900, SD = .30669), and for the underweight BMI group (M = 1.6671, SD = 0.18989) compared to the healthy group (M = 1.8735, SD = 0.32919). The decrease is highly significant for the overweight (M = 1.5652, SD = 0.25157), obese (M = 1.5704, SD = 0.27327), and highly obese BMIs (M = 1.5014, SD = 0.20872) compared to the control BMI. The remaining group (high risk WHR) does not show a significant difference from the control.

Serum TAG levels are highly significantly (p < .001) correlated with the BMI and WHR. The levels are significantly higher than the healthy BMI group (M = 0.8250, SD = 0.26805) in both the obese (M = 1.3032, SD = 0.63235) and highly obese (M = 1.3352, SD = 0.64160) and they increase highly significantly in the high risk group (M = 1.3650, SD = 0.55588) compared to the low risk group (M = 0.8980, SD = 0.33320). Other groups are not significantly different from controls. This result can be explained by the effect of the central obesity on the lipid metabolism. When the very low-density lipoprotein (VLDL) synthesis increases in the liver, the TAG synthesis will increase and the HDL synthesis will decrease. At the same time, TAG clearance

by the peripheral tissues will decrease, which leads to the increase in the TAG concentration (Aguilera, Gil-Campos, & Canete, 2008). The previous serum lipid profile analysis results show significant increases in total cholesterol, LDL, TAG, and a significant decrease in HDL in obese subjects. This suggests that obesity adversely affects the lipid profile, a conclusion also asserted by other researchers (Marti et al., 2001).

In summary, the data show that lower cholesterol concentrations means are associated with the low and moderate risk WHR groups. However, the BMIs are not associated with changes in cholesterol concentrations. The TAGs are lower for the underweight, healthy, and overweight BMIs, as well as for the low and moderate risk WHRs. As for LDL, the lower means are associated with the low risk WHR group, and for all BMIs, except for the highly obese. For the HDL levels, the higher means corresponds to the healthy BMI and the low and high risk WHRs. Thus, as a whole, the lower the weight the more favorable the lipid profile in terms of lower cholesterol, TGAs and LDL levels, and higher HDL levels.

Obesity, possibly through the action of IL-6, may enhance the production of CRP, which in turn may trigger or increase the low-grade systemic inflammation associated with overweight and obese individuals. There is evidence that higher circulating levels of CRP and IL-6 in the obese increase the risk of death by cardiovascular disease (Das, 2001). As seen in this study, high LDL concentration, along with CRP concentration, is also known to be high in obese subjects and plays a major role in cardiovascular diseases, such as atherosclerosis. This effect is enhanced by the CRP, which binds to LDL that stimulates its uptake by macrophages and leads to tissue damage (Heilbronn & Clifton, 2002).

Previous research also found that obesity-associated decreases in HDL along with increases in LDL and CRP, as in the case of this study, could increase the risk of development of atherosclerosis and cardiovascular disease throughout a subjects' life (Das, 2001). The increased risk is likely due to increased inflammation caused by these obesity-associated changes. In a study by Juompan, Fournié, and Benoist (1994), the authors concluded high levels of LDL in peripheral blood could cause a decrease in the circulating natural killer cells' activity, which may explain the high susceptibility of obese individual to infections.

Some research studies also suggest an influencing effect of obesity on the inflammatory status of the body (Das, 2001; Davì et al., 2002; Heilbronn & Clifton, 2002). In this study, the significant increases in CRP and IgA in obese individuals, and the established roles of these

molecules in inflammation, add to existing evidence of the high incidence of inflammation in obese individuals. The highly significant concentration of CRP, which plays a role in cardiovascular diseases via its inflammatory response, increases susceptibility to cardiovascular disease in obese individuals.

