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ORIGINAL ARTICLE

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Body mass index in adults with congenital heart disease

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Abstract

Objective: To investigate the status of body mass index (BMI) in adult people with congenital heart disease (ACHD).

Methods: Five hundred thirty-nine adults with CHD (53.8% men) were seen in the outpatient clinic from 2013 to 2015 and compared to a reference population (n = 1737). The severity of CHD was categorized as mild, moderate, and severe according to standard guidelines. Patients were categorized based on BMI as underweight (<18.5), overweight (25-30), or obese (>30). Echocardiography and magnetic resonance imaging were used to measure ventricular function while exercise capacity was estimated via cardiopulmonary exercise test.

Results: Adults with CHD had slightly lower BMI than the reference group (24.1 ± 4.3 vs 24.6 ± 4.3; P = .012). Men in the mild and severe group (23.9 ± 3.6; 23.3 ± 4.4 vs 25.1 ± 3.7; P = .007; P = .023) and women in the severe group (21.6 ± 3.3 vs 24.2 ± 4.7; P < .001) had lower BMI compared to the reference group. In the subgroups, men with ventricular septal defect, coarctation of aorta/ventricular septal defect and Fontan circulation and women with Fontan circulation had lower BMI than the reference group. Underweight was more prevalent in women with severe lesions compared to the reference group (22.2% vs 3.8%; P < .001). BMI was associated with age and exercise capacity in patients with mild and moderate lesions, while higher BMI was related to better ventricular function in women with Fontan circulation.

Conclusion: Underweight was more prevalent in ACHD patients with severe lesions. Special attention should be paid to the possible existence of underweight-related comorbidities.

KEYWORDS
body mass index, congenital heart disease, echocardiography, morbidity

1 | INTRODUCTION

Presently, the majority of children with congenital heart disease (CHD) survive into adulthood, even those with most complex lesions.[1] Therefore, factors that influence long-term cardiac outcomes are of increasing importance. The increasing prevalence of overweight and obesity in the past three decades has become a universal serious public health problem,[2] especially, obesity is an independent risk factor for cardiovascular disease and associated with an increased risk of morbidity and mortality as well as reduced life expectancy.[3]

Many cardiologists who treat patients with adult CHD (ACHD) focus on residual lesions, heart failure, arrhythmias and medication, while lifestyle choices such as dietary behavior and physical activity often take the back seat and are not well emphasized during the clinical visit. Insufficient formal physical activity advice by the physician[4,5] and encouragement toward a sedentary lifestyle as a result of overprotection [6,7] in CHD patients might be important contributors to the development of overweight and obesity. Indeed, several studies have shown that ACHD patients are not immune to overweight/obesity, and might be affected by the global obesity epidemic.[8-14] These findings to some extent are worrisome, since ACHD patients are at higher risk to develop metabolic syndrome than their healthy peers.[9]

On the other hand, being underweight is an established predictor of morbidity and mortality in acquired heart failure[15] and may be an equally important marker of increased health risk as overweight/obesity in specific CHD populations.[6,8] Studies in pediatric populations have also observed that certain groups of complex patients with CHD, particularly those with univentricular disease and those who have undergone the Fontan operation, are more likely to be underweight, and less likely to be obese than patients with simple CHD.[5,16] To the best of our knowledge, the prevalence of underweight in ACHD patients has not been described previously, although a recent study showed high prevalence of underweight in CHD patients.[17] In the current study, we sought to investigate the status of BMI in different ACHD lesions and its association with different factors such as age, exercise capacity, and ventricular function in order to prevent and manage subsequent detrimental comorbidity risks.

2 | METHODS

2.1 | Study sample

A retrospective electronic file review was performed on all patients aged ≥18 years presenting to Ghent University Hospital—ACHD outpatient clinic between June 2013 and May 2015 and living within the Flemish region. Patients with chromosomal and genetic abnormalities and other comorbidities (eg, Down syndrome, Marfan syndrome, Duchenne muscular dystrophy and any malignancy or tumor) that could affect body habitus and those with Eisenmenger physiology, mental retardation, and severe psychological disorders were excluded from the study. Complete data on measured weight and height were required for study inclusion. For patients with more than one outpatient visit in this time frame, the morphometric data were recorded from the most recent outpatient appointment. Considering these criteria, 539 patients aged 18-56 years (53.0% male) of total 877 patients were included. The study protocol was approved by the local ethical committee of Ghent University Hospital. The requirement for informed consent was waived because of the retrospective nature of the study.

