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Guidelines/Recommandations

Physical activity and type 2 diabetes. Recommendations of the SFD (Francophone Diabetes Society) diabetes and physical activity working group[☆]

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Abstract

Although regular physical activity is an integral part of T2D management, few diabetic patients have a sufficient level of physical activity. However over the past decade or so, the beneficial effects of regular physical activity have been well demonstrated, both in T2D prevention (50% reduction in the incidence of T2D in subjects with high metabolic risk) as well as T2D management for the improvement of glycaemic control (mean 0.7% improvement of HbA_{1c}) and the reduction of T2D-related comorbidities (improvement in blood pressure values and lipid profile, decrease in insulin resistance). Physical activity has both acute effects (effects of one exercise session) and more prolonged effects of exercise when it is repeated on a regular basis (training effect). In addition, the physical activity recommendations have been extended to a wide range of physical activities (by combining both endurance and muscle strengthening exercises), thus varying the physical activity practiced according to the patient's available time, practice sites, preferences and interests. Following a pathophysiology review, the effects of physical activity will be discussed and presented in terms of evidence-based medicine. The recommendations will be defined and practical prescribing information will be suggested, while taking into account that clinicians are concerned with answering questions regarding how, where and with whom: how can patients be motivated to practice a physical activity over the long-term? And how can qualified exercise trainers and appropriate practice settings be found?

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The latest recommendations from the Société Francophone du Diabète (SFD) on physical activity in type 2 diabetic patients

(T2D) conclude “that regular physical activity could delay the occurrence of diabetes in at-risk T2D subjects” and “that studies are needed to confirm a reduction in cardiovascular morbidity and mortality through regular physical exercise in the population of T2D patients” [1]. Several intervention studies have since demonstrated the role of regular physical activity in the prevention of T2D, as well as its beneficial effects on glycaemic control and comorbidities associated with T2D. For clinicians, the question no longer concerns the efficacy of physical activity but rather

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how, where and with whom: how can patients be motivated to practice a physical activity over the long-term? And how can qualified exercise trainers and appropriate practice settings be found?

1. Definitions and physiological review

1.1. Physical activity-physical inactivity-sedentary lifestyle

Physical activity is defined as “any bodily movement produced by the contraction of skeletal muscles, which results in energy expenditure that is greater than that at rest”. This means that physical activity is not limited to sports but also includes the physical activity of daily life associated with work, home, transportation and non-competitive leisure time [2].

Physical activity is usually quantified in terms of metabolic equivalents (MET), with one MET equal to the energy expenditure of a subject seated at rest. This is equivalent to an oxygen consumption of 3.5 ml per kilogram of body weight per minute (~ 1 kilocalorie/kg of body weight/hour).¹

1.2. Physical inactivity and sedentary behaviour

Over the last several years, a distinction has been made between physical inactivity and sedentary behaviour [3]. Sedentary behaviour refers to all behaviours in which the dominant position is seated or lying, and energy expenditure is very low or even non-existent. It includes various activities such as watching television or videos, working at the computer, reading, driving, etc.—activities in which the energy expenditure is around 1 to 1.5 METs [4]. The recent acceleration in availability of multiple types of screens (computer, television, cell phones, etc.) for all age ranges, at work, at school, at home and during spare time, partially explains the current interest in studying sedentary behaviour and its potential health consequences.

1.3. Acute effect of exercise on glucose metabolism (review in [5])

1.3.1. During exercise

Muscular exercise increases the muscle uptake of glucose in healthy subjects, as in type 2 diabetics. Muscle contraction stimulates the transport and metabolism of glucose in the involved muscles during exercise through non-insulin dependent pathways [6].

1.3.2. Post-exercise period

This is characterised by increased muscle sensitivity to insulin. An increase in glucose uptake in response to insulin is therefore seen for several hours after the exercise session has finished (regardless of the type of exercise, whether endurance or resistance exercise) in healthy subjects, as in T2D. There is also an increase in the glycogen storage capacity as a result of increased glycogen synthase activity. This phenomenon occurs only in the muscles involved in the exercise and partially depends on the level of glycogen depletion induced by the exercise [7].

1.4. Effects of training on glucose and lipid metabolism (review in [8,9])

Endurance training increases insulin sensitivity in subjects whether they are healthy, insulin-resistant, normoglycaemic or have T2D. These data were obtained both in cross-sectional studies (comparing inactive subjects to those doing endurance training) and intervention studies (in which subjects with a low activity level underwent training). Glucose uptake, which was measured using a hyperinsulinic euglycaemic clamp in the same subjects before and then after 6 weeks of endurance training, increased from 30 to 40%. This effect was seen 48 to 72 hours after the last exercise session, which thus ruled out an acute effect from the last bout of exercise performed.

Training (whether endurance and/or resistance) produces multiple effects on glucose metabolism: an increase in post-receptor insulin signalling, in the quantity of GLUT-4 (hence increased glucose transport), in the oxidative capacity of muscles, in the quantity of glucose and insulin delivered to the muscles through increased capillary density and NO-dependant vasodilatation, reduction in liver glucose production, and changes in muscle composition (increase in the proportion of type I oxidative fibres). In addition, resistance training specifically increases muscle mass and therefore the total capacity for glucose use.

Endurance training also increases the aerobic use of fatty acids during moderate intensity muscular exercise by increasing adipocyte lipolysis and muscle use of free fatty acids (by increasing the number of mitochondria and mitochondrial enzymes involved in beta oxidation).

1.5. Other effects of regular physical activity [2]

Exercise training results in cardiovascular and muscular adaptation (increases in oxidative capacity of skeletal muscle, in capillarisation and in muscular blood flow) [10].

