

The Role of Physical Exercise in Obesity and Diabetes

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Summary

The prevalence of obesity is increasing world-wide. Obesity is associated with a plethora of metabolic and clinical constraints, which result in a higher risk for the development of cardiovascular complications and metabolic disease, particularly insulin resistance and type 2 diabetes. Obesity is an acknowledged determinant of glycemic control in patients with type 1 diabetes and accounts for the majority of premature death due to cardiovascular events. Physical exercise is generally recommended in patients with diabetes in order to prevent the development of or reduce existing obesity, as adopted by every international treatment guideline so far. Regular physical exercise has a beneficial impact on body composition, cardiovascular integrity, insulin sensitivity and quality of life. However, only a minority of patients participates in regular physical exercise, due to individual or disease-related barriers. In type 2 diabetes, there is robust evidence for beneficial effects of physical exercise on glycemic control, cardiovascular health and the development of diabetes-related long-term complications. In type 1 diabetes and patients treated with insulin, a higher risk for exercise-related hypoglycemia has to be considered, which requires certain prerequisites and adequate adaptations of insulin dosing. Current treatment guidelines do only incompletely address the development of exercise-related hypoglycemia. However, every patient with diabetes should participate in regular physical exercise in order to support and enable sufficient treatment and optimal glycemic control.

Keywords:

Obesity, physical exercise, diabetes, hypoglycemia

Zusammenfassung

Die Prävalenz der Adipositas nimmt weltweit zu und erhöht das Risiko, an Diabetes zu erkranken. Sport gilt als bewährte Methode in der Behandlung von Adipositas und wird insbesondere für eine erfolgreiche Diabetes-Therapie empfohlen. Sport wirkt sich positiv auf die Körperkomposition, das kardiovaskuläre System und die Lebensqualität aus. Allerdings schaffen es nur wenige Menschen mit Diabetes, Sport regelmässig und dauerhaft durchzuführen. Der Nutzen für

die glykämische Kontrolle und kardiovaskuläre Risikofaktoren ist klar belegt für Menschen mit Typ-2-Diabetes. Bei Behandlung mit Insulin muss besonderes Augenmerk auf eine adäquate Dosisanpassung der Insulintherapie gelegt werden, um mitunter schwere Hypoglykämien zu vermeiden. Sport sollte von jedem Menschen mit Diabetes regelmässig ausgeübt werden, um die bestehende Therapie zu unterstützen und zu ergänzen.

Schlüsselwörter:

Adipositas, Sport, Diabetes, Hypoglykämie

Résumé

La prévalence de l'obésité augmente dans le monde entier et, avec elle, le nombre de facteurs de risque cardiovasculaire. L'obésité est associée à une variété de troubles métaboliques et cliniques qui se traduisent par un risque plus élevé de souffrir de maladies cardiovasculaires ou métaboliques. En particulier, le développement de la résistance à l'insuline et du diabète sucré de type 2 est étroitement lié à l'obésité. Mais les personnes atteintes de diabète de type 1 développent également des facteurs de risque cardiovasculaire beaucoup plus fréquemment et bénéficient d'une réduction de poids dans leur contrôle glycémique. Pour prévenir le surpoids ou pour réduire le surpoids existant, le sport est considéré comme la méthode la plus largement acceptée et éprouvée. Le sport est considéré dans toutes les directives de traitement comme une condition de base pour une thérapie du diabète réussie. L'exercice régulier a un effet positif sur la composition corporelle, le système cardiovasculaire, la sensibilité à l'insuline et la qualité de vie. Cependant, peu de personnes atteintes de diabète parviennent à intégrer le sport dans leur vie de façon régulière et permanente. Les avantages de l'exercice pour la qualité du contrôle glycémique, la réduction des facteurs de risque cardiovasculaire et la prévention des complications associées au diabète sont clairement documentés pour les personnes atteintes de diabète de type 2. Chez les personnes atteintes de diabète de type 1 (et les personnes atteintes de diabète de type 2 traitées à l'insuline), une attention particulière doit être accordée à l'adaptation adéquate de l'insulinothérapie. Le sport en combinaison avec

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une insulinothérapie existante peut augmenter de manière significative le risque d'hypoglycémie parfois sévère, et les directives thérapeutiques actuelles ne peuvent que partiellement réduire ce risque. Néanmoins, un programme sportif régulier et individualisé devrait être suivi par chaque personne atteinte de diabète afin de soutenir et de compléter de manière optimale la thérapie antidiabétique existante.