In conclusion, results of this study support the link between immunological parameters, increased weight and obesity, and the resulting unhealthy lipid profile of the subjects. It is evident that even the young age of the subjects does not spare their immune system from the ill effects of obesity. Therefore, it is recommended that more focus be placed on the maintenance of healthy weight and achieving a healthy body fat distribution because, as evident in this study, fat distribution measured by WHR affects several immune and health parameters. Additionally, in some instances, for example the cholesterol level, WHR is a stronger and more accurate indicator than total body fat that is assessed by the BMI. Further, it is recommended that more research be carried out to clarify the clinical implications of the changes in the immune system and functions that are induced by obesity. More research is needed to study other immunologically related parameters and to determine whether changes in the immune system parameters and function will be achieved and maintained once healthy weight is reached and maintained. Finally, these findings indicate the importance of investigating any differences that may be present between the different sexes and age groups in the local population.

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Appendix

Table A1

Descriptive Statistics and Test of Significance for Serum IgM, IgG, and IgA Concentrations for BMI Categories

	BMI	Min mg/L	Max mg/L	Mean mg/L	Std. error	Std. deviation	*p*
IgM	Underweight	0.53	2.49	1.3513	0.10549	0.51681	
	Healthy	0.61	3.57	1.4823	0.14987	0.76418	0.873
	Overweight	0.64	3.12	1.5543	0.14708	0.70536	
	Obese	0.68	2.76	1.4388	0.10348	0.51742	
	Highly obese	0.61	3.13	1.4633	0.15014	0.68804	
IgG	Underweight	7.81	15.90	12.4017	0.48978	2.39942	
	Healthy	6.36	18.00	12.9965	0.61605	3.14124	
	Overweight	7.88	19.00	12.9078	0.54696	2.62314	0.764
	Obese	7.69	17.10	12.7756	0.46564	2.32818	
	Highly obese	8.67	17.30	13.4224	0.48893	2.24056	
IgA	Underweight	1.24	3.22	2.1813	0.10974	0.53759	
	Healthy	0.89	4.36	2.1196	0.17937	0.91463	
	Overweight	0.99	5.02	2.2474	0.17721	0.84987	0.049*
	Obese	1.02	5.37	2.3356	0.21667	1.08337	
	Highly obese	1.21	6.19	2.9152	0.27776	1.27287	

Note: A one-way ANOVA was used to test for significance.
.05. ** $p < .01$.

Table A2

Descriptive Statistics and Test of Significance for CRP Concentrations for BMI Categories

	BMI	Min mg/L	Max mg/L	Mean mg/L	Std. error	Std. deviation	*p*
CRP	Underweight	0.10	1.53	0.4312	0.08488	0.41584	
	Healthy	0.10	7.14	0.8062	0.27805	1.41780	
	Overweight	0.23	47.40	4.6278	1.99597	9.57234	0.000 **
	Obese	0.10	21.80	5.8836	1.18252	5.91259	
	Highly obese	1.20	43.40	11.2467	2.48872	11.40476	

Note: A one-way ANOVA was used to test for significance.
.05. ** $p < .01$.

Table A3

Descriptive Statistics and Test of Significance for Serum Cholesterol, TAGs, LDL-C, and HDL-C Concentrations for BMI Categories

	BMI	Min mmol/L	Max mmol/L	Mean mmol/L	Std. error	Std. deviation	*p*
Cholesterol	Underweight	3.22	5.28	4.1317	0.10396	0.50931	
	Healthy	3.45	6.45	4.4988	0.16135	0.82271	
	Overweight	2.92	6.33	4.3248	0.14305	0.68605	0.185
	Obese	2.99	5.78	4.5032	0.14328	0.71638	
	Highly obese	3.49	5.40	4.5590	0.12941	0.59305	
Triglyceride	Underweight	0.45	1.98	0.8700	0.07357	0.36041	
	Healthy	0.47	1.53	0.8250	0.05257	0.26805	
	Overweight	0.49	2.80	1.0387	0.11690	0.56064	0.001**
	Obese	0.73	3.00	1.3032	0.12647	0.63235	
	Highly obese	0.67	3.16	1.3352	0.14001	0.64160	
LDL-C	Underweight	1.73	3.65	2.4642	0.09435	0.46221	
	Healthy	1.76	3.98	2.6000	0.11624	0.59271	
	Overweight	1.85	4.39	2.7513	0.12060	0.57836	0.000**
	Obese	2.11	4.30	3.0120	0.12350	0.61750	
	Highly obese	1.94	3.92	3.1024	0.11102	0.50877	
HDL-C	Underweight	1.18	2.01	1.6671	0.03876	0.18989	
	Healthy	1.46	2.88	1.8735	0.06456	0.32919	
	Overweight	1.20	2.23	1.5652	0.05246	0.25157	0.000**
	Obese	1.10	2.47	1.5704	0.05465	0.27327	
	Highly obese	1.20	2.06	1.5014	0.04555	0.20872	

