

The Development of an Exercise Advisor App for Type 1 Diabetes: Digitization Facilitates More Individualized Guidance

Sarah M. McGaugh, MSc¹, Stephanie Edwards, MPH², Howard Wolpert, MD², Dessi P. Zaharieva, PhD³, Nany Gulati, PhD⁴, and Michael C. Riddell, PhD^{1,5} 

Journal of Diabetes Science and Technology
2022, Vol. 16(3) 760–763
© 2020 Diabetes Technology Society



Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/1932296820979811
journals.sagepub.com/home/dst



Abstract

Maintaining blood glucose levels in the target range during exercise can be onerous for people with type 1 diabetes (T1D). Using evidence-based research and consensus guidelines, we developed an exercise advisor app to reduce some of the burden associated with diabetes management during exercise. The app will guide the user on carbohydrate feeding strategies and insulin management strategies before, during, and after exercise and provide targeted and individualized recommendations. As a basis for the recommendations, the decision trees for the app use various factors including the type of insulin regimen, time of activity, previous insulin boluses, and current glucose level. The app is designed to meet the various needs of people with T1D for different activities to promote safe exercise practices.

Keywords

exercise, mobile app, technology, type 1 diabetes

Background

Exercise is an integral part of a healthy lifestyle for people with type 1 diabetes (T1D). Regular exercise helps in achieving better glycemic control and decreases the risk of cardiovascular diseases.^{1–4} Further, it enhances insulin sensitivity and reduces total daily insulin needs.^{5,6} Despite the benefits of regular physical activity for people with T1D,^{5,7,8} health-care professionals believe that the lack of formal education on exercise-related metabolism and limited time are common barriers to prescribing guidance around exercise management.⁹ Although guidelines for exercise management have been published, they are generally not readily accessible to clinicians or people living with T1D.^{5,6,10,11} With low activity levels¹² and an increased prevalence of obesity in this population,¹³ evidence-based exercise strategies^{5,6} need to be easily accessible to people with T1D in their everyday lives. A recent study surveying 1542 adults with T1D found that glucose management during exercise was the most difficult task, with 85% of the people desiring application (app)-based technology to help manage glucose levels during this time.¹⁴ The potential value of digital apps for diabetes self-management has recently been highlighted by consensus reports from the joint European Association for the Study of Diabetes (EASD) and the American Diabetes Association (ADA) Diabetes Technology Working Group.^{15,16} Despite surges in the use of technology by people with T1D,

and their potential to improve HbA1c levels,¹⁷ there are still significant gaps between research and the technology in mobile health for T1D management.¹⁸

Here we describe an app, based on the consensus guidelines for exercise management in T1D,⁶ which aims to provide personalized guidance on insulin dosing and carbohydrate intake strategies for facilitating glucose control around exercise.

Development of the Exercise Advisor App: Decision Tree Structure

In the software development process, the decision tree from published international consensus guidelines⁶ was deconstructed

¹School of Kinesiology and Health Science, York University, Toronto, Ontario, Canada

²Connected Care, Lilly Innovation Center, Cambridge, MA, USA

³Department of Pediatric Endocrinology and Diabetes, Stanford University, School of Medicine, Stanford, CA, USA

⁴Global Scientific Communications, Eli Lilly Services India Pvt. Ltd, Bengaluru, India

⁵LMC Diabetes & Endocrinology, Toronto, Canada

Corresponding Author:

Michael C. Riddell, PhD, School of Kinesiology and Health Science, York University, 4700 Keele St, Toronto, Ontario M3J 1P3, Canada.
Email: mriddell@yorku.ca

and expanded from a total of eight branches to three separate decision trees for aerobic, mixed, and anaerobic exercise with 11, 11, and four pathways, respectively (Supplemental Figure 1). Additional decision-making around insulin management and/or carbohydrate intake is based on user-input glycemic measures at -90, -60, -15 minutes and the users' perceptions of the exercise intensity.

Aerobic Exercise

Whether exercise is planned or spontaneous, the initial recommendation for aerobic exercise (Supplemental Figure 1A) is based on whether a bolus insulin dose has been taken or will be taken within three hours of exercise. If so, a bolus reduction is suggested. The degree of reduction depends on the activity type and time between the meal and exercise. Percent basal rate reductions and carbohydrate feeding strategies are outlined depending on the insulin regimen, time of activity, previous boluses, and current glucose level. Starting glucose levels at exercise onset are an important determinant of the suggested guidelines,¹⁹ for example, if a user has hyperglycemia prior to exercise, a bolus reduction or basal rate reduction may not be necessary.

