

## Prader-Willi Syndrome Is Associated with Activation of the Innate Immune System Independently of Central Adiposity and Insulin Resistance

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**Background:** Subjects with Prader-Willi syndrome (PWS) have a reduced life expectancy due to cardiovascular disease. Increased systemic low-grade inflammation is postulated as a contributor, despite reported lower visceral fat mass and increased insulin sensitivity.

**Objectives:** Our aim was to compare inflammatory markers and arterial stiffness in PWS and adiposity-matched obese control subjects.

**Design:** We conducted a cross-sectional cohort study comparing 12 PWS subjects, 12 obese subjects matched for percentage body fat and central abdominal fat mass, and 10 healthy normal-weight subjects.

**Main Outcome Measures:** Dual-energy x-ray absorptiometry was used to assess body composition, flow cytometry to quantify activation markers on immune cells, and ELISA for measurement of C-reactive protein, adiponectin, and IL-6. Insulin resistance was estimated by homeostasis model assessment and arterial stiffness by applanation tonometry.

**Results:** PWS and obese subjects had similarly increased homeostasis model assessment and arterial stiffness. Nevertheless, PWS subjects showed significantly higher IL-6 ( $4.9 \pm 1.0$  vs.  $2.5 \pm 0.4$  pg/ml;  $P = 0.02$ ) and nonsignificantly higher C-reactive protein ( $10.5 \pm 3.2$  vs.  $4.0 \pm 1.0$  ng/ml;  $P = 0.08$ ). Neutrophil activation markers CD66b and CD11b were higher in PWS compared to obese subjects ( $P < 0.01$ ), reflecting an activated innate immune system. These markers were positively related to central adiposity in lean and obese subjects ( $r = 0.49$ ;  $P < 0.05$ ), but not in PWS subjects.

**Conclusions:** PWS subjects compared to adiposity-matched obese subjects demonstrate similar insulin resistance but increased low-grade inflammation. The dissociation of inflammation and central adiposity suggests that activation of innate immunity may be either a specific genetic feature of PWS or linked to the commonly associated obstructive sleep apnea syndrome, and might offer a treatment target to reduce cardiovascular disease. (*J Clin Endocrinol Metab* 95: 3392–3399, 2010)

**P**rader-Willi syndrome (PWS) is the most common known genetic cause of obesity, occurring in about one in 25,000 live births (1). It results from a lack of expression of the paternal alleles from the 15q11–q13 region on chromosome 15—the PWS critical region (PWSCR), an area that contains genes whose function is still poorly understood. The phenotype of PWS is characterized by marked hyperphagia starting in early childhood, severe obesity, GH deficiency, hypogonadism, sleep disorders, intellectual impairment, and behavioral disorders. In contrast to “simple” obesity, it has been documented that subjects with PWS have a lower visceral fat mass relative to their weight (2), which is associated with less insulin resistance compared with weight-matched obese controls (3). However, the greater insulin sensitivity in PWS appears paradoxical with the known increased cardiovascular morbidity and mortality, which is, however, appropriate for the reported higher levels of circulating inflammation markers (4–6). This observation differs from the frequently reported finding in simple obesity that insulin resistance is strongly related to both visceral adiposity and the degree of low-grade inflammation (7). However, many studies in PWS compare subjects matched for body weight and body mass index (BMI) only, but do not correct for the difference in central adiposity. In fact, accurate body composition is infrequently assessed. Considering that visceral fat mass is a major confounder in metabolic effects and low-grade inflammation, it is difficult to draw firm conclusions from these studies as to whether higher insulin sensitivity in PWS subjects is a result of lower visceral fat mass or other factors unrelated to body composition. Therefore, in the present study, we assessed activation of the immune system in PWS compared with obese control subjects matched for age, gender, and total and central adiposity. This is the first study investigating activation of circulating immune cells together with circulating inflammation markers and assessment of arterial stiffness in relation to insulin resistance and body composition.

## Subjects and Methods

### Subjects

Subjects with diagnosed PWS ( $n = 12$ ) were recruited through the specialized Prader-Willi Syndrome Clinic at Royal Prince Alfred Hospital, Camperdown NSW, Australia. Obese ( $n = 12$ ) and lean ( $n = 10$ ) control subjects were recruited by advertisements in local newspapers and public message boards. The study was approved by the Research and Ethics Committee of St. Vincent's Hospital. All subjects gave written informed consent before starting the study. All PWS subjects had the diagnosis confirmed by cytogenetic testing (seven deletions, five uniparental disomy). Three PWS subjects and two obese control subjects had documented hypertension (blood pressure  $>130/80$  mm Hg).

