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Differences in specific abdominal fat depots between metabolically healthy and unhealthy children with overweight/obesity: The role of cardiorespiratory fitness

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Objectives: Fat depots localization has a critical role in the metabolic health status of adults. Nevertheless, whether that is also the case in children remains under-studied. Therefore, the aims of this study were: (i) to examine the differences between metabolically healthy (MHO) and unhealthy (MUO) overweight/obesity phenotypes on specific abdominal fat depots, and (ii) to further explore whether cardiorespiratory fitness plays a major role in the differences between metabolic phenotypes among children with overweight/obesity.

Methods: A total of 114 children with overweight/obesity (10.6 ± 1.1 years, 62 girls) were included. Children were classified as MHO ($n = 68$) or MUO. visceral (VAT), abdominal subcutaneous (ASAT), intermuscular abdominal (IMAAT), psoas, hepatic, pancreatic, and lumbar bone marrow adipose tissues were

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measured by magnetic resonance imaging. Cardiorespiratory fitness was assessed using the 20 m shuttle run test.

Results: MHO children had lower VAT and ASAT contents and psoas fat fraction compared to MUO children (difference = 12.4%–25.8%, all $p < 0.035$). MUO-unfit had more VAT and ASAT content than those MUO-fit and MHO-fit (difference = 34.8%–45.3%, all $p < 0.044$). MUO-unfit shows also greater IMAAT fat fraction than those MUO-fit and MHO-fit peers (difference = 16.4%–13.9% respectively, all $p \leq 0.001$). In addition, MHO-unfit presented higher IMAAT fat fraction than MHO-fit (difference = 13.4%, $p < 0.001$). MUO-unfit presented higher psoas fat fraction than MHO-fit (difference = 29.1%, $p = 0.008$).

Conclusions: VAT together with ASAT and psoas fat fraction, were lower in MHO than in MUO children. Further, we also observed that being fit, regardless of metabolic phenotype, has a protective role over the specific abdominal fat depots among children with overweight/obesity.

KEYWORDS

abdominal subcutaneous fat, aerobic capacity, hepatic fat, lumbar bone marrow fat, pancreatic fat, psoas fat, visceral fat, youth

1 | INTRODUCTION

One out of five children have obesity worldwide.[1] This figure is alarming since obesity is associated with cardiometabolic and psychosocial comorbidity as well as premature adult mortality.[1–3] However, it is known that not all individuals, adults, and children, with obesity possess the same cardiometabolic health risks. Indeed, two landmark studies showed that there is a subset of the population with obesity who do not present any cardiometabolic alterations (i.e., dyslipidemia, hyperglycemia, or hypertension),[4,5] referred as metabolically healthy obesity (MHO). From the first study[4] describing the MHO phenotype to date, many other studies have examined the characteristics of the MHO phenotype compared to their metabolically unhealthy obesity (MUO) peers.[6–9] Specifically, Bluher and Schwarz reported a number of factors and conditions which have been suggested to determine the MHO phenotype, including visceral adipose tissue (VAT), hepatic fat, and muscle fat content.[7] Specifically, these abdominal fat depots are a major public health challenge because of its elevated prevalence, associated morbidity, and expected increase in the short and mid-term.[10,11]

In adults, a recent position statement determined that the fat depots localization has a critical role in the metabolic health status.[12] Likewise, there is evidence showing that ectopic adipose tissue accumulation is a strong predictor of MUO phenotype in adults.[12] In adolescents with overweight/obesity, Sénéchal et al.[13] found that hepatic triglyceride content, body mass index, and waist circumference were the dominant predictors of cardiometabolic risk. Nevertheless, whether the localization of specific abdominal fat depots plays a critical role in the metabolic health of preadolescent children with overweight/obesity remains unexplored.

On the other hand, it seems that cardiorespiratory fitness might have a major role in the characterization and prognosis of the MHO phenotype.[6,8] Moreover, cardiorespiratory fitness level may reduce the differences between metabolic phenotypes and modify the prognosis.[6,14–18] Most of the research in this topic has been conducted either in adolescents or adults, yet, whether being fit has a role on the differences in MHO and MUO phenotypes and in specific abdominal fat depots in children with overweight/obesity is lacking.

