The various colours of type 2 diabetes: Pathogenesis and epidemiology in different ethnic groups
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Cold-induced activity of brown adipose tissue in young, lean men of South-Asian and European origin

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Abstract

Background
South Asians have a disproportionately high risk of developing abdominal obesity, insulin resistance and type 2 diabetes. Brown adipose tissue (BAT) has been identified as a possible target to fight obesity and protect against metabolic disturbance. We explored whether lower BAT activity in South Asians compared with Europids may contribute to the high risk of metabolic disturbance.

Methods
We studied 20 healthy men (ten Europids/ten South Asians, BMI 18-25 kg/m², age 18-32 years). Following 2 h of cold exposure (16-18°C) after an overnight fast, ¹⁸F-fluorodeoxyglucose (¹⁸F-FDG) positron-emission tomography (PET)-computed tomography (CT) and ¹²³I-metaiodobenzylguanidine (¹²³I-MIBG) single-photon emission computed tomography (SPECT)-CT were performed to visualise metabolic BAT activity and sympathetic stimulation of BAT. Metabolic BAT activity was defined as maximal standard uptake value (SUV\text{max}) of ¹⁸F-FDG, and sympathetic stimulation of BAT as semiquantitative uptake value (SQUV) of ¹²³I-MIBG.

Results
The median (interquartile range) SUV\text{max} of ¹⁸F-FDG in South Asians (7.5 [2.2-10.6]) was not different from the median SUV\text{max} obtained in Europids (4.5 [2.2-8.4]; \( p=0.59 \)). There was no correlation between BAT activity and insulin sensitivity. Correlations between SQUV of ¹²³I-MIBG and SUV\text{max} of ¹⁸F-FDG were positive, both in the total population (\( \rho=0.80, p<0.001 \)) and after stratification by ethnicity (Europids, \( \rho=0.65, p=0.04 \); South Asians: \( \rho=0.83, p=0.01 \)).

Conclusions
This is the first study to prospectively investigate ethnic differences in metabolic BAT activity during cold exposure. We did not find differences in BAT activity between South Asians and Europids. Therefore, it seems unlikely that BAT plays an important role in the development of unfavourable metabolic profiles in South Asians.
Introduction

Several studies have shown that South Asians have a disproportionately high risk of developing abdominal obesity, insulin resistance and type 2 diabetes (1-4). Next to the higher prevalence, these metabolic disturbances also seem to develop at an earlier age in South Asians than in populations of European origin. The explanation for these ethnic differences is complex and only partially clear (3,5).

Given its high capacity to dissipate excess energy, brown adipose tissue (BAT) has recently been identified as a possible target to fight obesity and protect against metabolic disturbance (6-9). As such, ethnic differences in BAT activity might be a contributing factor to the adverse metabolic profile in South-Asian people. So far, data on ethnic differences in the activity of BAT in humans are limited to one retrospective study that found no significant difference in the prevalence of BAT between white and black patients with cancer (10). However, only a limited number of black patients were included in this study. Furthermore, as BAT is optimally visualised during cold exposure and the patients included in this retrospective study were not exposed to cold, only BAT detected incidentally was assessed (10). Therefore, BAT, while present, may not have been detected in some of the patients, thereby masking true ethnic differences in BAT activity. We aimed to explore whether a lower BAT activity in South Asians, in comparison with Europids, may contribute to this high risk of metabolic disturbance. In addition, we compared the insulin sensitivity and sympathetic stimulation of BAT, the latter being an important determinant of BAT activity, between South Asians and Europids.

