Introduction

Diabetes Mellitus (DM) is a multifactorial metabolic disease associated with several conditions, including physical inactivity, genetic predisposition, poor nutrition, and obesity [1,2]. The association between DM (especially T2DM) and obesity is well established: obese individuals have a twentyfold risk of developing diabetes compared with individuals of normal weight [3].

The strong association between obesity and cardiometabolic disorders motivated the development of several techniques used to determine body adiposity, such as body mass index (BMI), waist circumference (WC), and waist-hip ratio (WHR) [4,5], BMI being a general obesity indicator and both WC and WHR abdominal obesity indicators [6]. Recently, Bergman et al [7] proposed the body adiposity index (BAI) as an alternative to BMI to possibly overcome deficiencies in the latter method in assessing overweight body adiposity index (BAI) as an alternative to BMI to possibly overcome deficiencies in the latter method in assessing overweight body adiposity, such as body mass index (BMI), waist circumference, and body adiposity index in the risk assessment for type 2 diabetes mellitus.

Design and methods: A total of 1,572 individuals from the general population of Vitoria City, Brazil and 620 Amerindians from the Aracruz Indian Reserve, Brazil were randomly selected. BMI, waist circumference, and BAI were determined according to a standard protocol. Type 2 diabetes mellitus was diagnosed by the presence of fasting glucose ≥126 mg/dL or by the use of antidiabetic drugs.

Results: The area under the curve was similar for all anthropometric indices tested in the Amérindian population, but with very different sensitivities or specificities. In women from the general population, the area under the waist circumference was significantly higher than that of the body adiposity index. Regarding risk assessment for type 2 diabetes mellitus, the body adiposity index was a better risk predictor than body mass index and waist circumference in the Amerindian population and was the index with highest odds ratio for type 2 diabetes mellitus in men from the general population, while in women from the general population waist circumference was the best risk predictor.

Conclusion: Body adiposity index was the best risk predictor for type 2 diabetes mellitus in the Amérindian population and men from the general population. Our data suggest that the body adiposity index is a useful tool for the risk assessment of type 2 diabetes mellitus in admixture populations.
Espírito Santo, Brazil. The sampling plan had the objective of ensuring that the research would be socioeconomically, geographically, and demographically representative of the residents of this municipality. The resident population aged 25–64 years in the city of Vitoria was studied. According to the census carried out by the IBGE Foundation in 1996, the resident population of Vitoria included 265,874 inhabitants. The sampling was performed in four stages: by district, IBGE census sector, drawing lots to choose homes, and drawing lots to choose an individual from each home. The survey was conducted with just one resident from the home that was selected, within the age group of the study. The draw was carried out by using a randomization mechanism. We selected 2,268 residential homes located in Vitoria and visited them. We explained the purposes of the research to the individual selected at each of these homes and invited the individual to participate in the study, after obtaining his or her written consent. The selected individuals were asked to attend the Cardiovascular Investigation Clinic of the University Hospital for tests to be performed on the following day. Of the total sample, 1,572 individuals attended (715 males and 857 females).

Aiming to replicate the data found in the population of Vitoria (WHO-MONICA project guidelines), we also used data from a cross-sectional study of risk factors for cardiovascular diseases that was carried out in two Indian groups (Guarani and Tupinikin) living on the Aracruz Indian Reserve, Espírito Santo State, on the southeast Brazilian coast. All individuals (n = 620; 292 males and 328 females) aged 20 years or more were eligible for the study. During small meetings in each of the five small settlements within the Reserve, the eligible individuals were invited to participate in the study. Data were collected from February 2003 to April 2004, and 670 (80.3% of the eligible population) attended the local health unit to undergo clinical and laboratory examinations necessary to identify cardiovascular risk factors.

This study was approved by the ethics committee for Research on Human Subjects of the Espirito Santo Federal University and National Ethics Committee for Human Research (CONEP Register Number 4599).

