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People with type 1 diabetes exhibit lower exercise capacity compared to a control population with similar physical activity levels

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Abstract

Aims: We aimed to assess physical activity (PA) levels, adherence to PA guidelines, and fitness capacity in individuals with type 1 diabetes (T1D) and control population.

Methods: This cross-sectional study included 232 T1D and 248 controls. PA levels (IPAQ-SF questionnaire), adherence to guidelines (>150min/week of moderate-to-vigorous PA), fitness capacity (VO_2max, maximal incremental test on a cycle ergometer and 1RM test) were assessed, along with other clinical variables.

Results: Total PA levels (T1D 2202 ± 1839 vs. controls 2357 ± 2189 METs/min/week), adherence (T1D 53.1% vs controls 53.2%), and sedentariness (T1D 27.3% vs. controls 25.1%) were similar between groups. However, participants with T1D exhibited significantly lower levels of VO_2max (29.1 ± 10.5 vs. 32.5 ± 11.5 mlO_2/kg/min, $p<0.001$), work capacity (2.73 ± 1.03 vs. 3 ± 10 W/kg of body weight, $p=0.004$) and strength capacity (2.29 ± 0.53 vs. 2.41 ± 0.79 kg/kg body weight in 1RM, $p=0.01$) than controls, after adjusting for sex and age.

Conclusions: Individuals with T1D exhibit lower fitness capacity compared to a control population, regardless of age and sex, even when presenting similar levels of total physical activity and adherence to guidelines.

Key words: type 1 diabetes mellitus, exercise, physical fitness, sedentary lifestyle, guideline adherence

1. Introduction

People living with type 1 diabetes (T1D) are encouraged, as the general population, to engage an active lifestyle for the promotion of health care and well-being [1]. Benefits from an active lifestyle are widely demonstrated, including improvements in cardiovascular risk factors, lipid profiles, endothelial function, and insulin requirement, among others [2,3]. Until recently, there was no agreement about the positive effects of physical activity on glycemic control in people with T1D [4]. However, recent studies using continuous glucose monitor sensors (CGMS) indicate improvements in time in range of glucose levels and a reduction in glycemic variability among those individuals with T1D engaging in high levels of physical activity [5]. Additionally, it has been reported that high intensity interval training (HIIT) promotes better stability in glycemic control compared to conventional aerobic training [6]. Moreover, high levels of physical activity have been associated with reduced cardiovascular events and total mortality in both the general population [7, 8] and individuals with T1D [9,10]. Remarkably, T1D has been linked to a major increase in cardiovascular risk, irrespective of optimal glycemic control [11, 12]. Consequently, increasing physical activity levels emerges as a promising strategy to counteract the increased cardiovascular risk caused by diabetes.

The American Diabetes Association (ADA) recommends a combination of different types of physical exercise, such as aerobic, strength, balance, and flexibility training. These recommendations include reducing sedentary time and increasing the time expended in moderate-to-vigorous physical exercise (MVPA), with the goal of a total activity higher than 150 minutes a week [13]. Despite the previously described benefits of physical exercise, studies concerning current levels of physical activity and the level of adherence to physical activity recommendations in adult people with T1D are limited. In a recent study, conducted on a small sample of patients wearing accelerometers, it was reported that only 32% of the participants living with T1D meet physical activity recommendation [14]. On the other hand, a cross-sectional study in two different cohorts of patients with T1D recruited in two different periods in 2008 and in 2018, using IPAQ questionnaires, revealed a reduction in sedentary lifestyle from 14% to 6.3% [15], highlighting an increased awareness among individuals with T1D to engage in more physical activity. Considering sedentariness as a cardiovascular risk factor, it is important to assess the concurrent existence of other cardiovascular risk factors, such as high body mass index (BMI), smoking habits, dyslipidemia, or hypertension, since these factors are also related to total and cardiovascular mortality [16].

There is recent evidence from observational studies that people with T1D could present lower cardiorespiratory capacity compared to people without diabetes [17, 18]. The authors hypothesize that this reduction in cardiorespiratory capacity could be attributed to cardiac autonomic neuropathy or cardiomyopathy. Another study performed with adolescent participants with T1D also identified a reduction in cardiorespiratory capacity (measured through VO_2max) compared to a group of adolescents without diabetes. Importantly, the participants of this study with T1D were less active than the control counterparts [19].

The reduced cardiorespiratory capacity observed in patients with T1D needs to be understood more comprehensively, considering both the level of physical activity and adherence to guidelines. Thus, the main objective of this study was to assess and compare physical activity levels, adherences to guidelines and fitness capacity in individuals with T1D and a control population without diabetes.

2. Material and Methods

2.1. Subjects

Participants were included by convenience sampling. Participants with T1D included in the study, aged between 18 and 55 years, had been diagnosed with T1D for a minimum of one year at the time of inclusion. They were recruited from the Hospital Clinic de Barcelona and from Diabetes Association of Catalonia (ADC). The clinical characteristics and fitness capacity of individuals with T1D were compared with controls. Adults without any chronic diseases were recruited during the same period to provide a control group. These participants were family members and friends or colleagues from the hospital staff and local community, to whom a body composition and physical activity assessment were proposed. All participants in the study had no cardiorespiratory pathologies or osteo-muscular limitations that could impede the assessment of maximal physical activity.

2.2. Procedures

A cross-sectional observational study was conducted. All the participants that joined the study received both written and oral explanations about the procedures before providing their informed consent for participation. The study was approved by the Ethics and Research Committees of Hospital Clinic de Barcelona (CEIC register number 2009/4933). The study took place at the laboratory of Exercise and Diabetes of the IDIBAPS-Hospital Clinic (Barcelona).

2.2.1. Physical activity and performance capacity

The short form of the International Physical Activity Questionnaire (IPAQ-SF) was used to assess sedentary lifestyle and to classify participants as presenting vigorous, moderate, or low physical activity levels. The classification of low physical activity was considered sedentary lifestyle or sedentariness [20]. The IPAQ-SF records the physical activities carried out during the 7 days before the interview was conducted, detailing the type, intensity, and duration of each activity. According to ADA and WHO guidelines [13, 21], participants were classified as adherent or non-adherent if they completed or no more than 150 minutes a week of Moderate-to-Vigorous Physical Activity (MVPA).

To determine maximal aerobic capacity, participants performed a maximal incremental test on a cycle ergometer (Wattbike PRO, Nottingham, UK) measuring maximal work capacity (workload in Watts) and maximal oxygen consumption (VO_2max) by means of a gas collection system (Ergocard Pro, Medisoft, Sorinnes, Belgium). Also, maximal muscular strength capacity was measured by the one-repetition maximum test (1 RM test) in a leg press exercise (Salter SA, Spain).