Methods

We studied a group of 20 (ten Europid, ten South-Asian) healthy, lean, male volunteers (18-32 years, BMI 19-25 kg/m²). All the South-Asian men were Hindustani-Surinamese. The term ‘Hindustani-Surinamese’ refers to people of South-Asian ancestral origin and their offspring who migrated to the Netherlands via Surinam (a former colony of the Netherlands). The study participants were considered South Asian if both their parents, as well as their four grandparents, were of South-Asian origin. Nine out of the ten South-Asian participants were born in the Netherlands. The study participants were recruited through public advertisements. All underwent a physical examination and a fasting blood sample was drawn. In order to determine the metabolic activity (i.e. glucose uptake) of BAT, the participants underwent 18F-fluoro-deoxyglucose (18F-FDG) positron-emission tomography (PET)-computed tomography (CT). For the assessment of the sympathetic stimulation of BAT, a 123I-metaiodobenzylguanidine (123I-MIBG) single-photon emission computed tomography (SPECT)-CT was
performed. As two South Asians did not complete their last study visit (for reasons unrelated to the study protocol), $^{123}$I-MIBG SPECT-CT was performed in 18 of the 20 study participants. Both $^{18}$F-FDG and $^{123}$I-MIBG were administered after an overnight fast. The interval between $^{18}$F-FDG PET-CT and $^{123}$I-MIBG SPECT-CT was set between 1 and 2 weeks. To overcome any order bias $^{18}$F-FDG PET-CT and $^{123}$I-MIBG SPECT-CT were performed in random order. Furthermore, as healthy South Asians are less insulin sensitive than their European counterparts at a given BMI and age (11), and insulin sensitivity might influence BAT activity (12), we performed hyperinsulinaemic-euglycaemic clamps to assess insulin sensitivity in both ethnic groups. The institutional ethics committee of the Academic Medical Center approved the study protocol and all participants provided written informed consent.

Anthropometric and laboratory measurements
Weight was recorded in light clothing on a SECA mechanical scale to the nearest 100 g (SECA, Hamburg, Germany). Height was recorded to the nearest 0.01 m. Blood pressure was measured in seated position (Omron-M5-1, Omron Corporation, Kyoto, Japan). HbA$_1c$ was measured by ion-exchange chromatography on a Tosoh-G8 analyser (Tosoh Bioscience, Tokyo, Japan). Levels of fasting plasma glucose (FPG), insulin (sandwich enzyme immunoassay; Roche Diagnostics, Rotzkreuz, Switzerland), total cholesterol, HDL-cholesterol, LDL-cholesterol, triacylglycerol (enzymatic colorimetric method for all cholesterol and triacylglycerol measurements, Roche Diagnostics) and creatinine (colorimetric) were assessed.

$^{18}$F-FDG PET-CT scanning protocol
All participants were exposed to mild cold (~17°C, controlled by use of an airconditioning system) for the duration of 2 h. Shivering was neither reported by participants nor noticed by research staff. After 1 h of cold exposure, approximately 200 MBq of $^{18}$F-FDG was administered intravenously and the cold exposure was continued for another hour. Upper-body (from base of the skull to groin) static PET was performed 60 min after $^{18}$F-FDG injection. PET-CT images were acquired using a Gemini time-of-flight multidetector helical PET-CT scanner (2 min/bed position) (Philips Medical Systems, Eindhoven, the Netherlands). In areas where $^{18}$F-FDG uptake was identified by PET and the presence of fat was identified by computed tomography (CT; Hounsfield units between −250 and −50), the mean standardised uptake value (SUV$_{\text{mean}}$) and the maximal standardised uptake value (SUV$_{\text{max}}$), defined as activity (Bq/ml) within the region of interest (ROI) ÷ injected dose (Bq/g body weight), were determined (Hybrid Viewer, Hermes Medical Solutions, Stockholm, Sweden). Anatomical regions of interest were the cervical, supraclavicular and superior mediastinal depots. In these areas an SUV of $^{18}$F-FDG of at least 2.0 g/ml was considered to indicate BAT (6).
**I-MIBG-SPECT-CT scanning protocol**

All participants were pretreated with potassium iodide to block thyroid uptake of $^{123}$I-MIBG. Again, the participants were exposed to mild cold for 2 h. After 1 h of cold exposure, approximately 185 MBq of $^{123}$I-MIBG was administered intravenously; exposure to cold was continued for another hour. The next day, 24 h after $^{123}$I-MIBG injection, a SPECT-CT scan was performed at the same anatomical region (13).