2. Beneficial effects of regular physical activity

2.1. Physical activity and type 2 diabetes prevention

The five large intervention studies that have been published since the mid-1990s confirmed the benefits of lifestyle changes (physical activity and/or nutrition) in individuals at risk of developing T2D (impaired glucose tolerance). Methodologically, these intervention studies lasted at least 3 years, were

¹ Different intensities of physical activity are thus also defined:

Low intensity: less than three METs (less than three times the energy spent at rest); moderate intensity: three to six METs; high intensity: six to nine METs; very high intensity: more than nine METs. The recommendations for walking in terms of intensity are walking between three and five METs (brisk walking). The American recommendations for the general population are to practice aerobic physical activity at a total volume equal to 500 to 1000 MET minutes/week. Using the example of brisk walking (speed 5 km/h, intensity four METs), this amounts to 150 minutes per week for a total volume of 600 MET-min/week (150 min \times four METs) and 250 minutes per week for a total volume of 1000 MET-min/week (250 min \times four METs).

Table 1
Main characteristics of studies on the prevention of type 2 diabetes with physical activity.

Study	Number of subjects (age)	BMI (kg/m ²)	Inclusion criteria	Mean study duration (years)	Type of physical activity	Incidence of diabetes at the end of the study (RR reduction of DT2 in E vs. CT group)	Long-term cumulative incidence of T2D (group I vs. CT)
Pan et al. 1997 (Da Quing [China]) [11]	577 MW (45 ± 9 years)	26	IGT	6	Endurance	CT: 67.7 % E: 46 % (RR: –51 %)	At 20 years –43 %
Tuomilehto et al. 2001 (FDPS [Finland]) [12]	522 MW (40–64 years)	31	IGT	3.2	Endurance + resistance	CT: 23 % E: 11 % (RR: –58 %)	At 7 years –43%
Knowler et al. 2002 (DPPS [USA]) [13]	3224 MW (34 ± 6 years)	34	IGT	2.8	Endurance	CT: 19.8 % E: 14.3 % (RR: –58 %)	At 10 years –34%
Kosaka et al. 2005 (Japan) [15]	458 M (40–50 years)	24	IGT	4	Endurance	CT: 9.3 % E: 3 % (RR: –67.4 %)	
Ramachandran et al. 2006 (IDPP [India]) [14]	269 MW (46 ± 6 years)	26	IGT	3	Endurance	CT: 55 % E: 39.5% (RR: –28.2%)	

It should be noted that in all these studies (except for the study by DaQuing), the results are based on the combined efforts of physical activity and diet (usually balanced diet without weight loss). M: men, W: women, IGT: impaired glucose tolerance, CT: control group (advice only), E: exercise group, I: intervention group (overall lifestyle changes: diet + physical activity), RR: relative risk; FDPS: Finnish Diabetes Prevention Study, DPPS: Diabetes Prevention Program Study, IDPP: Indian Diabetes Prevention Program

randomised with a control group, and included a large number of subjects of various ethnic backgrounds (Table 1) [11–15]. They reported similar results, namely a 28 to 67% decrease of T2D incidence in subjects with impaired glucose tolerance after 3 to 6 years. These intervention studies thus convincingly confirmed (level I proof) that physical activity, as part of a lifestyle modification programme, is a major means of preventing T2D in subjects with high metabolic risk (impaired glucose tolerance).²

2.2. An effect of physical activity independent of diet

The focus of the five cited studies was the combined effect of dietary recommendations and physical activity (and often moderate weight loss). Only the Chinese study by Da Quing [11], one of the oldest, included an exercise group alone. The prevalence of T2D after 6 years decreased by 46% in the exercise group compared to the control group (vs. 42% in the diet plus exercise group and 31% in the diet group alone), which thus demonstrated the significant effect of physical activity per se. In order to explain these results, the Finnish Diabetes Prevention Study (DPS) extended the follow-up and management of the study cohort for one year. The subjects were re-evaluated after 4 years [16]. When all of the subjects were considered independent of the treatment group, the results showed that walking at least 2.5 hours per week reduced the risk of T2D by nearly 65%. This was independent of the effects of dietary advice or the baseline BMI and its changes during the follow-up period. This study also found that both moderate intensity physical activity and low intensity physical activity are beneficial, again independent of dietary intake or BMI. These data suggest that in these populations with high metabolic risk who are physically inactive and usually obese, the duration of physical activity and the total energy expended, i.e. the “volume” of physical activity, is more important than the intensity at which it is done.

2.3. What happens after the period of intensive coaching

In the five intervention studies, the mean duration of the intervention period was 3 to 4 years. The results of the follow-up at 7, 10 and 20 years in three of these studies have been published [17–19] (Table 1). Compared to the control group, the subjects of the intervention group had a 34 to 43% lower incidence of T2D over a cumulative period of 7 to 20 years. Therefore lifestyle change intervention for 3 to 6 years can prevent or delay the occurrence of T2D for at least 14 years after the active intervention period [18].

2.4. Obesity or physical inactivity and risk of type 2 diabetes?

The results of the intervention studies raise the question as to what is more predictive of T2D: obesity or physical inactivity? The independent association of obesity and physical activity was

studied on the population of the American Nurses' Health Study (68,907 women without history of diabetes, cardiovascular disease or cancer) over a 16-year period [20]. Multivariate analysis, which included the variables of age, smoking, and family history of T2D, showed that the risk of T2D progressively increases with the increase in BMI ($P < 0.001$), increase in waist circumference ($P < 0.001$) and decrease in normal physical activity ($P < 0.001$). Obesity and physical inactivity independently contribute to the development of T2D, but the significance of the risk related to obesity could be greater than that due to insufficient physical activity³. These results however show that the benefits of physical activity are not limited to normal-weight subjects, as obese subjects also benefit from a reduced risk of T2D when they partake of regular physical activity.