Therefore, the objectives of this study were: (i) to examine the differences between MHO and MUO on specific abdominal fat depots, and (ii) to further explore whether having higher levels of cardiorespiratory fitness plays a major role in the differences between metabolic phenotypes among children with overweight/obesity. We hypothesized that MUO children will have higher abdominal fat in the different depots examined compared to MHO. However, we believe that cardiorespiratory fitness might have a role in the differences found between phenotypes.

2 | METHODS

2.1 | Study design and participants

The present cross-sectional study is under the framework of the EFIGRO project (Clinical-Trials.gov ID: NCT02258126). The EFIGRO trial aimed to evaluate the effects of a multidisciplinary intervention program on hepatic fat fraction, cardiometabolic risk factors, and psychological health in children with overweight/obesity. Data collection took from September 2014 to June 2017.

From the 116 children initially recruited at the Pediatric Endocrinology Unit of the University Hospital of Arava, a total of 114 (10.6 ± 1.1 years, 62 girls) participants with valid data for being categorized as either MHO or MUO were included in this study. Eligibility criteria were the following: (i) having overweight or obesity based on the cut-off provided by the World Obesity Federation,[19] (ii) being aged 9–11 years, (iii) having at least one parent or caregiver willing to participate in the educational program sessions, (iv) not having any medical condition or taking medication that could affect the study results, and (v) in the case of girls, not having the menstruation at baseline. More information about the study methodology has been described elsewhere.[20]

Parents or legal guardians read the objectives and measurements of the project and signed the informed consent before the participation in the study. The children also gave their assent before enrolment. This study followed the ethical guidelines of the Declaration of Helsinki 1965 (revised Edinburgh 2013) and was approved by the Ethics Committee of Clinical Investigation of Euskadi (ref. PI2014045).

2.2 | Measurements

2.2.1 | Anthropometric assessment

Body mass (kg) and stature (cm) (SECA models) were measured in underwear and without shoes, and then body mass index was calculated (kg/m^2). All measurements were collected twice, and the mean value were recorded for analyses. Fat mass was obtained by dual-energy x-ray absorptiometry (DXA) using the Hologic QDR 4500 W (Hologic). All DXA scans and analysis were performed using the GE encore software (v. 4.0.2) by the same blinded researcher and following the International Society of Clinical Densitometry recommendations.[21] Then, fat mass index was calculated dividing fat mass (kg) by stature (m) squared.

2.2.2 | Cardiometabolic risk factors

Systolic and diastolic blood pressure was measured twice from the non-dominant arm with an automatic oscillometric device (Omron M6) in a sitting position. Each reading was taken with a 10 min interval and the lowest reading was used for analyses. Serum triglycerides (mmol/L), high-density lipoprotein cholesterol (HDL, mmol/L), and fasting glucose (mmol/L) were measured from morning fasting blood samples collected at the hospital.[20]

2.2.3 | Defining metabolically healthy and unhealthy phenotype

The MHO or MUO phenotype was categorized based on the age- and sex-specific cut-off points provided by Jolliffe and Janssen, which are linked to the International Diabetes Federation and Adult Treatment Panel III.[22] Children were classified as MHO if they did not present any value indicating metabolic abnormalities, and MUO when they met one or more of the following altered cardiometabolic risk factors: blood pressure, triglycerides, HDL, or glucose (Table S1). According to previous literature,[6] waist circumference was not included in the definition of metabolic health, since most of the individuals with overweight/obesity presented high waist circumference.

2.2.4 | Adiposity variables

VAT, abdominal subcutaneous adipose tissue (ASAT), intermuscular abdominal adipose tissue (IMAAT), and psoas, hepatic, pancreatic, and lumbar bone marrow fat fractions were acquired by magnetic resonance imaging (Magnetom Avanto, 1.5T, Siemens Healthcare; Figure S1A–D).

A semiautomatic software for VAT, ASAT, and IMAAT segmentation was used. Active contours algorithm was applied to fine-tune the boundaries between the abdominal viscera area and the internal border of the abdominal muscular tissue by a researcher with extended experience in the analyses.[23] The K-method was used as thresholds for classifying pixels as fat and muscle in the depots examined.[24,25] Hepatic fat fraction was analyzed with a phased-array surface coil and a spine array coil, and running Siemens Medical System software (v.syngo.MR B17A), following the manufacturer instructions.[26] For pancreatic fat fraction acquisition, the 3D multi-echo gradient echo sequences were analyzed using the OsiriX software (v. 6.0. Bernex, Switzerland). The analysis