Anaerobic Exercise

For anaerobic exercise (Supplemental Figure 1B), the guidelines are determined by the current glucose level and if the user is on multiple daily injections (MDIs) or continuous subcutaneous insulin infusion (CSII) therapy. Intense anaerobic exercise may result in hyperglycemia,^{20,21} and therefore, insulin dose reductions are not recommended; however, those on CSII have the ability to increase their basal rate temporarily (by ~20%) in situations of elevated glycemia pre-exercise. Carbohydrate supplementation is only promoted if the glucose level is below the target range (<90 mg/dL).

Mixed Exercise

Mixed exercise (Supplemental Figure 1C) is a combination of the aerobic and anaerobic exercise decision trees, although the order of exercise may be altered. For example, the anaerobic exercise would be prompted first if the user's glucose level is at or below the target range, but if the glucose level is above the target range, then aerobic activities are prompted first.²²

All three types of activities determine the post-exercise recommendation based on glucose readings.

Uses of the App

- The app may allow insulin users to better self-manage their glycemia for different forms of exercise.
- The app provides insulin dosing and weight-based carbohydrate supplementation recommendations, as

well as preemptive bedtime guidance to help prevent nocturnal hypoglycemia post-exercise.

Design and Functioning of Exercise Advisor App

During the user setup, the type of insulin regimen (CSII or MDI) and type of glucose management (continuous glucose monitoring [CGM] or blood glucose monitoring) are initially identified during the user "onboarding" process. This process automatically adjusts the decision tree algorithm. After setting exercise start and end time, activities are selected from a list provided, already categorized internally as aerobic, anaerobic, or mixed; however, users can change this category for some of the activities by selecting from the terms "steady", "sprint", or "mixed". Exercise prompts prior to anticipated start time are initially based on whether the exercise will occur within 60 minutes of the current time or later. Planning more than 60 minutes ahead (ideally 90 minutes) allows for more advanced planning strategies for basal (and potentially bolus) insulin delivery such that reductions in circulating insulin levels are achievable for aerobic exercise.²³ However, if exercise is within 60 minutes, different strategies are initiated, primarily focusing on carbohydrate feeding. Alternatively, if the user wants to avoid carbohydrate feeding, the app can also promote activities that tend not to promote a large drop in glycemia. If scheduling allows, pre-exercise prompts alert users at specific times (ie, meal before exercise, T-90 minutes, T-60 minutes, T-15 minutes) to adjust the recommendations according to their glucose level and estimated active/on-board insulin. The app sets a recommended target blood glucose level for each activity type, visually showing the user whether they are within, below, or above their target glucose level; basic insulin and/or starting point strategies; and a summary learnings screen (Figure 1A-1D). For example, during the 15-minute pre-activity glucose check-in, if the blood glucose level is between 151 and 250 mg/dL, the app will alert the user by displaying the message "consider aerobic warmup."

The main screen of the app shows the timing of the expected activity, current, and target glucose levels, active carbohydrates, as well as insights of what measures should be taken for safe exercise to occur. If these suggestions are not confirmed in the app, the recommendations are changed. Furthermore, depending on the pre-exercise glucose level, the app automatically recommends several activities that generally minimize the need for carbohydrate snacking if blood glucose is in the target range (90-124 mg/dL) or below target (<90 mg/dL). Once the activity commences, a timer starts, allowing the activity to be stopped or extended, if required. After the exercise, personal notes can be recorded to indicate how the user felt about their workout and glycemia (ie, satisfied, dissatisfied). Prompts occur 15 minutes after exercise to provide the user with strategies to support glycemic control in recovery. All logged exercise events are