2.2.2. Clinical and biochemical parameters

Participants with T1D were evaluated for peripheral neuropathy by symptoms, physical examination, and vibratory perception thresholds, using biothesiometry exploration [22]. Data on albuminuria and ophthalmological informs were assessed from medical registers. The presence of peripheral neuropathy, retinopathy, or albuminuria higher than 30 mg/24h, or any combination of three of them, was considered having diabetes complications. Participants with history of cardiovascular disease such as coronary heart disease, heart failure or stroke were excluded. Participants were asked about type of treatment, which included multiple daily insulin injections (MDI), continuous subcutaneous insulin infusion (CSII), or advanced hybrid closed loop systems (AHCL), as well as daily doses of insulin, that were adjusted relative to body weight (units/kg of body weight). Hypertension was defined as systolic blood pressure ≥ 140 mmHg and/or diastolic blood pressure ≥ 90 mmHg and/or in use of anti-hypertensive drugs. Dyslipidemia was defined as triglycerides ≥ 150 mg/dl and/or LDL-C ≥ 130 mg/dl and/or HDL-C <

50 mg/dl for women or < 40 mg/dl for men. The chronic use of statins was also a criterion for dyslipidemia [23]. Smoking habits were classified as never smoker or smoker in any time (current or former). Glycated hemoglobin (HbA1c) and lipid determinations were determined by standard protocols. Estimated glucose disposal rate (eGDR) was calculated as an indirect method to assess insulin resistance in individuals with T1D [24].

2.2.3. Anthropometric measurements

Weight, height, and waist circumference were measured in fasting, in light clothing, and without shoes. Total body, abdominal and visceral fat, and lean mass composition were measured by densitometry using DXA (Lunar iDXA body composition, GE Healthcare). A whole-body scan in the supine position was performed and data were analyzed using the Encore 2011 software.

2.2.4. Statistical Analysis

Descriptive data are presented as mean values and standard deviation (SD) for continuous variables and as percentages for categorical variables. The Student t-test was used to compare continuous variables, and Chi-square was used for categorical variables. Pearson tests were performed for variable correlations. ANCOVA test was performed when required, being the variables sex and age as covariate variables. Logistic regression analysis was used to examine the association of categorical and continuous independent variables with one dichotomous dependent variable. The level of significance was set at p-value < 0.05. The analyses were performed with the software SPSS Statistics, v 26 (IBM Inc) and the Statgraphics Centurion 18 (Statgraphics Technologies, Inc, USA).

3. Results

3.1. Analysis of the entire study including individuals with and without Type 1 Diabetes (T1D)

A total of 480 individuals were included in the study, comprising 232 individuals with T1D (48.3%). The detailed characteristics of each group are outlined in Table 1. The T1D group had a lower percentage of women compared to the control group (36.6 vs. 53.2%, p < 0.001), although both groups had similar mean ages (37.6 ± 12.4 years for T1D and 36.5 ± 10.6 years for controls). The duration of diabetes evolution among the T1D participants was 16 ± 10 years and the mean glycated hemoglobin (HbA1c) was 7.6 ± 1.2% (55 ± 15 mmol/mol). 83.2% percent were in use of MDI and 16.8% were in CSII; no one was in use of AHCL. In addition, 21.1% of the participants with T1D had at least one diabetes-related complication.

The participants with T1D exhibited a higher prevalence of dyslipidemia (23.8 % vs. 11.3%, p = 0.001) and hypertension (14.9% vs. 5.4%, p < 0.001), but had a lower prevalence of smokers compared to controls (26.5% of active or former smokers in T1D vs. 37.1% in controls, p = 0.045). Participants with T1D showed similar values of BMI (24.9 ± 3.8 vs. 24.3 ± 3.8 kg/m^2, p = 0.41) to controls, and there were no differences in other body composition parameters such as total fat, abdominal or visceral fat, or leg lean mass. There were also no differences in total cholesterol, HDL-C, LDL-C, or triglycerides between groups with and without T1D.

Considering that sex and age can significantly influence body composition and fitness results, these variables were included as covariates in the analysis, as detailed in the Statistical Analysis section (above). The prevalence of sedentariness, as per IPAQ criteria, was 27.3% in participants with T1D, similar to the control group (25.1%). Regarding adherence to at least 150 min per week of Moderate-to-Vigorous Physical Activity (MVPA), both groups exhibited similar percentages (53% for T1D and 53.2% for controls). Furthermore, there were no significant differences in total physical activity levels between T1D and controls (2202 ± 1839 vs. 2357 ± 2189 METs/min/week, respectively, $p = 0.132$). Despite all these similar rates of sedentariness, MVPA and PA levels, we observed lower levels of cardiorespiratory capacity (VO_2max: 29.15 ± 10.56 vs. 32.59 ± 11.54 ml O_2/kg/min, $p < 0.001$) and work capacity (2.73 ± 1.03 vs. 3.00 ± 1.00 W/kg, $p = 0.004$) in participants with T1D. Similarly, a reduced muscular strength capacity is observed, assessed through the 1RM test, among individuals with T1D compared to controls (2.29 ± 0.53 vs. 2.41 ± 0.79 kg/kg of body weight, $p = 0.01$) (see Table 1 and Figure 1). Supplementary table 1 provides detailed information on the weights of each covariate in the analysis. A further division of both groups by sex, as shown in Supplementary Table 2, revealed that both women and men exhibited lower VO_2max levels compared to their respective control counterparts. However, women with T1D presented similar work capacity and muscular strength capacity as control women.

3.2. Analysis of individuals with criteria of adherence to the physical activity guidelines

Participants adhering to the physical activity guidelines (≥ 150 min of Moderate-to-Vigorous Physical Activity [MVPA] per week) were separately analyzed with the intention to focus on those that are more physically active, categorized as adherents (Table 2). After adjusting for sex and age, individuals with T1D continued to exhibit reduced physical fitness capacity, displaying lower levels of VO_2max (33.5 ± 10.8 vs. 36.8 ± 11.3, $p = 0.002$), work capacity (3.2 ± 0.9 vs. 3.4 ± 0.8 W/kg, $p = 0.008$) and 1RM test performance (2.4 ± 0.5 vs. 2.7 ± 0.8 kg/kg body weight, $p = 0.008$) compared to controls. Moreover, adherent participants with T1D showed a higher prevalence of dyslipidemia (21.3 vs. 9 %, $p = 0.001$) and hypertension (13.1 vs 3.6 %, $p = 0.005$) compared to adherent controls. Smoking habits, body composition, and the profile of lipoproteins and lipids were similar in both groups. Supplementary Table 3 provides detailed information on the weights of each covariate in the analysis.