Mots-clés:

Obésité, éducation physique, diabète, hypoglycémie

Introduction

Obesity is defined as a body mass index (BMI) ≥ 30 kg/m². World-wide prevalence is continuously rising and assumed to reach 18% in men and surpass 21% in women by the year 2025 [1]. Obesity is associated with a striking reduction in life expectancy due to metabolic, cardiovascular and psychologic constraints, which promote the development of cardiovascular disease, diabetes, depression and certain kinds of cancer. It has been suggested that the steady rise in life expectancy during the past two centuries may come to an end because of the increasing prevalence of obesity [2].

In particular, obesity-associated co-morbidities include impaired glucose tolerance, type 2 diabetes (T2DM). Successful treatment of diabetes is a complex and challenging task requiring multiple contemporaneous strategies including lifestyle optimization, adequate antidiabetic medication and individual education. Weight loss and physical exercise represent the fundamental basis of obesity prevention, and its regular implementation is recommended in every international treatment guideline for patients with diabetes [3]. Additionally, exercise can also have important impacts on wellbeing and Quality of Life, especially in young people [5]. Although generally recommended, the majority of patients fail to reach the weekly goals of physical activity [4].

Even though its benefits are indisputable, there are some challenges that have to be addressed in order to enable and motivate patients with diabetes to participate in regular, structured physical exercise.

Treatment of obesity and diabetes – role of physical exercise in type 1 diabetes (T1DM)

Patients with T1DM frequently develop cardiovascular risk factors such as hypertension or dyslipidemia, resulting in a higher risk for cardiovascular disease. Moreover, obesity prevalence increases at a faster rate as compared to the general population [6,7]. Currently, around 50% of patients with T1DM are either overweight or obese.

In order to understand the role of exercise in obesity and diabetes it is helpful to take a glance at the physiological adaptations during exercise first.

Briefly, exercise can be divided into aerobic and anaerobic exercise, depending on the type of energy supply. Aerobic exercise is endurance exercise (“cardio”) such as running, biking or swimming, typically with repeated strain of large muscle groups over a long time period.

Higher performance over a short period can be accomplished during anaerobic exercise. Anaerobic energy supply

relies mainly on glycolysis without oxygen supply, leading to the accumulation of lactate. Examples for exclusively anaerobic physical activity include resistance exercise like weightlifting or sprint training [8]. The hormonal and metabolic response differs substantially in regard to the type of exercise. In healthy subjects, blood glucose stays in the range of 4–6 mmol/l during exercise despite the 4–6 times increased demand for energy by the used muscles. Initially, this increased demand is covered by local glycogen stores in the muscle tissue. Already shortly afterwards, external energy supplies are needed. In healthy subjects, suppression of insulin secretion and increasing glucagon levels are responsible for increased glucose production and subsequently fat oxidation. Muscle contractions lead to increased insulin-independent glucose uptake via glucose transporter 4 (GLUT4) [9]. Glucose uptake stays increased for up to 24–48 hours after the exercise is finished [4].

Continuous insulin treatment – a necessity increasing the risk for obesity

Unintentional body weight gain may appear with intensive insulin treatment [10]. Insulin inhibits protein catabolism, stimulates lipogenesis and decreases basal metabolic rate [7,11,12]. Moreover, exogenous insulin administration often supersedes physiologic requirements, thereby altering body composition in favor of increased body fat deposits [11–14].

The Diabetes Control and Complications Trial (DCCT) reported an average body mass gain of 4.6 kg following intensive insulin therapy over five years. Weight gain appeared regardless of administration via multiple daily injections or an insulin pump [15]. A recent meta-analysis reported that weight gain was determined by the absolute dose of daily insulin [16]. In newly diagnosed T1DM, the initiation of intensive insulin therapy is often accompanied by significant weight gains due to corrections in glycosuria, diuresis, and catabolism [7]. However, moderate weight gain did not negatively affect cardiovascular risk profile when associated with improved glycemic control [17].

Glycemic control in T1DM

The association between increased physical exercise and improvement of glycemic control is not as clear as in patients with T2DM. Former studies even demonstrated a deterioration of glycemic control due to significantly higher glycemic variability during and after exercise in patients with T1DM [5,6,18].