protocol was performed following a previously reported protocol.[27,28] Three regions of interest were noted in the head, body, and tail of the pancreas. Lumbar bone marrow fat fraction was obtained by using sagittal, coronal, and transverse localizers of the abdomen from the diaphragm to the symphysis pubis. A manual delineation of the vertebrae was done in the sagittal plane by two specialized radiologist researchers. Similarly, two specialists manually marked the contour of the psoas at the height of L3 vertebra with the aim of extracting the fat fraction of the muscle. For lumbar bone and psoas delineation analysis, MANGO software was used. Then, once the regions of interest were obtained, MATLAB was used to obtain fat fraction data. The mean value obtained of each adiposity measure was calculated and used for analyses. An extended information can be found elsewhere.[10,29,30]

2.2.5 | Cardiorespiratory fitness

Cardiorespiratory fitness was assessed by the 20-m shuttle run test which is known to be reliable and valid.[31] This test is considered as a surrogate measure of cardiorespiratory fitness assessed using gas analysis. In brief, the test consisted of running back and forth, 20 m apart, following an audio signal. The initial speed starts at 8.5 km/h with increments of 0.5 km/h each minute. The test finished when the children could not follow the pace of the audio signal on two consecutive occasions, or stopped due to the fatigue. The number of laps reached was recorded and used for analyses. Further, according to previous literature,[32,33] children with cardiorespiratory fitness level above the age- and sex-specific 20th percentile were categorized as fit.

TABLE 1 Descriptive characteristics of the study participants among metabolic phenotypes, and its differences.

	MHO			MUO			*p**
	N	**Mean**	**SD**	***N***	**Mean**	**SD**	
Age (years)	68	10.4	1.0	46	10.9	1.1	**0.005**
Sex							0.697
Boys (*N*, %)	30	44		22	48		
Girls (*N*, %)	38	56		24	52		
Body mass (kg)	68	53.1	10.2	46	57.2	10.8	**0.039**
Stature (cm)	68	145.3	8.2	46	147.3	7.6	0.191
Body mass index (kg/m^2)	68	25.0	3.0	46	26.2	3.6	**0.048**
Fat mass index (kg/m^2)	67	9.8	2.2	46	10.6	2.6	0.089
Weight status[a]							0.542
Overweight (*n*, %)	31	46		18	39		
Obese (*n*, %)	37	54		28	61		
Metabolic risk factors							
Systolic blood pressure (mmHg)	68	95.7	10.2	46	97.6	10.7	0.337
Diastolic blood pressure (mmHg)	68	60.0	6.5	46	64.4	10.0	**0.005**
Triglycerides (mmol/L)	68	66.3	22.7	46	106.3	45.6	**<0.001**
HDL cholesterol (mmol/L)	68	56.8	9.3	46	41.9	7.5	**<0.001**
Glucose (mmol/L)	68	84.8	5.1	46	86.3	5.7	0.129
Cardiorespiratory fitness (laps)	66	22.6	12.9	43	19.6	9.7	0.184
Fitness level							0.088
Fit (*n*, %)	34	51.5		15	34.9		
Unfit (*n*, %)	32	48.5		28	65.1		

Note: Data are presented as mean and standard deviations unless otherwise indicated. Statistically significant values are shown in bold. MHO was classified as having 0 risk factor and MUO as ≥1 risk factor.

Statistically significant values are shown in bold ($p < 0.05$).

Abbreviations: HDL, high-density lipoprotein; MHO, metabolically healthy overweight/obesity; MUO, metabolically unhealthy overweight/obesity; SD, standard deviation.

[a]Weight status was categorized based on the World Obesity Federation cut-offs.[18]

**p* value shows differences between metabolic phenotypes (MHO vs. MUO). Statistically significant values are shown in bold ($p < 0.05$).

TABLE 2 Bivariate Pearson correlation between the different fat depots examined.

	VAT (cm^2)	ASAT (cm^2)	IMAAT (%)	Psoas fat (%)	Hepatic fat (%)	Pancreatic fat (%)	Lumbar bone marrow fat (%)
VAT (cm^2)	1	**0.540****	**0.562****	**0.512****	**0.341****	**0.203***	**0.278***
ASAT (cm^2)	**0.540****	1	**0.603****	**0.304****	**0.213***	0.171	0.177
IMAAT (%)	**0.562****	**0.603****	1	**0.482****	0.160	0.175	**0.226***
Psoas fat (%)	**0.512****	**0.304****	**0.482****	1	0.134	0.059	0.172
Hepatic fat (%)	**0.341****	**0.213***	0.160	0.134	1	0.128	**0.329****
Pancreatic fat (%)	**0.203***	0.171	0.175	0.059	0.128	1	**0.239***
Lumbar bone marrow fat (%)	**0.278***	0.177	**0.226***	0.172	**0.329****	**0.239***	1

Note: Statistically significant values are shown in bold ($p < 0.05$).