3.3. Analysis of individuals with T1D with adherence or not to physical activity guidelines

To better understand which variable could influence on the lower fitness levels in participants with T1D, the group was separated by adherence or not to physical activity guidelines (Table 3). The specific analysis of individuals with T1D shows that 53.1% of participants met the 150 min/week MVPA recommendation. The percentage of women was higher in the non-adherent (71.8 %) than in the adherent group (28.2 %, $p < 0.001$). Non-adherents were older (40.8 ± 12.1 vs. 35 ± 12 years, $p < 0.001$), but there was not a difference on the years of diabetes evolution (17.3 ± 10.5 vs. 14.9 ± 9.6 years, $p = 0.095$) than adherent participants. Non-adherents were not different for diagnostic of hypertension, dyslipidemia or smoking habits once compared to the adherents to guidelines, once adjusted for age and sex.

It was identified that there were no differences in glycated hemoglobin and insulin requirements, type of treatment (MDI vs. CSII), insulin resistance, measured by eGDR, or lipoprotein and lipids profile between adherent or not groups. Non-adherent participants had higher total body fat, abdominal and visceral fat ($p < 0.05$) and, as expected, lower VO_2max and work capacity than adherent ones ($p < 0.001$). Muscular strength was not different between groups. Age and sex were used as covariates in the covariate analysis. Supplementary Table 4 provides detailed information on the weights of each covariate in the analysis.

In figure 2 is shown a positive correlation of METs with VO_2max (fig 2A), with work capacity (fig 2B) and with 1RM (fig 2C) and a negative correlation of VO_2max with total body fat (fig 2D) in both controls and T1D groups. These correlations and others are also presented in

Supplementary Table 5 for T1D, and in Supplementary Table 6 for control group. Remarkably, in the participants with T1D, the variables BMI, abdominal fat, visceral fat, age and years of evolution with diabetes were negatively correlated with METs, VO_2max, work capacity and 1RM. Otherwise, legs lean mass correlated positively with METs, VO_2max, work capacity and 1RM. Values of HbA1c and eGDR did not correlate with total physical activity or physical fitness criteria. Control participants presented similar results as T1D group. As expected, total fat, abdominal fat and BMI were negatively correlated with METs, VO_2max, work capacity and 1RM, except for visceral fat, that was not associated with any physical fitness variable.

4. Discussion

The main contribution of this study lies in identifying that individuals with T1D exhibit lower physical fitness capacity than those without diabetes, despite maintaining similar levels of total physical activity and prevalence of sedentariness. Remarkably, these differences in cardiorespiratory and strength capacities persist even among individuals who meet adherence criteria for the physical activity recommendations.

It is well established that improving exercise capacity and cardiorespiratory fitness is an important goal in reducing cardiovascular events and mortality in the general population [8] and there is evidence that the same happens with people with T1D [9]. In groups of children and adolescents with T1D [25, 26], it has been observed that total PA levels are significantly lower compared with similar populations without diabetes, and these lower levels were associated with higher cardiovascular risk factors. However, the PA levels of adults with T1D have not been fully assessed. In our study, the prevalence of a sedentary lifestyle was about 27% in T1D and 25% in the control group, without differences in total levels of PA or adherence to physical activity guidelines. In a previous report with Spanish general population, the prevalence of sedentariness was higher than the present one, around 35% [27], nevertheless, the population of that study was older. Using accelerometers to access PA [14], it was recently reported that only 32% of their population with T1D fulfilled the physical activity recommendations, similar to the 31% described by Leroux and colleagues [28]. The use of accelerometers is an objective method, based on motion measurement and not on the subjective perception of each individual on their own physical activity. Accelerometers, however, have some limitations, especially in the interpretation of low-intensity physical activity or static activities, such as strength training or indoor cycling [29]. In order to understand the different prevalences of PA described in different studies, it is important to consider the different criteria that have been used for its measurement. In the present study, we used the IPAQ criteria, which indicates 27% of sedentary lifestyle in the group with T1D, at the same time that we used the ADA/WHO adherence to PA criteria, which indicates that 47% of the participants do not accomplish the recommendations.

Then, considering the current criteria for sedentary lifestyle and adherence to guidelines, our study shows that cardiorespiratory and strength performances are reduced in individuals with T1D when compared to controls counterparts. Similar data on VO_2max have been previously published on an adolescent population with T1D, despite the described group being less physical active [18]. Furthermore, Brazeau et al. described, in 75 adults with T1D and 75 healthy matched controls, lower levels of VO_2max in individuals with T1D in comparison to controls [17]. The results from our study are in the same line but add more information, as we included cardiorespiratory fitness and strength capacity. In our sample there was a gender bias inclusion for T1D. Although the sample size of our study was different in women and men, the statistical tests are valid for unbalanced designs. Also, as observed in other studies, percentage of women are lower than man with adherence to physical activity in part due to activity inequality [30, 31].

It is important to note the factors that could explain the differences in cardiorespiratory capacity. In an analysis of correlation, we identified that age and years of diabetes evolution have a negative correlation with fitness levels, as could be expected, and in agreement with other authors [32]. Because it is known that age is one of the major factors related to fitness capacity [32], our study adjusted this factor for both groups of participants, T1D and controls, minimizing this effect on VO_2max levels. Eckstein and cols. [18] found impaired maximal and submaximal VO_2 performances in individuals with a recent diagnosis of diabetes. Additionally, in long-term evolution of T1D, Heyman et al. have described alterations in microvascular perfusion that impair blood delivery to skeletal muscle and defects in mitochondria functionality, which would impair aerobic fitness capacity. In fact, these abnormalities were more frequent in those individuals with higher HbA1c levels or long-standing diabetes [33]. When we analyzed the fitness capacity separating by sex, we observed that VO_2max was reduced in T1D in both sexes in relation to controls. However, women with T1D presented similar workload capacity and muscular strength than control women. These differences between sexes suggest that women with T1D may be more resilient than men in these aspects despite the metabolic challenges posed by diabetes. Further studies are needed to stablish the impact of sex on work capacity and muscular strength capacity in T1D.

