

# A Body shape index significantly predicts MRI-defined abdominal adipose tissue depots in non-obese Asian Indians with type 2 diabetes mellitus

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## ABSTRACT

**Introduction** We aimed to determine the correlations of volumes of subcutaneous abdominal adipose tissue (SCAT) (anterior, posterior, superficial and deep), total SCAT, intraperitoneal adipose tissue, retroperitoneal abdominal adipose tissue (RPAT), total intra-abdominal adipose tissue (IAAT), pancreatic volume, liver span, total body fat (TBF) and truncal fat mass (TFM) with anthropometric indices, *viz.*, A Body Shape Index (ABSI), Hip Index, their Z scores and Anthropometric Risk Index in non-obese (body mass index (BMI) <25 kg/m<sup>2</sup>) Asian Indians with type 2 diabetes mellitus (T2DM).

**Research design and methods** Non-obese patients with T2DM (cases; *n*, 85) and BMI-matched, healthy subjects (controls; *n*, 38) underwent anthropometry, dual energy X ray absorptiometry (DXA) for estimation of TBF, TFM and 1.5 T MRI for estimation of volumes of abdominal adipose tissue depots, pancreas and liver span. Spearman's correlation analysis and Receiver Operator Characteristic curve analysis were applied.

**Results** The Z score of ABSI (Z\_ABSI) showed significantly positive correlation with volumes of all depots of abdominal SCAT, total IAAT and RPAT in cases. Area under the curve for Z\_ABSI (0.87) showed higher sensitivity: 82.0%, specificity: 81.5%, at a predictive cut-off value of 0.49 for abdominal adiposity.

**Conclusion** In non-obese Asian Indians with T2DM, the Z\_ABSI showed significant correlation with IAAT and SCAT and higher predictive accuracy for abdominal adiposity.

**Highlights of the study** This is the first MRI-based study in the context of ABSI in non-obese (BMI <25 kg/m<sup>2</sup>) Asian Indians with T2DM. Findings indicate that Z\_ABSI has high predictive accuracy for abdominal adiposity in non-obese Asian Indians. The Z\_ABSI index showed significantly positive correlation with volumes of adipose tissue depots, *viz.*, abdominal SCAT, total IAAT and RPAT in cases.

## INTRODUCTION

The prevalence of type 2 diabetes mellitus (T2DM) is high in South Asians,<sup>1</sup> and about 1/5th of Asian Indian patients with T2DM are non-obese (body mass index (BMI) <25 kg/m<sup>2</sup>).<sup>2</sup> While Asian Indians have comparatively more subcutaneous abdominal adipose

## Significance of this study

### What is already known about this subject?

- Abdominal obesity is a major cause of insulin resistance and type 2 diabetes mellitus (T2DM) in non-obese (body mass index (BMI): <25 kg/m<sup>2</sup>) Asian Indians. We had previously shown the association of intra-abdominal adiposity and hepatic fat with T2DM in non-obese (BMI: <25 kg/m<sup>2</sup>) Asian Indians.

### What are the new findings?

- In this study, the Z score of A Body Shape Index (Z\_ABSI) showed significantly positive correlation with volumes of all depots of subcutaneous abdominal adipose tissue, total intra-abdominal adipose tissue and retroperitoneal adipose tissue in non-obese Asian Indians with T2DM. Area under the curve for Z\_ABSI (0.87) showed higher sensitivity: 82.0%, specificity: 81.5%, at a predictive cut-off value of 0.49 for abdominal adiposity.

### How might these results change the focus of research or clinical practice?

- The results of this study indicate high predictive value of the Z\_ABSI for prediction of intra-abdominal obesity and T2DM in non-obese Asian Indians.

tissue (SCAT), intra-abdominal adipose tissue (IAAT) and hepatic fat associated with insulin resistance and higher cardiometabolic risk than whites,<sup>3</sup> a reliable anthropometric parameter to correlate with abdominal adiposity needs further research.

Several anthropometric indices have been used to determine cardiovascular risk, most common being BMI and waist circumference (WC). These parameters have been used in the clinical assessment of cardiovascular risk in Asian Indians.<sup>4</sup> Recently, A Body Shape Index (ABSI), Hip Index (HI), their Z scores and the Anthropometric Risk Index (ARI) have attracted research interest for their

**Table 1** Demographic, anthropometric and body composition profile of cases and controls

| Variables                            | Unadjusted for age |                  |                  | Adjusted for age |                  |                  |
|--------------------------------------|--------------------|------------------|------------------|------------------|------------------|------------------|
|                                      | Cases (n, 85)      | Controls (n, 38) | P value          | Cases (n, 85)    | Controls (n, 38) | P value          |
| Body mass index (kg/m <sup>2</sup> ) | 22.2±2.0           | 21.3±2.1         | 0.21             | 22.6±1.6         | 22.4±1.7         | 0.33             |
| Waist circumference (cm)             | 83.7±6.8           | 81.8±7.7         | <b>&lt;0.01</b>  | 84.1±4.8         | 84.5±5.6         | <b>&lt;0.05</b>  |
| Hip circumference (cm)               | 89.5±4.6           | 90.8±7.3         | 0.23             | 87.3±4.8         | 91.3±5.0         | 0.06             |
| WHR                                  | 0.92±0.0           | 0.89±0.0         | <b>&lt;0.001</b> | 0.93±0.0         | 0.90±0.0         | <b>&lt;0.001</b> |
| Wht-R                                | 0.51±0.04          | 0.49±0.04        | 0.12             | 0.52±0.04        | 0.48±0.04        | 0.10             |
| Mid-arm circumference (cm)           | 27±2.3             | 27.4±5.4         | 0.52             | 27.2±2.8         | 27.6±3.1         | 0.53             |
| Mid-thigh circumference (cm)         | 48.5±3.9           | 48.7±4.8         | 0.24             | 49.7±3.8         | 48.7±4.4         | 0.26             |
| Biceps skinfolds (mm)                | 12.6±7.3           | 8.2±4.1          | <b>&lt;0.01</b>  | 13.8±6.3         | 8.3±5.7          | <b>&lt;0.01</b>  |
| Triceps skinfolds (mm)               | 13.4±5.2           | 17.9±7.4         | <b>&lt;0.01</b>  | 15.5±0.3         | 19.3±6.3         | <b>&lt;0.01</b>  |
| Thigh skinfold (mm)                  | 26.2±8.9           | 22.4±5.7         | <b>&lt;0.01</b>  | 26.2±7.5         | 23.5±6.6         | <b>&lt;0.01</b>  |
| Calf skinfold (mm)                   | 20.8±7.4           | 10.9±4.9         | <b>&lt;0.01</b>  | 20.1±5.8         | 12.4±5.7         | <b>&lt;0.01</b>  |
| Subscapular skinfold (mm)            | 20.8±5.6           | 19.5±7.9         | 0.80             | 21.9±6.7         | 22.3±6.9         | 0.8              |
| Subscapular-triceps ratio            | 1.4±0.04           | 1.3±0.09         | 0.30             | 1.4±0.03         | 1.3±0.08         | 0.29             |
| Suprailiac skinfold (horizontal)     | 19.7±5.1           | 15.8±5.4         | <b>&lt;0.01</b>  | 19.7±4.6         | 16.2±5.8         | <b>&lt;0.01</b>  |
| Suprailiac skinfold (vertical) (mm)  | 21.2±4.5           | 17.2±3.9         | <b>&lt;0.05</b>  | 20.8±4.7         | 18.0±8.4         | <b>&lt;0.05</b>  |
| Suprailiac skinfold (average) (mm)   | 19.2±5.3           | 16.8±4.7         | <b>&lt;0.05</b>  | 18.9±5.0         | 7.8±4.2          | <b>&lt;0.05</b>  |
| Abdominal skinfold (vertical) (mm)   | 24.1±6.5           | 24.7±5.3         | 0.87             | 24.6±8.1         | 23.8±5.7         | 0.61             |
| Abdominal skinfold (horizontal) (mm) | 22.9±6.2           | 23.7±5.4         | 0.60             | 24.6±8.1         | 24.8±5.7         | 0.91             |
| Abdominal skinfold (average) (mm)    | 23.8±7.5           | 24.1±5.3         | 0.71             | 24.7±8.1         | 24.0±5.7         | 0.66             |
| Abdominal skinfolds (total) (mm)     | 48.7±10.6          | 43.8±18.9        | 0.07             | 48.7±13.8        | 43.8±21.2        | 0.05             |
| Body composition (DXA)               |                    |                  |                  |                  |                  |                  |
| Total fat mass (kg)                  | 17.3±4.9           | 18±5.4           | 0.46             | 16.9±3.8         | 17.5±4.7         | 0.46             |
| Truncal fat mass (kg)                | 8.5±2.9            | 9.7±2.8          | <b>&lt;0.05</b>  | 8.5±2.2          | 9.2±2.3          | <b>&lt;0.05</b>  |
| Truncal fat (%)                      | 32.5±6.8           | 31.5±8.2         | 0.52             | 32.5±6.3         | 31.5±7.9         | 0.48             |
| Total fat (%)                        | 27.7±6.2           | 30.1±8.3         | 0.08             | 27.8±5.4         | 30.1±7.9         | 0.06             |