Anthropometrical Investigations

Anthropometric parameters were measured according to a standard protocol [9]. Body weight was measured on a calibrated scale, to the nearest 0.1 kg. Height was measured using a wall-mounted stadiometer, to the nearest 0.5 cm. WC was measured at the mean point between the lowest rib margin and the iliac crest with the subject standing and at the maximum point of normal expiration. Hip circumference was measured to the nearest 0.1 cm around the thighs, at the height of the greater trochanter, in the standing position. BMI was calculated as body weight (kg) divided by height squared (m²). BAI was calculated using hip circumference and height (BAI = [hip (cm)/height (m)1.5]−1) [7].

Biochemical Measurement

Fasting glucose was evaluated using standard techniques applied to 12-h fasting blood samples [10]. We adopted an epidemiological classification of DM [11]. Thus, T2DM was diagnosed by the presence of fasting glucose ≥126 mg/dL, or by the use of antidiabetic drugs, except insulin.

Statistics Analyses

Categorical variables are presented as percentages, whereas continuous variables are presented as mean ± standard deviation. To evaluate the performance models, a receiver operating characteristic (ROC) curve was built and the AUC was used to measure the discriminatory power for T2DM. Areas under the ROC curves between the markers were compared using a parametric method, with GraphROC for Windows software [12]. The optimal cutoff points for BAI, BMI, and WC were established based on the highest combination of sensitivity and specificity. In addition, the positive and negative predictive values (PPV and NPV, respectively) for each anthropometric index were determined. Logistic regression analyses were used to assess the risk association between the different measurements (WC, BMI, and BAI) and T2DM. To standardize measures, all indices were transformed to z scores [13]. All analyses were adjusted by age, mean blood pressure, and total cholesterol. The adjustment of the models was verified using the Hosmer-Lemeshow test (p>0.05). Statistical analyses were carried out using SPSS (version 20) software (Chicago, IL, USA), with the level of significance set at 5%.

Results

Amerindian Population

Demographic data related to age, BMI, BAI, WC, fasting glucose, and T2DM percentage stratified by sex are summarized in Table 1.

Cutoffs, sensitivity, specificity, PPV, NPV, and AUC are reported in Table 2. In this population, although the overall accuracy of tested measures in the risk assessment for T2DM were not significantly different between men and women, important differences regarding sensitivity, specificity, and predictive values were observed when comparing men and women for all three of

Table 1. Characteristics of subjects in the Amerindian and General population.

| Characteristics          | Amerindians | General Population |
|-------------------------|-------------|--------------------|
|                         | Men         | Women              | Men         | Women              |
| n                       | 292         | 328                | 715         | 857                |
| Age, years              | 37.3±14.6   | 37.1±14.5          | 44.7±10.9   | 44.8±10.8          |
| BMI, Kg/m²              | 24.6±3.6    | 26.2±5.0           | 25.9±4.0    | 26.6±5.5           |
| BAI                     | 21.7±4.924  | 29.9±6.4           | 26.0±3.5    | 32.9±5.6           |
| Waist Circumference, cm | 83.5±9.5    | 84.5±11.6          | 89.2±10.9   | 83.6±12.9          |
| Fasting Glucose, mg/dL  | 92.4±17.0   | 89.7±18.1          | 105.6±28.5  | 104.4±34.6         |
| NIDDM, %                | 2.4%        | 2.7%               | 6.9%        | 8.6%               |

BMI, body mass index; BAI, body adiposity index; T2DM, type 2 diabetes mellitus. doi:10.1371/journal.pone.0100223.t001
Table 2. Determination of the optimal cutoffs values and AUC for BMI, BAI and WC in Amerindian and General population.