2.2 | Weight status in patients and control group

As recommended by WHO, patients were classified based on BMI as underweight (<18.5 kg/m^2), normal weight (18.5-24.9 kg/m^2), overweight (≥25-29.9 kg/m^2), and obese (≥30 kg/m^2).[18] To enable statements on the weight status of the ACHD patients, their data were compared with the means and distributions of an available control group. This control group was based on data obtained from the general Belgian population recruited in the Health Interview Survey.[19] A total number of 1737 participants (48.4% male) aged 18-56 years from the Flemish part of Belgium represented the reference group, without any individual matching.

2.3 | Background data

The following data were collected from the electronic patient file: age, gender, date of visit, height, weight, cardiac diagnosis, surgical status, preexisting comorbidities, and the reason for the patient visit. Data on cardiovascular risk factors such as blood pressure, cholesterol level, diagnosis of diabetes mellitus, and smoking were also included. Categorization or cutoff values of respective risk factors were based on criteria from the European guidelines on cardiovascular disease prevention in clinical practice.[20] Left ventricular ejection fraction was assessed by transthoracic echocardiography,[21] while ventricular ejection fraction in single ventricle physiology (patients with Fontan) was assessed by magnetic resonance imaging when was indicated. Exercise capacity was estimated by maximal oxygen consumption (VO2 max) measured via cardiopulmonary exercise testing (CPET) [22] which was performed in 70% of ACHD patients.

2.4 | ACHD lesion severity categorization

Severity of the defect was categorized as mild (n = 185, aged 18-53 years), moderate (n = 283, aged 18-56 years), and severe (n = 71, aged 18-48 years) using a consensus-based classification scheme.[23] If more than one cardiac lesion was present, the lesion considered hemodynamically most significant was recorded as the main diagnosis. We did a minor modification to the scheme by moving the group of patients with transposition of great arteries (TGA) who underwent arterial switch operation (ASO) from the severe lesions group to the moderate group, since those patients have stable medical condition. Patients with repaired ventricular septal defect (VSD), secundum or sinus venosus atrial septal defect (ASD), ligated or occluded patent ductus arteriosus (PDA), percutaneously or surgically repaired valvular pulmonary stenosis (VPS), and isolated congenital mitral valve disease (MVD) were classified as mild lesions. Patients with either coarctation of aorta (COA) repair or coarctation of aorta combined with VSD repair (COA/VSD), valvular or supvalvular aortic stenosis repair (AS) including residual aortic regurgitation (AR) or Ross procedure (AS/AR), atrioventricular septal defect repair (AVSD), tetralogy of Fallot repair (TOF) and TGA with ASO were considered as moderate lesions. Patients with total cavopulmonary connection (TCPC)/Fontan operation, TGA with atrial switch (Senning or Mustard) operation, pulmonary atresia (PA) and double outlet right ventricle (DORV) repair, and truncus arteriosus (truncus A) repair were classified as complex lesions.

2.5 | Statistical analysis

All statistical calculations were performed using SPSS, software version 22.0 (IBM, New York, New York). A *P* value of <.05 was considered statistically significant. Descriptive data were expressed as percentages and means ± standard deviation. To compare between lesion groups and subgroups, one-way analysis of variance was performed for continuous BMI, while chi-square analysis was performed for categorical BMI. One-Sample *t* test was used to compare the patient's continuous BMI with the mean of the reference group. Linear regression analysis was used to investigate the association between the BMI and age, VO_2 max and ventricular function.