Values are presented as Mean±SD,  $P<0.05$ : statistically significant.

Significant  $P$  values are shown in bold.

DXA, dual energy X ray absorptiometry; WHR, waist-to-hip ratio; Wht-R, waist-to-height ratio.

potential as novel anthropometric indices to predict metabolic risk. The ABSI is calculated by dividing WC by the allometric regression of weight and height<sup>5</sup> while the HI is derived by normalizing hip circumference for a given height and weight based on a power law.<sup>4</sup> The ARI is derived by multiplying the calculated HRs of hip circumference, HI, BMI and ABSI.<sup>6</sup> Some recent data suggest that these indices provide valid prediction of risk of diabetes,<sup>7</sup> cardiovascular diseases<sup>8</sup> and mortality risk in Koreans<sup>9</sup> and Australians.<sup>10</sup> However, the predictive accuracy of these indices for T2DM in Asian Indians remains unexplored. Since abdominal obesity (specifically abdominal and liver adiposity) increase metabolic and cardiovascular risk,<sup>11</sup> any recently derived anthropometric indices must be validated against a standard measure. Specifically, it is not known if these indices could be correlated to volumes of IAAT, SCAT, liver span and pancreatic volume. Further, since many Asian Indians are non-obese and yet have T2DM, correlation studies would

be of particular importance in this subgroup. In this case-control study on non-obese (BMI<25 kg/m<sup>2</sup>) Asian Indians with T2DM, we correlated the ABSI, HI, the Z scores of ABSI, HI and ARI with MRI-identified SCAT, IAAT and pancreatic volumes, liver span and dual energy X ray absorptiometry (DXA) quantified body composition measurements.

## METHODOLOGY

This study was conducted in adherence to the ethical guidelines of the declaration of Helsinki 2013.<sup>12</sup> Data for this study were obtained retrospectively from our previous report.<sup>13</sup> The sample size for this MRI based study was calculated as minimum of 40 non-obese (BMI: <25 kg/m<sup>2</sup>) with T2DM as cases and a minimum of 20 BMI-matched, non-diabetic subjects as controls. The power of the study was 99.7% with an alpha error of 5% at 95% CI.

