Help! Someone Is Beeping . . .

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At the American Diabetes Association annual meeting a couple of years ago, Dr Timothy Bailey was giving a presentation on continuous glucose monitors (CGMs) to a few hundred physicians, clinicians, and researchers. From the speaker's podium he heard beeps somewhere in the audience and immediately recognized from the characteristic spacing of the beeps that someone wearing a CGM was hypoglycemic. Beeping is relatively nondirectional, so many diabetes professionals with diabetes in the back of the room began slapping pockets and rustling bags to check their own CGM monitors. The source of the beeping only became clear later when someone in the middle of a row near the back of the room slipped out of their chair. With the source identified, nearby clinicians could then assist with glucose gel and call paramedics who took over care of the recovering but disoriented person.

CGMs are marvelous medical devices that report the wearer's glucose level from a sensor under the skin attached to a transmitter sent wirelessly to a receiver or controller in a pocket, on a belt or on the screen of an insulin pump. Alerts and alarms in the form of vibrations or beeps from the receiver warn the wearer when a change in the glucose level requires attention. (Alarms bring attention to more critical situations than alerts.) Sometimes, as in the case above, the person wearing the device may not respond to or even hear the beeps, leaving it to those around the person to step in to help. Luckily, the situation surrounding most CGM alarms is less dramatic than the one at the conference.

Unfortunately, excessive device alarms can create alarm fatigue,¹ especially when they are unnecessary, erroneous, or too frequent. This may lead to ignoring critical alarms or turning them off all together.

Issues that surround CGM alarms can be complex for users and others. Perhaps you've sat in a meeting or restaurant close to someone who generates occasional short bursts of beeps. At first you're not sure what the sounds mean but you can't help but notice the beeper's reactions. He may ignore them (that worries you a bit) or go hand fishing for the receiver that is beeping. He could glance at it, press a button, and within a second slip the device back in its usual place. This may be so automatic that he does not seem to realize what he just did.

Another time, the wearer may glance at the device screen and quietly slip a candy or glucose tab out of a pocket or bag

into his mouth. Or he may go fishing in another pocket for an insulin pump to see if that is beeping and then press a button or two on the pump to deliver a bolus of insulin. Less commonly, the person beeping might be acting oddly or unresponsive as in the case above, and you or someone else calls 911. If this scenario happens on a plane flight and imaginations go wild, people nearby may start to wonder if the devices and beeps signal a terrorist, especially if the wearer is acting erratically from hypoglycemia.

On a more personal level, imagine you are the wife, husband, or significant other of a CGM wearer and you hear beeping in the middle of the night. As a type 3 diabetic (support person), you have a goal to understand the alarms and assist in a successful resolution so both of you can go back to sleep. But first you have to notice the alarm, select it from a variety of similar sounds, identify what it means, and then communicate with the person beeping to see if he or she is awake and responding appropriately.

Decision trees spring up. Is this the first time the low or high glucose alarm has sounded? Do you need to awaken the person to eat or take a bolus? Did the person hear an earlier set of beeps while you were asleep and already consumed carbs and gone back to sleep? Is the beeping simply a repetition of the low glucose alarm even though treatment is gradually raising the glucose above the low threshold? Is the alarm coming from an insulin pump alerting that the cartridge is low? Is a vibration that awakens you coming from the CGM or from a jackhammer being used to repair a broken water pipe down the street? Maybe the beeping is just a false positive with the CGM reading way off, and you can both go back to sleep.

Then there's awakening to a soothing silence in the middle of the night. In the mind of the support person drifting back to sleep, worrisome scenarios may arise: Is the CGM malfunctioning, is the sensor no longer responsive, or has nagging finally caused the wearer to turn the alarms off?

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The daily life of a CGM wearer can be alarming, literally and figuratively. Alarms can occur often and for confusing reasons. They are usually triggered when the glucose level has reached a high or low target preselected by the person and/or his treating physician, such as 80 mg/dL (4.4 mmol/L) to prevent hypoglycemic events or 140 to 200 mg/dL (7.8 to 11.1 mmol/L) to signal hyperglycemia. They can also sound when the glucose is rapidly rising or falling more than 1 to 3 mg/dL per minute (60 to 180 mg/dl per hour), to forecast a high or low glucose and allow the wearer to respond.

Further confusion can be caused by lag times and repetition of alarms. The typical lag time between a person's actual glucose level and the glucose readout on the CGM is generally less than 8 minutes. However, lag times tend to be longer following the treatment of hypoglycemic events when the CGM's algorithm needs extra time to ensure that an upward trend in the glucose has actually begun. During recovery from a low glucose, a series of hypo alarms may occur depending on the glycemic index of the food selected to treat the low glucose. A user may select a shorter time interval between alarms in the CGM settings for earlier recognition if the first alarm is not heard, while someone else may select longer wait times between repetitions to minimize alarm overload.

Another concern with CGM beeps is they compete with multiple sources of noise pollution from refrigerators, clothes dryers, alarm clocks, smart phones, back-up alarms on delivery trucks, GPS navigation devices, and thousands of other sources. Nondirectional sound and similarity of tones make identifying the source and its cause difficult.

CGM alarms can be changed from beeps to more discrete vibrations. Vibrations help when an audible alarm would be too loud for a business meeting, school, or movie theater, but not loud enough to awaken family members. In addition, people may switch alarms off during the night to avoid disruption of their own or others' sleep. A young child may even be instructed to switch off alarms in school by a teacher to minimize disruptions in class.