3 | RESULTS

3.1 | Descriptive data

ACHD patients were defined as "mild" [*n* = 185 (34.3%), aged 32.6 ± 8.9 years], "moderate" [*n* = 283 (52.5%), aged 32.3 ± 9.7 years), and "severe" [*n* = 71 (13.2%), aged 28.9 ± 7.8 years] group (Table 1). ACHD patients were younger (32.0 ± 9.3 vs 38.7 ± 10.7; *P* < .001) and had lower BMI (24.1 ± 4.3 vs 24.6 ± 4.3; *P* = .012) than participants in the reference group (Table 1). The rate of underweight, overweight, and obese classification were similar across ACHD group and reference group as shown in Table 1. ACHD patients reported lower smoking (10.6% vs 21.8%, *P* = .03) and showed a lower prevalence of dyslipidemia (6.1% vs 17.4%, *P* = .01) compared to the reference group, while the prevalence of hypertension (10.6% vs 17.3%, *P* = .17) and diabetes (1% vs 5%, *P* = .07) did not differ between the two groups. The prevalence of these cardiovascular risk factors did not differ between the mild, moderate, and severe group except for hypertension, which was more common in the moderate group (12.8%) compared to the mild (4.8%) and severe group (7%). Left ventricular ejection fraction measured by echocardiography was mildly impaired in the mild (4.6%), moderate (3.1%), and severe group (10%) (data not shown). The mean single ventricle ejection fraction measured by MRI in Fontan patients was 59.5 ± 9%. The mean VO_2 max in ACHD patients was in the mild group (29.9 ± 8.8) ml/kg/min, in the moderate group (30.0 ± 8.2) ml/kg/min, and in the severe group (24.0 ± 6.8) ml/kg/min. Data on VO_2 max in the subgroup lesions are also provided (Table 2).

BMI was positively associated with age and negatively associated with VO_2 max in patients with mild and moderate lesions (*P* < .001). In the meantime, BMI was not associated with the left ventricular ejection fraction in patients with mild and moderate lesions. BMI in patients with severe lesions was neither associated with age (*P* = .327) nor with VO_2 max (*P* = .833), however, higher BMI in women with Fontan circulation was related to better single ventricle ejection fraction.

TABLE 1 Demographics and baseline characteristics of the study population

Parameter	Mild group	Moderate group	Severe group	Total CHD group	Reference group	*P* value
Number (%)	185 (34.3%)	283 (52.5%)	71 (13.2%)	539 (100%)	1737 (100%)	
Age (years)	32.6 ± 8.9	32.3 ± 9.7	28.9 ± 7.8	32.0 ± 9.3	38.7 ± 10.7	<.001
Gender (% male)	44.1%	61.3%	49.3%	53.8%	48.4%	.445
Height (cm)	171 ± 9.4	173.1 ± 10.0	171.4 ± 10.3	172.2 ± 9.9	172.5 ± 9.6	.491
Weight (kg)	70.7 ± 13.4	73.8 ± 15.7	66.3 ± 14.5	71.7 ± 14.9	73.6 ± 15.0	.004
BMI (kg/m^2)	24.1 ± 4.0	24.5 ± 4.8	22.7 ± 3.9	24.1 ± 4.3	24.6 ± 4.3	.012
Underweight (%)	8.1	3.9	12.7	6.5	3.3	.294
Normal weight (%)	57.5	60.6	62.0	59.7	55.8	.576
Overweight (%)	26.3	22.3	22.5	23.7	31.5	.217
Obese (%)	8.1	13.1	2.8	10.0	9.4	.884
Smoking (%)	12.7	10.3	7.2	10.6	21.8	.031
Dyslipidemia (%)	7.2	5.7	5.8	6.1	17.4	.013
Hypertension (%)	5.0	12.8	7.2	10.6	17.3	.176
Diabetes (%)	1.1	0.7	–	1.0	5.0	.072
Ejection fraction (%)	60.5%	61%	60.1%	60.5%		
VO_2 max (ml/kg/min)[a]	29.9 ± 8.8	30.0 ± 8.2	24.0 ± 6.8			
Peak heart rate (bpm)[a]	165.0 ± 18.0	169.0 ± 20.0	156.0 ± 21.5			

Abbreviation: BMI, body mass index.

Note: P value presented the association between the total CHD group and the reference group, *P* value less than .05 is considered significant association.

[a]Not all subjects included (45.5% of mild, 81.5% of moderate, and 94.3% of severe), data are given at the mean ±SD standard deviation.