There were no smokers in the PWS group, but within the obese control group, one subject was currently smoking and four had smoked previously. A positive family history of cardiovascular disease was recorded in three PWS and six obese control subjects. Three PWS subjects had type 2 diabetes (treated with metformin alone, metformin/gliclazide, and metformin/Mixtard 30/70). In addition, two obese control subjects had type 2 diabetes (treated with metformin/gliclazide/insulin glargine and metformin/sitagliptin/rosiglitazone). The two subjects on insulin treatment had fasting insulin levels close to the mean levels of their corresponding group (PWS subject,  $14.6 \mu\text{U/ml}$ ; obese subject,  $17.1 \mu\text{U/ml}$ ). Five PWS subjects and one obese control subject had diagnosed obstructive sleep apnea syndrome (OSAS). Three PWS and two obese control subjects were treated with statins, and one PWS and one obese control subject were treated with aspirin 300 mg/d. Four PWS subjects took psychotropic medication, including anticonvulsants and antidepressants, whereas two obese control subjects took antidepressants. Six of seven male PWS subjects were treated with low-dose testosterone, whereas one of four PWS females took hormone replacement therapy. No PWS subjects had received GH. All lean control subjects were healthy nonsmokers taking no medication. All subjects were studied in the fasting state, before taking any medication or insulin.

### Study design

All subjects visited our Clinical Research Facility at 0800 h after a 10-h fast. All PWS subjects were supervised by parents or caregivers to ensure that the fasting instructions were followed. Height was measured by a stadiometer, and weight was measured in a hospital gown. BMI was calculated by dividing weight (in kilograms) by height (in meters) squared ( $\text{kg/m}^2$ ). Waist circumference was measured as the widest distance between the lower end of the ribs and the anterior superior iliac spines, and hip circumference as the widest circumference between the anterior superior iliac spines and the greater trochanters. Waist-to-hip ratio was calculated by dividing the waist circumference by the hip circumference.

Brachial blood pressure was measured by an Automatic Oscillometric Digital Blood Pressure Monitor (Omron HEM-705CP; Omron Corp., Tokyo, Japan). Two measurements were taken under standardized conditions with the subject sitting at approximately a  $45^\circ$  angle in bed.

A fasting blood sample was taken, and plasma and serum were stored at  $-20$  and  $-80$  C and assayed at a later date, as described below. Homeostasis model assessment (HOMA) for insulin resistance (HOMA-IR) and for  $\beta$ -cell function (HOMA- $\beta$ ) was used to estimate the degree of insulin resistance and  $\beta$ -cell function, respectively, as described previously (8).

### Body composition

Whole body dual-energy x-ray absorptiometry (Lunar DPX; GE-Lunar Corp., Madison, WI) was used to analyze body composition. As previously described (9), a central abdominal window was outlined manually extending from the upper border of L2 to the lower border of L4 and laterally to the outer margin of the rib cage. The fat in this window was measured and expressed as mass (central abdominal fat in kilograms) and as percentage of the total soft tissue content in this area. Although this window contains both intraabdominal fat and sc abdominal fat, it excludes 30% of the latter, has a relatively high intraabdominal and low sc abdominal fat content, and has been shown to be strongly inversely related to insulin sensitivity assessed by the euglycemic hyperinsulinemic clamp (9). Our

group has previously demonstrated a coefficient of variation (CV) of less than 6% for central abdominal fat, based on data from 10 female subjects scanned on four separate occasions (9).

### Immune cell preparation and flow cytometry analysis

Fresh whole blood was stained with fluorochrome-conjugated antibodies to various cell surface markers (CD66b, CD14, CD62L, CD11b, CD3, CD69, and CD25; BD Biosciences, San Diego, CA) using standard procedures, followed by red blood cell lysis and fixation with FACS Lyse (BD Biosciences). All analyses were performed on a BD FACSCalibur (BD Biosciences) with an excitation laser line argon (488 nm) and red diode (635 nm), and running CellQuest software (version 3.3; BD Biosciences). Data were analyzed with FlowJo software version 7 (TreeStar Inc., Ashland, OR).

For comparative quantification of activation marker expression, the mean fluorescence intensity (MFI) of the marker was divided by the MFI of the unstained control, which gives the relative MFI that can be compared among different cell subsets and subjects.