Notably, the degree of glycemic control has implications for achieving performance capacity, as lower cardiorespiratory fitness has been observed in people with T1D with insufficient control of diabetes [34]. In our study, however, we did not find associations between cardiorespiratory fitness and glycemic control that could explain this effect. One possible explanation could be that the current HbA1c value is not representative of the glycemic history of each participant. Nevertheless, the growing accumulation of data from continuous glucose monitoring systems (CGMS), which an increasing number of patients are having access to, would help us in the future years to understand the influence of glycemic control on cardiorespiratory fitness. Insulin resistance (IR) is a multifactorial condition observed in obesity and type 2 diabetes, coming from a complex interplay of environmental and genetic factors. Nevertheless, individuals with T1D also manifest different degrees of IR. Physical activity stands out as a significant environmental factor capable of enhancing insulin sensitivity [35,36]. The estimated glucose disposal rate (eGDR) serves as an indirect measure of IR and is derived from correlations with hyperinsulinemic-euglycemic clamps, specifically conducted to assess IR in patients with T1D [24]. In our study, we anticipated improvements in insulin resistance among individuals with T1D adherents to PA guidelines. However, we did not observe significant changes in eGDR values in either group, whether adherent to PA guidelines or not. This absence of change in eGDR suggests that the index may not be sufficiently sensitive to detect alterations in IR within the population with T1D from our study, particularly considering that clinical variables such as waist circumference, HbA1c levels, and hypertension status were similar between the two groups.

Related to cardiovascular risk factors, our data show a higher prevalence of dyslipidemia, hypertension and HbA1c levels above the control target, but higher presence of participants that never smoked in the participants with T1D. These values of HbA1c and prevalence of cardiovascular risk factors are maintained in the group with T1D that are adherent to guidelines. Our study showed that patients with T1D presented HbA1c of 7.6 ± 1.2 (55 ± 8.6 mmol/mol) and the prevalence of hypertension of 14.9%, dyslipidemia of 23.8% and active or former smoking habits of 26.1%. Previous reported data [37], based on the national registry from Catalonia including 15.008 individuals with T1D, showed slightly higher glycemic control (HbA1c 7.9% / 63 mmol/mol) and a higher prevalence of hypertension (23%), dyslipidemia (30%) and smoking habits. Unfortunately, this registry does not provide any data on physical activity to compare with our diabetes sample.

Regarding body composition, our analyses did not reveal significant differences in total, abdominal, or visceral fat between the T1D and the control groups. Notably, differences emerged only when examining participants with T1D according to their adherence to physical activity guidelines, where the more physically active group had the lower fat composition. These findings suggest that the presence of T1D alone does not appear to exert a substantial influence on body composition and, at the same time, our results indicate a correlation between elevated PA levels and lower body fat. This supports the importance of an active lifestyle in reducing fat accumulation in individuals with T1D. However, a recent review by Van der Schueren et al. [38] reported a higher prevalence of obesity in individuals with T1D. This could be attributed to factors such as the anabolic insulin effect and/or the higher intake of carbohydrates to manage or prevent hypoglycemic episodes [39]. In contrast, our study did not observe a similar effect either in sedentary people or in those who are more physically active.

The present study has some limitations. Inclusion of participants was done in an open method, as they were recruited from our reference hospital and from the regional association of patients with diabetes. Thus, the selection does not ensure a statistically representative distribution of all people with T1D but allows describing the characteristics of this specific population group from different origins of recruitment in the same city. In addition, the assessment of the levels of adherence to the physical activity guidelines was carried out by recording activities and not using an accelerometer. The activity records are subjective methods that can be influenced by the perception of each person, but in contrast, are usually easier to implement in large samples of participants.

In conclusion, individuals with T1D exhibit a diminished physical fitness capacity in comparison to a control population, regardless of age and sex, even when presenting similar levels of physical activity and adherence to guidelines. Understanding the implications of these findings is crucial to implement appropriate counseling and interventions. Further studies are needed with the aim to promote optimal cardiovascular health in individuals with T1D.

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Conflict of interest and funding

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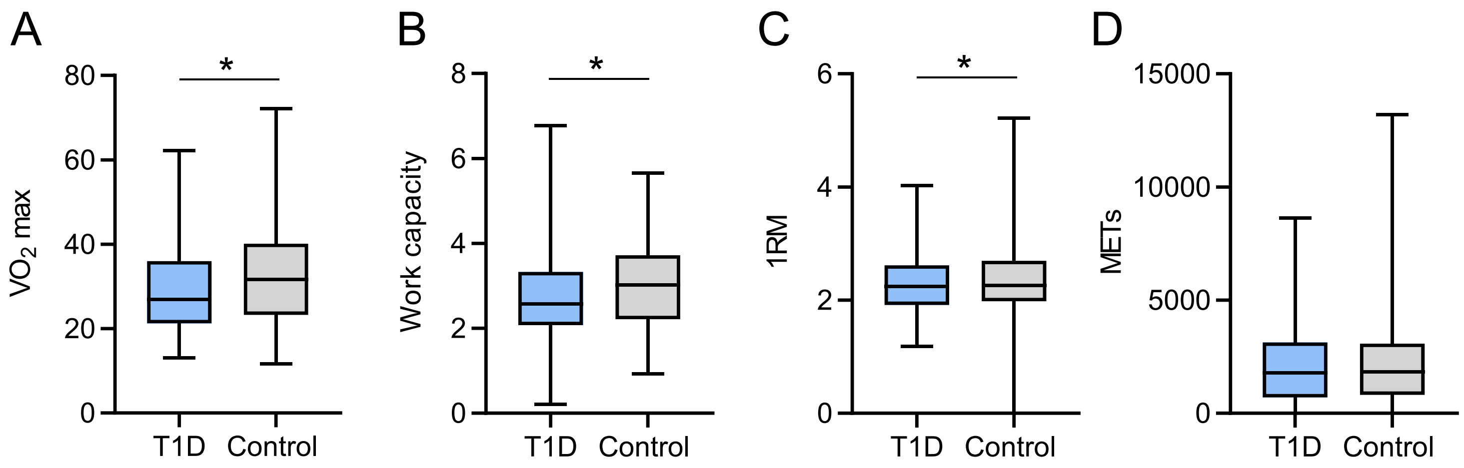
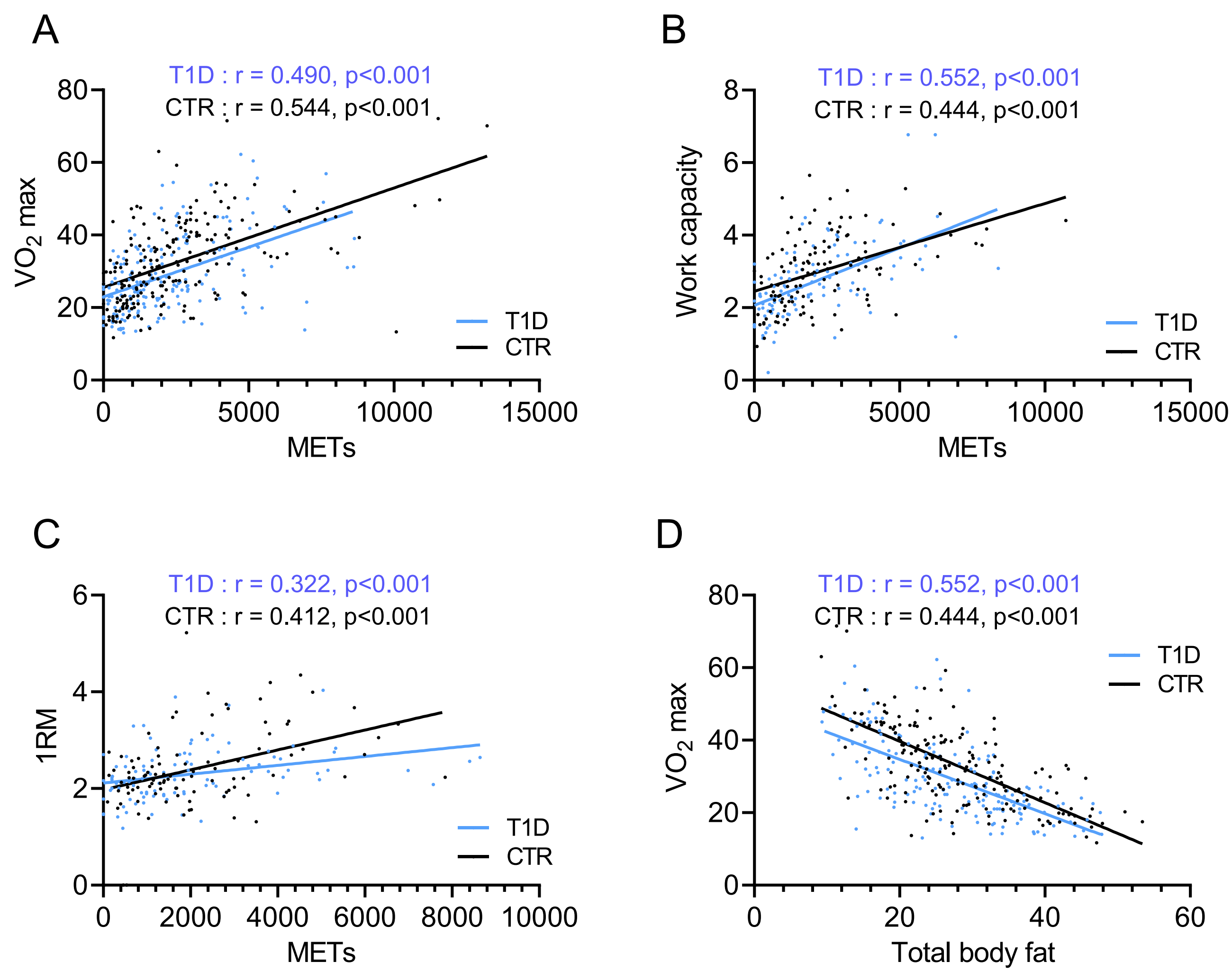
Figure legends 1 and 2

