

What are the health benefits of physical activity in type 1 diabetes mellitus? A literature review

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Abstract Physical activity improves well-being and reduces the risk of heart disease, cancer and type 2 diabetes mellitus in the general population. In individuals with established type 2 diabetes, physical activity improves glucose and lipid levels, reduces weight and improves insulin resistance. In type 1 diabetes mellitus, however, the benefits of physical activity are less clear. There is poor evidence for a beneficial effect of physical activity on glycaemic control and microvascular complications, and significant risk of harm through hypoglycaemia. Here we review the literature

relating to physical activity and health in type 1 diabetes. We examine its effect on a number of outcomes, including glycaemic control, lipids, blood pressure, diabetic complications, well-being and overall mortality. We conclude that whilst there is sufficient evidence to recommend physical activity in the management of type 1 diabetes, it is still unclear as to what form, duration and intensity should be recommended and whether there is benefit for many of the outcomes examined.

Keywords Complications · Glycaemic control · HbA_{1c} · Physical activity · Review · Type 1 diabetes

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Abbreviations

CVD Cardiovascular disease
BMD Bone mineral density
 $\dot{V}O_{2\max}$ Maximal aerobic capacity

Introduction

Physical activity reduces the risk of coronary heart disease, stroke, osteoporosis, and colon and breast cancer in the general population [1]. There is also evidence that physical activity reduces obesity, osteoarthritis, lower back pain and clinical depression and improves mental well-being in this population. With regard to type 2 diabetes, randomised controlled trials have demonstrated that physical activity can delay the progression of impaired glucose tolerance to type 2 diabetes when combined with changes to the diet [2]. In patients with established type 2 diabetes, physical activity improves glycaemic control and reduces medication dose, weight and cardiovascular risk factors [3].

In light of this evidence, diabetes organisations strongly advocate a role for physical activity in the management of

diabetes [4, 5]. Much of the advice relates to type 2 diabetes. The ADA suggests that ‘persons with type 2 diabetes should undertake at least 150 min per week of moderate to vigorous aerobic exercise spread out during at least 3 days during the week, with no more than two consecutive days between bouts of aerobic activity. Aerobic exercise should be at least at moderate intensity, corresponding approximately to 40–60% of $\dot{V}O_{2\max}$ (maximal aerobic capacity). For most people with type 2 diabetes, brisk walking is a moderate-intensity exercise. Additional benefits may be gained from vigorous exercise (>60% of $\dot{V}O_{2\max}$)’ [4]. The benefits of resistance exercise have also recently been recognised [6], and the ADA suggests that patients with type 2 diabetes should be encouraged to perform resistance exercise ‘at least twice weekly on non consecutive days, but more ideally three times a week, as part of a physical activity program for individuals with type 2 diabetes, along with regular aerobic activities. Each training session should minimally include five to ten exercises involving the major muscle groups (in the upper body, lower body, and core) and involve completion of 10–15 repetitions to near fatigue per set early in training, progressing over time to heavier weights (or resistance) that can be lifted only eight to ten times. A minimum of one set of repetitions to near fatigue, but as many as three to four sets, is recommended for optimal strength gains’ [4]. There is also guidance on type 1 diabetes stating that all levels of exercise can be performed, and providing guidelines for safe exercise [7, 8].

The weight of evidence for the benefits of physical activity in patients with type 2 diabetes, whilst by no means satisfactory, still exceeds that available for type 1 diabetes. Much of the guidelines applied to patients with type 1 diabetes are based on understanding gained from studies on individuals without diabetes or with type 2 diabetes, both clearly very different conditions. Furthermore, whilst there is evidence that (young and complication-free) patients with type 1 diabetes undertake as much physical activity as people without diabetes, these levels remain suboptimal [9, 10]. There is also a further group of patients who report fear of hypoglycaemia as a barrier to physical activity [11]. It is therefore important to clarify the role of physical activity in the management of type 1 diabetes.