2.5. Ten hours of television per week and risk of type 2 diabetes

Independent of the level of physical activity, sedentary behaviour such as watching television is associated with a significantly higher risk of developing T2D and obesity [21]. In the Nurses' Health Study cohort, after adjusting for normal physical activity, each 2-hour period per day spent in front of the television during the follow-up increased the risk of obesity by 23% and T2D by 14%. Conversely, even low-intensity activities such as standing or walking around the house (which partially encompasses household chores) are associated with a lower risk of T2D: a 12% reduction for each 2-hour period per week. In this cohort, the authors estimate that 30% of new obesity cases and 43% of new T2D cases could be prevented with a more active lifestyle: less than 10 hours per week in front of the television and more than 30 minutes of brisk walking (or equivalent energy expenditure) per day. This positive relationship between time spent watching television and the incidence of T2D was also shown in male subjects from the Health Professionals Follow-up Study cohort.

There is therefore a continuum in the relationship between the level of physical activity and sedentary activity and the risk of T2D (and obesity): time spent in front of the television is associated with the highest risk of developing T2D and/or obesity, and this risk is reduced as the time spent performing low intensity activities increases (in increasing order of T2D risk reduction: standing then walking around the house or at work).

In conclusion, physical activity is an important means of T2D prevention, with a level I proof. This prevention should be developed as part of an overall approach of lifestyle changes, such as shown in intervention studies, including balanced diet, a limitation on sedentary activities (time spent sitting) and regular physical activity (grade A recommendations).

² The level of proof used is that defined by the HAS (French National Authority for Health).

³ In a joint analysis of the effects of BMI and physical activity, if women with normal weight and who regularly participate in physical activity (exercise ≥ 21.8 MET h/week) are used as a reference, the relative risk of T2D is 16.75 for obese women who do not participate in physical activity (exercise < 2.1 MET hr/week), 10.74 for obese women who regularly participate in physical activity, and 2.08 for thin women who do not have physical activity. For each level of BMI, greater physical activity is associated with lower risk of T2D development.

2.6. Effects of regular physical activity on glycaemic control of type 2 diabetics

Thomas et al. [22] published a meta-analysis on the effects of regular physical activity on glycaemic control in T2D. Fourteen randomised studies (377 subjects, mean age 60 years, intervention period between 8 weeks and 12 months) were analysed. Compared to the control group, the practice of regular physical activity significantly improved glycaemic control, with a mean decrease in the HbA_{1c} of 0.6% (95% confidence interval [CI]: −0.9 to −0.3; $P < 0.05$). It was a specific independent effect of physical activity, since it was the only factor that had varied amongst the groups studied. This effect was observed without variation in weight (therefore probably with an increase in lean mass, as was reported in a single study) but with reduction in visceral fat and subcutaneous adipose tissue. Finally, none of the studies reported complications related to diabetes in the exercise group (no hypoglycaemia was reported).

This meta-analysis therefore confirms with level I proof that physical activity in people with T2D significantly improves glycaemic control independent of variations in weight.

The most recent meta-analysis [23] made a distinction between supervised and structured exercise (endurance training or resistance training or a combination of both types) versus physical activity recommendations for daily life. Forty-seven randomised, controlled studies were analysed (8538 patients). The results showed that supervised and structured exercise programmes based on endurance training, resistance training or the combination of both resulted in a significant decrease in HbA_{1c} (−0.51% to −0.73%) compared to the control group (endurance: −0.73%, 95% CI: −1.06 to −0.40%; resistance training: −0.57%, 95% CI: −1.1 to −0.01%, and combination of both types of training: −0.51%, 95% CI: −0.79 to −0.23%). In addition, supervised and structured exercise of over 150 min/week was associated with a greater HbA_{1c} reduction (−0.89%) compared to 150 minutes or less per week (−0.36%). The physical activity recommendations were also associated with a significant decrease of the HbA_{1c} but only if the recommendations were combined with dietary advice (−0.43%, 95% CI: −0.59 to −0.28%). According to large prospective interventional studies that examined the effects of HbA_{1c} variation on the morbidity and mortality of T2D subjects, a mean reduction of HbA_{1c} of 0.6 to 0.8% in relation with regular physical activity should have beneficial effects on T2D mortality and morbidity. No meta-analysis to our knowledge has been published on this subject in T2D patients. However, these effects of physical activity on mortality and morbidity have been well demonstrated in the general population [2]. Some studies done in T2D patients also show that regular physical activity has a significant effect on cardiovascular mortality, lipid profile, blood pressure and the Framingham Risk Score (level II proof). This was the case in the Look AHEAD Study (*Action for health in diabetes*) [24], a randomised prospective study with the objective of determining the metabolic and cardiovascular benefits of intensive lifestyle intervention (nutrition and physical activity) in overweight or obese T2D patients. The follow-up was scheduled for 13.5 years. In the intensive group, the objective was a 7% decrease in weight