As well as too loud, alarms can also be too weak to hear during sleep or in a noisy environment or when the wearer is busy or preoccupied. Desperation drives innovation. A clever solution some CGM wearers use is wrapping a rubber band around their CGM set on vibrate to connect to a smartphone that has an earthquake detection app. The vibration from the CGM activates the smart phone alarm that is loud and piercing enough to awaken even a sound sleeper. Other users drop their receiver into a glass on a bedside table to magnify vibrations, sometimes adding glass beads to enhance the sound. Parents may install a baby monitor in their child's room to hear an otherwise inaudible CGM alarm.

Other problems with beeps occur. They often begin at the most inconvenient times, such as during a musical performance or business meeting or right after the CGM wearer starts on a long commute with the receiver inside a purse in the back seat or trapped inside a pocket under the seat belt.

The multiplicity and similarity of alarms is confusing. One stand-alone CGM system lists 17 different reasons for which it will trigger an alert, while a combined pump plus CGM system lists 47 different sources for which an alert may sound to attract the user's attention. The number of alerts is unlikely to decrease as developments progress toward closed loop systems.

Bluetooth technology is about to change the noisy world of CGMs by connecting them to the cloud. A simple vibration switch will be unable to silence cloud noise as CGMs connect through cell phones, computers, and devices in wall sockets and relay glucose data into the cloud. Distant family, friends, and clinicians will suddenly be introduced to the beeping world of diabetes. At what glucose level or pattern of erratic glucose behavior will these people need or want to be notified? Although reimbursement is becoming available for downloading and interpreting CGM data, how much data can clinicians tolerate? Alarm fatigue's cousin, data fatigue, is likely to infect the clinical world unless the data gets summarized and arrives with meaningful solutions.

Suggestions to Improve CGM Alarms

At different times, alarms are essential, nuisances, too loud, not loud enough, or simply turned-off. Although little research into human factors design has occurred in this important area,¹ CGM benefits will be enhanced once we understand how to fit the alarm into the daily lives of people with diabetes and those who live around them. Perception and acceptance of alerts and alarms varies from user to user, so device companies would be wise to allow users to tailor their medical devices to their lifestyle, auditory capacity, and depth of sleep, especially as accuracy and precision continue to improve. Here are a few proposed solutions:

- a. CGM systems could benefit from an algorithm that continually estimates a person's expected glucose value 20 or 30 minutes into the future, along with the current glucose. A simple glycemic speedometer could help avoid acute metabolic deterioration.
- b. Customization of alerts is sorely needed with the encouragement of regulatory bodies. For example, a wearer may not care if his or her glucose is rapidly falling from a level of 360 mg/dL (20 mmol/L) but will want this alarm once his or her glucose reaches 180 or 150 mg/dL (10 or 8.3 mmol/L). Similarly, a rapid rise after treatment of hypoglycemia may not be of interest to a wearer unless the glucose is likely to rise above an upper target. Wearers could be allowed to filter out nuisance alarms and tailor their CGM to their preferences and needs.
- c. For the image conscious, a more discrete alarm could be transferred to the wearer's smart phone when it is in range. Looking at a message on a nonmedical device is more socially acceptable than fishing in a pocket or

- purse for a pump or CGM receiver. Cell-phone-like customizations, including volume controls, would be helpful.
- d. CGMs could allow the user to select the type (sound, vibration, or both) and intensity of alarms for different times of day. For example, a sound sleeper may want maximum volume at night but not while teaching a class.
 - e. Car radios have been able to adjust volume to accommodate environmental noise since the 1980s; why not CGMs?
 - f. For the convenience of many and especially for the visually impaired, talking CGMs could vocalize glucose results and trends.
 - g. For safety, in addition to user selected values, all CGMs could have critical high and low alerts that are locked, such as 55 mg/dL (3 mmol/L) for lows and 300 mg/dL (16.7 mmol/L) for highs. (A low alarm is currently locked in one CGM.)
 - h. Clinicians and trainers can instruct new device wearers in how to overcome annoying, less useful alarms and remind users that the frequency of alarms reduces as they use their CGM data to gradually improve their glucose outcomes.
 - i. Parents, spouses, friends, and support people also require training in how to interpret different alarms independent of the willingness or ability of the wearer to explain the sound at the time it occurs. A handy “CGM Interpretation Card” could be included in training materials to provide clearer risk ratios for each alert and alarm.
 - j. As low-power Bluetooth technology spreads to CGMs, integration of activity monitor data into CGMs may allow better prediction of hypoglycemic events.

Conclusion

A person beeping might sound amusing at first but this can easily become annoying. Careful designs are needed for CGM sounds to minimize glycemic risks and to prevent a type 3 diabetic (support person) from becoming a type 4 (support person, now divorced) after too many sleep

disruptions or interpersonal communication derangements originating from “helpful” medical alerts. Any medical device that produces confusion, uncertainty, or annoyance is not acceptable.

A better understanding of how alerts might be matched to multidecibel environments is needed. This could be merged with additional research regarding the “alarm behavior” of people with diabetes in daily life and how this may be influenced by the external environment, peer pressure, or other reasons why people deal with alarms differently. A survey of CGM wearers regarding any modifications of CGM alarm settings beyond the on or off positions would be productive.

The diabetes world will benefit from newer CGM systems with improved accuracy, better algorithms, and increased options that reduce false-positive alarms, make alarms more meaningful and acceptable, and keep people from switching them off. An open discussion about alarms in general and their usage in daily life is needed to improved health and glycemic control, and more rapidly reduce time spent in hypoglycemia and hyperglycemia. Let’s make CGM alarms less alarming.

Abbreviation

CGM, continuous glucose monitor.

Declaration of Conflicting Interests

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