The treatment of diabetes involves ensuring adequate delivery of fuel to muscle. During exercise, particularly in elite athletes, this can be a particular challenge. However, due to new insulins and technology we are better able to help athletes with diabetes succeed. This talk will discuss the barriers to exercise and competition in individuals with diabetes, and will detail approaches to overcome them. Case studies of successful athletes will be discussed and conclusions for helping all individuals with type 1 diabetes achieve their goals will be shared.

References:


HELPING ENDURANCE ATHLETES MANAGE DIABETES

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Disclosure of Potential Conflicts of Interest

Consultantship
• Abbott Diabetes Care
• Astra Zeneca
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• NovoNordisk
• Omada Health
• OptumRX

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• Dexcom

Hypoglycemia in the 2010 Olympics
From Kris Freeman’s Blog

Kris Freeman Blog: After the 2010 Olympics

Given the promising way the season started and the dismal way it developed I am a serious contender for the most volatile and inconsistent skier on the world cup. Recognizing this I am going back to the drawing board on my diabetes care regimen. I have already been fitted with the latest Dexcom continuous glucose monitor and thus far it seems very promising... Over the past two years I had such tunnel vision towards the Olympics that I stopped integrating new developments in diabetes treatment into my glucose management. I was more focused on training. Clearly this was a mistake. I cannot fully utilize my training when I have glucose issues.

Kris Freeman Data

Since the Olympics I have been formulating a strategy for my insulin dosing... I decided... to do 4-6 time-trials... I set my basal insulin at my current rate which is 0.5 units per hour. I planned to ski 30k with the first 20k at just above threshold with maximal effort over the last 10k... My hypothesis was that my blood glucose would remain constant for the first 20k and then rise over the last 10k due to the anaerobic nature of a maximal effort. To my surprise my glucose remained constant throughout the effort. I fed an average of 10 ounces of Gatorade per 5 kilometers.
Racing with diabetes presents many challenges but simply living on the road can be difficult as well. It is well documented that I had some severe low blood sugar while I was racing last year but to compound that I was also having low sugar while at rest. It was not uncommon for me to have sugars falling into the 50’s during travel or while sleeping. Having low blood sugar wastes adrenaline and leads to long term fatigue.

Nov 2010 blog http://blogs.fasterskier.com/krisfreeman/

Why Should People with Diabetes Exercise?

- Same potential benefits as for people without diabetes
- Plus added benefits of improving insulin sensitivity and possibly improving BG control

Diabetes Care 39:2065-2079, 2016

What Are the General Recommendations?

- All adults should decrease the amount of time spent in daily sedentary behavior
- Prolonged sitting should be interrupted with bouts of light activity every 30 minutes for glucose benefits
- Additionally, daily structured exercise, not allowing more than 2 days to elapse between exercise sessions, is recommended to enhance insulin action.
- Ideally exercise should consist of both aerobic and resistance training

Diabetes Care 39:2065-2079, 2016
**Additional Recommendations for T1D**

- Blood glucose responses to PA in all people with type 1 diabetes are highly variable based on activity type/timing and require different adjustments.
- May need adjustments in carbohydrate intake and/or insulin requirements.
- Technology can help.

*Diabetes Care* 39:2065-2079, 2016

**Exercise Challenges for Individuals with Diabetes**

- Varying workouts—type/duration/intensity
- Different responses to training vs competition
- Unpredictability
- Risk for hypoglycemia
- Impact of hyperglycemia on performance
- Physical factors (sweat/water/heat/cold)
- Everything else that impacts individuals without diabetes…

**Exercise Physiology 101**

- Muscles use glucose as primary energy source initially—this comes from muscle glycogen stores.
- Once these sources are depleted there is a balance between glucose production (mostly from hepatic glycogenolysis) and glucose uptake by exercising muscle.
- Immediately post-exercise there is a rapid decrease in catecholamines and increase in insulin levels with restoration of muscle glycogen.