Note: A one-way ANOVA was used to test for significance.
.05. ** $p < .01$.

Table A4

Descriptive Statistics and Test of Significance for Serum IgM, IgG, and IgA Concentrations Versus the WHR Categories

	WHR	Min mg/L	Max mg/L	Mean mg/L	Std. error	Std. deviation	*p*
IgM	Low Risk	0.53	0.53	1.4515	0.06958	0.63010	
	Moderate Risk	0.91	0.91	1.8073	0.21707	0.71995	0.111
	High Risk	0.61	0.61	1.3277	0.11744	0.59883	
IgG	Low Risk	6.36	19.0	12.8684	0.28585	2.58845	
	Moderate Risk	9.04	17.1	13.5036	0.79305	2.63024	0.675
	High Risk	7.69	17.3	12.6900	0.49017	2.49937	
IgA	Low Risk	0.89	4.55	2.1804	0.08210	0.74345	
	Moderate Risk	1.24	4.58	2.8764	0.34918	1.15809	0.020*
	High Risk	0.99	6.19	2.6281	0.27017	1.37759	

Note: A one-way ANOVA was used to test for significance.
.05. ** $p < .01$.

Table A5

Descriptive Statistics and Test of Significance for Serum CRP Concentrations Versus the WHR Categories

	WHR	Min mg/L	Max mg/L	Mean mg/L	Std. error	Std. deviation	*p*
CRP	Low Risk	0.10	47.4	2.6401	0.71401	6.46560	
	Moderate Risk	1.62	33.6	9.4418	3.02218	10.02345	0.001**
	High Risk	0.40	43.4	7.7181	1.77776	9.06482	

Note: A one-way ANOVA was used to test for significance.
.05. ** $p < .01$.

Table A6

Descriptive Statistics and Test of Significance for Cholesterol, TAGs, LDL-C, and HDL-C Concentrations for the WHR Categories.

	WHR	Min mmol/L	Max mmol/L	Mean mmol/L	Std. error	Std. deviation	*p*
Cholesterol	Low Risk	2.92	6.45	4.2898	0.07479	0.67724	
	Moderate Risk	3.57	5.78	4.4273	0.20562	0.68195	0.011*
	High Risk	3.49	6.33	4.7485	0.12114	0.61772	
Triglyceride	Low Risk	0.45	1.98	0.8980	0.03680	0.33320	
	Moderate Risk	0.67	3.16	1.6100	0.30594	1.01469	0.000**
	High Risk	0.72	2.86	1.3650	0.10902	0.55588	
LDL-C	Low Risk	1.73	3.98	2.6020	0.05673	0.51369	
	Moderate Risk	2.23	4.30	3.0682	0.18380	0.60959	0.000**
	High Risk	1.94	4.39	3.2062	0.11663	0.59472	
HDL-C	Low Risk	1.14	2.88	1.6900	0.03387	0.30669	
	Moderate Risk	1.21	1.77	1.4409	0.04831	0.16022	0.010*
	High Risk	1.10	2.06	1.5800	0.04061	0.20709	

Note: A one-way ANOVA was used to test for significance.
.05. ** $p < .01$.

Supplementary Materials

Table S1

Multiple Comparisons Between the Mean IgA Concentration for the Healthy BMI Group and the Other Groups

BMI (H)	BMI Category	Mean differences[a]	Std. error	*p*
Healthy	Underweight	-0.06163	0.27040	0.999
	Overweight	-0.12778	0.27344	0.990
	Obese	-0.21598	0.26757	0.928
	Highly obese	-0.79562	0.28026	0.042*

[a] The mean difference is the difference between healthy BMI mean and each BMI category mean.
.05. ** $p < .01$.