Fear of hypoglycemia is frequently mentioned by patients with T1DM. However, with adequate instruction and planning, almost all activities can be performed safely. The impact of exercise on glycemic control in T1DM is complex and depends on the type of exercise, current insulin concentrations, carbohydrate ingestion, and others [4].

Different types of carbohydrate, for example defined by the glycemic index, may lead to different and occasionally unexpected glycemic responses. Typically, complex carbohydrates can be used as continuous energy supply during longer activities whereas rapidly metabolized carbohydrates such as glucose are suitable for the correction of decreasing blood sugar readouts [4,19].

Insulin and the risk for hypoglycemia – practical aspects

Plasma concentrations of (long-acting) insulin analogues cannot be decreased during exercise, leading to inadequately higher concentrations of insulin during and after exercise. This might increase glycemic variability and the risk for hypoglycemia [4,20]. Moreover, hyperinsulinemia inhibits lipolysis, making glucose the main source of fuel supply during exercise. Two main strategies have been developed in order to compensate for higher insulin sensitivity and increased glucose requirements. An obvious approach for prevention of hypoglycemia during exercise is the ingestion of additional carbohydrates, based on the pre-exercise blood glucose concentration, time of the last meal and circulating insulin levels. Therefore, estimating the optimal dose of additional carbohydrates ingested prior to exercise may be a challenging task and requires experience from both, patients and medical experts. An approximate approach can be reviewed in table 1.

Adding carbohydrates means additional calories, which might reduce the efficacy of intended weight loss. Therefore, reductions of insulin dose may be the preferred strategy. In general, reductions in basal insulin and/or prandial insulin are useful if duration and intensity of exercise can be predicted. However, reduction of insulin doses may not be enough to compensate for unexpected increases in physical activity. Therefore, ingestion of additional carbohydrates may still be necessary. An overview of insulin dose reduction can be reviewed in table 2.

In the last few years, the use of continuous glucose monitoring (CGM) devices has become increasingly important in diabetes. It was demonstrated that CGM is as accurate during exercise with the same delay of 15–20 s as in non-exercising conditions [21]. CGM may reduce hypoglycemia frequency,

and knowing the current glucose trend can be of high value for exercising subjects with T1DM [22].

Similar results were found for patients with T2DM. Even a single session of high-intensity interval training (HIT, 10 × 60 seconds of cycling at 90% of maximal heart rate, interspersed with 60 seconds rest) was capable to reduce the time in hyperglycemia (defined as CGM glucose >10 mmol/l; HIT: 4.5 ± 4.4 vs. control: $15.2 \pm 12.3\%$, $p = 0.04$) and postprandial glycemic excursions (postprandial area under the curve for CGM glucose; HIT: 728 ± 331 vs. control: 1142 ± 556 mmol/l × 9 h, $p = 0.01$) [23].

A systematic review and meta-analysis illustrated beneficial effects on glycemic excursions following physical exercise in patients with T2DM using CGM. Physical exercise significantly decreased average daily CGM glucose concentrations (-0.8 mmol/l; $p = 0.01$) and time spent in hyperglycemia (defined as CGM glucose >10 mmol/l: -129 min, $p < 0.01$) without promoting hypoglycemia (time spent in hypoglycemia, defined as CGM glucose <4.0 mmol/l: -3 min, $p = 0.47$) [24].

The role of physical exercise in T2DM

Glycemic control in T2DM

In a meta-analysis of 47 randomized controlled clinical trials (RCTs), patients participating in structured, supervised aerobic exercise (-0.73%), resistance training (RT) (-0.57%), or combined training modalities (-0.51%) achieved significant reductions in HbA1c as compared to control participants, who were only given oral advice to perform physical activity [25]. Reductions in HbA1c were higher if the duration of physical activity exceeded 150 minutes per week, compared to shorter training schedules (0.89% vs. 0.36%).