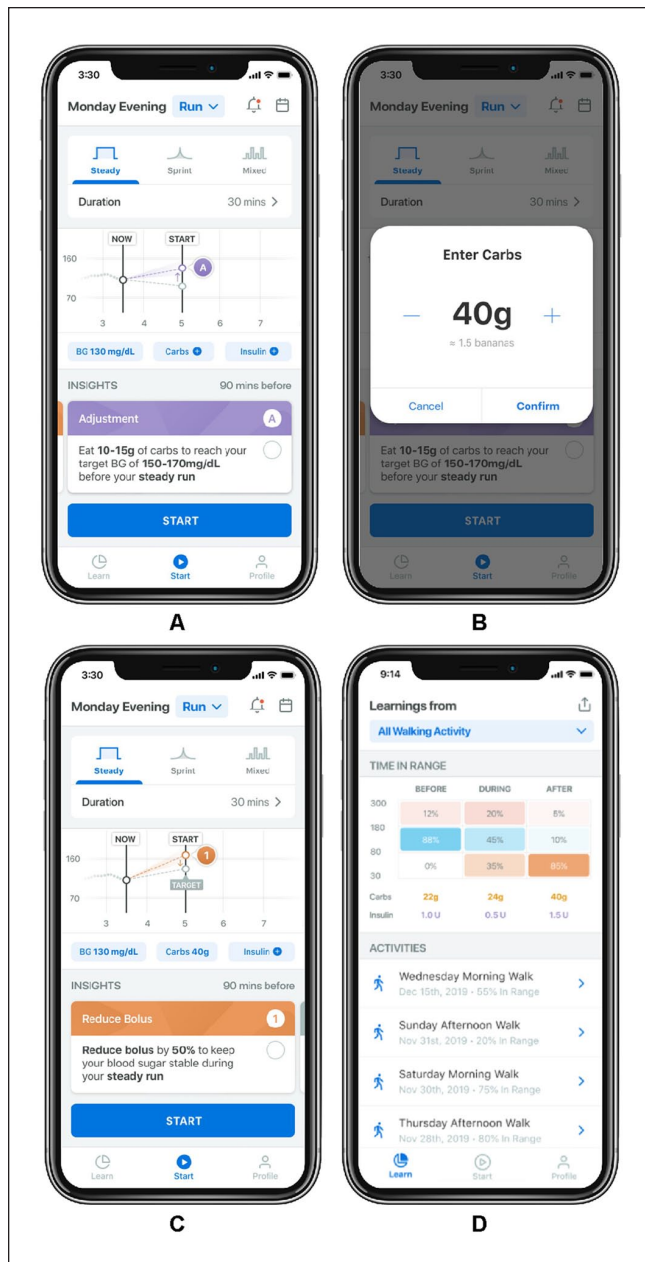


Figure 1. Example screenshots of the prototype exercise application. (A) Example: pre-exercise glucose target and carbohydrate intake recommendation 90 minutes before exercise for an individual below target glucose level prior to a steady state run. (B) Example: carbohydrate intake manual data capture screen. (C) Example: meal bolus reduction prior to a steady state run. (D) Example: learning screen.

recorded and can be reviewed later. Future app iterations may incorporate advanced onboarding features such as individualized insulin settings (e.g., basal rates, insulin to carbohydrate ratio, etc.), integrated CGM, wearable technologies for exercise intensities, and perhaps machine learning technology.

Summary

This prototype personalized exercise advisor app is designed to meet the various needs of people with T1D and addresses an important therapeutic need for the facilitation of exercise. It has been created for people with T1D and requires multiple user inputs; therefore, it might not be an ideal user experience for everyone with diabetes. However, we believe that it is the first step toward better understanding the real-world challenges of managing insulin administration and carbohydrate intake for exercise. With this knowledge and information, there will be opportunities in the future to create more automated activity guidance for everyone with diabetes.

Abbreviations

CGM, continuous glucose monitoring; CSII, continuous subcutaneous insulin infusion; MDI, multiple daily injection; T1D, type 1 diabetes.

Acknowledgements

The authors would like to thank Healthmade for their design ideas for the current version of the smart phone application.


Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: SMM has no conflict of interest. HW and SSE are employees and stockholders of Eli Lilly and Company. DPZ has received speaking honoraria from Medtronic, Ascensia Diabetes Care, and Insulet. NG is an employee of Eli Lilly Services India Pvt. Ltd. MCR has received speakers' fees from Eli Lilly, Novo Nordisk, Medtronic, Dexcom, and Insulet.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was funded by Lilly Innovation.

ORCID iD

Michael C. Riddell  <https://orcid.org/0000-0001-6556-7559>

Supplemental Material

Supplemental material for this article is available online.

References

1. Wu N, Bredin SSD, Guan Y, et al. Cardiovascular health benefits of exercise training in persons living with type 1 diabetes: a systematic review and meta-analysis. *J Clin Med*. 2019;8(2):253.
2. Joyner MJ, Green DJ. Exercise protects the cardiovascular system: effects beyond traditional risk factors. *J Physiol (Lond)*. 2009;587(Pt 23):5551-5558.
3. Lambers S, Van Laethem C, Van Acker K, Calders P. Influence of combined exercise training on indices of obesity, diabetes