Gallen IW et al. *Diabetes, Obesity and Metabolism* 13:130-136, 2011

**Muscle Glucose Uptake**


*Rose, A. J., & Richter, E. A.* *Physiology*, 2015

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**Gary Hall: Learning About Swimming**

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**Why Not Race?**
Typical Training Day Meal for Michael Phelps

Michael Phelps eats 12,000 calories a day — six times what a normal adult male eats. After waking up at 4 a.m., a typical day’s meals of meals for the Olympic gold medalist continue:

**BREAKFAST**
- 1 hour before exercise
- Oatmeal with fresh fruit
- Greek yogurt
- 2 eggs

**LUNCH**
- 1 hour before exercise
- Grilled chicken salad with mixed greens
- Quinoa side dish
- 2 slices of whole wheat bread

**DINNER**
- 1 hour before exercise
- Grilled fish with vegetable medley
- Brown rice
- Mixed vegetables

Nutrition

Gary Hall, Jr: Training Day
600 gm carbs

<table>
<thead>
<tr>
<th>Time</th>
<th>Fasting</th>
<th>Post-E</th>
<th>Lunch</th>
<th>Snack</th>
<th>Pre-D</th>
<th>Bedtime</th>
</tr>
</thead>
<tbody>
<tr>
<td>BG</td>
<td>140</td>
<td>110</td>
<td>165</td>
<td>190</td>
<td>190</td>
<td>190</td>
</tr>
<tr>
<td>Carbs</td>
<td>30 gm</td>
<td>30 - 60 gm</td>
<td>160 gm</td>
<td>15 - 45 gm</td>
<td>60 gm</td>
<td>160 gm</td>
</tr>
<tr>
<td>Insulin</td>
<td>1/15 g</td>
<td>3/30</td>
<td>Dual</td>
<td>1/15</td>
<td>1/20</td>
<td>Lantus</td>
</tr>
<tr>
<td>Exercise</td>
<td>Swim laps</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>35 Lantus</td>
</tr>
</tbody>
</table>

Fit the Therapy to the Patient

Biphasic Effect of Exercise on Glucose Requirements in Adolescents with T1 DM
*Euglycemic Clamp Study*

Adjustments for Exercise

- Patients with type 1 diabetes on ultralente insulin and preprandial lispro insulin were studied.
- 90 minute postprandial exercise for 30 - 60 minutes at 25%, 50% and 75% VO$_{2\text{max}}$ was performed
- Insulin doses given at 100%, 50% or 25% of the current dose of lispro (~1 unit/10 g CHO)

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Results: One Example

![Graph showing changes in glu from baseline (mg/dl) over time during exercise at 50% VO$_{2\text{max}}$ for 30 min]

Guidelines for the reduction in premeal RA dose

<table>
<thead>
<tr>
<th>Exercise Intensity (%VO$_{2\text{max}}$)</th>
<th>% Dose Reduction</th>
<th>30 min</th>
<th>60 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>25</td>
<td>50</td>
<td></td>
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<tr>
<td>50</td>
<td>50</td>
<td>75</td>
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<td>75</td>
<td>75</td>
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</tbody>
</table>

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Sensor Rate-of-Change Guided CHO Algorithm for Exercising Youth with T1DM

![Graph showing sensor rate-of-change guided CHO algorithm for exercising youth with T1DM]

**Protocol A**
- If BG <90 mg/dL, take 10 g CHO.
- If BG 90-108 mg/dL, take 20 g CHO.
- If BG 109-124 mg/dL, take 30 g CHO.

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York University/Diabetes Hope Foundation-Diabetes Youth Sports Camp

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<90 mg/dL 90-108 mg/dL 109-124 mg/dL

Sensor rate of change indicates...
BG Level at Start of Exercise

Starting glycemia below target (<90 mg/dl)
- Ingest 10-20 g of glucose before starting exercise
- Delay exercise until BG >90 mg/dl and monitor closely for hypoglycemia

Starting glycemia near target (90-124 mg/dl)
- Ingest 10 g of glucose before starting aerobic exercise
- Anaerobic exercise and high intensity interval training sessions can be started

Starting glycemia at target level (124-180 mg/dl)
- Aerobic exercise can be started
- Anaerobic exercise and high intensity interval training sessions can be started but glucose concentrations could rise

Starting glycemia slightly above target (180-270 mg/dl)
- Aerobic exercise can be started
- Anaerobic exercise and high intensity interval training sessions can be started but glucose concentrations could rise

Starting glycemia above target (>270 mg/dl)
- If the hyperglycemia is unexplained, check blood ketones. If ketones modestly elevated (0.6-1.4 mmol/L), limit exercise to a light intensity for a brief duration (<30 min). A small pre-exercise corrective dose of insulin might be needed. If blood ketones >1.5 mmol/L, exercise is contraindicated and glucose management should be initiated rapidly by the patients diabetes health care team.