from baseline at 1 year, which was subsequently maintained, and at least 175 minutes per week of physical activity. Patients from the intensive group were followed every week for 6 months and then at longer intervals. The standard treatment was limited to three annual group sessions for dietary education and physical activity support. A total of 5145 patients were randomised: 2575 in the standard group and 2570 in the intensive group. The characteristics at inclusion were comparable in both groups (age: 58.7 years; BMI: 36 kg/m²; diabetes duration: 6.8 years; HbA_{1c}: 7.3%; 59.8% women). The results obtained after 4 years of follow-up in 93% of initially randomised patients showed that weight loss at 4 years was significantly greater in the intensive group than in the standard group (−4.7% vs. −1.1%, $P < 0.001$). The level of physical activity that had increased by 20.4% at 1 year in the intensive group remained stable at +5.4% at 4 years, versus a decrease of 1.1% in the standard group. The improvement in metabolic parameters remained significant at 4 years in the intensive group with regard to HbA_{1c}, HDL cholesterol and systolic blood pressure. The level of LDL cholesterol was lower in the standard group, with significantly more patients with LDL cholesterol values less than 1 g/l (64.5% vs. 61% in the intensive group, $P = 0.01$); this was due however to higher use of lipid-lowering agents. While the prescription of oral diabetes medications, insulin and antihypertensive agents was significantly decreased in the intensive group, a greater proportion of these patients attained the objective of an HbA_{1c} less than 7% (57.4% vs. 51.1% in the standard group, $P < 0.001$) and blood pressure lower than 130/80 mm Hg (62.9% vs. 60.5% in the standard group, $P = 0.09$). This study confirms the benefits of intensive lifestyle intervention (nutritional counselling and physical activity), both on weight loss and on the levels of certain cardiovascular risk factors (blood pressure, HDL cholesterol, HbA_{1c}), thus providing hope for possible cardiovascular protection.

3. Physical activity in presence of chronic complications of type 2 diabetes

3.1. Cardiovascular complications: can physical activity have harmful cardiovascular effects?

The prescription of physical activity in diabetics meets some reluctance for fear of causing an acute cardiac accident. This fear may be justified based on the following factors:

- diabetes is associated with increased cardiovascular risk. Cardiovascular diseases are the main cause of morbidity and mortality in type 2 diabetic subjects, including coronary artery disease (which is all the more serious since it can be silent) and myocardial injury, which results in cardiac failure [25,26];
- physical exercise increases sympathetic nervous system activity, while simultaneously decreasing vagal tone; as a result circulating catecholamines are secreted proportional to the intensity of the exercise. The consequences may be harmful and may explain the risk of ventricular arrhythmias or thrombotic accidents related to platelet activation, with subsequent myocardial infarction or sudden death.

Although this increased risk is present for high intensity exercises (>6 METs), it can be compensated for to a great extent in the medium- and long-term through regular training, which is the risk-protection paradox of exercise. In the study by Mittelman et al. [27], the risk of myocardial infarction during or after intense exercise greatly decreased proportional to the usual physical activity of the subjects. Compared to inactive subjects at rest (reference category), the relative risk during or after intense exercise increased to 107 in these same inactive subjects versus 19.4 in patients with one to two training sessions per week, and 2.4 when there were three to four training sessions [27]. With regard to cardiac rehabilitation, the multicentre registry developed by the Groupe Exercice Réadaptation Sport (Sport Rehabilitation Exercise Group [GERS]) of the Société Française de Cardiologie (French Cardiology Society) researched the occurrence of serious clinical events (death, infarction, cardiac arrest or any event requiring resuscitation) during or within one hour of exercise on over 25,000 rehabilitation patients at the centre under the required safety conditions. This risk was exceptional, being estimated at 0.74 per million exercise hours, and without any deaths [28]. Physical activity in fact had many cardiovascular benefits, which were associated with multiple physiological mechanisms (anti-ischaemic, anti-arrhythmic, and anti-thrombotic; effects on risk factors; and psychological effects). The benefits of physical activity in the prevention of coronary artery disease were independent, with an inverse and dose-dependent relationship. The epidemiological INTERHEART study [29], done in 52 countries and involving 29,000 people, found a strong correlation between nine factors that were studied and the risk of myocardial infarction. Six of those factors increased the risk (diabetes, hypertension, current smoking, increased ApoB/ApoA1 ratio, abdominal obesity and psychosocial stress), and three of them were protective factors, including regular intake of fruits and vegetables and regular physical activity (at a volume of 3 to 4 hours of moderate physical activity per week), which significantly decreased the risk of myocardial infarction by 28%. These factors had independent effects.

In conclusion, there are many arguments supporting beneficial cardiovascular effects of physical activity as primary and tertiary prevention in healthy subjects, such as with T2D.

In addition, cardiorespiratory fitness (determined during a maximal exercise test with the measurement of maximal oxygen consumption) is now recognised as a strong and independent predictive factor of mortality. Maximal oxygen consumption, which is an excellent individual indicator of exercise capacity, can be increased through physical activity. Any gain of one MET (3.5 ml/kg/min) of functional capacity resulted in a 12% reduction in mortality in healthy subjects, such as those with T2D, regardless of whether the subjects had cardiovascular disease or not [30].

3.2. Can physical activity have a harmful effect on retinopathy?

It is often thought that physical activity could lead to worsening of retinopathy through two mechanisms: intravitreal

haemorrhaging or retinal detachment. The American Diabetes Association therefore advises against even moderate practice of sports activities in cases of retinopathy, which risk resulting in increased pressure or producing similar effects as a Valsalva manoeuvre. The Valsalva manoeuvre can lead to a special form of retinopathy (called Valsalva), which presents as intraretinal or intravitreal haemorrhaging that is often premacular. Otherwise, even in cases of proliferative retinopathy, physical activity such as walking, swimming, and use of a stationary bicycle is authorised.

Given these data, the harmlessness of physical activity and sports, even if intensive, with regard to retinopathy must be stressed. For example, an American study showed the lack of association between worsening of retinopathy and practicing sports, even with intense sports such as weightlifting, and even in cases of severe diabetic retinopathy [31]. On the contrary, the practice of a great amount of physical activity is associated with a reduced risk of having diabetic proliferative retinopathy in women with diabetes [32].

In summary, although it is common sense that severe retinopathy be detected and treated before starting intensive sports, or that boxing not be recommended to patients with proliferative retinopathy at risk for bleeding, the existence of treated retinopathy should not discourage the practice of physical and sports activities.