Capillary blood glucose prior to exercise (mmol/l)	Recommended action
<5.0	15–30 grams (g) of fast-acting carbohydrates Additional carbohydrates during exercise as needed
5.0–8.0	~0.5–1.0 g/kg body mass/hour of exercise, depending on exercise intensity and circulating insulin levels
8.1–14.0	Start with exercise Consumption of additional carbohydrates when capillary blood glucose drops to <8.0
14.1–19.0	Blood test for ketone bodies Initiate mild- to moderate-intensity exercise Intense exercise should be avoided until glucose levels drop to <14 mmol/l
>19.0	Blood test for ketone bodies Avoid any exercise if moderate to large amounts of ketones are present If ketones are negative (or trace), insulin correction (e.g., 50% correction) before exercise might be useful Initiate mild to moderate exercise Intense exercise should be avoided until glucose levels drop to <14 mmol/l

Table 1: Additional carbohydrates based on pre-exercise capillary blood glucose

Exercise intensity	Bolus reduction for 30 minutes of exercise (%)	Bolus reduction for 30 minutes of exercise (%)	Basal insulin reduction for 60 minutes of exercise (%)
Mild (walking, gardening)	25	50	30
Moderate (jogging, light cycling)	50	75	50
Intense (intense cycling, running, dancing)	75	100	90–100

Table 2: Reductions in bolus and basal insulin doses for 30 or 60 minutes of aerobic exercise performed within 2–3 hours after a meal

Supervision was an important determinant of treatment success, as was illustrated by meta-analysis of 27 RCTs. Supervised exercise training was capable to improve glycaemic control and insulin sensitivity as measured by total daily insulin dose. However, when supervision was removed from participants both, compliance and glycaemic control decreased significantly [26,27].

Improvements in both, body composition and glycaemic control were observed in older patients (60 to 80 years of age) with T2DM, as was illustrated by a recent RCT. After six months, the decrease in HbA1c was most pronounced in those patients allocated to a combined resistance training and a diet program as compared with resistance training or diet alone (HbA1c reduced by 1.2 ± 1.0 vs. $0.4 \pm 0.8\%$, $p < 0.003$ after six months), while lean mass increased likewise (mean increase in lean mass was 0.5 ± 1.1 kg for combined intervention and -0.4 ± 1.0 in diet intervention only) [28].

Moreover, structured physical exercise training reduced requirements in prescribed antidiabetic medication. After 16 weeks of resistance training, daily doses of anti-diabetic medication decreased by 72% in the exercise group as compared with the control group [29].

Cardiovascular risk factors in T2DM

A meta-analysis of 12 RCTs of structured physical exercise in patients with T2DM reported significant reductions in low-density lipoprotein cholesterol (LDL-C, reductions approximated 5% after eight weeks or more of physical exercise) [30]. Another meta-analysis of 14 RCTs showed significant improvements in glycaemic control, reductions in visceral obesity and plasma triglycerides, whereas LDL-C and overall body weight remained stable [31]. In the meta-analysis of 42 RCTs, structured exercise decreased systolic and diastolic blood pressure (-2.42 mm Hg for systolic and -2.23 mm Hg for diastolic blood pressure, respectively). Concentrations of high-density lipoprotein cholesterol increased (HDL-C; $+0.04$ mmol/l) in parallel to a favorable decrease in LDLC (-0.16 mmol/l) [32].

Cardiovascular morbidity and mortality in T2DM

As the most fundamental effect, physical exercise increases cardiorespiratory fitness (CRF) [33]. A meta-analysis of epidemiological studies in healthy participants illustrated an inverse association of CRF with cardiovascular morbidity. Another meta-analysis confirmed and extended these results, indicating that higher fitness levels as measured by aerobic

capacity offered cardiovascular protection (risk ratio for all-cause cardiovascular mortality 0.87 (confidence interval (CI) 0.84–0.90) [34].

Even walking as the very basis of physical activation offered cardiovascular protection. A prospective cohort study recruited 2896 adult patients with T2DM and calculated their cardiovascular mortality depending on the mean walking duration per week. Patients walking at least 2 hours per week had a 39% lower all-cause mortality rate and a 34% lower cardiovascular mortality rate [35]. Cardiovascular mortality decreased further in patients walking 3–4 hours per week (all-cause mortality hazard ratio (HR), 0.46; 95% confidence interval (CI), 0.29–0.71; cardiovascular mortality HR, 0.47; 95% CI, 0.24–0.91) and was highest in those patients reporting moderate increases in heart rate and breathing (all-cause mortality HR, 0.57; 95% CI, 0.41–0.80; cardiovascular mortality HR, 0.69; 95% CI, 0.43–1.09) [35]. Dose-responsiveness was confirmed in another meta-analysis of 17 studies evaluating cardiovascular risk reductions related to physical exercise [36]. Higher extents of physical exercise were associated with lower risk for all-cause cardiovascular mortality (0.61 [0.52–0.70]) and cardiovascular disease (0.71 [0.60–0.84]).