Abbreviations: ASAT, abdominal subcutaneous adipose tissue; IMAAT, intermuscular abdominal adipose tissue; VAT, visceral adipose tissue.

*$p < 0.05$.; **$p < 0.01$.

2.3 | Statistical analyses

Descriptive characteristics of the study sample are presented as mean and standard deviation or frequency and percentage for continuous and categorical variables, respectively. Descriptive characteristics' differences between MHO and MUO were examined by one-way analysis of variance (continuous variables) or chi-square test (categorical variables). To know how the different specific abdominal fat depots correlate each other, we performed bivariate Pearson correlation.

In order to test differences between MHO and MUO in adiposity variables (VAT, ASAT, IMAAT, psoas, hepatic, pancreatic, and lumbar bone marrow fat fractions), analysis of covariance adjusted for basic confounders was applied (Model 1). Also, we explored whether the inclusion of either fat mass index (Model 2) or body mass index (Model 3) as covariate changed the findings observed. Sensitivity analysis including only children with obesity was also performed.

To examine the differences on specific abdominal fat depots between the combination of metabolic phenotypes (MHO and MUO) and fitness level (fit and unfit) categorization, we applied a general linear model analysis, under analyses of covariance methods, using the combination of MHO/MUO and fit/unfit as fixed factor, the different fat depots examined as dependent variable, and age, sex, and stature (if needed) as covariates.

All the analyses were performed using SPSS software (v. 22.0) and the level of significance was set at $p < 0.05$.