3.3. Can physical activity have a harmful effect on nephropathy and microalbuminuria?

One session of exercise can temporarily increase microalbuminuria (due to the increase in blood pressure during exercise). This increase however is transitory, and exercise-induced microalbuminuria is not a predictive marker of permanent microalbuminuria in T2D [33]. To the contrary, epidemiological studies suggest an association between regular physical activity and improved renal function in diabetic patients. In addition, animal studies show that endurance training delays the progression of diabetic nephropathy [34]. In the event of renal failure, physical activity in the form of muscle strengthening helps to fight against sarcopenia. In patients on dialysis, regular exercise improves muscle oxidative capacity, quality of life, blood pressure control, lipid profile, arterial rigidity, insulin sensitivity, markers of inflammation and anaemia [35].

All in all, the presence of nephropathy is not a contraindication for practicing physical activity. It may be easier after treatment of anaemia with erythropoietin. It is also important to ask patients in whom abnormal microalbuminuria is found whether they had performed intense physical activity the day before the sample was taken.

3.4. Can physical activity have a harmful effect on neuropathy?

Physical activity has a beneficial effect, which is demonstrated in the prevention of diabetic neuropathy. For example, in a randomised study of 78 patients with type 1 or type 2 diabetes, it was observed that 4 hours of brisk walking per week

on a treadmill over a 4-year period reduced the occurrence of sensorimotor neuropathy [36].

The effects of the variability of physical activity level on the occurrence of perforating ulcer of the foot could also be seen in 100 patients with neuropathy or foot deformities, and in whom a pedometer was used to monitor physical activity for an average of 37 weeks [37]. Activity was overall lower in patients who presented with a perforating ulcer of the foot during follow-up. Most importantly, their activity was more varied, particularly in patients who had this complication within the preceding 2 weeks.

With regard to diabetic neuropathy, a recent article studied 33 subjects with this condition who were divided into four groups [38]: neuropathy without complications, presence of a perforating ulcer of the foot, history of amputation of the forefoot, and history of leg amputation. It showed in particular that the maximum pressure observed in the opposite foot increased in cases with perforating ulcer of the foot, leading to the conclusion that protection is necessary not only for the damaged foot but the opposite one as well.

In conclusion, the presence of degenerative complications of diabetes is not a contraindication to the practice of regular physical activity. The potential aggravating effects of physical activity on existing complications are mostly counterbalanced by the beneficial effects.

4. Physical activity recommendations

4.1. General population

Knowledge about the relationship between the quantity of physical activity (the “dose”) and its health consequences (the “response”) are at the basis of physical activity recommendations for the general population. There is currently a large amount of data showing that levels of at least moderate usual physical activity already provide substantial health benefits. In particular, the most important advantage is obtained in inactive subjects who become at least moderately active; additional benefits, which are obtained when the level of practice increases in subjects that are already at least moderately active, have been demonstrated but could be of lower magnitude. For very high levels of physical activity, the potential benefits should also be weighed against the possible risks of intensive practice.

The current public health recommendation for physical activity in adults (up to age 65 years) is the practice of an endurance physical activity (aerobic) of at least moderate intensity (such as brisk walking) from 150 to 300 minutes per week, or the practice of an endurance physical activity (aerobic) of higher intensity from 75 to 150 minutes per week. A combination of moderate and high intensity endurance activities can also be used to reach the recommended level (or volume). Using the concept of MET, the goal should be about 500 to 1000 MET minutes per week through a combination of moderate intensity and high intensity activity. For an adult, reaching the objective of 500 MET minutes per week is equivalent to brisk walking (4.8 km/h) for 150 minutes per week or running (10.5 km/h) for 50 minutes per week. From an integrative perspective, practicing

high intensity activities is a complementary step, or can be a later step, in an individual’s progression for attaining or exceeding the minimum recommended level. The practice of two weekly, non-consecutive sessions of resistance activity (muscle strengthening activity) is also recommended, through the implementation of eight to 10 exercises that use the major muscle groups (with eight to 12 repetitions for each exercise) [39].

The recommended activities are both daily activities (subject to sufficient intensity and duration, e.g. walking, provided that it is done at a brisk pace and for at least 10 consecutive minutes) and more structured exercises, e.g. fitness club, obviously including sports activities. As regular physical activity increases, there must be a simultaneous decrease in time spent at sedentary behaviour, starting with a reduction in time spent in front of a screen (television/video, computer), or more generally, time spent sitting.

4.2. Type 2 diabetes patients

Three basic principles should be encouraged and implemented together.

4.2.1. Combating sedentary behaviour

The objective is to decrease the time spent at sedentary activities from 1 to 2 hours per day, so that gradually the total time spent sedentary (between getting up and going to bed) is less than 7 hours per day.

The quality of this sedentary time should also be modified by “splitting up” the sedentary time (for example, time spent sitting at a desk or behind the computer), with breaks of at least one minute. During the break, subjects change from the seated or lying position to the standing position using what is considered to be low intensity physical activity [40].

4.2.2. Increasing physical activity in daily life

Type 2 diabetic patients are encouraged to increase their daily physical activity (so-called unstructured activities) by walking more and using stairs instead of elevators or escalators.

4.2.3. Practicing structured physical and/or sports activities

Current recommendations concerning type 2 diabetic patients are focused on improving glycaemic balance, weight maintenance, and reducing cardiovascular risk [41]. They combine:

- endurance exercises:
 - frequency: at least 3 days/week with a maximum of two consecutive days without physical activity,
 - intensity: at least moderate, being equivalent to 40–60% VO₂ max,
 - duration: a minimum of 150 minutes per week of moderate intensity activity, done in sessions of at least 10 minutes, spread out during at least 3 days during the week;
- strength training (muscle strengthening):
 - frequency: at least two times per week, on non-consecutive days,

- moderate intensity: 50% of one repetition maximum [1 RM]) to high intensity (75–80% of one RM),
- duration: each session should include a minimum of five to 10 exercises involving the main muscle groups with 10–15 repetitions each until fatigue occurs, with progression over time to higher loads lifted eight to 10 times (= one series),
- series: three series of eight to 10 repetitions per exercise.