Fig. 1 | Physical fitness characteristics in individuals with T1D and controls. Box plots show the median (centerline), the second and third quartiles (the upper and lower bond of the box) and the whiskers represent minim and maxim values in the groups: T1D (blue), n=232, and controls (grey), n=248. A) Cardiorespiratory capacity - VO_2max values (mlO_2/kg/min), $p < 0.001$; B) Work capacity (maximal Watts/kg of body weight), p=0.004; C) 1RM in press legs (maximal weight lifted/kg of body weight), p=0.01; D) Total physical activity - METs (METs/min/week in IPAQ-short form), p=ns
* means statistically significant

Fig. 2 | Correlations of variables in the groups T1D (blue) and controls (black). A) Total physical activity - METs (METs/min/week in IPAQ-short form) and VO_2max (mlO_2/kg/min); B) Total physical activity - METs (METs/min/week in IPAQ-short form) and Work capacity (maximal Watts/kg of body weight); C) Total physical activity - METs (METs/min/week in IPAQ-short form) and 1RM in press legs (maximal weight lifted/kg of body weight); D) VO_2max (mlO_2/kg/min) and Total body fat (DXA, %)


A
B
C
D
VO2 max
Work capacity
1RM
METs
*
T1D
Control
0
20
40
60
80
2
4
6
8
5000
10000
15000


A
T1D : r = 0.490, p<0.001
CTR : r = 0.544, p<0.001
VO2 max
METs
T1D
CTR
B
T1D : r = 0.552, p<0.001
CTR : r = 0.444, p<0.001
Work capacity
METs
T1D
CTR
C
T1D : r = 0.322, p<0.001
CTR : r = 0.412, p<0.001
1RM
METs
T1D
CTR
D
T1D : r = 0.552, p<0.001
CTR : r = 0.444, p<0.001
VO2 max
Total body fat
T1D
CTR

People with type 1 diabetes exhibit lower exercise capacity compared to a control population with similar physical activity levels

Methods

Data collection

Observational cross-sectional study

Study population

232 T1D
- diabetes 16.0 ± 10.1 yr.
- HbA1c 7.6 ± 1.2 (55 ± 2.1)

248 controls

Inclusion criteria

Type 1 diabetes

Healthy controls

18 - 55 yr

Measures

Physical activity levels

Maximal exercise test

1 RM strength test

Key results

	Type 1 diabetes	Healthy controls	
Total physical activity levels	2202 ± 1839	2357 ± 2189	METs/min/week
Sedentariness	27.3	25.1	%
VO_2max	29.1 ± 10.5	32.5 ± 11.5*	mlO2/kg/min
Work capacity	2.73 ± 1.03	3.00 ± 1.00*	W/kg of body weight
Strength capacity (1RM)	2.29 ± 0.53	2.41 ± 0.79*	kg/kg of body weight