CHO Intake Before, During, and After Exercise

<table>
<thead>
<tr>
<th>Endurance exercise in athletes with and without diabetes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meal (low fat, low glycemic index) consumed before exercise</td>
</tr>
<tr>
<td>A minimum of 1 g CHO/kg body weight according to exercise intensity and type</td>
</tr>
<tr>
<td>Meal or snack consumed immediately before exercise (high glycemic index)</td>
</tr>
<tr>
<td>No CHO required for performance</td>
</tr>
<tr>
<td>Meal consumed after exercise (up to 30 min)</td>
</tr>
<tr>
<td>No CHO required for performance</td>
</tr>
<tr>
<td>Exercise (30-60 min duration)</td>
</tr>
<tr>
<td>Small amounts of CHO (10-15 g/h) could enhance performance</td>
</tr>
<tr>
<td>Exercise (60-150 min duration)</td>
</tr>
<tr>
<td>30-60 g CHO/h</td>
</tr>
<tr>
<td>Exercise (&gt;150 min); mixture of CHO sources</td>
</tr>
<tr>
<td>60-90 g CHO/h spread across the activity (e.g. 20-30 g CHO q20 min) Use CHO sources that use different gut transporters (e.g. glucose and fructose)</td>
</tr>
</tbody>
</table>

Insulin Adjustments

Prolonged endurance exercise (mainly aerobic)

- Bolus insulin dose reduction at the meal before exercise
  Advised when exercise occurs within ~120 min of bolus dose; the magnitude of reduction varies according to timing, type, duration and intensity of exercise

- Before exercise, basal insulin dose reduction (of ~20%) in patients on MDI
  Useful especially if exercise is done less than every 3 days or if the frequency of exercise is high throughout the day

- Basal nocturnal insulin dose reduction (of ~20%) after exercise in patients on MDI or pumps to avoid night lows
  Particularly important if the exercise was done in the afternoon or early evening

- Temporary basal rate change (for pumpers)
  Basal rate can be suspended during exercise, but keeping some basal delivery is preferred; to take into account insulin pharmacokinetics, a basal rate reduction should occur before exercise (up to 90 min); resume normal basal rate at the end of exercise or later in recovery depending on glucose trends

- Prolonged endurance exercise (predominantly aerobic)

- CHO intake before exercise
  See prior table

- CHO intake during exercise
  Typically up to 60 g/h if no insulin dose adjustments have been made

- CHO intake after exercise
  Useful to reduce the risk of hypoglycemia and improve recovery; might need a reduced bolus insulin dose depending on the length and duration of exercise

- Sprint before or after exercise
  Can help reduce the risk of hypoglycemia

- 20 minute cool down period
  Can help reduce the risk of post-exercise hyperglycemia
Decision Tree for Exercise of >30 Minutes

Is activity being done in fasting or post-absorptive state with low levels of bolus insulin on board?

- Yes
  - Consider basal insulin dose reduction and/or CHO snack
  - Reduce bolus insulin by 25-75% at the meal before exercise depending on the intensity of activity.

- No
  - Consider increased CHO intake at 0.5-1 g/kg/hr based on intensity/duration of exercise and BG levels.

Is the patient on CSII?

- No
  - Consume additional CHO as needed (eg, 20-30 g/h).
  - Consider 20% basal reduction on days with prolonged activity.

- Yes
  - Consume additional CHO as needed (eg, 20-30 g/h).
  - Consider 20% basal reduction on days with prolonged activity.
  - For the first meal after exercise (within 90 min), consider consumption of 1-1.2 g/kg of CHO and reduction of insulin bolus by ~50%; to reduce risk of delayed nocturnal hypoglycemia, reduce overnight basal by 20% or consume a bedtime snack without insulin.

Insulin adjustment for the meal preceding exercise

**Table 3:** Suggested reductions in bolus insulin dose before exercise, based on intensity of exercise, for exercise started within 24 hours of consumption of the meal.

Mean ± SE plasma glucose during the experimental sessions (represented by box) and 60 min of recovery (n = 12 for aerobic exercise and no-exercise control; n = 11 for resistance exercise). □, no-exercise control; ▲, aerobic exercise; ●, resistance exercise; ◆, exercise control; ⡃, no-exercise control; ⡃, aerobic exercise. Mean ± SE glucose as measured by CGM from 1 to 12 h postexercise. □, no-exercise control session; ◆, aerobic exercise session; ▲, resistance exercise session.
Mean ± SE plasma glucose during exercise and recovery for aerobic exercise performed before resistance exercise (AR, dashed line with ○) and resistance exercise performed before aerobic exercise (RA, solid line with ●) (n = 11). Difference from baseline during exercise where P < 0.05. †Difference between conditions where P < 0.05. ‡Change throughout recovery from end-exercise level where P < 0.05.