The aim of this literature review was to examine the health benefits of physical activity in type 1 diabetes. Specifically, we analysed physical activity outcomes on fitness, glycaemic control, insulin requirements, vascular risk factors, microvascular complications, cardiovascular disease (CVD), mortality, well-being, beta cell function, osteoporosis and cancer.

Methods

We searched for interventions aimed at increasing physical activity for patients with type 1 diabetes in MEDLINE (OVID). Keywords and free text search were conducted without any

limits on study design, study outcome, language or peer reviewed journals. We limited our search to include entries from 1970 to March 2011. For type 1 diabetes, we used both ‘type 1 diabetes mellitus’ and ‘insulin dependent diabetes mellitus’ to increase the sensitivity of the search strategy. Multiple terms reflecting physical activity were used (see the Electronic supplementary material [ESM] Table 1 for further details).

Inclusion criteria were defined mainly based on population and intervention along with a broader outcome category. The population was clinically diagnosed patients with type 1 diabetes. Any intervention that aimed to increase physical activity for more than 7 days, irrespective of intensity, was included in the review. We did not exclude articles based on comparator. Outcomes were broadly defined as physical fitness, glycaemic control and insulin requirements, other vascular risk factors, vascular complications and well-being. HbA_{1c} was used as a primary measure of blood glucose control because it is readily available and validated against hard clinical endpoints. Articles that included other measures of glucose control (fasting blood glucose, continuous glucose monitoring) were also included. All study designs, except case reports and case series with fewer than five patients, were included in the review.

The titles and abstracts of all articles identified were divided and reviewed by four members of the research team (M. Chimen, K. Nirantharakumar, A. Kennedy, P. Narendran). Papers identified as relevant or of uncertain relevance based on the abstracts were further evaluated by M. Chimen and checked by P. Narendran. Any discrepancies were resolved by discussion among all members of the research team.

A narrative synthesis was done for each outcome category indicating the direction of the effect for the outcome. Where results among articles were mostly consistent for a given outcome the effect size has been given as a range. A. Kennedy and R. Andrews used previous reviews on the effect of physical activity on type 2 diabetes to contrast the findings of type 1 diabetes and type 2 diabetes.

Results

We selected 48 articles out of the 1,920 identified in the literature search (ESM Fig. 1). These articles were included in the results for each outcome analysed. Table 1 indicates the quality of physical activity benefit on the selected outcomes, and Fig. 1 outlines these benefits compared with those in type 2 diabetes.

Physical fitness $\dot{V}O_{2\max}$ is a measure of physical fitness and reflects the maximal capacity of the body to transport and utilise oxygen. It is a validated and commonly used measure of fitness that is predictive of mortality [12]. Studies of

Table 1 Evidence for physical activity benefit in type 1 diabetes and type 2 diabetes

Outcome measure	Physical activity benefit ^a in T1D [ref.]	Physical activity benefit ^a in T2D [ref.]
Physical fitness	2 [19, 26] 4 [13, 20, 21, 23–25]	1 [64]
Muscle strength	2 [55]	2 [65]
Glycaemic control	3 [31, 38, 66, 67] 4 [68]	1 [3, 28, 29]
Insulin requirement	4 [21, 23] 5 [30]	2 [65]
Lipids	3 [19] 4 [13, 20, 21, 23, 25] 5 [30, 43]	1 [28, 69]
Blood pressure	4 [38] 5 [43]	1 [28]
Endothelial function	4 [23] 8 [46]	3 [45]
Insulin resistance	4 [20, 21, 24] 5 [30]	1 [70] 2 [71]
Microvascular complications	8 [51]	6 [4]
Cardiovascular disease	6 [53]	6 [4]
Mortality	6 [9]	6 [4]
Wellbeing	8 [56]	2 [72]
Beta cell function	No available evidence	3 [59]
Osteoporosis	No available evidence	No available evidence
Cancer	No available evidence	No available evidence

^a The benefit is assigned as number according to strength of evidence [73]:

1. Systematic reviews and meta-analyses
2. Randomised controlled trials with definitive results (confidence intervals that do not overlap the threshold clinically significant effect)
3. Randomised controlled trials with non-definitive results (a point estimate that suggests a clinically significant effect but with confidence intervals overlapping the threshold for this effect)
4. Non-randomised control trial
5. Case series
6. Cohort studies
7. Case-control studies (no instances in this table)
8. Cross-sectional surveys
9. Case reports (no instances in this table)