TABLE 2 Subgroups according the severity of lesions with exercise capacity

Lesion	*n*	Age	*n* (VO_2 max)	VO_2 max
Mild group				
VSD	78	33.6 ± 8.1	34	30.4 ± 7.3
ASD	54	31.8 ± 9.8	24	31.5 ± 11.0
VPS	30	32.6 ± 9.2	11	24.5 ± 6.6
PDA	14	32.0 ± 9.6	6	33.8 ± 10.3
MVD	9	29.0 ± 6.3	4	26.6 ± 5.2
Moderate group				
AS/AR	86	31.5 ± 8.5	63	30.6 ± 7.7
COA/VSD	73	32.2 ± 9.0	55	31.6 ± 9.4
TOF	74	36.3 ± 11.3	68	27.1 ± 7.0
AVSD	34	29.2 ± 7.0	25	29.8 ± 7.4
TGA/ASO	16	24.7 ± 6.3	15	34.9 ± 9.1
Severe group				
TCPC	30	27.6 ± 7.2	27	22.3 ± 6.1
PA/DORV	21	34.0 ± 8.3	19	21.7 ± 6.3
TGA/AtSO	14	28.62 ± 6.2	14	28.5 ± 6.4
TrA	6	21.3 ± 2.2	6	29.2 ± 5.8

Data are given at the mean ±SD standard deviation.
Abbreviations: AR, aortic regurgitation; AS, aortic stenosis; ASD, atrial septal defect; AVSD, atrioventricular septal defect; COA, coarctation of aorta; MVD, mitral valve disease; *n*, number; PA/DORV, pulmonary atresia/double outlet right ventricle; PDA, patent ductus arteriosus; TGA/ASO, transposition of great arteries/arterial switch operation; TGA/AtSO, transposition of great arteries/atrial switch; TOF, tetralogy of Fallot; TrA, truncus arteriosus; VPS, valvular pulmonary stenosis; VSD, ventricular septal defect; VO_2 max, maximal oxygen uptake.

3.2 | Continuous BMI differences

Men had lower BMI in patients with ventricular septal defect (VSD) (23.8 ± 3.2 vs 25.1 ± 3.7; $P = .022$), coarctation of aorta (COA/VSD) (23.4 ± 3.7 vs 25.1 ± 3.7; $P = .007$), and Fontan circulation (20.5 ± 2.7 vs 25.1 ± 3.7; $P < .001$) compared to reference group (Table 3). For women, only those with Fontan circulation had lower BMI than the reference group (21.4 ± 3.6 vs 24.2 ± 4.7; $P = .003$) (Table 3). None of the subgroups had significantly higher BMI than the reference group. Further, the 14 different subgroups were rearranged in the 3 severity groups: mild, moderate, and severe. We found a significant gender interaction, whereby men with mild and severe lesions group showed a lower BMI than men in the reference group (23.9 ± 3.6; 23.3 ± 4.4 vs 25.1 ± 3.7; $P = .007$; $P = .023$), respectively, only women with severe lesions group had lower BMI than women in the reference group (21.6 ± 3.3 vs 24.2 ± 4.7; $P < .001$) (Figure 1).

3.3 | Categorical BMI differences

The status of BMI categories is highlighted (Table 4). In men, there was no significant difference in BMI category distribution between the groups. Men with mild lesions had less obesity and overweight (and thus more underweight and normal weight) compared to the reference group ($P = .012$). In women, the status of BMI categories differed between groups: less obese and more underweight patients in the severe group ($P < .001$) compared to the mild and moderate group. Women with severe lesions had less obesity and overweight (and thus more underweight and normal weight) compared to the reference group.

4 | DISCUSSION

Our results showed that adults with CHD were at equal risk to be overweight and obese but had slightly lower body mass index than the normal population. This was more prevalent in men than in women, although women in the severe group showed more prevalence of underweight. In the subgroups, men with ventricular septal defect, coarctation of aorta/ventricular septal defect and Fontan circulation and women with Fontan circulation had lower BMI than the reference group. BMI was associated with age and exercise capacity in patients with mild and moderate lesions and with ventricular function in patients with Fontan circulation.