An Infinia SPECT-CT imaging system (General Electric, Fairfield, CT, USA) with a medium-energy all-purpose collimator and a 128×128 matrix was used to acquire SPECT images. A 15% window was set for the main energy peak of $^{123}$I (159 keV). SPECT images were iteratively reconstructed (using ordered subset expectation maximization) and corrected for attenuation using low-dose CT (no intravenous contrast). In areas where uptake of $^{123}$I-MIBG was identified by SPECT and the presence of fat was identified by CT, both the mean and semi-quantitative uptake of $^{123}$I-MIBG were calculated as, respectively, the mean or maximal (decay corrected) count per voxel in the volume of interest (VOI) ÷ mean count per voxel in a reference region (i.e. the mediastinum) (Hybrid Viewer) (13).

**Alignment of $^{18}$F-FDG PET-CT and $^{123}$I-MIBG SPECT-CT**

The $^{18}$F-FDG PET-CT and $^{123}$I-MIBG SPECT-CT were aligned using the CT images with Hybrid Viewer. The results of this automated non-rigid registration algorithm were visually validated. The specific VOIs on the anatomical images of $^{18}$F-FDG PET-CT in which metabolically active BAT was present were copied to the aligned $^{123}$I-MIBG SPECT-CT images. Subsequently, the semiquantitative uptake of $^{123}$I-MIBG in these VOIs was calculated (13).

**Hyperinsulinaemic–euglycaemic clamp**

The clamps were performed in the morning after an overnight fast. A cannula was inserted into the antecubital vein of the left arm. This cannula was used to infuse human soluble insulin (Actrapid; Novo Nordisk, Alphen aan den Rijn, the Netherlands) and 20% wt/vol dextrose. A second cannula was inserted into a vein on the dorsum of the right hand, which was placed into a heated hand box to arterialise the venous blood for blood sampling (14).

Infusion of human insulin was started at 1.5 mU kg$^{-1}$ min$^{-1}$, and 20% dextrose solution was infused at a variable rate to achieve a blood glucose concentration of 5.0 mmol/l, which was maintained for 120 min. Plasma glucose concentrations were measured every 5 min at the bedside. In the last 30 min, blood samples were drawn at 10 min intervals for the measurement of insulin concentration. Insulin sensitivity was expressed as the mean glucose disposal rate (mg kg$^{-1}$ min$^{-1}$) during the last 30 min (i.e. the steady state) of the euglycaemic clamp.
Statistical analysis
The characteristics of the study participants were reported as medians with interquartile range (IQR). The $p$ values for differences between South Asians and Europids in population characteristics, BAT volumes, SUV (mean and maximal) values of $^{18}$F-FDG, mean and semi-quantitative uptake value (SQUV) of $^{123}$I-MIBG and insulin sensitivity were determined with a Mann-Whitney $U$ test. Spearman’s correlations between the SUV$_{\text{max}}$ of $^{18}$F-FDG and both the SQUV of $^{123}$I-MIBG and insulin sensitivity were determined. Data analysis was performed using SPSS software 18.0 (Chicago, Illinois). A $p$ value <0.05 was considered statistically significant.

Results
Table 1 shows the characteristics of our study population after stratification by ethnicity. Apart from a higher FPG and a lower HDL-cholesterol, the characteristics of the South Asians were similar to those of the Europids. Both in the Europids and the South Asians, $^{18}$F-FDG uptake in BAT was visually observed in eight out of ten male volunteers. Uptake of $^{123}$I-MIBG in BAT was observed in seven out of ten Europids, whereas six out of eight South Asians showed $^{123}$I-MIBG uptake in BAT (Fig. 1). The median SUV$_{\text{max}}$ of $^{18}$F-FDG (i.e. metabolic activity of BAT) was not significantly different between South Asians (7.5 [2.2-10.6]) and Europids (4.5 [2.2-8.4]) ($p=0.59$ [Table 1]). Furthermore, there were no ethnic differences in median SUV$_{\text{mean}}$ of $^{18}$F-FDG (2.4 g/ml in both groups) or in median BAT volume (16.0 [5.5-64.5] cm$^3$ in Europids, 38.4 [8.4-59.3] cm$^3$ in South Asians; $p=0.57$). In addition, we found no significant difference between both the mean and the maximal SQUV (i.e. sympathetic stimulation of BAT) of $^{123}$I-MIBG between the ethnic groups ($p=0.26$ for the mean and $p=0.41$ for maximal SQUV of $^{123}$I-MIBG).