**Table 2** Correlation analysis for the ABSI and HI in cases and controls

| Anthropometric measures and variables of body composition        | ABSI             |                 |               |                  | HI               |                 |               |                 |
|--|------------------|-----------------|---------------|------------------|------------------|-----------------|---------------|-----------------|
|  | Controls (n, 38) |                 | Cases (n, 85) |                  | Controls (n, 38) |                 | Cases (n, 85) |                 |
|  | <i>rho</i>       | <i>P</i> value  | <i>rho</i>    | <i>P</i> value   | <i>rho</i>       | <i>P</i> value  | <i>rho</i>    | <i>P</i> value  |
| Age (years)  | -0.14            | 0.40            | 0.38          | <b>&lt;0.001</b> | -0.13            | 0.41            | <b>0.21</b>   | <b>&lt;0.05</b> |
| BMI (kg/m <sup>2</sup> )   | -0.31            | 0.05            | 0.02          | 0.81             | -0.37            | <b>&lt;0.05</b> | -0.21         | <b>&lt;0.05</b> |
| WHR  | -0.10            | 0.96            | 0.73          | <b>&lt;0.001</b> | -0.65            | 0.12            | <b>-0.57</b>  | <b>&lt;0.01</b> |
| WHT-R  | 0.78             | <b>&lt;0.01</b> | 0.62          | <b>&lt;0.001</b> | 0.54             | <b>&lt;0.01</b> | 0.10          | 0.95            |
| Mid arm circumference  | -0.11            | 0.51            | 0.21          | <b>&lt;0.05</b>  | -0.12            | 0.48            | -0.10         | 0.32            |
| Mid-thigh circumference  | 0.18             | 0.28            | 0.06          | 0.58             | -0.00            | 0.96            | -0.22         | <b>&lt;0.05</b> |
| Skinfolds (mm)   |                  |                 |               |                  |                  |                 |               |                 |
| Biceps   | 0.12             | 0.47            | -0.04         | 0.70             | 0.30             | 0.06            | <b>0.30</b>   | <b>&lt;0.01</b> |
| Triceps  | 0.03             | 0.83            | 0.20          | 0.05             | 0.22             | 0.20            | <b>0.50</b>   | <b>&lt;0.01</b> |
| Thigh  | 0.46             | <b>&lt;0.05</b> | 0.04          | 0.10             | 0.37             | <b>&lt;0.05</b> | 0.16          | 0.13            |
| Calf   | 0.17             | 0.31            | 0.20          | 0.05             | 0.20             | 0.23            | 0.31          | <b>&lt;0.01</b> |
| Peripheral skinfolds (total)                                     |                  |                 |               |                  |                  |                 |               |                 |
| Subscapular  | 0.55             | 0.20            | 0.11          | 0.28             | 0.57             | <b>&lt;0.01</b> | 0.38          | <b>&lt;0.01</b> |
| Subscapular-triceps ratio  | 0.28             | 0.09            | 0.30          | <b>&lt;0.01</b>  | 0.22             | 0.19            | -0.07         | 0.50            |
| Suprailiac (horizontal)  | 0.19             | 0.26            | 0.13          | 0.22             | -0.06            | 0.73            | -0.60         | <b>&lt;0.01</b> |
| Suprailiac (vertical)  | 0.07             | 0.66            | 0.13          | 0.08             | 0.16             | 0.34            | 0.08          | 0.44            |
| Suprailiac (average)   | 0.05             | 0.76            | 0.18          | 0.09             | 0.02             | 0.89            | 0.00          | 0.95            |
| Abdominal (vertical)   | 0.12             | 0.49            | 0.19          | 0.07             | 0.11             | 0.50            | 0.04          | 676             |
| Abdominal (horizontal)   | 0.12             | 0.20            | 0.17          | 0.10             | 0.15             | 0.41            | -0.02         | 0.80            |
| Abdominal skinfolds (total)                                      | 0.27             | 0.15            | 0.12          | 0.26             | 0.12             | 0.52            | -0.03         | 0.77            |
| Truncal skinfolds (total)  | 0.40             | <b>&lt;0.05</b> | 0.14          | 0.18             | 0.42             | <b>0.01</b>     | -0.01         | 0.92            |
| Total body fat (%) (on DXA)                                      | 0.33             | <b>&lt;0.05</b> | 0.23          | <b>&lt;0.05</b>  | 0.31             | 0.06            | -0.04         | 0.96            |
| Truncal fat (%) (on DXA)   | -0.20            | 0.22            | 0.40          | <b>&lt;0.05</b>  | -0.16            | 0.32            | 0.27          | <b>&lt;0.05</b> |
| Truncal fat mass (kg) (on DXA)                                   | -0.22            | 0.17            | 0.23          | <b>&lt;0.05</b>  | -0.23            | 0.15            | 0.12          | 0.27            |
| Truncal fat mass (kg) (on DXA)                                   | -0.17            | 0.30            | 0.25          | <b>0.02</b>      | -0.24            | 0.14            | -0.05         | 0.64            |
| Volumes of abdominal fat, pancreas and liver span on MRI (1.5 T) |                  |                 |               |                  |                  |                 |               |                 |
| Anterior SCAT (cm <sup>3</sup> )                                 | -0.30            | 0.07            | 0.30          | <b>&lt;0.01</b>  | 0.29             | 0.07            | 0.12          | 0.25            |
| Posterior SCAT (cm <sup>3</sup> )                                | 0.07             | 0.66            | 0.24          | <b>&lt;0.05</b>  | -0.10            | 0.52            | 0.02          | 0.85            |
| Superficial SCAT (cm <sup>3</sup> )                              | -0.23            | 0.16            | 0.23          | <b>&lt;0.05</b>  | -0.25            | 0.13            | 0.06          | 0.56            |
| Deep SCAT (cm <sup>3</sup> )                                     | -0.03            | 0.86            | 0.23          | <b>&lt;0.01</b>  | -0.06            | 0.70            | 0.05          | 0.63            |
| Total abdominal SCAT   | -0.19            | 0.24            | 0.28          | <b>&lt;0.01</b>  | -0.15            | 0.19            | 0.06          | 0.54            |
| Retroperitoneal fat (cm <sup>3</sup> )                           | -0.04            | 0.80            | 0.35          | <b>&lt;0.01</b>  | -0.15            | 0.34            | -0.21         | <b>&lt;0.05</b> |
| Intraperitoneal fat (cm <sup>3</sup> )                           | -0.04            | 0.81            | 0.32          | <b>&lt;0.01</b>  | -0.14            | 0.38            | -0.34         | <b>&lt;0.01</b> |
| Total intra-abdominal fat (cm <sup>3</sup> )                     | -0.04            | 0.80            | 0.37          | <b>&lt;0.01</b>  | -0.15            | 0.36            | -0.33         | <b>&lt;0.01</b> |
| Pancreatic volume (cm <sup>3</sup> )                             | 0.16             | 0.34            | 0.19          | 0.07             | -0.23            | 0.16            | -0.06         | 0.54            |
| Liver span (mm)  | 0.18             | 0.28            | 0.06          | 0.54             | 0.10             | 0.54            | -0.14         | 0.19            |

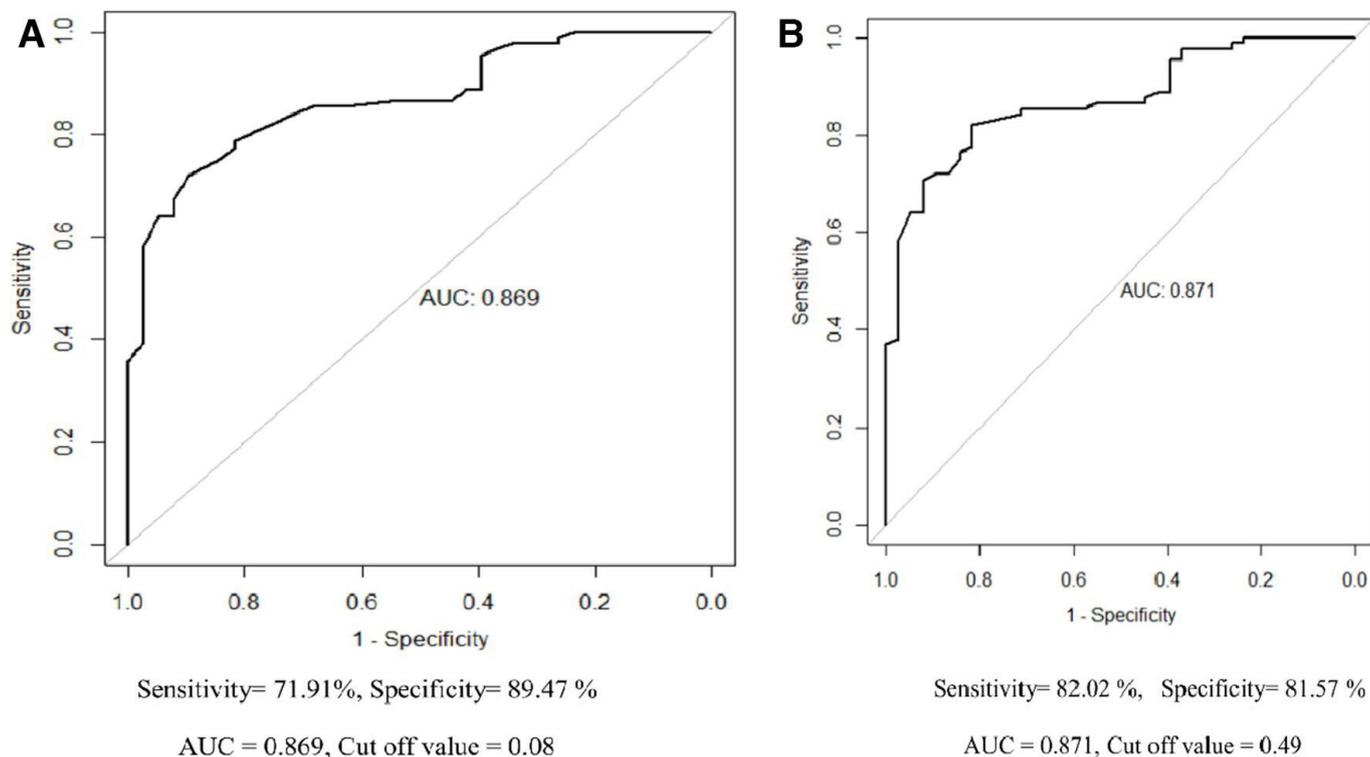
*P*<0.05: statistically significant.