4.1 | Other cardiovascular risk factors in ACHD patients

Probably due to the lower BMI and the lower smoking frequency in our patients compared with the reference group, dyslipidemia was less prevalent,[24] although the prevalence of hypertension and diabetes did not differ from the control group. The presence of higher hypertensive patients in the moderate group compared to those in mild and severe is referred to aortic coarctation. Some authors have also reported lower levels of total cholesterol in ACHD patients compared to a general population sample group,[25] while the prevalence of diabetes was not different.[14,25,26] In the context of long-term outcome, these results are encouraging to some extent, since recent data indicated that the metabolic syndrome is more common among adults with CHD than in the general population,[5] especially in those with central obesity.

4.2 | Overweight/obesity and underweight in ACHD patients

Data from previous studies on BMI and frequency of underweight, overweight, and obesity in ACHD patients were diverse.[8-10] The most recent data showed that one-quarter of ACHD patients were obese, and ACHD patients are at equal risk as their matched peers to be overweight and obese independently of the severity of the lesion.[8] Likewise our findings, as the overall distribution of overweight/obesity in our cohort is in line with the contemporary general population, our finding indicates that the population of adults with CHD follows the same pattern, although our data are cross-sectional rather than longitudinal.

TABLE 3 BMI in men and women with subgroup lesions compared to reference group

Mild lesions	Controls	VSD	*P*	ASD	*P*	PDA	*P*	VPS	*P*	MVD	*P*
BMI men	25.1 ± 3.7	23.8 ± 3.2	**.022**	24.1 ± 3.4	.320	25.6 ± 1.8	.978	24.9 ± 5.1	.622	20.2 ± 1.7	.144
BMI women	24.2 ± 4.7	23.8 ± 4.3	.138	24.5 ± 4.4	.616	23.7 ± 4.6	.431	25.4 ± 4.8	.673	23.7 ± 3.8	.431
Moderate lesions	**Controls**	**CoA/VSD**	***P***	**AS/AR**	***P***	**Arterial switch**	***P***	**AVSD**	***P***	**TOF**	***P***
BMI men	25.1 ± 3.7	23.4 ± 3.7	**.007**	25.4 ± 4.6	.640	23.8 ± 4.8	.167	24.0 ± 2.9	.280	25.3 ± 4.3	.567
BMI women	24.2 ± 4.7	24.5 ± 5.2	.743	24.8 ± 4.7	.938	21.2 ± 2.4	.281	23.9 ± 3.5	.269	24.1 ± 4.9	.390
Severe lesions	**Controls**	**Fontan/TCPC**	***P***	**Atrial switch**	***P***	**PA/DORV**	***P***	**Truncus A**	***P***		
BMI men	25.1 ± 3.7	20.5 ± 2.7	**<.001**	24.7 ± 5.4	.578	24.4 ± 3.9	.359	22.7 ± 2.2	.145		
BMI women	24.2 ± 4.7	21.4 ± 3.6	**.003**	22.3 ± 2.4	.374	22.3 ± 3.0	.119	20.1 ± 2.0	.177		

Abbreviations: AR, aortic regurgitation; AS, aortic stenosis; ASD, atrial septal; AVSD, atrioventricular septal defect; BMI, body mass index; CoA, coarctation of the aorta; DORV, double outlet right ventricle; truncus A, arteriosus; MVD; mitral valve disease; PA, pulmonary atresia; PDA, patent ductus arteriosus; SD, standard deviation; TOF, tetralogy of Fallot; TCPC, total cavopulmonary connection; VPS, valvular pulmonary stenosis; VSD, ventricular septal defect.

Note: Bold data indicate *P* value < .05 based on one-sample *t* test comparing patients with the control group.