### Measurement of arterial stiffness

Applanation tonometry of the radial artery was used to measure the augmentation index (AIx), a marker of arterial stiffness. A high-fidelity transducer (SphygmoCor; AtCor Medical, Sydney, Australia) was placed over the radial artery, compressing, but not occluding, the artery against the underlying radius. The central arterial waveform was derived from the peripheral waveform using a validated transfer function (10). AIx was calculated as the ratio of the augmentation pressure and pulse pressure ( $\times 100\%$ ) (11). This technique provides intraarterial/aortic pressure measurements similar to those obtained invasively (12, 13). Previous studies have shown that AIx is inversely related to heart rate (14). Therefore, AIx was normalized to a heart rate of 75 bpm (AIx-HR75) to allow comparison between individuals. In our hands, the day to day CV for repeated fasting measurements of AIx on 4 separate days was 5.3% (15).

### Biochemical variables

Plasma glucose was determined by the glucose oxidase method using a YSI glucose analyzer (model 2300 STAT PLUS 230V; YSI, Inc., Yellow Springs, OH). Serum insulin was measured by a commercial RIA (Linco, St. Charles, MO). Serum total cholesterol, high-density lipoprotein (HDL) cholesterol, and triglycerides were determined spectrophotometrically at 490 nm by enzymatic colorimetry (Roche, Basel, Switzerland). High-sensitivity C-reactive protein (CRP) was measured using a Beckman Coulter Synchron LX system Chemistry Analyser, with reagents and calibrators (Beckman Coulter Inc., Sydney, Australia). CV was 3.7% at a level of 4.9 mg/liter, and the sensitivity was 0.2 mg/liter. IL-6 was measured with a commercial high sensitive ELISA kit (R&D Systems Inc., Minneapolis, MN). CV was 6.3% at a mean level of 0.7 pg/liter. High molecular weight (HMW) adiponectin and total adiponectin were measured with a commercial multimeric EIA kit (ALPCO Diagnostics, Salem, NH). CV was 3.7 and 9.6% for total and HMW adiponectin, respectively.

### Statistical analysis

Data are presented as mean  $\pm$  SEM for comparisons between groups. Database completion was above 99%, with one body composition, one IL-6 level, and one immune cell analysis each missing for one male PWS subject (three different subjects). Anal-

yses were performed using Statistica 6.0 (StatSoft, Tulsa, OK). Comparisons between groups were performed using the unpaired *t* test (for normally distributed data) and the Mann Whitney-*U* test (for skewed data). Correlations between variables were expressed as Pearson's or Spearman's correlation coefficients.  $P < 0.05$  was considered significant.

## Results

### Clinical parameters

Anthropometric and biochemical characteristics of PWS, obese, and lean subjects are summarized in Table 1. Groups were matched for gender and age, and importantly, PWS and obese subjects were matched for body weight, BMI, and total body and abdominal fat mass. In PWS and matched obese subjects, HOMA-IR (an estimate of insulin resistance) and HOMA-B (an estimate of  $\beta$ -cell function) were significantly elevated compared with lean controls but without difference between groups. Only height and lean body mass were different between PWS and obese control subjects. PWS and obese subjects had similar low HDL-cholesterol levels compared with lean subjects, but PWS subjects differed from obese subjects by lower levels of total and low-density lipoprotein (LDL)-cholesterol. Triglyceride levels were not different between groups. Although free fatty acids (FFA) seemed to be higher in PWS compared with obese and lean controls, this difference was not statistically significant ( $P = 0.28$  and  $0.37$ , respectively). In all groups, levels of FFA were not associated with measures of obesity, central adiposity, inflammation, or insulin resistance.

### Circulating inflammation markers

Circulating levels of total and HMW adiponectin were not different across groups (Fig. 1). IL-6 levels were highest in PWS subjects ( $4.9 \pm 1.0$  pg/ml) compared with obese ( $2.5 \pm 0.4$  pg/ml;  $P < 0.05$ ) and lean ( $0.8 \pm 0.2$  pg/ml;  $P < 0.05$ ) subjects. CRP levels in PWS were more than double that of obese subjects ( $10.5 \pm 3.2$  vs.  $4.0 \pm 1.0$  ng/ml;  $P = 0.08$ ), and both groups had significantly higher CRP levels than lean subjects ( $1.1 \pm 0.5$  ng/ml;  $P < 0.05$ ).