Significant *P* values are shown in bold.

ABSI, A Body Shape Index; BMI, body mass index; DXA, dual energy X ray absorptiometry; HI, Hip Index; SCAT, subcutaneous abdominal adipose tissue; WHR, waist-to-hip ratio; WHT-R, waist-to-height ratio.

After obtaining informed consent, a cohort of non-obese (BMI<25kg/m<sup>2</sup>) Asian Indians with T2DM (diagnosed within previous 1 year, cases n, 85) on metformin monotherapy and non-obese, healthy subjects (controls n, 38) underwent comprehensive phenotyping (BMI and skinfold measurements at eight sites; namely, peripheral

skinfolds (biceps, triceps, thigh and calf skinfolds), truncal skinfolds (subscapular, suprailiac and abdominal skinfolds (horizontal and vertical)) and subscapular-triceps ratio. In addition, circumference measurements of waist, hip, mid-arm and mid-thigh were done and waist-to-hip ratio (WHR), waist-to-height ratio (WHT-R)



**Figure 1** (A) Area under curve for ABSI on ROC analysis. (B) Area under curve for the Z\_ABSI on ROC analysis. ABSI, A Body Shape Index; ROC, receiver operator characteristics; Z\_ABSI, Z score of ABSI.

were calculated. DXA imaging was done for total body fat per cent (%TBF), truncal fat per cent (%TF) and truncal fat mass (TFM).

Further, 1.5 T MR imaging (T1-weighted axial scans between L2/L3 vertebrae<sup>13</sup> were done for volumetric assessment of abdominal adipose tissue compartments, viz., SCAT (anterior, posterior, superficial & deep), total SCAT, intraperitoneal adipose tissue (IPAT) and retroperitoneal adipose tissue (RPAT) and total IAAT.<sup>14</sup> In addition, pancreatic volume and liver span (surrogate measures of pancreatic and hepatic fat, respectively) were quantified as mentioned in our previous report. The detailed protocols for MRI and DEXA are available in the same study.<sup>13</sup> Due to logistic factors, MRI and DXA imaging were performed only in a representative sample size of 85 cases and 38 controls. Further, anthropometric indices namely ABSI, HI and the ARI were calculated using formulae mentioned below: (a)  $ABSI = WC \text{ (cm)} \times \text{weight (kg)}^{-2/3} \times \text{height (m)}^{5/6} = WC/BMI^{2/3} \times \text{height}^{1/25}$ ; (b)  $HI = \text{hip circumference (cm)} / (\text{average height of the group})^{0.310} \times (W/\text{average weight for the group})^{0.48215}$ .

To control for gender and age-specific differences in ABSI and HI, Z scores were derived using the formula  $Z \text{ index} = \text{index} - \text{index\_mean} / \text{index\_sd}$ , where index denotes ABSI or HI for each individual in the study, index\_mean is the mean value for individuals of the same age and sex, and index\_sd is the SD.<sup>5</sup> (c) ARI: It is calculated as the product of the logarithmic odd ratios from separate nonlinear regressions of the four indicators, namely, height, BMI, ABSI and HI.<sup>15</sup>

### Statistical analysis

Data were checked for normality and summarized as Means±SD/median with IQR as appropriate. Spearman's correlation analysis was done. Receiver operator characteristics (ROC) with area under the curve (AUC) analysis was applied to test for sensitivity, specificity and to derive cut-off values for the indices.  $P < 0.05$  was considered statistically significant. Statistical Package for Social Sciences (SPSS V.21, SPSS, Chicago, Illinois, USA) was used for data analysis.

### RESULTS

Significantly higher mean values were observed in cases for WC, WHR, WHt-R, truncal skinfolds and peripheral skinfolds (table 1). Data on volumes of SCAT, IAAT, pancreas and liver span in cases and controls are shown in online supplementary table 1.

### ABSI

The median values of ABSI with IQR in cases and controls were 0.082 with IQR (0.081–0.085) and 0.081 with IQR (0.07–0.08), respectively, with no significant differences ( $P=0.16$ ). In cases, significant positive correlations of the ABSI with age, WHR, WHt-R, mid-arm circumference, subscapular skinfolds and total truncal skinfolds whereas in controls, significant positive correlations were observed only for thigh and abdominal skinfolds and WHt-R. On DXA, significant positive correlation was observed in cases for ABSI with %TBF, %TF and TFM, while in controls, no significant correlation was observed