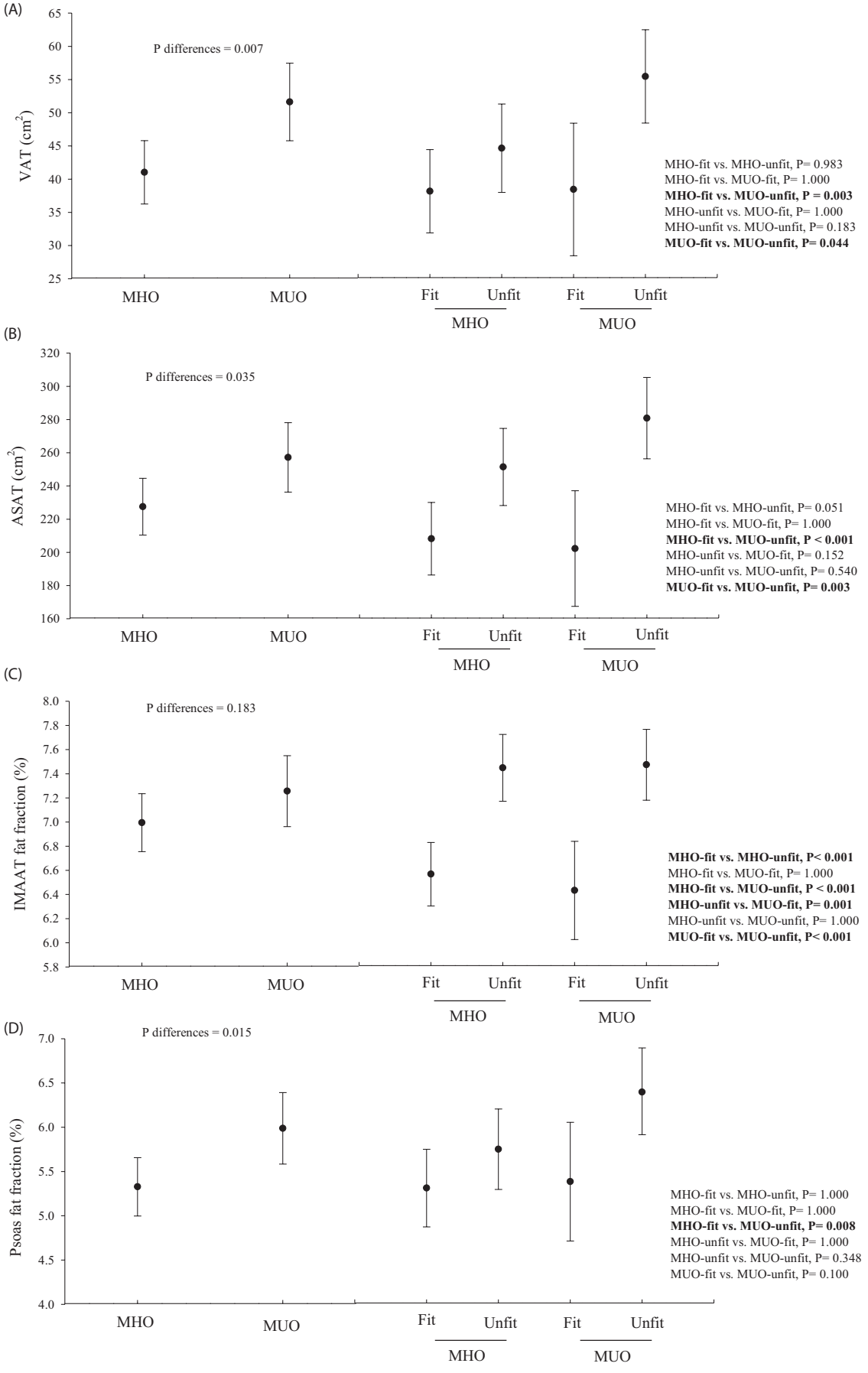
3 | RESULTS

3.1 | Descriptive characteristics of the study sample

The descriptive characteristics and differences of the MHO and MUO children are shown in Table 1. The prevalence of MHO was 59.6% ($n = 68$, 10.4 ± 1.0 years, 38 girls). Overall, MUO children had higher body mass, and presented higher body mass index, diastolic blood pressure, triglycerides, and lower HDL than their MHO peers (all $p \leq 0.048$).

Bivariate Pearson's correlations between the specific abdominal fat depots examined in this study can be found in Table 2. In short, VAT content was the most consistently associated variable with all abdominal fat depots examined (all $r \geq 0.203$, all $p < 0.05$). Otherwise, pancreatic fat fraction was the least associated variable with only significant relationship with VAT and lumbar bone marrow fat fraction (all $r \geq 0.203$, all $p < 0.05$).

FIGURE 1 Visceral adipose tissue (VAT, panel A), abdominal subcutaneous adipose tissue (ASAT, panel B), intermuscular abdominal adipose tissue (IMAAT, panel C), and psoas fat fraction (panel D) levels based on metabolic phenotypes (MHO and MUO, left side of the panel) and a combined categorization between metabolic phenotype (MHO and MUO, right side of the panel) and fitness level (fit and unfit). Data shown as adjusted means and 95% confidence interval (Table S4). Statistically significant values are shown in bold. Analysis of covariance model was adjusted for age, and sex. Stature was additionally included as covariate for those adipose tissue contents (i.e., VAT and ASAT). MHO was classified as having 0 risk factor and MAO as ≥1 risk factor. Fit group was categorized based on a cardiorespiratory fitness level above the age- and sex-specific 20th percentile cut-off point.[32] MHO-Fit sample (n ranged from 33 to 34 participants) MHO-Unfit sample ($n = 32$), MUO-Fit sample ($n = 15$), and MUO-Unfit (n ranged from 27 to 28 participants). Missing data was due to the magnetic resonance imaging (i.e., image was not valid for analyses). MHO, metabolically healthy overweight/obese; MUO, metabolically unhealthy overweight/obese.



3.2 | Differences between MHO and MUO on specific abdominal fat depots

Figures 1 and 2 show the comparisons in abdominal adiposity variables between metabolic phenotypes. MHO children had lower VAT and ASAT contents (Figure 1A,B, respectively), and psoas fat fraction (Figure 1D) compared to MUO children (difference ranged from 12.4% to 25.8%, all $p < 0.035$). No significant differences between metabolic phenotypes were observed for IMAAT (Figure 1C), hepatic (Figure 2A), pancreatic (Figure 2B), and lumbar bone marrow (Figure 2C) fat fractions (all $p > 0.1$). Table S2 (Model 1) shows the data graphically depicted in Figures 1 and 2. When fat mass index was additionally introduced as covariate in the model (Table S2, Model 2), the differences between MUO and MHO children in VAT (14%, $p = 0.036$) and psoas fat fraction (8.5%, $p = 0.037$) did not substantially change, while for ASAT were diminished and became non-significant ($p < 0.1$). When body mass index replaced fat mass index as covariate (Table S2, Model 3), the differences observed in Model 2 persisted although slightly more significant (VAT = 15%, $p = 0.030$; and psoas fat fraction = 8.5%, $p = 0.030$).