The correlation between the SQUV of $^{123}$I-MIBG and the SUV$_{\text{max}}$ of $^{18}$F-FDG was positive, both in the total population ($p=0.80$, $p<0.001$) and after stratification by ethnic group (Europids: $p=0.65$, $p=0.04$; South Asians: $p=0.83$, $p=0.01$; Fig. 2).

The steady-state insulin levels of the Europids were similar to those of the South Asians (Table 1). There was no statistically significant difference in insulin sensitivity between the ethnic groups. Furthermore, there was no correlation between BAT activity and insulin sensitivity in the total population or after stratification by ethnicity (total group: $p= -0.10$, $p=0.68$; Europids: $p=0.04$, $p=0.91$; South Asians: $p= -0.14$, $p=0.73$).

Discussion

This is the first study that prospectively investigated ethnic differences in metabolic BAT activity after cold exposure. We did not find differences in metabolic BAT activity or the sympathetic stimulation of BAT between South Asians and Europids. Therefore, it seems...
unlikely that BAT plays an important role in the development of the unfavourable metabolic profile in populations of South-Asian origin.

The ability to visualise metabolically active BAT in humans with \(^{18}\text{F}-\text{FDG PET-CT}\) under conditions of mild cold exposure has been reported in several studies \((6,8,9,15)\). In our study, metabolically active BAT was found with \(^{18}\text{F}-\text{FDG PET-CT}\) in 80% of all participants after 2 h of cold exposure \((16-18^\circ\text{C})\), which is in line with previous publications \([8]\). Furthermore, the median \(\text{SUV}_{\text{max}}\) of \(^{18}\text{F}-\text{FDG}\) in BAT is similar to values reported by Cypess et al, who also investigated BAT activity in lean, healthy men \((16)\).

It is rather cumbersome to compare our data for \(\text{SUV}_{\text{mean}}\) and BAT volume with the results of other studies, as the \(\text{SUV}_{\text{mean}}\) and the derived BAT volume are largely dependent on the position and the definition of the ROI. As is to be expected in an emerging field of research, there is no consensus on the most appropriate way to define the ROI. In our study, a threshold for \(\text{SUV}\) of \(^{18}\text{F}-\text{FDG}\) of at least 2.0 g/ml was considered to indicate BAT (i.e. our ROI). Cypess et al used the same threshold \((16)\). However, Vosselman et al used a threshold of 1.5 g/ml \((17)\), van Marken Lichtenbelt et al reported that they used a ‘set threshold’ \((8)\), whereas Carey et al and Ouellet et al considered an \(\text{SUV} >1.0\) g/ml as BAT \((18,19)\). The lower the chosen threshold, the higher the observed volume of BAT will be. For this reason, we cannot make direct comparisons between our results for \(\text{SUV}_{\text{mean}}\) and BAT volume and those of other studies.

The majority of the published studies on BAT activity have focused on individuals of European origin. However, there are data available on BAT activity after cold exposure in those with other ethnic backgrounds. For example, Saito et al studied BAT activity in Japanese men and women \((15)\), whereas Miao et al focused on Chinese individuals \((20)\). It should be realised, however, that individuals of Chinese and Japanese origins have different metabolic constitutions from those of South-Asian origin. For example, Karter et al found that type 2 diabetes prevalence was much higher in South Asians than in Chinese, Japanese and other, unspecified, Asians \((21)\). Moreover, type 2 diabetes seems to develop at an earlier age and at lower levels of BMI in South Asians than in other populations \((22)\). For these reasons, we specifically focused on the BAT activity in South Asians in our study.

This is the first study that prospectively compared BAT activity between ethnic groups. We found that the metabolic activity of BAT was not different between South Asians and Europids. We did not expect this finding, as both the tendency of South Asians to develop abdominal obesity and type 2 diabetes \((1,2,4)\) and the ontogenetic superfluity of the presence of BAT in the warm sub-Indian continent suggest BAT activity would be lower in South Asians than in Europids. As nine out of ten South Asians in our study were born in the Neth-
erlands, it is unlikely that environmental factors have influenced our results. Therefore, although surprising, our results suggest that the high risk of metabolic disturbance in South Asians, when compared with Europids, is not (partly) attributable to a relatively low BAT activity.