T1D, type 1 diabetes; T2D, type 2 diabetes

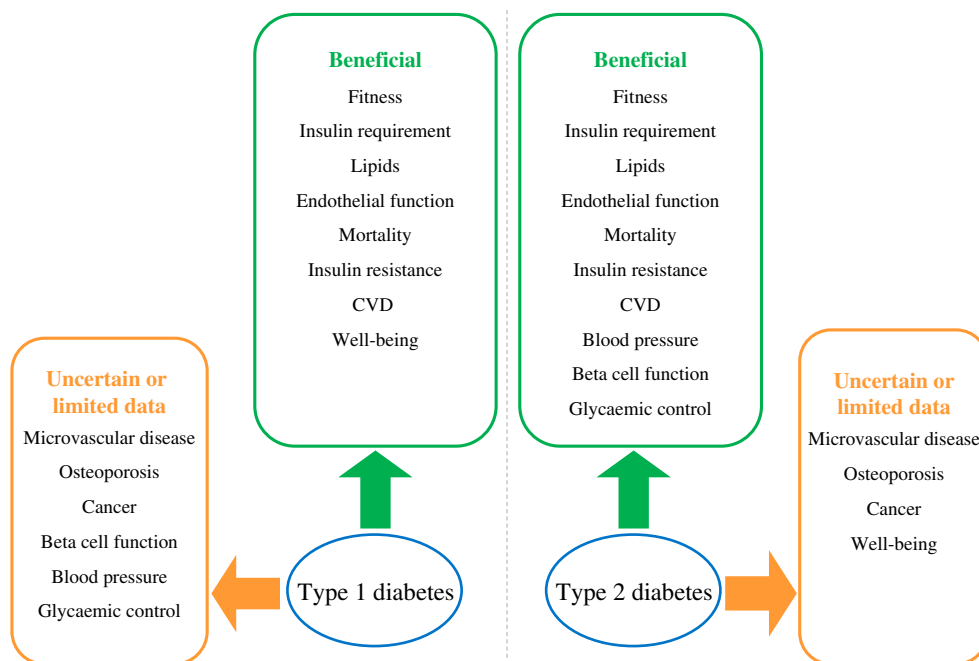
fitness in patients with type 1 diabetes are small but suggest that, despite similar levels of physical activity, young adults (17–44 years of age) with type 1 diabetes are less fit than matched individuals without diabetes [9, 10, 13, 14]. Abnormalities in cardiac muscle and autonomic nerve function [15], as well as a cardiac metabolism that favours NEFA over glucose as a fuel source [16], may contribute. However, not all studies found lower fitness levels in individuals with type 1 diabetes [17], and data on older patients with type 1 diabetes are not available. Patients with type 2 diabetes similarly have a significantly lower $\dot{V}O_{2\max}$ than healthy age-, BMI- and activity-matched participants without diabetes [18], but no studies to date have directly compared patients with type 1 diabetes and type 2 diabetes.

Supervised physical activity programmes do, however, improve fitness in patients with type 1 diabetes [19–21] (as well as those with type 2 diabetes [22]). Increases in $\dot{V}O_{2\max}$ of up to 27% have been reported in patients with type 1 diabetes [13, 23–26], and a similar proportional increase is seen in participants without diabetes [27].

Physical activity improves fitness in patients with type 1 diabetes

Glycaemic control and insulin requirements There is clear evidence that physical activity improves glycaemic control in patients with type 2 diabetes [3, 28, 29]. Depending on

Fig. 1 Health benefits of physical activity in type 1 and type 2 diabetes



the intensity and duration, physical activity appears to reduce HbA_{1c} levels in these patients by about 4.2 mmol/mol (0.6%) [3, 22, 29]. Insulin requirements are also reduced.