### Immune cell numbers and activation status

In PWS and lean subjects, a higher surface expression of CD62L was present on lymphocytes compared with obese subjects, reflecting a higher degree of lymphocyte activation in obese subjects only, but not in PWS (Fig. 2A). Expression of CD69 and CD25 was not different between groups. On granulocytes, a higher expression of CD66b and CD11b was noted in PWS compared with obese and lean subjects, whereas activation markers between lean and obese subjects were similar (Fig. 2B). On monocytes, CD11b expression was increased in both PWS and obese subjects, compared

**TABLE 1.** Mean anthropometric and metabolic measures

Variables	PWS	Obese	Lean
n (males/females)	12 (8/4)	12 (7/5)	10 (5/5)
T2D	3	2	0
Age (yr)	27.9 (2.2)	31.9 (2.5)	28.8 (1.1)
Height (cm)	154.8 (3.3) <sup>a,b</sup>	167.8 (2.1)	168.7 (2.9)
Weight (kg)	92.8 (7.1) <sup>b</sup>	95.9 (2.2) <sup>c</sup>	60.9 (2.2)
BMI (kg/m <sup>2</sup> )	39.0 (2.9) <sup>b</sup>	34.3 (1.2) <sup>c</sup>	21.4 (0.4)
Waist (cm)	114.4 (5.3) <sup>b</sup>	106.3 (2.4) <sup>c</sup>	72.7 (1.3)
WHR	0.93 (0.02) <sup>b</sup>	0.90 (0.02) <sup>c</sup>	0.79 (0.02)
Systolic BP (mm Hg)	124.1 (2.2)	126.8 (2.9)	119.5 (3.0)
Diastolic BP (mm Hg)	76.3 (2.5) <sup>b</sup>	68.3 (3.1)	65.2 (2.2)
Whole body fat mass (kg)	43.3 (4.8) <sup>b</sup>	40.3 (3.4) <sup>c</sup>	14.6 (1.7)
Whole body fat mass (%)	49.0 (2.5) <sup>b</sup>	43.1 (3.0) <sup>c</sup>	25.3 (3.0)
Whole body lean mass (kg)	43.2 (2.6) <sup>a</sup>	52.7 (2.6) <sup>c</sup>	43.7 (2.7)
Abdominal fat mass (kg)	3.1 (0.4) <sup>b</sup>	3.4 (0.3) <sup>c</sup>	1.0 (0.1)
Abdominal fat mass (%)	46.6 (2.2) <sup>b</sup>	46.3 (2.2) <sup>c</sup>	24.8 (2.2)
Fasting glucose (mmol/liter)	4.7 (0.2)	4.9 (0.3)	4.4 (0.1)
Fasting insulin (μU/ml)	15.1 (2.0) <sup>b</sup>	15.3 (1.4) <sup>c</sup>	8.6 (0.6)
HOMA-IR	3.2 (0.5) <sup>b</sup>	3.4 (0.4) <sup>c</sup>	1.7 (0.1)
HOMA-B	60.7 (6.8) <sup>b</sup>	60.2 (6.2) <sup>c</sup>	35.5 (3.1)
FFA (mmol/liter)	0.55 (0.09)	0.44 (0.04)	0.46 (0.05)
Total cholesterol (mmol/liter)	3.4 (0.2) <sup>a,b</sup>	4.7 (0.2)	4.2 (0.2)
HDL-cholesterol (mmol/liter)	0.9 (0.1) <sup>b</sup>	1.0 (0.0) <sup>c</sup>	1.4 (0.1)
LDL-cholesterol (mmol/liter)	2.1 (0.2) <sup>a</sup>	3.1 (0.2) <sup>c</sup>	2.5 (0.2)
Triglycerides (mmol/liter)	1.0 (0.1)	1.7 (0.4)	0.8 (0.1)

Data expressed as mean (SEM). BP, Blood pressure; T2D, type 2 diabetes; WHR, waist-to-hip ratio.

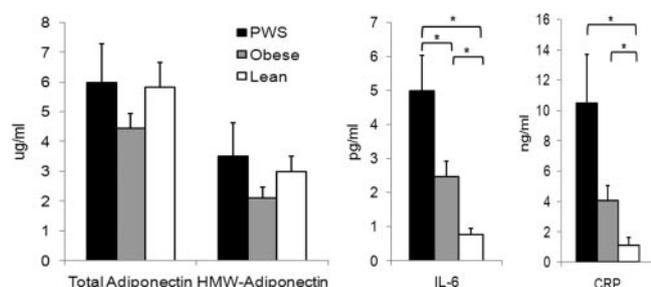
<sup>a</sup> PWS vs. obese,  $P < 0.05$ .