The similarity of obesity prevalence among ACHD patients to their peers was also indicated in other studies.[9,12,13] However, the obesity prevalence observed in the studies performed in the United States was higher[9] and even double[8] than what was found in the studies conducted in Europe.[12,13] This geographic comparison perhaps suggests that, like their otherwise-healthy peers,[2] US ACHD may be particularly affected by the global obesity epidemic. These findings are worrisome, since ACHD patients at higher risk to develop metabolic syndrome than their healthy peers.[9] Moreover, ACHD patients have premature morbidity and mortality compare to healthy adults, and often die from cardiovascular events.[27]

In contrast with Lerman et al,[8] we noticed that the BMI among our patients was influenced by the severity of the cardiac lesion, and underweight was more prominent in women with severe lesions and in men with mild lesions. Of note, that higher BMI in women with Fontan circulation in the current study was related to the better single ventricle ejection fraction. The association between higher BMI and lower mortality rate among ACHD patients was recently published.[12] The authors also showed that weight loss was related to an increased risk of death in patients with complex cardiac defects.[12] In line with these findings, Chung et al[10] have also reported that overweight/obesity in adults with Fontan circulation was associated with lower heart failure rates.

In a study investigated the association between obesity and early postoperative outcomes in ACHD, Zaidi et al[11] highlighted a high prevalence rate of overweight (29%) and obesity (22%) in those with moderate to severe ACHD requiring additional surgical palliation. Nevertheless, the authors stated that the overall presence of obesity did not influence the outcome (eg, morbidity or mortality) compared to the normal weight group.[11] Unfortunately, Zaidi and his colleagues did not provide data on functional status of the heart and therefore it was difficult to predict whether their outcome results related to a positive association between the BMI and cardiac function. These findings together with the aforementioned results affirm that being underweight might be a predictor of morbidity and mortality in severe ACHD patients as considered in patients with acquired heart failure,[15] although men in the mild lesions group in the current study have high prevalence of underweight.

The prevalence of 32.1% overweight/obesity in ACHD patients (Belgium) in the years 2000-2004 indicated by Moons et al[14] vs 33.7% reported in the current study 2013-2015 was nearly similar. Despite the increasing rate of overweight/obesity among the Belgian population in the last 10 years, the prevalence of overweight/obesity in ACHD patients remained nearly stable over this period. This may explain why Moons et al reported higher obesity rate in their ACHD patients compared to the controls in that period.

The BMI status among adults with different congenital heart lesions was described in a study performed in the Swedish population of ACHD patients.[13] The authors found that underweight is more prevalent and overweight/obesity less prevalent in men with congenital heart lesions compared to a reference population especially in those with a complex lesion, whereas in women, only limited differences between those with ACHD and the control population

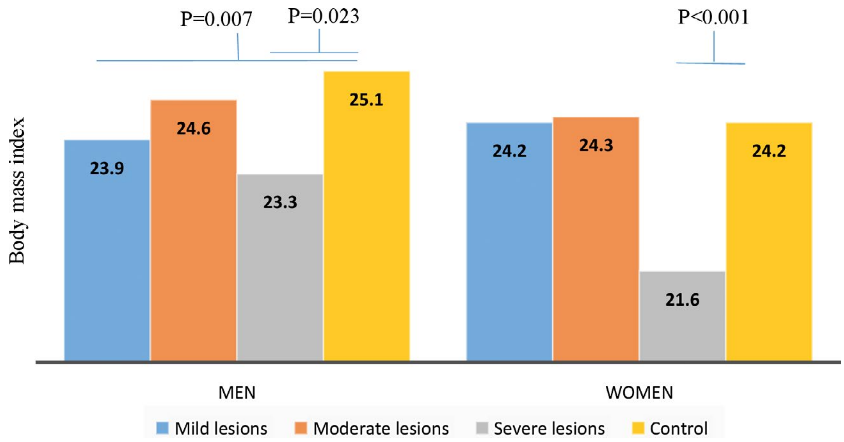

FIGURE 1 Body mass index in men and women with CHD compared to the control group

TABLE 4 Distribution of underweight, normal weight, overweight, and obesity in men and women with mild, moderate, and severe lesions