Studies investigating the effect of physical activity on glycaemic control in type 1 diabetes have so far largely failed to demonstrate a benefit, either on fasting blood glucose or HbA_{1c} (Table 2 and ESM Table 2). Table 2 lists interventional studies of the effect of physical activity on HbA_{1c} where the control group has type 1 diabetes, and ESM Table 2 lists other studies. These studies have predominantly involved adolescents or young adults. They have been both large cross-sectional studies in which physical activity has been estimated through validated questionnaires, as well as smaller randomised controlled and prospective interventional studies. These exercise programmes have generally been of 1–3 months duration, but even a 5-month programme failed to show glycaemic benefit [26]. Studies of resistance exercise programmes in type 1 diabetes have also failed to show a consistent glycaemic benefit [30, 31].

A number of factors may contribute to the lack of detectable benefit on glycaemic control. Energy consumption appears to be increased around the time of physical activity in individuals with type 1 diabetes, either as a source of fuel or to manage hypoglycaemia, and this may counteract any glucose-lowering effect of physical activity [27]. The majority of reported studies failed to incorporate the exercise schedule into an overall programme of diet and lifestyle intervention. Whilst this was not the aim of these studies, such an approach may help improve long-term glycaemic control. It is also intriguing that some of the studies reporting a glycaemic benefit have involved vigorous exercise, and these are in contrast to the majority of other studies, which did not report a benefit and employed a moderate exercise programme (Table 2 and ESM Table 2).

Parallel studies on type 2 diabetes suggest that greater activity intensity is associated with greater reductions in HbA_{1c} [32].

Studies on type 1 diabetes that have estimated glycaemic control through fasting blood glucose have also failed to show a consistent benefit [21, 31, 33, 34]. Predictably, however, these studies demonstrated that blood glucose decreases (without hypoglycaemia) around the time of exercise [35, 36], as it does in healthy individuals [37]. The lack of glycaemic benefit as assessed by HbA_{1c} may result from rebound hyperglycaemia immediately following exercise, and better control of this may show a benefit.

Studies on type 1 diabetes consistently demonstrate that physical activity is associated with reduced insulin requirements. This reduction varies from 6% [21] to over 15% [23, 30]. Whilst some of this may have been required to manage hypoglycaemia, it is possible that these reductions masked any glycaemic improvement as measured by HbA_{1c}. In support of this notion, insulin doses were reduced in two of the six studies (33%) [21, 23] in Table 2 that showed no HbA_{1c} improvement, as opposed to one of the five studies (20%) that did [38].

It therefore remains to be elucidated whether vigorous activity, incorporation of a dietary programme and/or appropriate insulin therapy can demonstrate that physical activity provides a glycaemic benefit in type 1 diabetes. It is also not clear whether physical activity will be of benefit in age groups outside those that include children and young adults.

Most studies did not record the frequency of hypoglycaemic events. Of the few that did, two observed no increase in the frequency of hypoglycaemia with exercise [24, 38], whilst one showed a minimal increase (that could easily have been addressed through insulin dose adjustment)

Table 2 Intervention studies evaluating the effect of physical activity on HbA_{1c} in patients with type 1 diabetes