**Table 3** Correlation analysis of ARI in cases and controls

| Anthropometric measures and variables of body composition       | ARI              |                 |               |                 |
|---|------------------|-----------------|---------------|-----------------|
|   | Controls (n, 38) |                 | Cases (n, 85) |                 |
|   | <i>rho</i>       | <i>P</i> value  | <i>rho</i>    | <i>P</i> value  |
| Age (years)   | -0.11            | 0.51            | 0.04          | 0.71            |
| BMI (kg/m <sup>2</sup> )  | -0.20            | 0.21            | -0.42         | <b>&lt;0.01</b> |
| WHR   | 0.17             | 0.30            | 0.45          | <b>&lt;0.01</b> |
| WHT-R   | 0.44             | <b>&lt;0.01</b> | 0.11          | 0.28            |
| Mid arm circumference   | -0.16            | 0.33            | -0.24         | <b>&lt;0.05</b> |
| Mid-thigh circumference   | -0.03            | 0.83            | -0.40         | <b>&lt;0.01</b> |
| Skinfolds (mm)  |                  |                 |               |                 |
| Biceps  | 0.23             | 0.18            | 0.13          | 0.24            |
| Triceps   | -0.04            | 0.82            | -0.10         | 0.35            |
| Thigh   | 0.34             | <b>&lt;0.05</b> | -0.20         | 0.06            |
| Calf  | 0.13             | 0.43            | 0.17          | 0.09            |
| Peripheral skinfolds (total)                                    | 0.20             | 0.22            | 0.40          | 0.34            |
| Subscapular   | 0.34             | 0.22            | -0.07         | 0.48            |
| Subscapular triceps ratio                                       | 0.25             | 0.14            | 0.12          | 0.25            |
| Suprailiac (horizontal)   | -0.02            | 0.99            | -0.13         | 0.21            |
| Suprailiac (vertical)   | 0.09             | 0.59            | -0.13         | 0.21            |
| Suprailiac (average)  | 0.13             | 0.42            | -0.14         | 0.19            |
| Abdominal (vertical)  | 0.15             | 0.40            | -0.30         | <b>&lt;0.01</b> |
| Abdominal (horizontal)  | 0.20             | 0.28            | -0.28         | <b>&lt;0.01</b> |
| Abdominal skinfolds (total)                                     | 0.05             | 0.77            | -0.32         | <b>&lt;0.01</b> |
| Truncal skinfolds (total)                                       | 0.13             | 0.43            | -0.24         | <b>&lt;0.05</b> |
| Total body fat (%) (on DXA)                                     | 0.18             | 0.25            | -0.15         | 0.18            |
| Truncal fat (%)   | 0.09             | 0.55            | -0.16         | 0.16            |
| Truncal fat mass (kg)   | -0.01            | 0.92            | -0.20         | 0.07            |
| Volumes of abdominal fat, pancreas and liver span on MRI (1.5T) |                  |                 |               |                 |
| Anterior SCAT (cm <sup>3</sup> )                                | 0.09             | 0.58            | -0.05         | 0.59            |
| Posterior SCAT (cm <sup>3</sup> )                               | 0.04             | 0.81            | -0.07         | 0.52            |
| Superficial SCAT (cm <sup>3</sup> )                             | 0.06             | 0.69            | -0.10         | 0.34            |
| Deep SCAT (cm <sup>3</sup> )                                    | 0.10             | 0.51            | -0.02         | 0.82            |
| Total abdominal SCAT (cm <sup>3</sup> )                         | 0.07             | 0.64            | -0.09         | 0.40            |
| Retroperitoneal fat (cm <sup>3</sup> )                          | -0.13            | 0.41            | -0.04         | 0.70            |
| Intraperitoneal fat (cm <sup>3</sup> )                          | -0.21            | 0.18            | -0.05         | 0.59            |
| Total intra-abdominal fat (cm <sup>3</sup> )                    | -0.19            | 0.23            | -0.05         | 0.58            |
| Pancreatic volume (cm <sup>3</sup> )                            | -0.21            | 0.20            | -0.13         | 0.20            |
| Liver span (mm)   | 0.40             | 0.07            | 0.08          | 0.40            |

*P*<0.05: statistically significant.

Significant *P* values are shown in bold.

ARI, Anthropometric Risk Index; BMI, body mass index; DXA, dual energy X ray absorptiometry; SCAT, subcutaneous abdominal adipose tissue; WHR, waist-to-hip ratio; WHT-R, waist -to-height ratio.

for ABSI with the same variables. On MRI, significant positive correlations were observed in cases for ABSI with volumes of IPAT, RPAT and total IAAT, whereas moderately significant correlations were observed for volumes of all depots of abdominal SCAT (anterior, posterior, superficial, deep and total). In contrast to this pattern,

no significant correlation was observed for volumes of abdominal SCAT and IAAT in controls. Furthermore, no significant correlations were observed for ABSI with liver span and pancreatic volume (table 2). ROC analysis for ABSI showed sensitivity of 71.9%, specificity of 89.4% with AUC 0.86 for a cut-off value of 0.08 (figure 1A).