Table S2

Multiple Comparisons Between the Mean CRP Concentration for the Healthy BMI Group and the Other Groups

BMI (H)	BMI Category	Mean differences[a]	Std. error	*p*
Healthy	Underweight	0.37490	0.29072	0.902
	Overweight	-3.82167	2.01524	0.519
	Obese	-5.07745	1.21477	0.003**
	Highly obese	-10.44051	2.50421	0.005**

[a] The mean difference is the difference between healthy BMI mean and each BMI category mean.
.05. ** $p < .01$.

Table S3

Multiple Comparisons Between the Mean TAGs, LDL-C, and HDL-C Concentrations for the Healthy BMI Group and the Other Groups

	BMI (H)	BMI Category	Test	Mean differences[a]	Std. error	*p*
TAGs	Healthy	Underweight	Tamhane	-0.04500	0.09042	1.000
		Overweight		-0.21370	0.12818	0.673
		Obese		-0.47820	0.13696	0.014*
		Highly obese		-0.51024	0.14955	0.021*
LDL-C	Healthy	Underweight	Tukey	0.13583	0.13583	0.910
		Overweight		-0.15130	-0.15130	0.877
		Obese		-0.41200	-0.41200	0.070
		Highly obese		-0.50238	-0.50238	0.022*
HDL-C	Healthy	Underweight	Tukey	0.20638	0.07306	0.044*
		Overweight		0.30824	0.07388	0.001**
		Obese		0.30306	0.07230	0.001**
		Highly obese		0.37203	0.07573	0.000**

[a] The mean difference is the difference between healthy BMI mean and each BMI category mean.
.05. ** $p < .01$.

Table S4

Multiple Comparisons Between the Mean IgA Concentrations for the Low Risk WHR Group and the Other Groups

WHR (L)	WHR Category	Mean differences[a]	Std. error	*p* Tam	*p* Dun T	*p* G-H	Mean differences	*p* LSD
Low Risk	Moderate Risk	-0.69600	0.3587	0.216	0.205	0.17	-0.69600	0.025*
	High Risk	-0.44771	0.2824	0.326	0.320	0.26	-0.44771	0.039*

Note. Tam = Tamhane; Dun T = Dunnett T3; G-H = Games-Howell; LSD = Least Significant Difference Test.
[a] The mean difference is the difference between low risk WHR mean and each WHR category mean.
.05. ** $p < 0.01$.

Table S5

Multiple Comparisons of CRP Concentration by Risk Groups Using Tamhane's Post Hoc Test

	WHR (L)	WHR Category	Test	Mean differences[a]	Std. error	*p*
CRP	Low Risk	Moderate Risk	Tam	-6.80170	3.10538	0.144
		High Risk		-5.07795	1.91578	0.036*

[a] The mean difference is the difference between low risk WHR mean and each WHR category mean.
.05. ** $p < .01$.

Table S6

Multiple Comparisons Between the Risk Groups for Cholesterol, TAGs, LDL-C, and HDL-C Concentrations

	WHR (L)	WHR Category	Test	Mean differences[a]	Std. error	*p*
Cholesterol	Low Risk	Moderate Risk	Tukey	-0.13752	0.21362	0.796
		High Risk		-0.45871	0.14973	0.008**
TAGs	Low Risk	Moderate Risk	Tamhane	-0.71195	0.30815	0.123
		High Risk		-0.46695	0.11506	0.001**
LDL-C	Low Risk	Moderate Risk	Tukey	-0.46623	0.17367	0.023*
		High Risk		-0.60420	0.12173	0.000**
HDL-C	Low Risk	Moderate Risk	Tukey	0.24909	0.08918	0.017*
		High Risk		0.11000	0.06251	0.188

[a] The mean difference is the difference between low risk WHR mean and each WHR category mean.
.05. ** $p < .01$.