There have been some inconclusive results obtained from the LookAhead trial, a RCT comparing an intensive lifestyle intervention (ILI) to diabetes support and education in overweight and obese patients with T2DM. The primary endpoint was the development of cardiovascular disease. After a median follow-up time of 9.6 years, LookAhead was stopped due to futility, questioning the efficacy of physical activity in cardiovascular protection in T2DM. Even though being negative in terms of cardiovascular protection, Look Ahead reported numerous beneficial effects on diabetes-related morbidity. As a possible explanation, the event rate in Look-Ahead was over-estimated (0.7% compared to estimated 3.125% cardiovascular events per year). Moreover, participants and primary caretakers were unblinded and free to choose additional lifestyle programs besides the intervention of study protocol, which might have further decreased the cardiovascular event rate [37].

Barriers and facilitators of physical exercise in diabetes

A focus-group discussion investigated determinants of participation in a supervised exercise program and willingness to follow-up with physical exercise after completion in patients with T2DM. Motivation was the most critical factor in exercising, both during and following the program.

Participants reported the need for better transition to the post-program period, where supervision and support is rarely available. Co-morbidities were independent determinants of compliance, and participants suggested that the “optimal” exercise program offered time-wise flexibility and geographical proximity. After completion of the program, walking was the most frequently conducted type of physical activity [38]. A recent study investigated barriers to physical activity in general in patients with T2DM. The most commonly reported barriers were time constraints, fear of provoking additional disorders, exercise venue and weather [39].

Conclusion

Obesity is among the most important determinants of a higher risk for the development of T2DM and may significantly reduce glycemic control in T1DM. The implementation of regular physical exercise is recommended by all international treatment guidelines for diabetes. Whereas the long-term benefits for glycemic control, body composition, and quality

of life are indisputable for both types of diabetes, some aspects of physical exercise remain elusive. Patients treated with insulin have a higher risk for exercise-associated hypoglycemic events, and international guidelines cannot provide sufficient strategies fully addressing this important complication. Moreover, different types of physical exercise are associated with higher glycemic variability, thereby prohibiting its conduct in certain metabolic situations. Further barriers to regular physical activity exist that may exclude diabetic patients from its various benefits. Patients with diabetes should nevertheless be encouraged to participate in regular, consequent physical exercise, which should be supported by proper education, individualized treatment strategies and modern technologies of glucose monitoring.

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Key messages

- Patients with diabetes mellitus profit from physical exercise in a way similar to healthy individuals.
- Physical exercise may increase the risk for hypoglycemic events, especially in patients treated with insulin.
- Patients should be encouraged to participate in regular, consequent physical exercise, which should address patient-specific risk factors.
- Additional carbohydrates and insulin dose reductions may be necessary prior to exercise and have to be individualized, depending on body mass, current capillary blood glucose, circulating insulin concentrations, duration of exercise and exercise intensity.

Lernfragen

1. Welche dieser Antworten ist falsch? (Mehrfachantwort)
 - a) Sport kann allen Patienten mit Diabetes helfen kardiovaskuläre Risikofaktoren zu minimieren.
 - b) Sport verbessert die glykämische Kontrolle bei allen Patienten mit Diabetes.
 - c) Bei Patienten, die mit Insulin behandelt werden, findet optimaler Weise vor dem Sport eine Anpassung der Insulinmenge statt.
 - d) Spontaner Sport ist bei insulinbehandelten Patienten unmöglich.
 - e) Sport hilft immer dabei, Ketonkörper im Blut zu reduzieren und gilt daher als geeignete Therapie im Fall einer Ketonämie.
2. Welche dieser Antworten ist falsch? (Einfachantwort)
 - a) Sport verbessert die Lebensqualität bei Menschen mit Diabetes.
 - a) Sport minimiert kardiovaskuläre Risikofaktoren bei Menschen mit Typ-1-Diabetes.
 - a) Sport verbessert die kardiopulmonale Leistungsfähigkeit bei Menschen mit Typ-2-Diabetes.
 - a) Sport verbessert die glykämische Variabilität bei Menschen mit Typ-1-Diabetes.
 - a) Sport kann abhängig von der Art und Intensität zu Blutzuckeranstiegen führen.