**Table 4** Correlation analysis of Z\_ABSI and Z\_HI in cases and controls

| Anthropometric measures and variables of body composition       | Z_ABSI           |                  |               |                  | Z_HI             |                  |               |                  |
|---|------------------|------------------|---------------|------------------|------------------|------------------|---------------|------------------|
|   | Controls (n, 38) |                  | Cases (n, 85) |                  | Controls (n, 38) |                  | Cases (n, 85) |                  |
|   | <i>rho</i>       | <i>P</i> value   | <i>rho</i>    | <i>P</i> value   | <i>rho</i>       | <i>P</i> value   | <i>rho</i>    | <i>P</i> value   |
| BMI (kg/m <sup>2</sup> )  | -0.31            | 0.07             | -0.09         | 0.39             | -0.36            | 0.03             | -0.17         | 0.54             |
| WHR   | 0.12             | 0.50             | 0.71          | <b>&lt;0.001</b> | -0.65            | <b>&lt;0.001</b> | 0.50          | <b>&lt;0.001</b> |
| Wht-R   | 0.77             | <b>&lt;0.001</b> | 0.53          | <b>&lt;0.001</b> | 0.42             | <b>0.01</b>      | 0.09          | 0.42             |
| Mid arm circumference   | -0.11            | 0.53             | 0.07          | 0.50             | -0.13            | 0.47             | 0.07          | 0.50             |
| Mid-thigh circumference   | 0.319            | 0.07             | -0.16         | 0.12             | 0.15             | 0.39             | 0.06          | 0.57             |
| Skinfold measurement (mm)                                       |                  |                  |               |                  |                  |                  |               |                  |
| Biceps  | -0.15            | 0.38             | -0.008        | 0.94             | -0.07            | 0.71             | -0.09         | 0.38             |
| Triceps   | -0.29            | 0.10             | 0.24          | 0.02             | -0.21            | 0.25             | 0.12          | 0.27             |
| Thigh   | 0.25             | 0.15             | 0.05          | 0.65             | -0.07            | 0.68             | -0.06         | 0.61             |
| Calf  | -0.14            | 0.44             | 0.30          | 0.00             | -0.27            | 0.12             | 0.30          | <b>&lt;0.01</b>  |
| Peripheral skinfolds (total)                                    | 0.69             | <b>&lt;0.001</b> | 0.19          | 0.08             | 0.65             | <b>&lt;0.001</b> | -0.05         | 0.65             |
| Subscapular skinfolds (mm)                                      | 0.17             | 0.34             | 0.23          | <b>0.03</b>      | 0.03             | 0.88             | -0.17         | 0.12             |
| Subscapular-triceps ratio                                       | 0.47             | <b>&lt;0.01</b>  | 0.11          | 0.31             | 0.25             | 0.51             | -0.39         | <b>&lt;0.001</b> |
| Suprailiac (horizontal)   | -0.06            | 0.75             | 0.19          | 0.08             | <b>0.01</b>      | 0.96             | 0.03          | 0.77             |
| Suprailiac (vertical)   | -0.03            | 0.88             | 0.19          | 0.06             | -0.11            | 0.57             | -0.92         | 0.39             |
| Suprailiac (average)  | -0.04            | 0.83             | 0.20          | 0.06             | -0.08            | 0.64             | -0.03         | 0.75             |
| Abdominal (vertical)  | 0.22             | 0.25             | 0.12          | 0.28             | 0.15             | 0.42             | 0.07          | 0.52             |
| Abdominal (horizontal)  | 0.29             | 0.14             | 0.07          | 0.52             | 0.29             | 0.13             | 0.07          | 0.52             |
| Abdominal skinfolds (total)                                     | 0.35             | 0.05             | 0.07          | 0.50             | 0.21             | 0.29             | -0.03         | 0.81             |
| Truncal skinfolds (total)                                       | 0.24             | 0.16             | 0.18          | 0.08             | 0.42             | <b>&lt;0.05</b>  | 0.03          | 0.81             |
| Total body fat (%) (on DXA)                                     | -0.05            | 0.76             | 0.09          | 0.42             | -0.10            | 0.56             | -0.09         | 0.40             |
| Truncal fat (%) (on DXA)  | -0.11            | 0.52             | 0.14          | 0.23             | -0.17            | 0.31             | -0.13         | 0.25             |
| Volumes of abdominal fat, pancreas and liver span on MRI (1.5T) |                  |                  |               |                  |                  |                  |               |                  |
| Anterior SCAT (cm <sup>3</sup> )                                | -0.21            | 0.22             | 0.32          | <b>&lt;0.01</b>  | -0.24            | 0.15             | 0.02          | 0.87             |
| Posterior SCAT (cm <sup>3</sup> )                               | 0.04             | 0.80             | 0.23          | <b>&lt;0.05</b>  | -0.02            | 0.91             | -0.09         | 0.43             |
| Superficial SCAT (cm <sup>3</sup> )                             | -0.13            | 0.45             | 0.26          | <b>&lt;0.05</b>  | -0.19            | 0.27             | -0.09         | 0.40             |
| Deep SCAT (cm <sup>3</sup> )                                    | 0.10             | 0.56             | 0.27          | <b>&lt;0.05</b>  | 0.02             | 0.89             | -0.02         | 0.89             |
| Total Abdominal SCAT  | -0.08            | 0.62             | 0.29          | <b>&lt;0.01</b>  | -0.15            | 0.39             | -0.08         | 0.47             |
| Retroperitoneal fat (cm <sup>3</sup> )                          | -0.12            | 0.49             | 0.24          | <b>&lt;0.05</b>  | -0.208           | 0.22             | -0.03         | 0.80             |
| Intraperitoneal fat (cm <sup>3</sup> )                          | -0.09            | 0.58             | 0.21          | 0.05             | -0.18            | 0.29             | -0.27         | <b>&lt;0.05</b>  |
| Total intra-abdominal fat (cm <sup>3</sup> )                    | -0.11            | 0.54             | 0.25          | <b>&lt;0.05</b>  | -0.19            | 0.26             | -0.21         | <b>&lt;0.05</b>  |
| Pancreatic volume (cm <sup>3</sup> )                            | -0.19            | 0.27             | 0.06          | 0.57             | -0.25            | 0.14             | 0.02          | 0.84             |
| Liver span (mm)   | 0.20             | 0.23             | 0.07          | 0.50             | 0.08             | 0.65             | -0.26         | <b>&lt;0.05</b>  |

*P*<0.05: statistically significant.

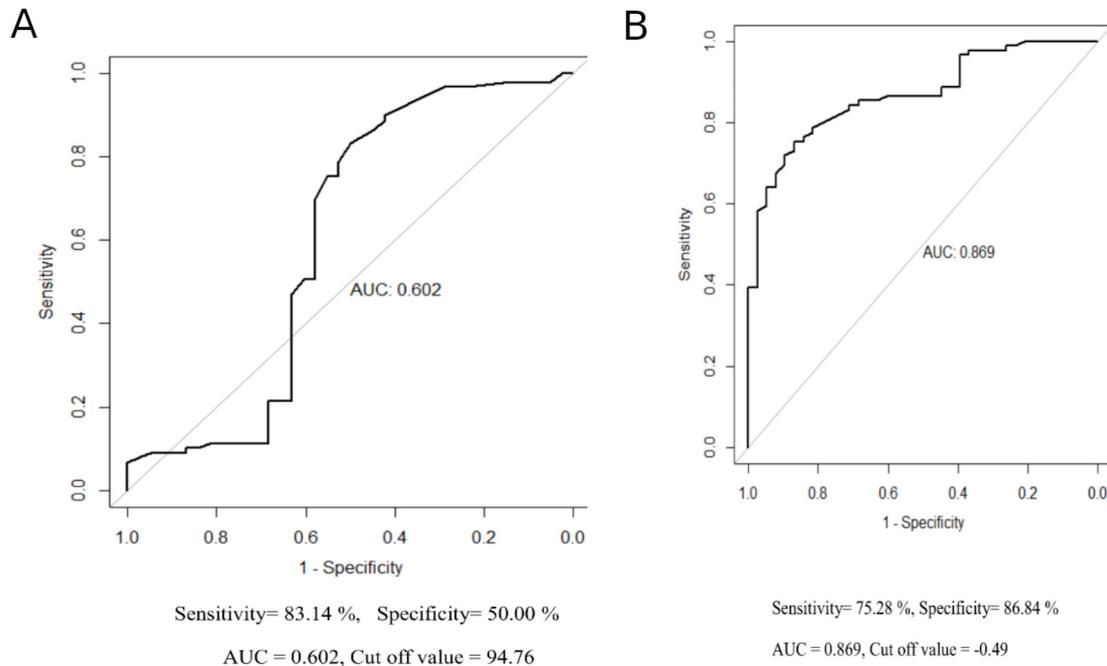
Significant *P* values are shown in bold.

ABSI, A Body Shape Index; BMI, body mass index; DXA, dual energy X ray absorptiometry; HI, Hip Index; SCAT, subcutaneous abdominal adipose tissue; WHR, waist-to-hip ratio; Wht-R, waist-to-height ratio; Z\_ABSI, Z score of ABSI; Z\_HI, Z score of HI.