| Population | Antropometric index | Cutoffs | Sensitivity | Specificity | PPV | NPV | AUC (95%CI) | p value |
|------------|---------------------|---------|-------------|-------------|-----|-----|-------------|---------|
| Amerindian |                     |         |             |             |     |     |             |         |
| Men        | BMI                 | 29.26   | 0.57        | 0.11        | 0.87| 0.11| 0.68 (0.42–0.94) | 0.110   |
|           | BAI                 | 25.15   | 0.86        | 0.24        | 0.74| 0.27| 0.84 (0.66–1.00)  | 0.002   |
|           | WC                  | 96.60   | 0.57        | 0.08        | 0.90| 0.08| 0.78 (0.59–0.97)  | 0.010   |
| Women      | BMI                 | 25.32   | 0.89        | 0.51        | 0.48| 0.62| 0.68 (0.55–0.80)  | 0.070   |
|           | BAI                 | 34.70   | 0.67        | 0.23        | 0.75| 0.24| 0.77 (0.63–0.92)  | 0.005   |
|           | WC                  | 85.65   | 0.89        | 0.43        | 0.56| 0.52| 0.74 (0.63–0.86)  | 0.010   |
| General    |                     |         |             |             |     |     |             |         |
| Men        | BMI                 | 28.33   | 0.51        | 0.22        | 0.73| 0.24| 0.70 (0.63–0.77)  | <0.001  |
|           | BAI                 | 28.75   | 0.51        | 0.19        | 0.76| 0.20| 0.69 (0.60–0.77)  | <0.001  |
|           | WC                  | 94.15   | 0.55        | 0.28        | 0.67| 0.31| 0.71 (0.63–0.78)  | <0.001  |
| Women      | BMI                 | 30.18   | 0.62        | 0.18        | 0.76| 0.20| 0.75 (0.68–0.81)  | <0.001  |
|           | BAI                 | 36.65   | 0.51        | 0.19        | 0.75| 0.19| 0.68 (0.60–0.75)  | <0.001  |
|           | WC                  | 89.75   | 0.74        | 0.26        | 0.69| 0.31| 0.79 (0.74–0.85)* | <0.001  |

T2DM, type 2 diabetes mellitus; BMI, body mass index; BAI, body adiposity index; WC, waist circumference; AUC, area under the ROC curve; CI, confidence interval; PPV, positive predictive value; NPV, negative predictive value.

*WC vs BAI, p = 0.02.
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Several studies have focused on the relationship between anthropometric indices of adiposity and DM risk. Wei et al [14], studying 721 Mexican-Americans aged 25–64 years, showed that WC was a better risk predictor to T2DM than BMI, independently of age and sex. Corroborating such results, Stevens et al [15], studying 12,814 African Americans and white participants aged 45–64 years, showed that AUC for WC was higher than for BMI in African men and women. On the other hand, Tulloch-Reid et al [16], studying Pima Indians, showed that the AUC was significantly larger for BMI than for either WC or WHR. Finally, Vazquez et al [5] through a meta-analysis involving 32 studies, showed that the pooled relative risks for the incidence of DM was similar for WC, BMI, and WHR.

Regarding the discriminatory power of anthropometric indices in the risk assessment for T2DM, our results do not corroborate the findings of Wei et al [14] and Stevens et al [15]: the AUC of WC was similar to BMI in both populations (general and Amerindian). However, in the general population, the AUC of WC was higher than that of BMI in women. The findings of Tulloch-Reid et al [16] showed that BMI, a representative index of general obesity, has a higher discriminatory power in the prediction of T2DM than WC, a representative index of the abdominal obesity, in Pima Indians. Differently, in the Amerindian population of our study, the BAI, a representative index of visceral fat, was a better risk predictor to T2DM than BMI, while WC was shown to be the strongest predictor. Corroborating, partially, such results, Talaei et al [21], studying 2981 individuals of the Iranian population for a period of seven years, showed that waist-to-height ratio (WHR) and BMI were better than BAI in the prediction of T2DM. On the other hand, our results showed that BAI is superior to BMI and WC in the risk assessment for T2DM in the Amerindian population and in men in the general population. Nevertheless, in women in the general population, both AUC and OR for zWC were superior to BMI in discriminatory power and risk assessment of T2DM, respectively. These data could, partially, be explained by a higher average age of women in the general population compared with women in the Amerindian population, which suggests less influence of ovarian hormones on cardiometabolic disorders associated with visceral fat [22].