* Statistically significant

Table 1. Characteristics of all participants with T1D diabetes and controls

	Type 1 diabetes (n = 232)	Controls (n = 248)	p-value
Clinical characteristics			
Age (years)	37.6 ± 12.4	36.5 ± 10.6	ns
Women (n, %)	85 (36.6)	132 (53.2)	< 0.001
Diabetes evolution (years)	16.0 ± 10.1	-	-
Type of treatment: MDI (%) / CSII (%)	83.2 / 16.8	-	-
Diabetes-related complications (%)	21.1	-	-
Dyslipidemia (%) *	23.8	11.3	0.001
Hypertension (%) *	14.9	5.4	< 0.001
Active or former smoker (%) *	26.5	37.1	0.045
Body composition **			
Weight (kg)	73.9 ± 13.0	70.8 ± 13.6	ns
BMI (kg/m^2)	24.9 ± 3.8	24.3 ± 3.8	ns
Waist circumference (cm)	84.2 ± 11.6	81.4 ± 11.5	ns
Total fat, DXA (%)	27.6 ± 9.4	28.6 ± 9.5	ns
Abdominal fat, DXA (%)	30.9 ± 12.9	31.5 ± 12.7	ns
Visceral fat, DXA (g)	549 ± 574	487 ± 568	ns
Legs lean mass, DXA (kg)	17.4 ± 3.7	16.7 ± 4.0	ns
Laboratory analysis **			
HbA1c, % (mmol/mol)	7.6 ± 1.2 (55 ± 8.6)	-	
Total cholesterol (mg/dl)	182.4 ± 32.9	183.8 ± 49.9	ns
HDL-c (mg/dl)	57.7 ± 16.2	61.6 ± 12.2	ns
LDL-c (mg/dl)	109.8 ± 28.3	110.7 ± 54.4	ns
Triglycerides (mg/dl)	71.4 ± 31.6	70.2 ± 37.3	ns
Physical activity and fitness			
Sedentary lifestyle (IPAQ criteria) (%) *	27.3	25.1	ns
Adherent (≥150 min/week MVPA) (%) *	53.1	53.2	ns
Total physical activity (METs/min/week) **	2202 ± 1839	2357 ± 2189	ns
VO_2max (ml O_2/kg/min) **	29.1 ± 10.5	32.5 ± 11.5	<0.001
Work capacity (W/kg body weight) **	2.73 ± 1.03	3.00 ± 1.00	0.004
1RM press legs (kg /kg body weight) **	2.29 ± 0.53	2.41 ± 0.79	0.010

Adherent (≥150 min/week MVPA): accomplish the 150 min/week of recommended Moderate and/or Vigorous Physical Activity. ns: non significative

* Logistic regression, adjusted for age and sex.

** ANCOVA, adjusted for age as covariate variable and sex as factor variable

(See Suppl Table 1 for more data from Logistic regression and ANCOVA)

Table 2. Characteristics of participants with T1D and controls with criteria for adherence to ADA and WHO physical activity guidelines (≥150 min/week MVPA)

	Type 1 diabetes	Controls	p-value [a]
n/ % of the total group	123 (53.1)	132 (53.2)	0.518
Clinical characteristics			
Women (n, %)	24 (19.5)	54 (40.9)	<0.001
Age (years)	35.0 ± 12.0	34.1 ± 8.2	ns
Dyslipidemia (%) *	21.3	8.1	0.001
Hypertension (%) *	13.1	3.6	0.005
Active or former smoker (%) *	24.6	29.5	ns
Body composition **			
Weight (kg)	74.7 ± 10.5	71.8 ± 13.5	ns
BMI (kg/m^2)	24.6 ± 2.7	23.9 ± 3.3	ns
Waist circumference (cm)	83.6 ± 9.6	80.3 ± 10.2	ns
Total fat, DXA (%)	26.7 ± 8.6	24.8 ± 7.9	ns
Abdominal fat, DXA (%)	26.7 ± 12.6	27.4 ± 10.7	ns
Visceral fat, DXA (g)	471 ± 424	398 ± 410	ns
Legs lean mass, DXA (kg)	18.6 ± 3.2	17.9 ± 4.0	ns
Laboratory analysis**			
HbA1c, % (mmol/ml)	7.6 ± 1.2 (55 ± 2.1)	-	-
Total cholesterol (mg/dl)	176.2 ± 31.5	171.5 ± 42.6	ns
HDL-c (mg/dl)	55.3 ± 14.6	55.7 ± 14.6	ns
LDL-c (mg/dl)	106.7 ± 27.6	97.5 ± 38.8	ns
Triglycerides (mg/dl)	69 ± 28.3	91.5 ± 49.0	ns
Physical activity and fitness			
Sedentary lifestyle (IPAQ criteria) (%) *	6.5	2.3	ns
Total physical activity (METs/min/week) **	3299 ± 1716	3418 ± 2177	ns
VO_2max (ml O_2/kg/min) **	33.5 ± 10.8	36.8 ± 11.3	0.002
Work capacity (W/kg body weight) **	3.22 ± 0.99	3.41 ± 0.89	0.008
1RM press legs (kg /kg body weight) **	2.43 ± 0.50	2.70 ± 0.81	0.008

Adherent (≥150 min/week MVPA): accomplish the 150 min/week of recommended Moderate and/or Vigorous Physical Activity. ns: non significative

* Logistic regression, adjusted for age and sex.

** ANCOVA, adjusted for age as covariate variable and sex as factor variable

(See Suppl table 2 for more data from Logistic regression and ANCOVA)

Table 3. Characteristics of participants with type 1 diabetes according to adherence to ADA and WHO physical activity guidelines (≥150 min/week MVPA).

	Non-adherent (<150 min/week MVPA)	Adherent (≥150 min/week MVPA)	p-value
n (% of the group)	109 (46.9)	123 (53.1)	
Clinical characteristics			
Women (n, %)	61 (71.8)	24 (28.2)	< 0.001
Age (years)	40.8 ± 12.1	35.0 ± 12.0	< 0.001
Diabetes evolution (years)	17.3 ± 10.5	14.9 ± 9.6	ns
Type of treatment: MDI (n, %) / CSII (n, %)	92 (84.4) / 17 (15.6)	101 (82.1) / 22 (17.9)	ns
Diabetes-related complications (%) *	15.9	26.2	ns
Daily insulin requirements/kg (units/kg)	0.59 ± 0.22	0.58 ± 0.25	ns
eGDR	8.70 ± 3.16	8.78 ± 2.40	ns
Dyslipidemia (%) *	26.7	21.3	ns
Hypertension (%) *	17	13.1	ns
Active or former smoker (%) *	46.2	29.5	ns
Body composition **			
Weight (kg)	72.8 ± 15.5	74.7 ± 10.5	ns
BMI (kg/m^2)	25.3 ± 4.7	24.6 ± 2.7	ns
Waist circumference (cm)	85.1 ± 13.9	83.6 ± 9.6	ns
Total fat, DXA (%)	32.0 ± 8.1	26.7 ± 8.6	0.007
Abdominal fat, DXA (%)	35.4 ± 11.7	26.7 ± 12.6	0.026
Visceral fat, DXA (g)	631 ± 692	471 ± 424	0.005
Leg lean mass, DXA (kg)	16.0 ± 3.8	18.6 ± 3.2	ns
Laboratory analysis **			
HbA1c, % (mmol/mol)	7.7 ± 1.2 (61 ± 9.5)	7.6 ± 1.2 (60 ± 9.5)	ns
Total cholesterol (mg/dl)	189.6 ± 33.4	176.2 ± 31.5	ns
HDL-c (mg/dl)	60.6 ± 17.6	55.3 ± 14.6	ns
LDL-c (mg/dl)	113.4 ± 28.8	106.7 ± 27.6	ns
Triglycerides (mg/dl)	74.2 ± 35.0	69 ± 28.3	ns
Physical activity and fitness			
Sedentary lifestyle (IPAQ criteria) (%) *	51.9	6.5	< 0.001
Total physical activity (METs/min/week) *	893 ± 870	3299 ± 1716	< 0.001
VO_2max (ml O_2/kg/min) **	23.5 ± 6.9	33.5 ± 10.8	< 0.001
Work capacity (W/kg body weight) **	2.16 ± 0.74	3.22 ± 0.99	0.002
1RM press legs (kg /kg body weight) **	2.17 ± 0.53	2.43 ± 0.50	ns