Study	n (Control/T1D)	Mean age±SD/age range (Years)	RCT?	Duration	Type of physical activity	T1D control group		T1D intervention group	
						HbA _{1c} before (mmol/mol) (%)	HbA _{1c} after (mmol/mol) (%)	HbA _{1c} before (mmol/mol) (%)	HbA _{1c} after (mmol/mol) (%)
No HbA _{1c} effect									
Yki-Jarvinen et al. [21]	6/7	NA	No	6 weeks	Supervised aerobic physical activity	70±5	70±5	70±5	70±5
Landt et al. [24]	6/9	14–16	No	12 weeks	Supervised aerobic physical activity	8.6±0.4	8.6±0.4	8.6±0.4	8.6±0.4
Wallberg-Henriksson et al. [26]	7/6	25–45	No	5 months	Non-supervised aerobic physical activity	10.6±0.6	10.4±0.6	10.4±0.6	10.5±0.6
Huttunen et al. [33]	16/16	8.2–16.9	No	3 months	Supervised aerobic physical activity	79±23	83±24	84±25	91±28
Laaksonen et al. [19]	28/28	32.5±5.7	Yes	12–16 weeks	Supervised aerobic physical activity	9.4±2.1	9.7±2.2	9.8±2.3	10.5±2.5
Fuchsjaeger-Mayrl et al. [23]	8/18	42±10	No	4 months	Supervised aerobic physical activity	66±12	66±11	67±14	69±18
HbA _{1c} improvement									
Dahl-Jorgensen et al. [68]	8/14	5–11	No	5 months	Supervised aerobic physical activity	8.2±1.1	8.2±1.0	8.3±1.3	8.5±1.6
Campaigne et al. [66]	9/10	9±0.47	Yes	12 weeks	Supervised vigorous physical activity	57±6	55±2	56±2	58±4
Durak et al. [31]	8/8 (crossover)	31±3.5	Yes	10 weeks	Supervised heavy resistance training	7.4±0.4	7.2±0.2	7.3±0.2	7.5±0.3
Perry et al. [67]	30/31	20–69	Yes	6 months	Non-supervised aerobic physical activity	123±21	117±18	142±49	127±21
Salem et al. [38]	48/moderate intensive 75/73	14.5±2.4	Yes	6 months	Supervised aerobic and resistance physical activity	13.4±1.9	12.9±1.6	15.1±2.2	13.8±1.9
						128±8	122±6	113±7	100±5
						13.9±0.61	13.3±0.54	12.5±0.65	11.3±0.5
						52±15	52±15	52±15	40±10
						6.9±1.4	6.9±1.4	6.9±1.4	5.8±0.9
						72±21	73±25	74±28	70±23
						8.7±2.0	8.8±2.3	8.9±2.6	8.6±2.1
						67±23	74±15	Moderate: 74±15	Moderate: 65±12
						8.3±2.1	8.9±1.4	Intensive 74±17	Intensive 62±11
								8.9±1.6	7.8±1.0

All studies quoted have included patients with type 1 diabetes in both the intervention and control groups. The studies are listed in chronological order according to whether or not physical activity improved HbA_{1c}.

NA, not available; RCT, randomised controlled trial; T1D, type 1 diabetes

[21]. Hypoglycaemia is, however, a perceived barrier to exercise in patients with type 1 diabetes [11] and therefore requires further study. It is clear that exercise-induced hypoglycaemia can occur in a laboratory environment without glucose supplementation [39] and that it can also occur in people without diabetes [40]. However, in cross-sectional studies [41], as well as all studies outlined in this review, it appears that hypoglycaemia is not a significant factor, and is a concern that can be managed using simple approaches to insulin and carbohydrate adjustment.

In summary, the available studies demonstrate that, in a trial setting, physical activity can be conducted safely and with minimal hypoglycaemia, and that regular moderate intensity exercise of the kind currently advocated by the diabetes associations can be adhered to by patients with type 1 diabetes over a medium-term period.

Physical activity improves insulin requirements in type 1 diabetes but shows a limited effect on glycaemic control

Vascular risk factors other than glucose Patients with type 1 diabetes are at risk of high blood pressure, triacylglycerols and LDL-cholesterol, and of low levels of HDL-cholesterol. These factors are associated with increased risk of vascular disease [42].

Most, but not all, studies of physical activity in patients with type 1 diabetes demonstrate a beneficial effect on lipid levels [13, 19–21, 23, 25, 43]. These studies involved exercise programmes lasting up to 4 months, and showed benefits similar to those demonstrated in individuals without diabetes, increasing HDL-cholesterol by 8–30%, while decreasing LDL-cholesterol by 8–14% and triacylglycerols by 13–15%. More specifically, there appears to be a reduction in apolipoprotein B, which is pro-atherogenic and is associated with premature mortality in type 1 diabetes [44]. Physical activity also increases levels of the anti-atherogenic apolipoprotein A-I [19]. There is general agreement amongst studies that these benefits are independent of changes in glycaemic control and weight and that they are most pronounced in those with an adverse lipid profile.