Part of the controversial results may be explained by the use of different statistical methods. In our study, the risk assessment for T2DM was measured by logistic regression analysis regarding the measures tested. In addition, as expected, differences in the optimum cutoff values between men and women were also observed. The best nominal predictor of T2DM, in both Amerindian men and women, was BAI, although with a greater accuracy in men (0.84×0.77).

The logistic regression analysis standardized to z scores showed that zBAI (men, OR = 6.32 [95%CI, 1.41–28.28]); (women, OR = 2.52 [95%CI, 1.08–5.87]) was a better risk predictor to T2DM than zWC (men, OR = 2.97 [95%CI, 1.16–7.60]); (women, OR = 1.84 [95%CI, 0.96–3.54]) and zBMI (men, OR = 2.70 [95%CI, 0.94–7.60]); (women, OR = 1.62 [95%CI, 0.91–2.89]) in both genders (Table 3).

### Discussion

Several studies have focused on the relationship between anthropometric indices of adiposity and DM risk.Wei et al [14], studying 721 Mexican-Americans aged 25–64 years, showed that WC was a better risk predictor to T2DM than BMI, independently of age and sex. Corroborating such results, Stevens et al [15], studying 12,814 African Americans and white participants aged 45–64 years, showed that AUC for WC was higher than for BMI in African men and women. On the other hand, Tulloch-Reid et al [16], studying Pima Indians, showed that the AUC was significantly larger for BMI than for either WC or WHR. Finally, Vazquez et al [5] through a meta-analysis involving 32 studies, showed that the pooled relative risks for the incidence of DM was similar for WC, BMI, and WHR.

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### Table 3. Risk assessment for T2DM according to zBMI, zBAI and zWC in Amerindian and General population.

| AMERINDIANS | OR (95%CI), p value | GENERAL POPULATION | OR (95%CI), p value |
|-------------|-------------------|--------------------|-------------------|
| zBMI        | 2.70 (0.94–7.76), 0.06 | 2.27 (1.57–3.28), <0.001 | 2.03 (1.44–2.86), <0.001 |
| zBAI        | 6.32 (1.41–28.28), 0.02 | 2.54 (1.49–4.33), <0.001 | 1.77 (1.37–2.29), <0.001 |
| zWC         | 2.97 (1.16–7.60), 0.02 | 2.03 (1.44–2.86), <0.001 | 2.37 (1.81–3.09), <0.001 |

**T2DM, type 2 diabetes mellitus; zBMI, body mass index z-score; zBAI, body adiposity index z-score; zWC, waist circumference z-score; OR, odds ratio; CI, confidence interval.**

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continuous variables (BMI, BAI, and WC) standardized to z score, while Schulze et al [20] estimated the risk for DM by comparing quintiles of the anthropometric features. In addition, factors such as ethnicity and distinct DM prevalence among the populations may affect the predictive power of the anthropometric indices of adiposity.

Our study has some limitations. First, we did not perform a BAI internal validation aiming to establish its capacity to assess the body fat in the study populations. For such, it would be necessary to compare BAI with some other method capable to accurately measuring the body fat percentage, as well as dual-energy X-ray absorptiometry (DEXA). Second, it would be interesting to associate these anthropometric indices (WC, BMI, and BAI) to methods able to assess the degree of insulin resistance, as well as the HOMA-IR.

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In summary, BAI may be suggested as a better risk predictor of T2DM than both BMI and WC in the Amerindian population and in men belonging to the general population. However, in women belonging to the general population, WC was superior to BMI and BAI in the prediction of T2DM. Thus, it is plausible to surmise that BAI is a useful tool for the T2DM risk assessment in admixture populations.

**Author Contributions**

Conceived and designed the experiments: ROA CMO. Performed the experiments: ROA CMO JGM. Analyzed the data: ROA CAMJ. Contributed reagents/materials/analysis tools: ACP JGM JEK. Wrote the paper: ROA CAMJ AGP.