### Z score of A Body Shape Index (Z\_ABSI)

The median values of ABSI\_Z score in cases, 0.64 with IQR (0.12–1.4) and controls, 1.02 with IQR (0.24–1.82) showed no significant difference (*p*=0.65). However, in cases, significant positive correlation was observed for this index with WHR and Wht-R, while the correlation coefficient of former was significantly higher than that of latter. Among skinfold measurements, significant positive correlation was observed for Z\_ABSI with triceps,

subscapular and calf skinfolds in cases, whereas in controls, significant positive correlation was observed for WHR, total peripheral skinfolds and subscapular-triceps ratio. On MRI, significant correlations were observed in cases for volumes of anterior, posterior, deep and superficial and total SCAT, IPAT, RPAT and total IAAT. Importantly, no significant correlation was observed with pancreatic volume and liver span with Z\_ABSI (table 3). ROC analysis showed sensitivity of 82.0% and specificity



**Figure 2** (A) Area under curve for the HI on ROC analysis (B) Area under curve for Z\_HI on ROC analysis. HI, Hip Index; ROC, receiver operator characteristics; Z\_HI, Z score of the Hip Index.

of 81.5% with AUC 0.87 for Z\_ABSI cut-off value of 0.49 (figure 1B).

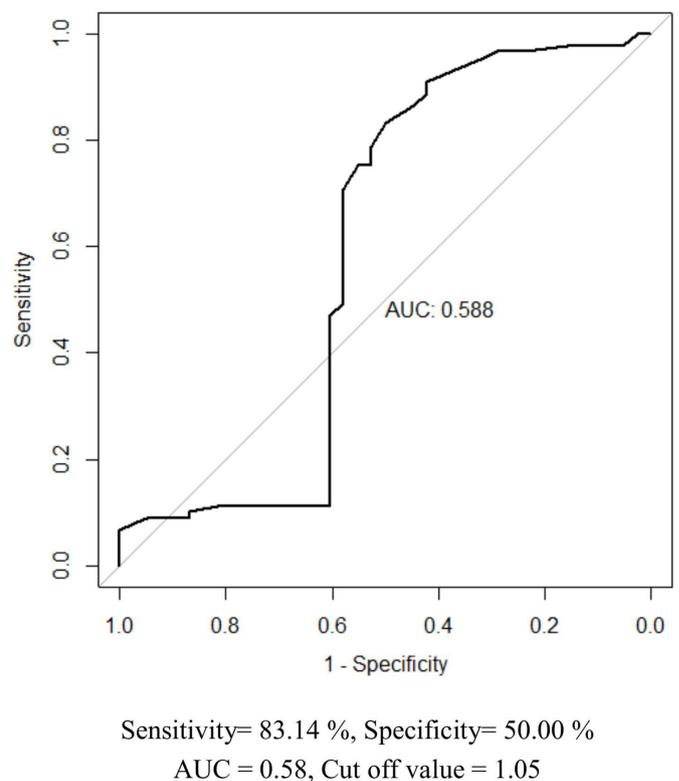
### Z\_HI

The median value of the Z\_HI in cases: 0.35 with IQR: (-0.96 to 0.31) was significantly lower ( $p=0.01$ ) as compared with controls, 0.11 with IQR (-0.63 to 0.87)]. In cases, significant positive correlation was observed for Z\_HI with WHR and calf skinfolds, but significant negative correlation was observed for subscapular-triceps ratio, volumes of IPAT, IAAT and liver span. Contrastingly, negative correlation with high significance was observed for Z\_HI with BMI, whereas significantly positive correlation was observed for WHt-R and sum of total truncal and peripheral skinfolds in controls. On MRI, no significant correlation was observed for Z\_HI with liver span, volumes of pancreas, SCAT, IPAT, RPAT and total IAAT in controls (table 4). ROC analysis showed sensitivity of 75.2% and specificity of 86.8% with AUC 0.87 for Z\_HI cut-off value of -0.49 (figure 2B).

### ARI

The median values for ARI in cases: 1.02, IQR (0.85–1.16) and controls: 1.05, IQR (0.85–1.25) did not differ significantly. Spearman's correlation analysis showed significant negative correlation in cases for ARI with BMI, WHR, mid-arm circumference and mid-thigh circumference. In addition, significant negative correlations were observed for ARI with TFM, abdominal skinfolds (vertical and horizontal) and total truncal skinfolds. In controls, significant positive correlation was observed for ARI with WHt-R and thigh circumference only. No significant correlation was observed for ARI with TFM, lean mass, % TBF and volumes of all abdominal adipose

tissue depots, pancreas and liver span on MRI (table 3). On ROC analysis, the AUC of 0.58 for ARI showed 83.1% sensitivity with 50% specificity for a cut-off value of 1.05 (figure 3).



**Figure 3** AUC for the ARI on ROC analysis. ARI, Adiposity Risk Index; AUC, area under the curve; ROC, receiver operator characteristics.

## DISCUSSION

Abdominal obesity and T2DM are significant risk factors for cardiovascular events in South Asians, at any given BMI.<sup>16</sup> In the current study, we report significantly positive correlations of the ABSI and Z\_ABSI with SCAT and IAAT volumes, and anthropometric measures in non-obese patients with T2DM. Importantly, we observed superior predictive value of the Z\_ABSI index for abdominal adiposity in non-obese patients with T2DM as compared with ABSI and other indices, irrespective of age and gender.

The ABSI correlates with mortality risk associated with abdominal obesity while showing minimal confounding effects of weight, height and BMI.<sup>6</sup> In a large study on non-diabetic, Caucasian subjects aged between 19 and 76 years and residing in Italy, Bertoli *et al*<sup>8</sup> reported significant association of the ABSI with all determinants of metabolic syndrome and IAAT thickness, latter measured using abdominal ultrasonography. When ABSI was combined with BMI, the association with IAAT thickness improved with better predictive accuracy for hypertriglyceridemia, low high density lipoprotein (HDL) cholesterol and impaired fasting glucose, even after adjustment for confounders.<sup>8</sup> These authors concluded that ABSI was a useful index for evaluating the independent contribution of WC, in addition to BMI, as a surrogate measure for central obesity and cardiometabolic risk. However, the Z\_ABSI was not applied in the study by Bertoli *et al*<sup>8</sup> despite a large sample size with data of abdominal adipose tissue determined by ultrasonography. In comparison, the correlations of the Z\_ABSI and ABSI with MRI-determined SCAT and IAAT volumes in our study on non-obese Asian Indian patients with T2DM are novel observations, despite a smaller but representative sample size. A study on elderly (mean age: 64±12 years) Japanese patients with T2DM (*n*, 607), showed that ABSI and Z\_ABSI were significantly associated with intra-abdominal fat area (estimated by dual-impedance analyzer and defined as 'visceral fat area'), and arterial stiffness (estimated by brachial-ankle pulse wave velocity). In this study, ABSI was strongly associated with IAAT thickness but not with BMI.<sup>17</sup>

The observations of the current study are also similar to the studies mentioned above; however, patients with T2DM in our study are younger and non-obese, and we carried out more detailed and accurate estimation of multiple adiposity depots, skinfolds and body fat as compared with the former studies. Importantly, our study is based on MRI which is superior to bioimpedance (as used by Khalil *et al*<sup>18</sup>) and ultrasonography (as used by Gönül *et al*<sup>19</sup>) for estimation of adiposity depots, as MRI uses magnetic field and radio waves to accurately quantify abdominal adipose tissue volume.<sup>20</sup> Further, previously no research has been done on correlation statistics of these novel anthropometric indices and liver span and pancreatic volume, especially in Asian Indians.