	Mild lesions (%)	Moderate lesions (%)	Severe lesions (%)	*P* value[a]	Total patient group (%)	Controls (%)	*P* value controls vs patients[b]
Men				.244			Versus total 0.062
Underweight BMI <18.5	7.3	4.0	2.9		4.8	1.4	Versus mild **0.012**
Normal weight BMI 18.5-24.9	58.5	59.0	60.0		59.0	45.0	Versus moderate 0.050
Overweight BMI 25-29.9	29.3	24.3	31.4		26.6	41.7	Versus severe 0.097
Obesity BMI ≥30	4.9	12.7	5.7		9.7	11.9	
Women				**<.001**			Versus total 0.214
Underweight BMI <18.5	9.6	4.6	22.2		9.2	3.8	Versus mild 0.304
Normal weight BMI 18.5-24.9	56.7	62.4	63.9		60.2	54.0	Versus moderate 0.456
Overweight BMI 25-29.9	24.0	19.3	13.9		20.5	28.9	Versus severe **<0.001**
Obesity BMI ≥30	9.6	13.8	0.0		10.0	13.3	

Abbreviations: BMI, body mass index; *n*, number.
Note: Bold data indicate any *P* value <.05.
[a]Chi-square test on differences in BMI category distribution between the three groups of lesions.
[b]Chi-square test on BMI category differences between controls and patients.

were found.[13] Likewise our findings, men in general have lower BMI than the reference population, specifically men with VSD, COA, and Fontan. In women, however only those in the severe group have lower BMI than the reference population. The underlying reasons of sex differences in BMI could be related to the fact that women normally have a higher percentage of body fat and lower muscle mass compared to men[28] and the heart lesion might affect the muscle development as well as muscle mass. The prevalence of underweight in men and women with complex lesions might affects the long-term outcome in this population. The reason for muscle affection by the congenital heart lesion is not clear. It can be speculated that a limited cardiac reserve hampers muscle development,[13] although it is more difficult to understand the finding of lower weight and BMI in men with VSD and COA.

Zomer et al[26] have reported a lower prevalence of obesity in the Dutch ACHD patients which is probably due to an overall healthy lifestyle be being more health conscious. Since, our study is retrospective and we do not have available data on dietary behavior, we referred to CPET data to assess exercise capacity. We found lower exercise capacity in our patients with severe lesions compared to those with mild and moderate lesions, although exercise capacity was markedly depressed in all groups. Diller et al[29] have demonstrated that exercise capacity is markedly decreased in ACHD patients, even among asymptomatic patients. Nevertheless, we noticed that the exercise capacity level expressed by VO_2 max in all subgroups in the present study was at least not worse than the published reference values.[30] Interestingly, some researchers indicated that most ACHD patients met the recommendation of 30 min of at least moderate activity per day[31] and ACHD patients seemed to follow the same level pattern as the general population.[32] Both studies showed that men were more active than women in this population.[31,32] This might clarify to some extent why men usually have lower BMI than women in this population.

To understand more thoroughly the association between the BMI of the ACHD patients and their functional status, a larger study with information on dietary behavior, physical activity, CPET, and MRI is necessary to fully elucidate the underlying reason for these BMI differences and its consequences.

4.3 | Study limitation

The present study has some limitations. These limitations are primarily related to the retrospective cohort design. Data on diabetes and cholesterol level relied on the patient interviews. The lack of potentially important contributing data such as dietary pattern and measured physical activity limits insight into the predictors of underweight and overweight/obesity. The younger age of our ACHD patients compared to reference population could slightly influence our results. Finally, these results are derived from a single center and some lesion subgroups were represented in small sample size, therefore, the present results cannot be generalized as representative of the total Belgian adults with CHD.

5 | CONCLUSION

Adults with CHD had slightly lower BMI than the reference group, in a sex-specific way. In women, only patients in the severe group especially those with Fontan circulation have lower BMI than the reference group. Higher BMI in women with Fontan circulation was an indicator of better ventricular function. Thus, special attention should be paid to the possible existence of underweight-related comorbidities.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest with the contents of this article.

AUTHOR CONTRIBUTIONS

Dr Zaqout conceptualized and designed the study, analyzed and interpreted the data, and drafted the initial manuscript; Dr Michels and Prof De Wolf contributed to study conception and design, acquisition of data, interpretation of data, and review and revision of the manuscript. Dr Vandekerckhove, Dr Demulier, Prof Francois, Prof Bove, Prof De Backer, and Prof De Henauw contributed to study conception and design, interpretation of data, and detailed review and revision of the manuscript; and all authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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