References

1. Collaboration NCDRF: Trends in adult body-mass index in 200 countries from 1975 to 2014: a pooled analysis of 1698 population-based measurement studies with 19.2 million participants. *Lancet* 2016;387:1377-1396.
2. Walls HL, Backholer K, Proietto J, McNeil JJ: Obesity and trends in life expectancy. *J Obesity* 2012;2012:107989.
3. American Diabetes Association: 4. Lifestyle management: Standards of medical care in diabetes-2018. *Diabetes Care* 2018;41(Suppl 1):S38-S50.
4. Riddell MC, Gallen IW, Smart CE, et al.: Exercise management in type 1 diabetes: a consensus statement. *Lancet Diabetes Endocrinol* 2017;5:377-390.
5. Quirk H, Blake H, Tennyson R, Randell TL, Glazebrook C: Physical activity interventions in children and young people with Type 1 diabetes mellitus: a systematic review with meta-analysis. *Diabet Med* 2014;31:1163-1173.

6. Bohn B, Herbst A, Pfeifer M, et al.: Impact of physical activity on glycemic control and prevalence of cardiovascular risk factors in adults with type 1 diabetes: A cross-sectional multicenter study of 18,028 patients. *Diabetes Care* 2015;38:1536-1543.
7. Conway B, Miller RG, Costacou T, et al.: Temporal patterns in overweight and obesity in Type 1 diabetes. *Diabet Med* 2010;27:398-404.
8. Colberg SR, Sigal RJ, Yardley JE, et al.: Physical activity/exercise and diabetes: a position statement of the American Diabetes Association. *Diabetes Care* 2016;39:2065-2079.
9. Holloszy JO: Exercise-induced increase in muscle insulin sensitivity. *J Appl Physiol* 2005;99:338-343.
10. de Ferranti SD, de Boer IH, Fonseca V, et al.: Type 1 diabetes mellitus and cardiovascular disease: a scientific statement from the American Heart Association and American Diabetes Association. *Diabetes Care* 2014;37:2843-2863.
11. Szadkowska A, Madej A, Ziolkowska K, et al.: Gender and Age – Dependent effect of type 1 diabetes on obesity and altered body composition in young adults. *Ann Agric Environ Med* 2015;22:124-128.
12. Russell-Jones D, Khan R: Insulin-associated weight gain in diabetes – causes, effects and coping strategies. *Diabetes Obes Metab* 2007;9:799-812.
13. Valla V: Therapeutics of diabetes mellitus: focus on insulin analogues and insulin pumps. *Exp Diabetes Res* 2010;2010:178372.
14. Jacob AN, Salinas K, Adams-Huet B, Raskin P: Potential causes of weight gain in type 1 diabetes mellitus. *Diabetes Obes Metab* 2006;8:404-411.
15. Effect of intensive diabetes management on macrovascular events and risk factors in the Diabetes Control and Complications Trial. *Am J Cardiol* 1995;75:894-903.
16. Misso ML, Egberts KJ, Page M, O'Connor D, Shaw J: Continuous subcutaneous insulin infusion (CSII) versus multiple insulin injections for type 1 diabetes mellitus. *Cochrane Database Syst Rev* 2010; CD005103.
17. Williams KV, Erbey JR, Becker D, Orchard TJ: Improved glycemic control reduces the impact of weight gain on cardiovascular risk factors in type 1 diabetes. *The Epidemiology of Diabetes Complications Study*. *Diabetes Care* 1999;22:1084-1091.
18. Kennedy A, Nirantharakumar K, Chimen M, et al.: Does exercise improve glycaemic control in type 1 diabetes? A systematic review and meta-analysis. *PLoS One* 2013;8:e58861.
19. Bally L, Kempf P, Zueger T, et al.: Metabolic effects of glucose-fructose co-ingestion compared to glucose alone during exercise in type 1 diabetes. *Nutrients* 2017;9:164.
20. The Diabetes Prevention Program (DPP): Description of lifestyle intervention. 2002;25:2165-2171.
21. Bally L, Zueger T, Pasi N, et al.: Accuracy of continuous glucose monitoring during differing exercise conditions. *Diabetes Res Clin Pract* 2016;112:1-5.