Adherent (≥150 min/week MVPA): accomplish the 150 min/week of recommended Moderate and/or Vigorous Physical Activity. ns: non significative
* Logistic regression, adjusted for age and sex.
** ANCOVA, adjusted for age as covariate variable and sex as factor variable
(See Suppl table 3 for more data from Logistic regression and ANCOVA)

Supplementary Table 1: Characteristics of all participants with T1D diabetes and controls. Influence of sex and age on each variable in the ANCOVA and Logistic Regression analyzes.

ANCOVA	p-value	p-value for sex	p-value for age
Body composition			
Weight (kg)	ns	<0.001	0.018
BMI (kg/m^2)	ns	0.001	<0.001
Waist circumference (cm)	ns	<0.001	<0.001
Total fat, DXA (%)	ns	<0.001	<0.001
Abdominal fat, DXA (%)	ns	<0.001	<0.001
Visceral fat, DXA (g)	ns	<0.001	<0.001
Legs lean mass, DXA (kg)	ns	<0.001	0.001
Laboratory analysis			
Total cholesterol (mg/dl)	ns	ns	0.001
HDL-c (mg/dl)	ns	0.003	0.016
LDL-c (mg/dl)	ns	ns	0.031
Triglycerides (mg/dl)	ns	0.023	ns
Physical activity			
Total physical activity (METs/min/week)	ns	<0.001	<0.001
VO_2max (ml O_2/kg/min)	<0.001	<0.001	<0.001
Work capacity (W/kg body weight)	0.004	<0.001	<0.001
1RM press legs (kg /kg body weight)	0.010	<0.001	<0.001
LOGISTIC REGRESSION			
Dyslipidemia (%)	<0.001	<0.001	ns
Hypertension (%)	0.001	<0.001	ns
Active or former smoker (%)	0.045	<0.001	ns
Sedentary lifestyle (IPAQ criteria) (%)	ns	<0.001	ns
Adherent (≥150 min/week MVPA) (%)	ns	<0.001	ns

Supplementary Table 2. Characteristics of all participants with T1D diabetes and controls, separated by sex.

	Women			Men		
Clinical characteristics	Type 1 diabetes (n = 82)	Controls (n = 132)	p-value	Type 1 diabetes (n = 147)	Controls (n = 114)	p-value
Age (years)	38.03 ± 12.43	37.30 ± 11.19		37.50 ± 12.44	35.62 ± 9.96	
Diabetes evolution (years)	16.78 ± 11.02	-	-	15.61 ± 9.61	-	-
Type of treatment: MDI (%) / CSII (%)	77.6 / 22.4	-	-	86.4 / 13.6	-	-
Diabetes-related complications (%)		-	-		-	-
eGDR	10.43 ± 2.73	-	-	8.30 ± 2.62	-	-
Dyslipidemia (%) *	28.4	13.4	ns	21.1	8.7	0.019
Hypertension (%) *	13.8	5.4	ns	15.5	5.5	ns
Active or former smoker (%) *	33.3	38.9	ns	22.5	34.8	0.045
Body composition **						
BMI (kg/m^2)	24.45 ± 4.35	23.76 ± 4.32	ns	25.26 ± 3.49	25.05 ± 2.93	ns
Waist circumference (cm)	78.70 ± 10.98	77.56 ± 12.02	ns	86.86 ± 11.10	86.06 ± 0.09	ns
Total fat, DXA (%)	34.82 ± 6.96	34.15 ± 8.21	ns	23.10 ± 7.81	22.58 ± 6.74	ns
Abdominal fat, DXA (%)	35.65 ± 11.39	35.15 ± 13.35	ns	27.87 ± 13.01	27.59 ± 10.84	ns
Visceral fat, DXA (g)	349 ± 458	406 ± 632	ns	683 ± 607	578 ± 473	ns
Legs lean mass, DXA (kg)	13.73 ± 1.95	13.71 ± 2.18	ns	19.69 ± 2.62	20.14 ± 2.75	ns
Laboratory analysis **						
HbA1c, % (mmol/mol)	7.70 ± 1.17 (61 ± 9.2)	-		7.68 ± 1.29 (60 ± 10.0)	-	
Total cholesterol (mg/dl)	189.8 ± 31.6	184.8 ± 52.8	ns	178.8 ± 33.1	179.6 ± 45.3	ns
HDL-c (mg/dl)	67.25 ± 17.29	64.9 ± 11.62	ns	53.10 ± 13.49	50.66 ± 8.08	ns
LDL-c (mg/dl)	108.8 ± 28.4	101.5 ± 52.2	ns	110.3 ± 28.4	134.9 ± 60.4	ns
Triglycerides (mg/dl)	66.65 ± 25.06	61.91 ± 30.18	ns	73.80 ± 34.29	103.66 ± 51.69	ns
Physical activity and fitness						
Sedentary lifestyle (IPAQ criteria) (%) *	37.0	28.2	ns	21.9	21.6	ns
Adherent (≥150 min/week MVPA) (%) *	28.2	40.9	ns	67.3	67.2	ns
Total physical activity (METs/min/week) **	1599.2 ± 1862.1	1712.4 ± 1597.5	ns	2533.3 ± 1746.3	3071.1 ± 2517.8	ns
VO_2max (ml O_2/kg/min) **	23.20 ± 7.46	26.31 ± 7.96	0.015	32.30 ± 10.63	39.07 ± 11.10	<0.001
Work capacity (W/kg body weight) **	2.07 ± 0.53	2.46 ± 0.76	ns	3.08 ± 1.06	3.65 ± 0.87	0.011
1RM press legs (kg /kg body weight) **	2.07 ± 0.47	2.14 ± 0.59	ns	2.49 ± 0.50	2.94 ± 0.88	0.004

Adherent (≥150 min/week MVPA): accomplish the 150 min/week of recommended Moderate and/or Vigorous Physical Activity. ns: non significative

* Logistic regression, adjusted for age

** ANCOVA, adjusted for age as covariate variable

Supplementary Table 3. Characteristics of participants with T1D and controls with criteria for adherence to guidelines (≥150 min/week MVPA). Influence of sex and age on each variable in the ANCOVA and Logistic Regression analyzes.