<sup>b</sup> PWS vs. lean,  $P < 0.05$ .

<sup>c</sup> Obese vs. lean,  $P < 0.05$ .

with lean subjects. PWS showed a weak trend toward increased CD11b expression compared with obese subjects ( $P = 0.1$ ). Obese subjects demonstrated decreased levels of CD62L expression compared with lean subjects (Fig. 2C), reflecting increased cell activation.

In lean and obese subjects, abdominal fat mass (percentage of central abdominal fat) was closely related to granulocyte expression of CD11b ( $r = 0.47$ ;  $P < 0.05$ ) as well as monocyte expression of CD11b ( $r = 0.57$ ;  $P < 0.05$ ; Fig. 3A) and CD62L ( $r = -0.50$ ;  $P < 0.05$ ). However, these associations were completely absent in the PWS group: granulocyte CD11b [ $r = 0.1$ ;  $P =$  not significant (n.s.)], monocyte CD11b ( $r = -0.14$ ;  $P =$  n.s.; Fig. 3B), and monocyte CD62L ( $r = -0.42$ ;  $P =$  n.s.). Activation markers of lymphocytes did not correlate with measures of central adiposity.



**FIG. 1.** Circulating levels of total and HMW adiponectin, IL-6, and CRP in subjects with PWS compared with obese and lean control subjects.

\*,  $P < 0.05$  between groups.

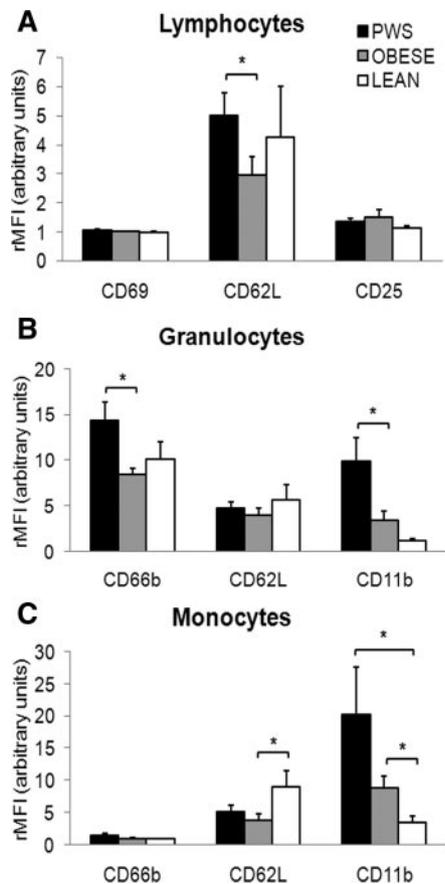
Most immune cell activation markers related closely to circulating inflammation markers: IL-6 levels correlated positively with lymphocyte CD25 ( $r = 0.43$ ;  $P < 0.05$ ), granulocyte CD66b and CD11b ( $r = 0.42$ ,  $P < 0.05$ ; and  $r = 0.65$ ,  $P < 0.05$ , respectively), and monocyte CD11b ( $r = 0.62$ ;  $P < 0.05$ ). Similarly, CRP levels correlated positively with lymphocyte CD25 ( $P = 0.46$ ;  $P < 0.05$ ), granulocyte CD11b ( $P = 0.48$ ;  $P < 0.05$ ), and monocyte CD11b ( $r = 0.54$ ;  $P < 0.05$ ).

### Arterial stiffness

Arterial stiffness (AIx) was elevated in PWS ( $17.6 \pm 3.0$ ) and obese subjects ( $14.5 \pm 2.7$ ) compared with lean subjects ( $0.6 \pm 3.8$ ;  $P < 0.05$ ) (Fig. 4A). The difference in AIx between PWS and obese subject did not reach statistical significance ( $P = 0.1$ ). Across the whole cohort, AIx was highly associated with levels of IL-6 ( $r = 0.64$ ;  $P < 0.05$ ), CRP ( $r = 0.52$ ;  $P < 0.05$ ), monocyte CD11b expression ( $r = 0.49$ ;  $P < 0.05$ ), and abdominal fat mass ( $r = 0.65$ ;  $P < 0.05$ ) (Fig. 4B). When PWS subjects were analyzed separately, the above correlations remained similar; however, they lost statistical significance due to the small cohort size (AIx vs. IL-6,  $r = 0.42$ ,  $P = 0.1$ ; AIx vs. CRP,  $r = 0.33$ ,  $P = 0.3$ ; AIx vs. monocyte CD11b,  $r = 0.19$ ,  $P = 0.57$ ; AIx vs. abdominal fat mass,  $r = 0.59$ ,  $P = 0.055$ ).