Similarly, when the analyses were repeated only in children with obesity (Table S3), the results showed that MHO had less VAT content and psoas fat fraction compared to MUO children (difference of 26.8% and 12.9% respectively, all $p \leq 0.039$). Borderline non-significant difference was observed in ASAT content (MUO = 292.8 vs. MHO 264.3 cm^2, difference = 10.8%, $p = 0.077$). No significant differences were observed in the remaining abdominal adiposity variables (all $p > 0.223$) between MHO and MUO children.

3.3 | The role of cardiorespiratory fitness on the differences between MHO and MUO on specific abdominal fat depots

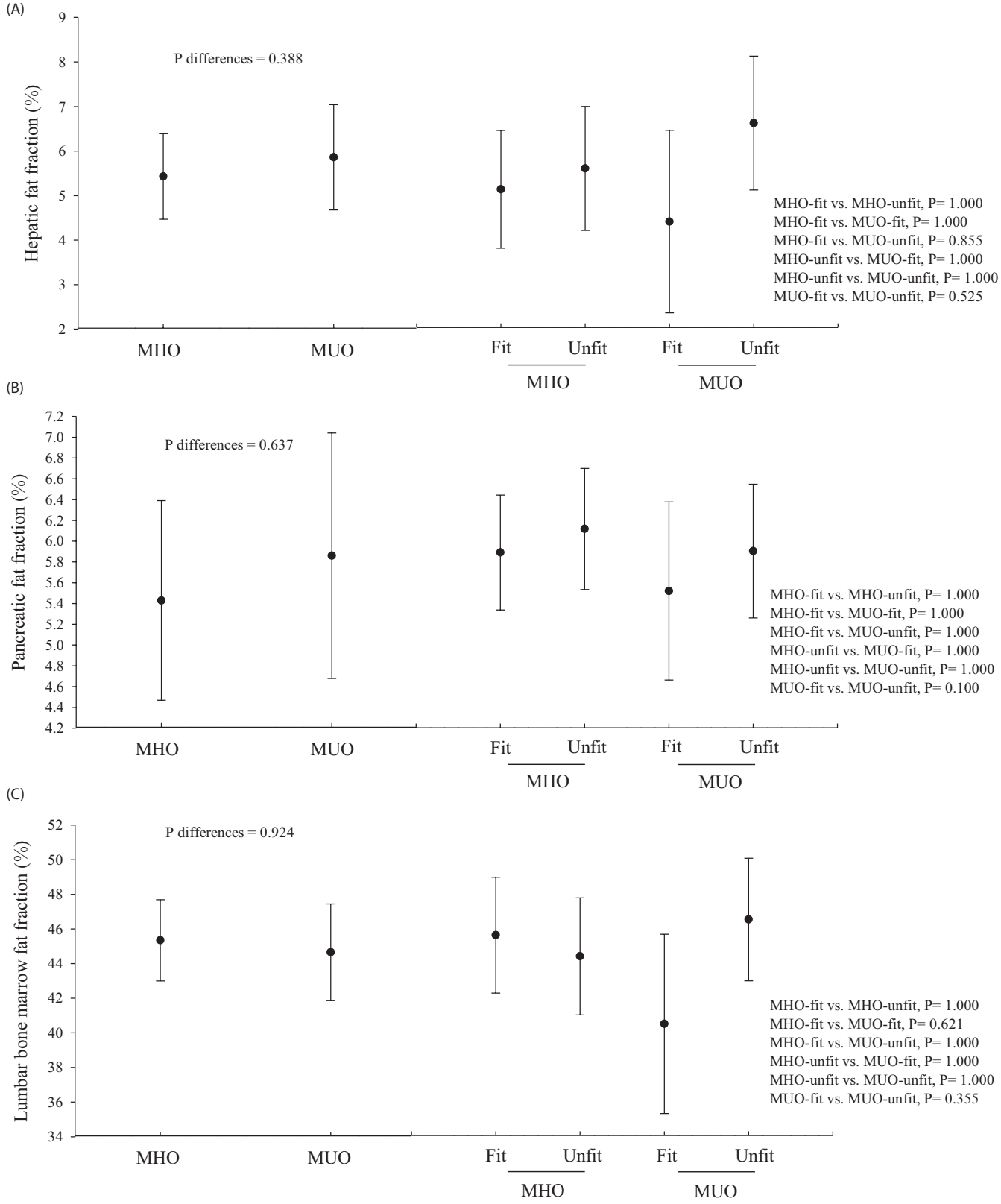
Figures 1 and 2 also depict the differences on abdominal adiposity levels between a combined categorization of the metabolic phenotype and fitness level (MHO-fit, MHO-unfit, MUO-fit, and MUO-unfit). MUO-unfit children had greater VAT (differences: 45.3% and 44.4%, all $p \leq 0.044$, Figure 1A) and ASAT (differences: 38.8% and 34.8%, all $p \leq 0.003$, Figure 1B) contents than either MUO-fit or MHO-fit, respectively. Similarly, MUO-unfit children presented higher IMAAT fat fraction (differences: 16.4% and 13.9%, all $p \leq 0.001$, Figure 1C) compared to MUO-fit or MHO-fit, respectively. In addition, MHO-unfit presented higher IMAAT than MHO-fit (difference: 13.4%, $p < 0.001$, Figure 1C). For psoas fat fraction, we also observed that those MUO-unfit showed higher fat fraction in this region compared to MHO-fit (difference: 21.2%, $p = 0.008$, Figure 1D). No significant difference was observed in the remaining sub-groups comparisons (all $p > 0.05$). There were no significant differences between the groups for hepatic, pancreatic, and lumbar bone marrow fat fractions (Figure 2A–C, all $p > 0.05$).