- and cardiovascular risk in type 2 diabetes patients. *Clin Rehabil.* 2008;22(6):483-492.
4. Codella R, Terruzzi I, Luz L. Why should people with type 1 diabetes exercise regularly? *Acta Diabetol.* 2017;54(7):615-630.
 5. 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(11):2065-2079.
 6. Riddell MC, Gallen IW, Smart CE, et al. Exercise management in type 1 diabetes: a consensus statement. *Lancet Diabetes Endocrinol.* 2017;5(5):377-390.
 7. Acosta-Manzano P, Rodriguez-Ayllon M, Acosta FM, Niederseer D, Niebauer J. Beyond general resistance training. Hypertrophy versus muscular endurance training as therapeutic interventions in adults with type 2 diabetes mellitus: a systematic review and meta-analysis. *Obes Rev.* 2020;21(6):e13007.
 8. Ostman C, Jewiss D, King N, Smart NA. Clinical outcomes to exercise training in type 1 diabetes: a systematic review and meta-analysis. *Diabetes Res Clin Pract.* 2018;139:380-391.
 9. Kime N, Pringle A, Zwolinsky S, Vishnubala D. How prepared are healthcare professionals for delivering physical activity guidance to those with diabetes? A formative evaluation. *BMC Health Serv Res.* 2020;20(1):8.
 10. Diabetes Canada Clinical Practice Guidelines Expert Committee. *Can J Diabetes.* 2018;42(Suppl 1):S54-S63.
 11. Adolfsson P, Riddell MC, Taplin CE, et al. ISPAD Clinical Practice Consensus Guidelines 2018: exercise in children and adolescents with diabetes. *Pediatr Diabetes.* 2018;19(Suppl 27):205-226.
 12. McCarthy MM, Funk M, Grey M. Cardiovascular health in adults with type 1 diabetes. *Prev Med.* 2016;91:138-143.
 13. Conway B, Miller RG, Costacou T, et al. Temporal patterns in overweight and obesity in type 1 diabetes. *Diabet Med.* 2010;27(4):398-404.
 14. Wilson LM, Tyler N, Jacobs PG, et al. Patient input for design of a decision support smartphone application for type 1 diabetes. *J Diabetes Sci Technol.* 2019;67:991.
 15. Fleming GA, Petrie JR, Bergenstal RM, Holl RW, Peters AL, Heinemann L. Diabetes digital app technology: benefits, challenges, and recommendations. A consensus report by the European Association for the Study of Diabetes (EASD) and the American Diabetes Association (ADA) Diabetes Technology Working Group. *Diabetes Care.* 2020;43(1):250-260.
 16. Fleming GA, Petrie JR, Bergenstal RM, Holl RW, Peters AL, Heinemann L. Diabetes digital app technology: benefits, challenges, and recommendations. A consensus report by the European Association for the Study of Diabetes (EASD) and the American Diabetes Association (ADA) Diabetes Technology Working Group. *Diabetologia.* 2020;63(2):229-241.
 17. Martos-Cabrera MB, Velando-Soriano A, Pradas-Hernández L, et al. Smartphones and apps to control glycosylated hemoglobin (HbA1c) level in diabetes: a systematic review and meta-analysis. *J Clin Med.* 2020;9:3.
 18. Martinez-Millana A, Jarones E, Fernandez-Llatas C, Hartvigsen G, Traver V. App features for type 1 diabetes support and patient empowerment: systematic literature review and benchmark comparison. *JMIR Mhealth Uhealth.* 2018;6(11):e12237.
 19. Riddell MC, Zaharieva DP, Tansey M, et al. Individual glucose responses to prolonged moderate intensity aerobic exercise in adolescents with type 1 diabetes: the higher they start, the harder they fall. *Pediatr Diabetes.* 2019;20(1):99-106.
 20. Aronson R, Brown RE, Li A, Riddell MC. Optimal insulin correction factor in post-high-intensity exercise hyperglycemia in adults with type 1 diabetes: the FIT study. *Diabetes Care.* 2019;42(1):10-16.
 21. Riddell M, Perkins BA. Exercise and glucose metabolism in persons with diabetes mellitus: perspectives on the role for continuous glucose monitoring. *J Diab Sci Technol.* 2009;3(4):914-923.
 22. Yardley JE, Kenny GP, Perkins BA, et al. Effects of performing resistance exercise before versus after aerobic exercise on glycemia in type 1 diabetes. *Diabetes Care.* 2012;35(4):669-675.
 23. Zaharieva DP, McGaugh S, Pooni R, Vienneau T, Ly T, Riddell MC. Improved open-loop glucose control with basal insulin reduction 90 minutes before aerobic exercise in patients with type 1 diabetes on continuous subcutaneous insulin infusion. *Diabetes Care.* 2019;42(5):824-831.