### Effects of OSAS and statin treatment on inflammation

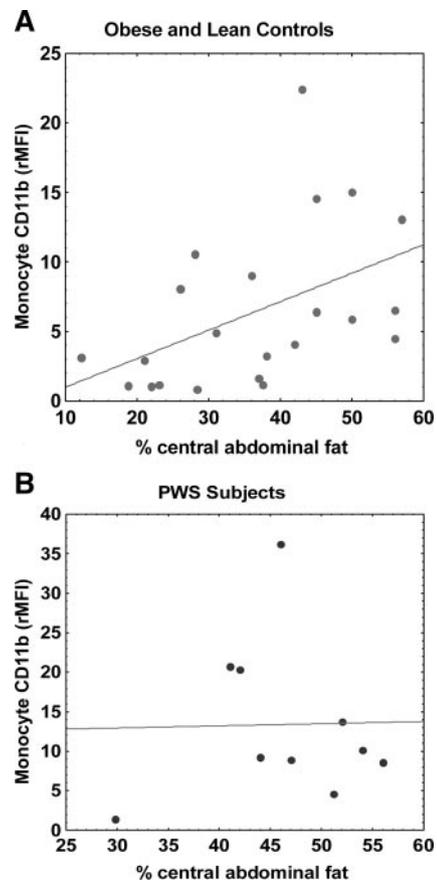
Five of 12 PWS subjects and one of 12 obese control subjects had diagnosed OSAS. This syndrome has been reported



**FIG. 2.** Expression of surface activation markers CD69, CD62L, and CD25 on lymphocytes (A), and CD66b, CD62L, and CD11b on granulocytes (B) and monocytes (C) in subjects with PWS (black bars) compared with obese (gray bars) and lean (white bars) control subjects. \*,  $P < 0.05$  between groups. rMFI, Relative MFI.

to be independently associated with systemic inflammation; however, the underlying mechanism is still poorly understood. A subgroup analysis of our PWS subjects with and without OSAS revealed that OSAS was associated with a trend toward higher CRP levels (17.3 vs. 5.6 ng/ml;  $P = 0.07$ ), higher CD62L expression on lymphocytes (70.6 vs. 36.2 arbitrary units;  $P = 0.017$ ), as well as higher monocyte expression of CD66b (2.4 vs. 1.1;  $P = 0.017$ ). Monocyte expression of CD11b was not different in subjects with and without OSAS (30.5 vs. 14.3;  $P = 0.32$ ). Importantly, PWS subjects with OSAS had a trend toward an increased abdominal fat mass (3.8 vs. 2.6 kg;  $P = 0.17$ ).

Three PWS and two obese subjects were on statin treatment, which is known to modulate systemic inflammation. Within the PWS group, subjects taking statins had higher FFA levels (0.85 vs. 0.43 mmol/liter;  $P = 0.017$ ) and a trend toward lower lymphocyte CD62L expression (27.9 vs. 59.4;  $P = 0.055$ ). Lipid levels were not different between PWS subjects with and without statins. Among obese subjects, those on statin treatment had lower HDL levels (0.8 vs. 1.0 mmol/liter;  $P = 0.04$ ), LDL levels (1.6 vs. 3.3 mmol/liter;  $P = 0.03$ ), and triglycerides (1.2 vs. 4.4 mmol/liter;  $P = 0.001$ ).



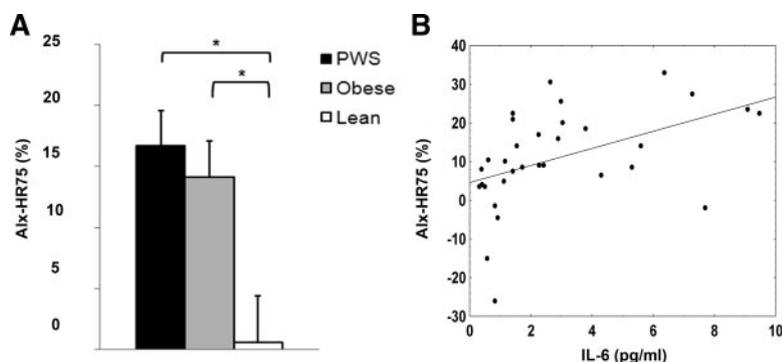
**FIG. 3.** Central adiposity predicts activation status of innate immune cells (monocyte expression of surface activation marker CD11b) in combined obese and lean control groups (A;  $r = 0.57$ ;  $P < 0.05$ ), but not in the PWS group (B;  $r = -0.14$ ;  $P = n.s.$ ). rMFI, Relative MFI.