4 | DISCUSSION

The main findings of our study were: (i) MHO phenotype presented lower VAT, ASAT, and psoas fat depots than their MUO peers, yet no differences between metabolic phenotypes were found in the remaining examined abdominal fat depots (i.e., IMAAT, hepatic, pancreatic, and lumbar bone marrow fat fractions); and (ii) being fit exerts a protective role over the differences between metabolic phenotypes in the specific harmful abdominal fat depots among children with overweight/obesity.

Growing evidence suggests that the accumulation of VAT is a key contributor to cardiovascular disease and metabolic risk.[12,34] In this study, we have observed that VAT was the most strongly associated abdominal fat depot with the metabolically unhealthy phenotype followed by ASAT, IMAAT, and lumbar bone marrow fat in children with overweight/obesity. Although assessing VAT is not a routine measure in clinical practice, the extent to which an increase in VAT could be associated with an increase in other ectopic fat depots (i.e., abdominal subcutaneous, intermuscular abdominal, psoas, hepatic, pancreatic, and lumbar bone marrow) is an important issue as a clinical vital sign. Therefore, our study shed lights on examining VAT as a good indicator of the amount of fat located in the different abdominal fat depots examined.

FIGURE 2 Hepatic fat fraction (panel A), pancreatic fat fraction (panel B), and lumbar bone marrow fat fraction (panel C) levels based on metabolic phenotypes (MHO and MUO, left side of the panel) and a combined categorization between metabolic phenotype (MHO and MUO) and fitness level (fit and unfit, right side of the panel). Data shown as adjusted means and 95% confidence interval (Table S4). Statistically significant values are shown in bold. Analysis of covariance model was adjusted for age, and sex. Stature was additionally included as covariate for those adipose tissue contents (i.e., VAT and ASAT). MHO was classified as having 0 risk factor and MAO as ≥1 risk factor. Fit group was categorized based on a cardiorespiratory fitness level above the age- and sex-specific 20th percentile cut-off point.[32] MHO-Fit sample (*n* ranged from 29 to 34 participants) MHO-Unfit sample (*n* ranged from 30 to 32 participants), MUO-Fit sample (*n* ranged from 13 to 15 participants), and MUO-Unfit (*n* ranged from 26 to 27 participants). Missing data was due to the magnetic resonance imaging (i.e., image was not valid for analyses). MHO, metabolically healthy overweight/obese; MUO, metabolically unhealthy overweight/obese.



To the best of our knowledge, this is the most comprehensive study comparing differences in various potentially harmful abdominal fat depots between MHO and MUO in children with overweight/obesity. Only few previous studies[35,36] observed differences between metabolic phenotypes in body mass index and waist circumference in children with obesity. However, they did not look into specific abdominal fat depots. Thereby, our study examined the differences between MHO and MUO in a broad and comprehensive number of abdominal fat depots (i.e.,

VAT, ASAT, IMAAT, psoas, hepatic, pancreatic, and lumbar bone marrow fat fractions).