In all cases, a very progressive approach is recommended to avoid the risk of accidents and to increase compliance. The importance of an initial period of supervised exercise, possibly with the expertise of a qualified sports medicine instructor or trainer, is emphasised. In addition, flexibility exercises can be added.

5. Aid for the prescription of physical activity

Practitioners have several tools available that can be used to help prescribe an appropriate physical activity [42].

5.1. Evaluation of the level of physical activity

The recorded parameters depend on the evaluation method used, and usually only partially reflect the level of physical activity.

The measurement of energy expenditure through the indirect calorimetric method and the doubly labelled water method, which is often used as a reference, only enable quantification in terms of energy and not in terms of normal physical activity.

The log or journal method of physical activity, analogous to that of a food log, is the reporting by the subjects themselves of their activities in a logbook at regular intervals. The use of this type of logbook is useful in practice and allows patients to perform a self-evaluation during follow-up. Questionnaires are the most common evaluation method of physical activity. To translate physical activity into energy expenditure, there are MET value tables that indicate the approximate energy cost of many daily and sport activities [43]. In the clinical setting, simple questions derived from the main available questionnaires enable patients' normal physical activity to be systematically assessed in several minutes according to context (professional, leisure time, sports, transport, as well as sedentary occupations) (Table 2). Otherwise, it would be misleading to try and change physical activity habits without some available information on the patients' living conditions: neighbourhood of residence; urban area; suburban or rural; climatic conditions; type of housing (house, apartment block); and nearby available services, facilities, open spaces and transportation infrastructure.

Pedometers, which are the simplest and most useful motion counters, measure the number of steps taken when walking or running. After measuring the length of the subject's normal stride, the result can be converted into the distance covered. Pedometers cannot be used to assess the intensity of the movement nor the energy expenditure related to the activity. The subjects themselves can use the pedometer for self-evaluation of their ambulatory activity, which can help in setting realistic objectives and evaluating whether they have been reached.

Table 2

Questions for evaluating the usual level of physical activity in the clinical setting.

Type of activity	Note
Professional	Primary occupation, weekly work time Approximate intensity of professional physical activity (low, moderate, high), as well as the duration and frequency
Domestic	Time spent sitting, standing, or carrying loads (light, medium, heavy). Activities done at home (e.g. home maintenance, etc.) Approximate intensity of domestic physical activity (low, moderate, high), as well as the duration and frequency
Leisure time and sports	Current and past activities by identifying walking activity done during the leisure time For each activity How long it has been practiced Approximate intensity (low, moderate, high) Duration of each activity session Frequency of practice (e.g. in the past year)
Transport, travel	Usual travel time (hours per day) Method of "active" travel (walking, biking, etc.)
Sedentary occupations	Time spent in front of a screen (TV/video/computer) (hours per day) At work Outside of work Time spent in sitting position (hours per day)

A recent meta-analysis showed a difference of more than 2000 steps per day on average by comparing the groups in the intervention studies that wore a pedometer to the groups without the instrument [44].

Accelerometers are more sophisticated motion counters, which are currently used mainly in research. The measurement of the acceleration-deceleration signal is used to obtain an estimation of movement and its intensity in everyday life. Individual profiles of physical activity and sedentary lifestyle can be defined.

Heart rate monitoring is based on the existence of a linear relationship between heart rate and oxygen consumption in persons undergoing exercise of gradual increased intensity. The method is particularly useful as part of a training programme with precise follow-up objectives in terms of target heart rate (for cases of coronary artery disease with stable chronic angina). In less active subjects, heart rate may be increased without relationship to physical activity in some circumstances (stress, high external temperature, etc.).

Recent technological developments have enabled the creation of devices that combine several methods such as the accelerometer, the heart rate monitor, and even GPS. Due to their high costs, these tools are currently used for research only.

5.2. Usefulness of exercise stress test

In addition to its role in the evaluation of myocardial ischaemia risk (see recommendations of the Société Française de Cardiologie and the SFD-ALFEDIAM [45,46]), the cardiopulmonary exercise test is used as a very precise assessment of the different stages of adaptative responses to exercise (respiratory,

cardiovascular and muscular) and to determine the maximal and sub-maximal physical capacity. Besides the invaluable diagnostic and prognostic information that it provides, cardiopulmonary exercise testing can be used to make an appropriate prescription for sports and physical activity, follow-up and readjustment of recommendations, as well as treatment adjustment (antihypertensive medication in particular).

As an aid to prescribing appropriate physical activity, stress testing can be used to determine three simple “reference points” to be explained to patients and that are useful in practice: (1) the dyspnea threshold, according to a 0 to 10 analogue scale, with “respiratory ease” as the recommended objective; (2) perceived intensity of the exertion according to the Borg scale: muscularly, the exertion should feel “a little difficult” (level 12 to 14); and (3) the training heart rate (THR). In practice, this is usually determined by the following formula: $THR = \text{resting heart rate (HR)} + K (\text{max HR} - \text{resting HR})$, in which K is 0.6. In order not to underestimate the THR in patients taking beta-blockers, the coefficient should be 0.8 [28]. If there is an ischaemic or rhythmic threshold, a THR that is 10 beats lower than this heart rate “threshold” is recommended.⁴

Walk testing can also be useful. The walking distance measured in 6 minutes (6-minute walk test) is a good indication of sub-maximal endurance capacities. It provides an estimation of tolerance to everyday activities and can be used to objectify the improvement of patients’ functional capacities.