Furthermore, total and HMW adiponectin levels were lower in subjects taking statins (1.4 vs. 4.9  $\mu\text{g/ml}$ ,  $P = 0.004$ ; and 0.3 vs. 2.3  $\mu\text{g/ml}$ ,  $P = 0.003$ , respectively). Other inflammation markers or immune cell activation markers were not different in subjects under statin treatment.

## Discussion

PWS is associated with an increased risk of cardiovascular morbidity and mortality, discrepant with previous reports of lower visceral fat mass and higher insulin sensitivity compared with nonsyndromic obesity (3, 16, 17). To assess the contribution of chronic inflammation to the cardiovascular risk in PWS, it is most important to match the groups compared for total and visceral adiposity to eliminate the impact of total and visceral fat mass as major confounders. To the best of our knowledge, this is the first study to carefully match PWS and obese control subjects for visceral and total adiposity, in addition to age and gender.

In our matched PWS and obese control subjects, we observed similar insulin and glucose levels and estimated insulin resistance (HOMA-IR) and insulin secretion (HOMA-B).



**FIG. 4.** Arterial stiffness (Aix) in subjects with PWS (black bar) compared with obese (gray bar) and lean (white bar) control subjects (A), and its association with increased levels of IL-6 (B;  $r = 0.64$ ;  $P < 0.05$ ). \*,  $P < 0.05$  between groups.

Nevertheless, we observed higher levels of IL-6 and a trend toward elevated CRP levels in PWS subjects. Furthermore, our results suggest that PWS is associated with increased activation of the innate immune system compared with simple obesity. Across all groups, most immune cell activation markers were positively related to levels of circulating inflammation markers. It has been previously reported that “simple” obesity is associated with increased expression of cell surface activation markers on neutrophils, monocytes, and T lymphocytes; and up-regulation of CD66b, CD11b, CD69, and CD25 and down-regulation of CD62L is thought to reflect increased immune cell activation (18–20). Interestingly, the observed down-regulation of CD62L on lymphocytes was only seen in obese subjects, not in PWS subjects, suggesting that in contrast to obese subjects, the observed cell activation is specifically seen in the innate immune system, excluding cells of the adaptive immune system (lymphocytes). Our results suggest that in PWS there is a disruption of the association between low-grade inflammation and central adiposity, different from that reported in obese subjects (7). Intriguingly, we observed in our PWS subjects that total and HMW adiponectin levels were similar compared with obese and lean controls. This is in contrast with previous reports (21–23) where PWS subjects had higher adiponectin levels in association with lower visceral fat mass and preserved insulin sensitivity. Our PWS subjects had similarly increased central adiposity and insulin resistance to obese control subjects, and finding similar adiponectin levels is not a surprise. However, the high adiponectin levels are in contradiction to the increased immune activation, inflammation, and increased cardiovascular morbidity in PWS because protective antiinflammatory and antiatherogenic effects of adiponectin have been reported (24).

Both IL-6 and CRP levels were highly correlated with measures of total and visceral adiposity, as well as HOMA-IR. Similarly, Aix, a marker of arterial stiffness, was closely related to IL-6, high-sensitivity CRP, and monocyte activation marker CD11b, as illustrated in Fig.

4. Aix was also related to measures of total and visceral adiposity, but not HOMA-IR. Our data suggest that immune activation is directly associated with endothelial dysfunction, increasing arterial stiffness and contributing to the elevated risk for cardiovascular disease in PWS. There are only sparse data on endothelial dysfunction in PWS, and only one study previously assessed arterial stiffness, flow-mediated vasodilatation, and venous occlusion plethysmography, but only comparing PWS to lean subjects (5). The venous occlusion

plethysmography, but not the Aix, was found to be abnormal in PWS. Our study adds new information about similarly impaired endothelial function in PWS and adiposity-matched obese subjects compared with healthy lean control subjects.