Evidence for the benefits of physical activity on blood pressure in type 1 diabetes is limited. Of four prospective intervention studies, two failed to detect a benefit with respect to systolic or diastolic blood pressure [23, 25], whilst two did (2–3%) [38, 43]. All four studies examined young adult patients with type 1 diabetes and involved very similar physical activity programmes. Three of the studies had relatively small study cohorts (26, 14 and 20 participants, respectively [23, 25, 43]), whereas one, which showed a diastolic blood pressure benefit, recruited 196 [38].

In contrast with these results, in type 2 diabetes there are now good data showing evidence for physical activity

improving blood pressure and lipids [28]. This discrepancy may be because patients with type 1 diabetes are younger and more likely to be normotensive and less likely to have dyslipidaemia, making it more difficult to demonstrate a benefit.

Impaired endothelial function is associated with vascular complications and can be reversed by physical activity both in individuals without diabetes and in those with type 2 diabetes [45]. Patients with type 1 diabetes, particularly those with microalbuminuria, display clear evidence of endothelial dysfunction [10]. Vascular function does improve following physical activity in type 1 diabetes, but not to the same extent as it does in individuals without diabetes [23, 46]. The improvement is evident across a number of vascular beds, not just the one supplying the exercising muscles, suggesting a systemic benefit of exercise. These benefits only persist for the period of physical activity and cease once regular activity is stopped. Nevertheless, exercise should be practised cautiously in patients with microalbuminuria as it increases with exercise intensity in adolescents with type 1 diabetes [47].

Patients with type 1 diabetes are more insulin resistant than matched non-diabetic individuals [10, 21]. Both resistance and endurance exercises improve insulin sensitivity in type 2 diabetes [48] and type 1 diabetes by up to 23% [20, 21, 24, 30].

Insulin resistance is independently associated with the risk of developing both macro- and microvascular complications in type 1 diabetes [49]. The beneficial effects of physical activity on insulin resistance, as well as on lipid levels and endothelial function, suggest that physical activity should reduce vascular complications in type 1 diabetes. What then is the evidence for this?

Physical activity improves lipid levels, endothelial function and insulin resistance but not blood pressure

Microvascular complications The presence of diabetic complications is associated with reduced physical activity in type 1 diabetes [50]. However, causality has not been demonstrated, and this association could be explained by the presence of complications impairing the ability to undertake physical activity, rather than physical activity decreasing the complications of diabetes. The best evidence for the protective effect of physical activity in type 1 diabetes currently comes from the Pittsburgh IDDM Morbidity and Mortality Study [51]. This is a longitudinal study of 628 largely white European adults with a long duration of diabetes (66% participants with over 20 years' duration). These adults were asked to estimate the physical activity they undertook during their teenage years. Their level of activity was found to be inversely associated

with the risk of nephropathy and neuropathy. The association was found in men but not women, and was not seen with retinopathy. Although this study controlled for a number of important factors, the subjective estimation of physical activity and the lack of reproducibility with retinopathy weakens the findings.

There are limited data for a microvascular benefit of physical activity in type 2 diabetes. Studies on type 2 diabetes have shown increased urinary protein excretion immediately after physical activity [52], but there is no evidence that physical activity influences the progression of nephropathy in humans.

CVD and mortality CVD is increased in both type 1 diabetes and type 2 diabetes and is the most common cause of death [42]. Whilst intervention studies have yet to demonstrate that physical activity reduces CVD in type 2 diabetes, there are clear associations in this disease between low levels of physical activity and CVD [28].

With respect to type 1 diabetes, the Pittsburgh IDDM Morbidity and Mortality study demonstrated that at 25 years' duration of diabetes, men who had participated in team sports during high school were three times less likely to report macrovascular disease and had mortality rates three times lower than those who did not [53]. This pattern was not seen in women, but their participation in team sports was lower (24% reported participation compared with 39% in men), possibly explaining the failure to detect statistical significance. The study also demonstrated that those patients who had participated in team sports during their youth tended to maintain higher levels of physical activity throughout adulthood.