5.3. Practice of physical activity: evaluation of promoting factors, obstacles and motivation

Awareness of the obstacles and promoting factors is the basis of educational assessment concerning physical activity support (see [42] for a review).

With regard to the obstacles, the caregiver must allow the patient to express these through the intermediary of the motivational interview [47]. An investigation is made for internal factors (feeling of permanent fatigue, fear of not obtaining concrete benefits, having no desire to show his/her body, being afraid of getting hurt, being afraid of others looking at them, not liking physical activity in general, having never done sports in his/her life, not feeling capable, lacking self-confidence, fear of hypoglycaemia, not feeling on the same level as others, etc.), lack of social support, obstacles with regard to health state (other co-morbidities such as arthrosis, respiratory insufficiency) and structural or institutional factors (means of transportation, financial means, lack of free time).

With regard to promoting factors, the focus is on internal factors (discovering new physical activities, discovering

pleasurable sensations when practicing certain activities, effects of physical activity on glycaemia, obtaining health benefits), institutional factors (swimming pool or walking routes near home, free time during the day, etc.) and reinforcement factors (diabetic associations that offer physical activity, significant others motivated to offer support for doing the physical activity, attitudes and behaviours of health personnel and others).

The doctor remains the primary source of information for patients regarding lifestyle changes (nutrition and physical activity). Barriers to the practice of physical activity that are detected by doctors in their patients, as well as the level of physical activity of the doctors, are correlated to the level of physical activity of their diabetic patients [48].

5.4. Places where physical activity can be practiced and relevant skills needed

5.4.1. Diabetes networks, sporting federations and associations

Physical activity is not easy to implement for many people with diabetes. It requires particular expertise that physiotherapists and professionals in adaptive physical activity (who have enriched their initial training with additional training in therapeutic education of the patient and pathology education) have acquired.⁵

This support will be temporary when beginning the physical activity, with subsequent help, for example, from associations or groups that will enable them to practice over the long-term.⁶

5.4.2. Possibility of occasionally enlisting cardiovascular rehabilitation organisations

Rehabilitation is directed at diabetic patients with cardiovascular disease in accordance with the indications but also, within the scope of primary prevention, at patients with high cardiovascular risk, particularly when behavioural modifications (food, smoking cessation and practice of regular physical activities) are difficult to achieve without support (the prescription of physical activity is fully integrated in the overall management of risk factors). Outpatient management is the rule in this class I, grade A indication [49].

In conclusion, strategies combining supervised management of physical activity in groups and with help (social, familial, patient associations, diabetes networks, etc.) with acquisition of necessary skills for improving health state and diabetes

⁴ Note: In practice, many T2D patients cannot perform a meaningful exercise stress test, i.e. “maximal” (maximal frequency equal to at least 85% of the maximum heart rate [MHR]) due to their deconditioning. In this case it is recommended that patients be encouraged to move more, to start walking again little by little and to wait until they have a “minimum” of physical conditioning before evaluating them again. Emphasis should be given to teaching patients to breathe properly during the exercise, which is an essential step, and can sometimes considerably improve exercise tolerance and therefore help to break the vicious circle of physical deconditioning.

⁵ In France, they practice primarily in the Diabetes Networks (<http://www.ancred.fr/les-reseaux.html>) or other networks (UNRS: <http://www.unrsante.fr/membres-adherents.html>) and in hospitals.

⁶ In France, the Association Française des Diabétiques (AFD) (<http://www.afd.asso.fr/AFDquisommesnous/AssociationsFédérées/tabid/108/Default.aspx>), Union Sports & Diabète (<http://www.usd.asso.fr>), and Collectif Interassociatif Sur la Santé (<http://www.leciss.org/>). Some sport federations for adults now offer physical activities that are adapted for chronic diseases: Fédération Française d’Athlétisme, de Randonnée Pédestre, de Natation, etc. This is also the case for multisport federations such as EPMM (Entraînement physique dans le monde moderne), Sport pour tous (<http://www.sportpourtous.org/index.php>) and FFEPPV (Fédération Française d’Education Physique et Gymnastique Volontaire) (<http://www.sport-sante.fr/accueil/>).

management in particular (importance of therapeutic education) seem to be the best guarantee for adopting and maintaining regular physical activity (grade B level of evidence).

6. Prescription and monitoring of physical activity in type 2 diabetes patients

6.1. Cases in which an assessment is necessary before physical activity in type 2 diabetes patients

For subjects who wish to participate in low intensity physical activities such as walking, the clinician must decide whether additional tests besides those already done need to be added to the diabetes assessment. As a general rule, the prescription of regular physical activity does not change the monitoring schedule of diabetes (check for metabolic control, investigations for degenerative complications).

If the patient wishes to begin a high intensity physical activity however, there may be an indication for performing an exercise stress test. This is also indicated in patients who potentially have a very high ischaemic risk, such as those with a long duration of exposure to diabetes and who present with multiple associated and poorly controlled risk factors [45,46]. The joint Société Française de Cardiologie/ALFEDIAM recommendations call for screening of silent ischaemia in the following patient categories:

- T2D starting from age 60 years, or when the diabetes has been diagnosed for 10 or more years and the patient has at least two traditional cardiovascular risk factors;
- T2D in patients over age of 45 years who want to take up physical activity again;
- T2D regardless of age and risk factors, whenever there is lower limb arteriopathy and/or carotid atheroma and/or a history of cerebrovascular accident;
- T2D regardless of age and risk factors, whenever there is proteinuria or renal failure;
- T2D regardless of age and risk factors, whenever there are at least two risk factors and microalbuminuria.