ANCOVA	p-value	p-value for sex	p-value for age
Body composition			
Weight (kg)	ns	<0.001	ns
BMI (kg/m^2)	ns	0.010	ns
Waist circumference (cm)	ns	<0.001	0.001
Total fat, DXA (%)	ns	<0.001	0.041
Abdominal fat, DXA (%)	ns	<0.001	0.008
Visceral fat, DXA (g)	ns	<0.001	<0.001
Legs lean mass, DXA (kg)	ns	<0.001	0.003
Laboratory analysis			
Total cholesterol (mg/dl)	ns	0.130	0.031
HDL-c (mg/dl)	ns	0.037	ns
LDL-c (mg/dl)	ns	0.036	ns
Triglycerides (mg/dl)	ns	0.001	ns
Physical activity			
Total physical activity (METs/min/week)	ns	0.024	ns
VO_2max (ml O_2/kg/min)	0.002	<0.001	0.011
Work capacity (W/kg body weight)	0.008	<0.001	0.038
1RM press legs (kg /kg body weight)	0.008	<0.001	ns
LOGISTIC REGRESSION			
Dyslipidemia (%)	0.001	<0.001	ns
Hypertension (%)	0.005	<0.001	ns
Active or former smoker (%)	ns	<0.001	ns
Sedentary lifestyle (IPAQ criteria) (%)	ns	<0.001	ns

Supplementary Table 4. Characteristics of participants with type 1 diabetes according to adherence to physical activity guidelines. Influence of sex and age on each variable in the ANCOVA and Logistic Regression analyzes.

ANCOVA	p-value	p-value for sex	p-value for age
Clinical data			
Daily insulin requirements/kg (units/kg)	ns	0.011	0.019
eGDR	ns	<0.001	<0.001
Body composition			
Weight (kg)	ns	<0.001	ns
BMI (kg/m^2)	ns	ns	0.008
Waist circumference (cm)	ns	<0.001	<0.001
Total fat, DXA (%)	0.007	<0.001	0.001
Abdominal fat, DXA (%)	0.026	0.002	0.001
Visceral fat, DXA (g)	0.005	<0.001	<0.001
Legs lean mass, DXA (kg)	ns	<0.001	0.003
Laboratory analysis			
HbA1c (% and mmol/mol)	ns	ns	ns
Total cholesterol (mg/dl)	ns	ns	0.013
HDL-c (mg/dl)	ns	<0.001	0.006
LDL-c (mg/dl)	ns	ns	ns
Triglycerides (mg/dl)	ns	ns	ns
Physical activity			
Total physical activity (METs/min/week)	<0.001	ns	0.009
VO_2max (ml O_2/kg/min)	<0.001	<0.001	<0.001
Work capacity (W/kg body weight)	0.002	<0.001	<0.001
1RM press legs (kg /kg body weight)	ns	<0.001	0.001
LOGISTIC REGRESSION			
Diabetes-related complications (%)	ns	ns	<0.001
Dyslipidemia (%)	ns	ns	<0.001
Hypertension (%)	ns	ns	<0.001
Active or former smoker (%)	ns	ns	ns
Sedentary lifestyle (IPAQ criteria) (%)	<0.001	ns	ns

Supplementary Table 5: Correlations of physical activity and physical fitness characteristics with other clinical characteristics in participants with type 1 diabetes

		Total Physical Activity (METs)	VO_2max (ml O_2/kg/min)	Work capacity (Wmax/kg)	1RM press legs (kg /kg body weight)
Age (years)	r	-0.287**	-0.362**	-0.440**	-0.364**
	p	<0.001	<0.001	<0.001	<0.001
BMI (kg/m^2)	r	-0.136*	-0.185*	-0.317**	-0.170
	p	0.040	0.011	0.001	ns
Total fat, DXA (%)	r	-0.442**	-0.646**	-0.762**	-0.581**
	p	<0.001	<0.001	<0.001	<0.001
Abdominal fat, DXA (%)	r	-0.383**	-0.543**	-0.658**	-0.494**
	p	<0.001	<0.001	<0.001	<0.001
Visceral fat, DXA (g)	r	-0.190**	-0.195*	-0.360**	-0.216*
	p	0.010	0.016	0.001	0.047
legs lean mass, DXA (kg)	r	0.191**	0.423**	0.376**	0.337**
	p	0.007	<0.001	<0.001	0.001
Years evolution	r	-0.227**	-0.255**	-0.318**	-0.218*
	p	0.001	0.001	0.001	0.041
Daily insulin (U/kg)	r	-0.033	0.091	-0.016	0.276**
	p	ns	ns	ns	0.006
HbA1c (% and mmol/mol)	r	0.016	-0.147	-0.080	0.070
	p	ns	ns	ns	ns
eGDR	r	-0.011	0.014	0.013	-0.11
	p	ns	ns	ns	ns
Total Physical Activity (METs/min/week)	r	-	0.490	0.552	0.322
	p		<0.001	<0.001	0.001

Supplementary Table 6: Correlations of physical activity and physical fitness characteristics with other clinical characteristics in control participants

		Total Physical Activity (METs)	VO_2max (ml O_2/kg/min)	Work capacity (Wmax/kg)	1RM press legs (kg /kg body weight)
Age (years)	r	-0.381	-0.208	-0.185	-0.262
	p	0.036	0.003	0.044	0.008
BMI (kg/m^2)	r	0.037	-0.205	-0.312	-0.076
	p	ns	0.004	0.001	ns
Total fat, DXA (%)	r	-0.415	-0.668	-0.785	-0.627
	p	<0.001	<0.001	<0.001	<0.001
Abdominal fat, DXA (%)	r	-0.327	-0.538	-0.620	-0.472
	p	<0.001	<0.001	<0.001	<0.001
Visceral fat, DXA (g)	r	-0.049	-0.142	-0.079	-0.064
	p	ns	ns	ns	ns
legs lean mass, DXA (kg)	r	0.374	0.445	0.524	0.409
	p	<0.001	<0.001	<0.001	<0.001
Total Physical Activity (METs/min/week)	r	-	0.544	0.444	0.412
	p		<0.001	<0.001	<0.001