Further follow-up of these adult patients showed that the level of physical activity in adulthood (measured using a validated questionnaire) predicted mortality at 6 years [9]. Sedentary men were three times more likely to die than active men, and a similar (but, again, non-significant) effect was seen in women. Unfortunately, data on the cause of death and the age groups benefitting from mortality reduction were not available. However, confounders were adjusted for and a large number of patients (548) was studied. This is currently the seminal study on this topic.

Physical activity is associated with reduced CVD and mortality in patients with type 1 diabetes

Well-being The incidence of depression is three times higher in type 1 diabetes compared with the general population [54]. Physical activity is associated with significantly greater satisfaction with life and well-being [55]. These benefits have so far only been demonstrated in adults and not in children [56].

Depression is also common in patients with type 2 diabetes. Increased physical fitness improves health-related quality of life scores in these patients (Medical Outcomes Study 36-item Short-Form Health Survey [SF-36] physical component) [4], but to date no studies have looked at the effect of exercise on well-being as measured by diabetes-specific questionnaires.

Beta cell function, osteoporosis and cancer The loss of beta cells that results in type 1 diabetes is a gradual process and significant beta cell function is present at the time of diagnosis [57]. The preservation of these cells improves glucose control, reduces long-term complications and more than halves the rate of hypoglycaemia [58]. Although the mechanism is unclear, physical activity appears to preserve beta cell function in animal models, patients with type 2 diabetes and healthy individuals [59]. This benefit of physical activity has not been examined in patients with type 1 diabetes.

Physical activity imparts a global anti-inflammatory effect by acting on the number and function of immune cells [60]. Whilst this is clearly of relevance to an immune-mediated disease such as type 1 diabetes, a direct effect of physical activity on (auto)immunity to the pancreatic beta cell has yet to be demonstrated.

Reduced bone mineral density (BMD), osteoporosis and increased risk of fracture (at any site) are recognised complications of type 1 diabetes [61]. In type 2 diabetes, fracture risk appears to be increased in the presence of normal, or even increased, BMD [61]. The increase in fracture risk in type 2 diabetes may be related to an increased risk of falls (due to neuropathy) or alteration of bone architecture. To our knowledge, there are no studies on the effect of physical activity on BMD or fracture risk in either type 1 diabetes or type 2 diabetes.

Cancer is a recognised complication of type 2 diabetes and obesity [62]. The data for type 1 diabetes is less clear [63]. Physical activity appears to protect the general population from cancer and improve outcomes in those who do develop cancer (surgical outcome, side effects of chemotherapy, subsequent prevention of recurrence). Again, this has not been examined in either type 1 or type 2 diabetes.

There are no studies investigating the effect of physical activity on beta cell function, osteoporosis or cancer in patients with type 1 diabetes

Conclusion

Physical activity improves physical fitness and strength, reduces cardiovascular risk factors and improves well-

being in type 1 diabetes (Fig. 1). It also significantly reduces insulin requirements. Whilst physical activity has yet to demonstrably improve glycaemic control as measured by HbA_{1c}, there are a number of potential explanations that require further investigation.

The few randomised control trials reported for type 1 diabetes to date have been small, of short duration and have not controlled for confounding factors such as diet or adjustment of insulin dosage. They do not provide guidance on the intensity, duration or type (aerobic/resistance) of physical activity that will provide the greatest benefit. There is an urgent need for large randomised controlled trials to examine these issues. There are also a number of important outcomes that have not been examined in type 1 diabetes.

The current evidence is, however, sufficient for clinicians to advocate physical activity as part of the management of patients with type 1 diabetes. The current evidence also suggests that physical activity can be undertaken safely and with defined benefits at the levels currently recommended by the major diabetes associations.

Duality of interest The authors declare that there is no duality of interest associated with this manuscript.

Contribution statement The authors contributed in the following ways: conception and design (MC, PN, KN), analysis and interpretation of data (MC, PN, KN, TTP, AK, RA), drafting the article (MC, PN) or revising it critically for important intellectual content (MC, PN, KN, AK, TTP, RA). All authors gave approval for the final version to be published.

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