In line with the observed lack of ethnic difference in metabolic BAT activity, we did not find a difference in the sympathetic stimulation of BAT between the Europids and South Asians in our study. We previously validated $^{123}$I-MIBG SPECT-CT as a method to visualise and quantify the sympathetic stimulation of BAT in the ten Europid men who were also included in the present study (13). In our previous study, we found that the correlation between the SQUV of $^{123}$I-MIBG and SUV$_{\text{max}}$ of $^{18}$F-FDG was positive. The current finding of a positive correlation in South Asians in the present study corroborates our previous results.

Our study did not show a correlation between BAT activity and insulin sensitivity either in the total population or after stratification by ethnicity. Animal studies have shown that the BAT activity in both obese and insulin-resistant mice is lower than in healthy mice (12). Furthermore, obese people have a lower BAT activity compared with their lean peers (8). In our study, all the individuals included were healthy and the absolute mean glucose disposal rates were within the expected range. Prospective follow-up studies are needed to determine how the correlation between BAT activity and insulin resistance develops over time.

This study has limitations. Our sample size was small, so caution must be applied when extrapolating these results to the broader community. Furthermore, the limited number of participants may have resulted in a lack of power to demonstrate small differences between the ethnic groups. However, the mean SUV$_{\text{max}}$ of $^{18}$F-FDG appeared higher in South Asians than in Europids. Therefore, it is unlikely that a greater sample size would alter our conclusion.

Furthermore, we did not perform a quantitative body-fat assessment in our study participants. For this reason, we cannot rule out the possibility that an ethnic difference in insulation, as a result of a difference in body-fat mass, has influenced our results on BAT activity. However, we did measure waist circumference and BMI, both of which have been shown to correlate well with total and regional measures of adiposity (23). Given the low, lean values of BMI and waist circumference in both the South Asians and Europids in our study, it is not likely that the absolute difference in fat mass between the ethnic groups was great enough to have affected our results significantly.

In addition, we used a room with a fixed temperature of 16-18°C to activate the BAT of our participants. This cooling method has shown to be effective for the assessment of BAT activity in several other studies (8,9,15). However, interindividual variation in the onset temperature of shivering has been reported, with some individuals starting to shiver at temperatures lower than 16-18°C (24). As the thermogenesis of BAT is deemed to be at its highest just
before the onset temperature of shivering (24), it is possible that BAT was not maximally activated in some of our study participants. As it is unknown whether the onset temperature of shivering differs between ethnic groups, it remains unclear whether our findings of a lack of ethnic differences in BAT activity were affected.

In conclusion, we found no difference in BAT activity during cold exposure between Europids and South Asians. Furthermore, we observed no ethnic differences in factors influencing BAT activity. Therefore, it seems unlikely that BAT plays an important role in the development of the unfavourable metabolic profile of populations of South-Asian origin.
Reference List

Cold-induced activity of brown adipose tissue in young, lean men of South-Asian and European origin


Table 1. Characteristics and BAT activity in the study population stratified by ethnicity