22. Battelino T, Phillip M, Bratina N, et al.: Effect of continuous glucose monitoring on hypoglycemia in type 1 diabetes. *Diabetes Care* 2011;34:795-800.
23. Gillen JB, Little JP, Punthakee Z, et al.: Acute high-intensity interval exercise reduces the postprandial glucose response and prevalence of hyperglycaemia in patients with type 2 diabetes. *Diabetes Obes Metab* 2012;14:575-577.
24. MacLeod SF, Terada T, Chahal BS, Boule NG: Exercise lowers postprandial glucose but not fasting glucose in type 2 diabetes: a meta-analysis of studies using continuous glucose monitoring. *Diabetes Metab Res Rev* 2013;29:593-603.
25. Umpierre D, Ribeiro PA, Kramer CK et al: Physical activity advice only or structured exercise training and association with HbA1c levels in type 2 diabetes: a systematic review and meta-analysis. *JAMA* 2011;305:1790-1799.
26. Umpierre D, Ribeiro PA, Schaan BD, Ribeiro JP: Volume of supervised exercise training impacts glycaemic control in patients with type 2 diabetes: a systematic review with meta-regression analysis. *Diabetologia* 2013;56:242-251.
27. Gordon BA, Benson AC, Bird SR, Fraser SF: Resistance training improves metabolic health in type 2 diabetes: a systematic review. *Diabetes Res Clin Pract* 2009;83:157-175.
28. Dunstan DW, Daly RM, Owen N et al: High-intensity resistance training improves glycemic control in older patients with type 2 diabetes. *Diabetes Care* 2002;25:1729-1736.
29. Castaneda C, Layne JE, Munoz-Orians L et al: A randomized controlled trial of resistance exercise training to improve glycemic control in older adults with type 2 diabetes. *Diabetes Care* 2002;25:2335-2341.
30. Kelley GA, Kelley KS: Effects of aerobic exercise on lipids and lipoproteins in adults with type 2 diabetes: a meta-analysis of randomized-controlled trials. *Public Health* 2007;121:643-655.
31. Thomas DE, Elliott EJ, Naughton GA: Exercise for type 2 diabetes mellitus. *Cochrane Database Syst Rev* 2006;CD002968.
32. Hayashino Y, Jackson JL, Fukumori N, Nakamura F, Fukuhara S: Effects of supervised exercise on lipid profiles and blood pressure control in people with type 2 diabetes mellitus: a meta-analysis of randomized controlled trials. *Diabetes Res Clin Pract* 2012;98:349-360.
33. Segal KR, Pi-Sunyer FX: Exercise and obesity. *Med Clin North Am* 1989;73:217-236.
34. Kodama S, Saito K, Tanaka S, et al.: Cardiorespiratory fitness as a quantitative predictor of all-cause mortality and cardiovascular events in healthy men and women: a meta-analysis. *JAMA* 2009;301:2024-2035.
35. Gregg EW, Gerzoff RB, Caspersen CJ, Williamson DF, Narayan KM: Relationship of walking to mortality among US adults with diabetes. *Arch Intern Med* 2003;163:1440-1447.
36. Kodama S, Tanaka S, Heianza Y et al: Association between physical activity and risk of all-cause mortality and cardiovascular disease in patients with diabetes: a meta-analysis. *Diabetes Care* 2013;36:471-479.
37. Johnston CA, Moreno JP, Foreyt JP: Cardiovascular effects of intensive lifestyle intervention in type 2 diabetes. *Curr Atheroscler Rep* 2014;16:457.
38. Casey D, De Civita M, Dasgupta K: Understanding physical activity facilitators and barriers during and following a supervised exercise programme in Type 2 diabetes: a qualitative study. *Diabet Med* 2010;27:79-84.
39. Adeniyi AF, Anjana RM, Weber MB: Global account of barriers and facilitators of physical activity among patients with diabetes mellitus: a narrative review of the literature. *Curr Diabetes Rev* 2016;12:440-448.

Antworten zu den Lernfragen:
 Frage 1: Antworten b), d) und e) sind richtig.
 Frage 2: Antwort d) ist richtig.

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