Apart from elevated inflammatory markers, no other major cardiovascular risk factors differed in our PWS and obese control group. There was no difference in blood pressure, Aix, or smoking status. The lipid profile showed a lower total and LDL-cholesterol in PWS compared with obese subjects, an observation consistent with previous reports (3). Circulating FFA, which have been reported to be positively related to measures of obesity and systemic inflammation in obesity (25), were not different between groups, consistent with previous reports (26). This suggests that FFA are unlikely to significantly contribute to the observed increased activation of the innate immune system. Statin treatment seemed to affect lipid levels in obese subjects only, whereas in PWS, statin treatment was not associated with altered lipid levels except for higher levels of FFA. This suggests that the rather beneficial lipid profile in PWS is not due to increased use of statin treatment in this group. Furthermore, statin treatment did not seem to significantly affect markers of inflammation or immune cell activation, except for the documented decrease in lymphocyte CD62L in PWS subjects, which suggests an antiinflammatory effect on this immune cell subset. However, it is important to mention that this study was not designed to investigate the effects of statins on immune activation, and prospective controlled studies are needed to clarify statin effects on inflammation, immune activation, as well as cardiovascular morbidity and mortality in subjects with PWS.

Importantly, some frequently diagnosed comorbidities could affect systemic inflammation in our PWS subjects. First, obstructive sleep apnea, which was diagnosed in five PWS subjects in contrast to only one obese control, is a syndrome that has itself been linked to increased low-grade in-

flammation (27, 28). Indeed, our subgroup analysis suggests that PWS subjects with OSAS tend to have higher levels of CRP and immune cell activation, although many of these differences are not or are only borderline significant. Second, subjects with PWS are known to be GH deficient, which is also reported to be associated with increased systemic inflammation (29–31) and endothelial dysfunction (32–34). None of our PWS subjects had been treated with GH before or at the time of study. Third, hypogonadism is a known feature of PWS and has been shown to be associated with increased systemic inflammation (35). Although most of our PWS subjects were receiving hormone replacement therapy, the doses were generally low, and we cannot exclude the possibility that mild hypogonadism somehow accounts for the observed increase in chronic inflammation.

The PWSCR on chromosome 15 is complex genetically, subject to strict genomic imprinting via an imprinting center. Control of the imprinting center is by DNA methylation and epigenetic mechanisms. The PWSCR contains many genes whose function is not well understood and harbors many small noncoding RNAs that play an important role in translational regulation of gene expression (36). Due to the absent or altered expression of a wide range of genes in the PWSCR, activation of the innate immune system could well be part of the genetic phenotype. Epigenetic modulations are well-recognized regulators of the immune response, and the largest part of the interindividual variances in immune response to pathogens is thought to be due to epigenetic modifications (37). Disturbed activity of the autonomic nervous system has been suggested to play a role in PWS (38), and a decreased parasympathetic activity could play a role in activation of the innate immune system, secondary to genetic dysregulation of the autonomic nervous system. Disturbance of this complex system could also play a role in the pathogenesis of OSAS, and it could be difficult to separate direct and indirect effects on regulation of the immune system.

It should be noted that studying subjects with PWS is associated with many challenges that restrict the number of study participants investigated. These challenges include difficult cannulation, subject lack of cooperation, and availability of willing family members or caregivers to take part in the research. However, a major strength of the present study is that we were able to use optimal methods to assess body composition that were previously validated against insulin sensitivity in obesity, which also allowed us to compare PWS subjects to obese subjects closely matched for both central and total adiposity as well as gender. In previous studies, apparent differences in inflammatory markers could be due to confounding differences in adiposity (total or central) or by gender mismatching, which itself influences total adiposity and fat distribution. It is important to note that there are

no validation data on estimating central abdominal fat mass in PWS, and we can't exclude an overestimation in PWS due to increased sc fat mass in this area. However, the same method has been used in previous PWS studies, where it commonly revealed a lower abdominal fat mass, in association with low insulin levels. The consistent association of high insulin levels and high abdominal fat mass to a similar degree in both PWS and matched obese subjects in this study suggests that the dual-energy x-ray absorptiometry methodology consistently provides a reasonable estimate for central obesity.

In summary, this study reports evidence for an overactivation of the innate immune system in PWS, independent of central adiposity and insulin resistance. Increased low-grade inflammation is associated with increased arterial stiffness, a recognized marker for increased cardiovascular risk. Therefore, we suggest that increased chronic low-grade inflammation, caused either by genetic and/or epigenetic abnormalities of PWS or by mechanisms linked to the commonly associated OSAS, may be a potential treatment target in the clinical setting to improve cardiovascular morbidity and mortality in PWS.

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