It is important to note that hip circumference was inversely related to the risk of T2DM in a meta-analysis, but conflicting results were shown in other studies.<sup>21</sup> Hip

circumference is a surrogate measure of gluteal obesity while the hip index (HI) was obtained by transformation of hip circumference using the power law relationship making it unrelated to BMI. A recent study on 687 middle-aged, healthy Chinese subjects showed that the HI was a poor predictor of diabetes risk as compared with hip circumference and WHR.<sup>22</sup> We applied both HI and Z\_HI and observed significant negative correlation in cases for HI with volumes of IAAT, RPAT and total IAAT. Interestingly, for Z\_HI, significant negative correlations were observed with total IAAT and liver span, but not with RPAT. It is important to note that the HI is an index of gluteal adiposity and the femoral-gluteal adipose is a metabolically static depot due to lower rate of blood flow, lipolysis and fatty acid release as compared with SCAT. In line with the same, in the current study, no significant correlations were noted for HI with all depots of SCAT in cases and controls, as HI is an index of gluteal obesity.<sup>23</sup> However, this needs to be investigated further to unravel the functional aspects.

The ARI has been shown to correlate significantly with all determinants of metabolic syndrome as shown in the Third National Health and Nutrition Examination Survey (NHANES III).<sup>24</sup> In our study, we noted significant correlations of the ARI and Z\_ARI with anthropometric measures, thigh, abdominal and truncal skinfolds but not with liver span, volumes of pancreas, SCAT and IAAT. This would have possibly resulted in low specificity of cut-off value, despite high sensitivity of the ARI in this study.

In our previous study, we had shown significant positive correlation of IAAT and liver span with pancreatic volume in non-obese Asian Indians with type 2 diabetes.<sup>13</sup> Quite strikingly, in the current study, none of the above-mentioned anthropometric indices showed significant correlations with pancreatic volume and liver span (surrogate measure of hepatic fat) on MRI, thus undermining the utility of anthropometric indices for detection or prediction of fatty liver or fatty pancreas. This is plausible as pancreatic volume and fatty liver assessment is usually done by ultrasonography or MRI that require precise imaging protocols and in such cases anthropometric indices may not be robust enough to quantify it.<sup>25</sup> We acknowledge the limitations of the study observations as MRI could not be performed on a large sample size of cases and controls due to reasons of economic feasibility. However, the study observations are worthy to be validated in other populations with larger sample sizes.

In summary, it is important to identify simple and cost-effective anthropometric measures that correlate with volumes of abdominal adipose tissue in Asian Indians, because of the close association of abdominal adiposity with cardiovascular risk in Asian Indians. For the first time, we show significant correlation of the Z\_ABSI index with abdominal adiposity in non-obese Asian Indians with T2DM. The superior predictive accuracy of the Z\_ABSI for abdominal adiposity, over ABSI, HI and ARI in this cohort underscores the utility of this index in low-cost clinical settings and epidemiological studies. Clearly, more studies

are required to validate this index in general population as well as in patients with diabetes.

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**Data availability statement** All data relevant to the study are included in the article or uploaded as supplementary information. All data are presented in the tables and in a supplementary file.

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**Suppl. Table 1:** Comparison of volumes of abdominal adipose tissue, Pancreas and Liver Span on MRI (1.5 Tesla) in cases and controls

| Volumes of abdominal adipose tissue, pancreas and liver span | Unadjusted for age |                  |                | Adjusted for age |                  |                |
|--|--------------------|------------------|----------------|------------------|------------------|----------------|
|  | Cases (n = 85)     | Controls (n= 38) | p value        | Cases (n =85)    | Controls (n= 38) | p value        |
| Superficial subcutaneous adipose tissue (cm <sup>3</sup> )   | 82.1 ± 22.4        | 82.4 ± 29.7      | 0.77           | 76.7 ± 26.9      | 84.8 ± 27.5      | 0.35           |
| Deep subcutaneous adipose tissue (cm <sup>3</sup> )          | 22.3 ± 9.4         | 19.6 ± 7.4       | 0.15           | 22.1 ± 6.5       | 20.3 ± 7.9       | 0.35           |
| Anterior subcutaneous adipose tissue (cm <sup>3</sup> )      | 47.2 ± 19.6        | 45.8 ± 20.1      | 0.56           | 48.3 ± 18.2      | 48.3 ± 20.6      | 0.98           |
| Posterior subcutaneous adipose tissue (cm <sup>3</sup> )     | 56.3 ± 18.4        | 54.8 ± 17.2      | 0.75           | 54.2 ± 19.5      | 58.0 ± 18.5      | 0.41           |
| Total subcutaneous adipose tissue (cm <sup>3</sup> )         | 101.1 ± 31.1       | 102.1 ± 37.5     | 0.86           | 101.9 ± 31.1     | 104.1 ± 32.9     | 0.64           |
| Intra-peritoneal adipose tissue (cm <sup>3</sup> )           | 30.2 ± 11.8        | 18.7 ± 8.5       | < <b>0.001</b> | 32.8 ± 11.3      | 18.5 ± 9.7       | < <b>0.001</b> |
| Retroperitoneal adipose tissue (cm <sup>3</sup> )            | 70.3 ± 28.4        | 46.0 ± 20.0      | < <b>0.001</b> | 67.5 ± 22.3      | 43.3 ± 26.4      | < <b>0.001</b> |
| Total intra-abdominal adipose tissue (cm <sup>3</sup> )      | 101.7 ± 38.7       | 68.5 ± 27.5      | < <b>0.001</b> | 68.5 ± 34.5      | 49.5 ± 35.8      | < <b>0.001</b> |
| Pancreatic volume (cm <sup>3</sup> )                         | 65.4 ± 21.4        | 52.8 ± 19.7      | < <b>0.01</b>  | 67.1 ± 22.5      | 52.8 ± 21.7      | < <b>0.01</b>  |
| Pancreatic volume index (cm <sup>3</sup> )                   | 36.5 ± 11.7        | 30.8 ± 10.5      | < <b>0.01</b>  | 38.6 ± 9.8       | 31.9 ± 11.5      | < <b>0.05</b>  |
| Liver span (mm)  | 161 ± 13.3         | 146.0 ± 17.2     | < <b>0.001</b> | 163.1 ± 13.7     | 145.0 ± 15.8     | < <b>0.001</b> |

Values are presented as Mean ± SD, P value < 0.05: Statistically significant