6.2. Drug interactions and physical activity

Sulfonylureas are capable of inducing hypoglycaemia during exercise of long duration (> 60 min) in well-controlled patients. In these particular cases (well-controlled patients who practice regular physical activity), a dose adjustment may sometimes be necessary, with a dose reduction (or even discontinuation) of the sulfonylurea before the exercise. It is especially important that the glycaemia is monitored at the beginning and at the end of the exercise (and that a snack with 20 g of carbohydrates be added if the glycaemia during or at the end of exercise is less than 0.80 g/l).

The hypoglycaemic risk relative to the use of glinides might be lower than that with the sulfonylureas, since these drugs have a more rapid and shorter effect than the sulfonylureas, as well as less glucose-lowering effect. Nevertheless, due to the lack of objective data, caution is warranted, and it is therefore advisable

to reduce the dose before exercising. Nonetheless, the only study to our knowledge that researched whether glinides could induce hypoglycaemia in patients with T2D during 60 minutes of moderate intensity muscular exercise, the use of glinides did not result in hypoglycaemia at the end of the session or in the evening [50].

Reduction in the dose of biguanides, acarbose and so-called “incretin” drugs (GLP-1 agonists and DPP-4 inhibitors) is not necessary, since these drugs do not carry the risk of inducing hypoglycaemia.

In addition it is also possible that oral antidiabetic medications may be need to be reduced after some time, once the training has become effective on the metabolic control [24].

Finally, for patients receiving insulin treatment, the recommendations given to insulin-dependent diabetic patients for reducing insulin doses are applicable. The choice and dosage of beta-blockers (the major indication of which is stable chronic angina) should be adapted in order to avoid significant exercise limitation. With regard to the risk of masking the signs of hypoglycaemia during prolonged exercise, it is especially important to intensify glycaemic monitoring in these patients.

7. In practice: prescription, monitoring, healthcare collaboration

7.1. Prescription of physical activity must be in accordance with the following rules

It is worth reiterating that type 2 diabetics are usually obese and physically inactive. Therefore physical activity must begin gradually using a personalised approach.

Type of activity: the most suitable prescription will combine endurance exercises (walking, cycling, swimming) and resistance exercises (strength training).

For strength training, free weights are not essential: a water bottle (250 ml = 250 g, etc.) can be used.

Intensity: for endurance exercises, the focus should be on exercise of moderate intensity (40 to 60% VO_2 max or 3–6 METs) and of long duration (≥ 30 minutes). Intense exercise ($> 60\%$ VO_2 max or > 6 METs, which is a level of exercise that makes the patient sweat and causes heavy breathing) can be planned to be done alone or in combination with moderate intensity endurance activity. The duration of physical activity can then be reduced (three 20-minute sessions at high intensity vs. five 30-minute sessions at moderate intensity).

Exercise duration: the objective is to achieve a minimum duration of 150 minutes per week (in three to seven sessions) using moderate intensity physical activity, or 90 minutes per week (in three sessions) for higher intensity physical activity. Each session, particularly for moderate intensity physical activity, can be divided into 10-minute fractions.

The minimal recommended frequency is three exercise sessions per week, with no more than two consecutive days without physical activity.⁷

⁷ The efficacy of endurance training on glycaemic control is specific to each exercise session, which emphasises the need to repeat sessions close to each

The diversity of physical activities, lack of monotony, and an aspect of fun promote long-term compliance.

7.2. Monitoring

Metabolic monitoring: this is indicated at the start of the practice, for educational purposes, so that patients can become aware of the effects of physical activity on their blood sugar levels. Self-monitoring of glycaemia (before and after exercise) is also recommended for type 2 diabetics at risk of hypoglycaemia (treatment with sulfonylureas, glinides and/or insulin) when they commit to physical activity, especially during the initiation period or when undertaking activity requiring unusual and/or prolonged effort. Consequently, when diabetics know their glycaemic responses to a given type of exercise, self-monitoring can be reduced when this type of exercise is performed.

The use of a logbook is recommended for recording the duration of sessions and especially the results of glycaemic self-monitoring before and after exercise. There are major benefits of recording these results: patients are able to adjust their doses of anti-diabetic medication with help from a diabetologist, and especially, this glycaemic self-monitoring demonstrates to the patient the beneficial effects of muscle activity on blood glucose levels.

It is important to emphasise that the post-prandial period is the best time to make use of the potential glucose-lowering effect of endurance exercise [51,52].

Other monitoring factors:

- careful examination of the feet before and after exercise (peripheral neuropathy);
- adequate equipment (in particular, footwear adapted to the practiced sport).

7.3. Partnerships/health-related institutions

Partnerships with health-related institutions (clubs, federations, associations) that have programmes and activities adapted to the issues of T2D patients are essential for the maintenance of physical activity behavioural changes and their long-term inclusion in patients' daily lives. The establishment of regular contacts between health professionals and organisers of these institutions is vital and aims to raise awareness and train organisers and to discuss management objectives. These partnerships are ideally springboards for resuming an activity, giving back confidence and initiating change.

8. Conclusion

Physical activity plays a major role in the prevention of T2D in at-risk subjects and in the management of T2D patients. The effects of physical activity go beyond the framework of

insulin resistance and help to obtain better glycaemic control, since they are also involved in controlling lipids, blood pressure, co-morbidities associated with T2D, cardiovascular risk and mortality, while improving the quality of life. A number of positive effects of physical activity on health status can be obtained in the absence of weight changes. The positive effects of exercise however are limited over time, which highlights the importance of the regularity of physical activity in this context and its long-term maintenance. The sustainability of an active lifestyle in T2D patients requires not only cooperation between different health professionals but also the establishment of partnerships in cities with those involved in physical and sports activities.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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other. The positive metabolic effects of muscular exercise (increased insulin sensitivity) are limited over time (maximum 30 hours), again highlighting the importance of the regularity of physical activity in this context.

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