<table>
<thead>
<tr>
<th>Variable</th>
<th>Europids (n=10)</th>
<th>South Asians (n=10)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Characteristic</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>22.4 (21.2-25.1)</td>
<td>23.2 (21.1-26.1)</td>
</tr>
<tr>
<td>Length (cm)</td>
<td>181 (180-185)</td>
<td>174 (170-178)</td>
</tr>
<tr>
<td>Weight (cm)</td>
<td>72.3 (67.4-79.4)</td>
<td>65.5 (63.0-71.9)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>22.6 (21.2-23.1)</td>
<td>22.3 (21.0-23.5)</td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
<td>79 (76-82)</td>
<td>79 (74-82)</td>
</tr>
<tr>
<td>Systolic blood pressure (mmHg)</td>
<td>117 (111-119)</td>
<td>119 (115-124)</td>
</tr>
<tr>
<td>Diastolic blood pressure (mmHg)</td>
<td>75 (72-77)</td>
<td>78 (75-79)</td>
</tr>
<tr>
<td>HbA1c (%)</td>
<td>5.2 (4.7-5.4)</td>
<td>5.2 (5.1-5.5)</td>
</tr>
<tr>
<td>HbA1c (mmol/mol)</td>
<td>33 (28-36)</td>
<td>33 (32-37)</td>
</tr>
<tr>
<td>Total cholesterol (mmol/l)</td>
<td>3.63 (3.52-3.96)</td>
<td>4.12 (3.38-5.02)</td>
</tr>
<tr>
<td>HDL-cholesterol (mmol/l)</td>
<td>1.56 (1.44-1.78)</td>
<td>1.45 (0.84-1.49)*</td>
</tr>
<tr>
<td>LDL-cholesterol (mmol/l)</td>
<td>1.86 (1.76-2.23)</td>
<td>2.25 (1.83-3.33)</td>
</tr>
<tr>
<td>Triacylglycerol (mmol/l)</td>
<td>0.56 (0.51-1.00)</td>
<td>0.65 (0.44-1.38)</td>
</tr>
<tr>
<td>TSH (mU/l)</td>
<td>2.6 (1.9-4.5)</td>
<td>2.75 (1.6-5.1)</td>
</tr>
<tr>
<td>Creatinine (µmol/l)</td>
<td>82 (78-94)</td>
<td>89 (79-97)</td>
</tr>
</tbody>
</table>

**Metabolic activity of BAT**

| Presence of BAT based on ¹⁸F-FDG PET-CT (n) | 8 | 8 |
| SUV max of ¹⁸F-FDG (g/l)                    | 4.5 (2.2-8.4) | 7.5 (2.2-10.6) |
| SUV mean of ¹⁸F-FDG (g/l)                   | 2.4 (1.6-3.3) | 2.4 (1.5-3.2)  |
| BAT volume based on ¹⁸F-FDG uptake (cm³)     | 16.0 (5.5-64.5) | 38.4 (8.4-59.3) |

**Sympathetic stimulation of BAT**

| Presence of BAT based on 24 h ¹²³I-MIBG SPECT-CT (n) | 7 | 6 |
| Maximal SQUV of ¹²³I-MIBG | 3.1 (2.3-3.9) | 3.9 (2.2-5.0) |
| Mean SQUV of ¹²³I-MIBG     | 4.0 (3.0-5.7) | 4.7 (4.3-6.1) |
| BAT volume based on ¹²³I-MIBG uptake (cm³) | 16.7 (6.2-52.6) | 36.3 (7.0-59.9) |

**Hyperinsulinaemic-euglycaemic clamp**

| FPG (mmol/l)                  | 4.6 (4.4-4.9) | 5.1 (4.7-5.2) |
| Baseline insulin (pmol/l)     | <15 (<15-28)  | 47 (<15-57)   |
| Steady-state glucose (mmol/l) | 5.0 (4.9-5.1) | 5.0 (4.9-5.0) |
| Steady-state insulin (pmol/l) | 545 (516-635) | 462 (316-769) |
| Glucose disposal rate (mg kg⁻¹ min⁻¹) | 10.2 (7.9-10.5) | 8.4 (7.3-10.0) |

Data are presented as n or median (IQR)

* Presence of BAT was determined visually

** Out of eight South Asians

* During the last 30 min (steady state) of the hyperinsulinaemic-euglycaemic clamp

p<0.05 for differences between Europids and South Asians

TSH, thyroid-stimulating hormone
Figure 1. (a,e) BAT in a South-Asian participant visualised with $^{18}$F-FDG PET-CT and $^{123}$I-MIBG SPECT-CT (maximum-intensity-projection images). $^{18}$F-FDG and $^{123}$I-MIBG uptake on corresponding transversal PET and SPECT images (b,f) is suggestive of BAT and is superimposed on adipose tissue on correlated transversal CT images (c,d and g,h, respectively)
Figure 2. The relationship between SUV$_{\text{max}}$ of $^{18}$F-FDG and maximal SQUV of $^{123}$I-MIBG in Europids (black circles) and South Asians (white circles); Spearman’s correlation coefficient $\rho=0.80$, $p<0.001$