Mean glucose (n = 12) as measured by continuous glucose monitoring from 1 to 12 h after exercise following aerobic exercise performed before resistance exercise (AR, dashed line) and resistance exercise performed before aerobic exercise (RA, solid line).

Competitive athletes: Prevention of post-exercise hypoglycemia

Food group Recommendations
Carbohydrates* ▪ Amount needed depends on intensity of the exercise ▪ In training camps, consider individual weight and duration of exercise
Proteins ▪ Consume 0.5 g/kg body weight ▪ Cool down muscles slowly to avoid rebound hyperglycaemia and allow gradual glycogen restoration

*There are many schools of thought about replenishing carbohydrates before and after exercise, these are not particularly studied in patients with type 1 diabetes.

Type of exercise Recommendations
Aerobic exercise ▪ Restore with 1 g of carbohydrates/kg body weight/hour of exercise as long as there is no hyperglycemia
Strenuous and exhausting exercise ▪ Restore with 1.5 g of carbohydrates/kg body weight/hour of exercise as long as there is no hyperglycemia
Strength training ▪ Restore with 0.5 g of carbohydrates/kg body weight/hour of exercise as long as there is no hyperglycemia

Proper cool down helps greatly to avoid or mitigate post-exercise hyperglycaemia

Competitive athletes: Prevention of post-exercise hyperglycaemia

- Post exercise hyperglycaemia is very common after a competition and affects many athletes
- There is always much higher chance of developing it when exercise intensity is high during, or at the end of competition*

*High intensity exercise increases catecholamine production stimulating hepatic glucose production and therefore hyperglycaemia. Exercise is always increased during high intensity exercise. Exercise is the major gluconeogenic precursor (new glucose) of the body potentially contributing to hyperglycaemia post exercise

Proper cool down helps greatly to avoid or mitigate post-exercise hyperglycaemia

Recovery and cool down

Early recovery may require:
1. Additional insulin if and/or a cool down period hypoglycaemia
2. Reduced insulin administration at the next meal or an extra snack if hypoglycaemia

Late recovery may require:
1. A low glycemic index snack and/or
2. Reduced basal insulin at bedtime (20%)

Cool down could significantly decrease blood lactate levels which may help to decrease post-exercise hyperglycaemia

Blood lactate concentration equivalent to exercise intensity above LACTATE THRESHOLDS
Blood lactate concentration slightly above RESTING LEVELS

P < 0.01

87.5% cyclists with Type 1 Diabetes finished under No extra insulin was used.
### Strategies For Reducing Hypoglycemia During Exercise

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce pre-exercise bolus insulin</td>
<td>Reduces hypox during and post exercise, reduces CHO requirement</td>
<td>Needs preplanning. Not helpful for late postprandial exercise</td>
</tr>
<tr>
<td>Reduce pre-exercise basal insulin</td>
<td>As above</td>
<td>As above, causes pre-exercise and late postexercise hyperglycemia</td>
</tr>
<tr>
<td>Take extra CHO</td>
<td>Useful for unplanned or prolonged exercise</td>
<td>May not be possible with some sports. Less helpful when weight control important. Can cause hyperglycemia</td>
</tr>
</tbody>
</table>

### Current Opinion in Endocrinology, Diabetes & Obesity 2009, 16:150–155

### Strategies For Reducing Hypoglycemia During Exercise

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-exercise or post-exercise sprint</td>
<td>Reduces hypox following exercise</td>
<td>Effect limited to shorter and less intense exercise. No effect on late hypoglycemia</td>
</tr>
<tr>
<td>Insulin pump therapy</td>
<td>Offers flexibility and rapid change in insulin infusion rates post-exercise</td>
<td>Expensive. May not be practical for contact sports (e.g., rugby/football/judo) and some water sports</td>
</tr>
<tr>
<td>Reducing basal insulin postexercise</td>
<td>Reduces nocturnal hypoglycemia</td>
<td>May cause morning hyperglycemia</td>
</tr>
</tbody>
</table>
How to Adjust Insulin for Aerobic Exercise

- ½ Usual Insulin Dose Meal Before
- 13-30 gm CHO if <130
- 15-30 gm CHO q30 mins
- 30-60 gm snack with ½ usual insulin dose
- Less basal overnight

The End