Our findings also support the role of on having lower VAT, ASAT, and psoas fat fraction on being metabolically healthy over metabolically unhealthy. Yet, in our study, it seems that the healthy/unhealthy metabolic profile is not related to other specific abdominal fat depots such as IMAAT, hepatic, pancreatic, and lumbar bone marrow fat fractions. No previous information is available for children, which hampers the comparison with other studies. In adolescents, our findings are in line with those by Lee et al.,[37] who observed a significant difference between MHO and MUO in VAT measured by magnetic resonance imaging in White and Black individuals with obesity. In contrast, Sénéchal et al.[13] did not observe differences in VAT or in ASAT measured by magnetic resonance imaging between the two phenotypes (i.e., MHO and MUO) in adolescents with obesity. With regard to the hepatic fat fraction, two studies[13,38] do not concur with our findings; thus, they observed that both hepatic triglyceride content and the presence of metabolic associated fatty liver disease were lower in MHO than in MUO adolescents. Differences between studies could be explained by the different characteristics of the study sample (children vs. adolescents), and the methodologies applied (magnetic resonance imaging vs. medical records). No studies were found showing differences between metabolic phenotypes in the remaining abdominal fat depots examined, which makes it a clear field for further research. We also observed that the differences between metabolic phenotypes in the fat depots examined persisted independently of the fat mass index or body mass index, which is an important finding to highlight. Indeed, our findings might elucidate that those children categorized as MUO, besides of having more overall adiposity compared to those MHO children, they have specifically more ectopic fat, which could partially explain their worse metabolic profile.

This study provides novel insights into the determinants of MHO phenotype. Based on the current findings, it seems plausible that VAT, ASAT, and psoas fat might be the underlying drivers for MUO. However, randomized controlled trials and/or longitudinal studies are needed to corroborate our hypothesis. Specifically, a recent position stand showed that VAT is the most diabetogenic and atherogenic fat depot,[12] albeit, as we have seen in our study, it is relevant to monitor other ectopic fat depots.

Given the strong and consistent association of cardiorespiratory fitness with metabolic phenotypes,[6] it was plausible that being fit could influence the differences on abdominal fat depots among metabolic phenotypes. In this context, we have observed that comparing those children grouped in the best condition (MHO and fit) to those within the worse condition (MUO and unfit) presented lower VAT, ASAT, IMAAT, and psoas fat fraction. Importantly, even within-metabolic phenotypes, fitter children presented lower VAT, ASAT, IMAAT, and psoas fat fraction than unfit children. Moreover, we observed that the role of fitness was even greater when the child was in a worse condition (i.e., have more room for improvement) as previously explored.[39] Interestingly, there were not differences between metabolic phenotypes for those children who were unfit, which bolsters the importance of cardiorespiratory fitness in this relationship. Therefore, our findings support the protective role of being fit on metabolic health already in childhood, and add to the current body of knowledge its beneficial effect on harmful abdominal fat depots. Public health policies should focus on promoting vigorous physical activity, which is associated with improvements in cardiorespiratory fitness,[40] to reduce the harmful abdominal fat depots in children with overweight/obesity.[41]

This study presents some limitations to be acknowledged. First, the cross-sectional design does not allow for causal inference. Second, the limited sample size in children with obesity reduces the power of the analyses; yet, the sensitivity analyses performed in children with obesity showed similar findings. The strengths of this study are the comprehensive study on the specific abdominal fat depots using magnetic resonance imaging in more than 100 children, the novelty of the topic, and the consistency of the findings in children with overweight/obesity and in those with obesity.

5 | PERSPECTIVE

Specific location of abdominal adiposity deposition could explain differences between metabolic phenotypes. Indeed, VAT, together with ASAT, and psoas fat fraction were lower in MHO than in MUO children, while there were no differences in other abdominal fat depots such as hepatic, pancreatic, intermuscular, or lumbar bone marrow fat fractions. Further, being fit seems to play a protective role over abdominal fat depots in both metabolic phenotypes. However, future randomized controlled trials are needed to corroborate our findings.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest relevant to this article to disclose.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

CONSENT

Parents or legal guardians were informed of the aims of the project and signed written informed consent.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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