Contents available at ScienceDirect

Diabetes Research and Clinical Practice

journal homepage: www.elsevier.com/locate/diabres

International Diabetes Federation

Review

Continuous glucose monitoring: A review of the technology and clinical use

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ARTICLE INFO

Article history:
Received 14 March 2017
Received in revised form
27 June 2017
Accepted 8 August 2017
Available online 1 September 2017

Keywords:
CGM
Continuous glucose monitor
Continuous glucose monitoring
Personal
Professional
Sensor integrated insulin pump

ABSTRACT

Continuous glucose monitoring (CGM) is an increasingly adopted technology for insulin-requiring patients that provides insights into glycemic fluctuations. CGM can assist patients in managing their diabetes with lifestyle and medication adjustments. This article provides an overview of the technical and clinical features of CGM based on a review of articles in PubMed on CGM from 1999 through January 31, 2017. A detailed description is presented of three professional (retrospective), three personal (real-time) continuous glucose monitors, and three sensor integrated pumps (consisting of a sensor and pump that communicate with each other to determine an optimal insulin dose and adjust the delivery of insulin) that are currently available in United States. We have reviewed outpatient CGM outcomes, focusing on hemoglobin A1c (A1C), hypoglycemia, and quality of life. Issues affecting accuracy, detection of glycemic variability, strategies for optimal use, as well as cybersecurity and future directions for sensor design and use are discussed. In conclusion, CGM is an important tool for monitoring diabetes that has been shown to improve outcomes in patients with type 1 diabetes mellitus. Given currently available data and technological developments, we believe that with appropriate patient education, CGM can also be considered for other patient populations.

Contents

Abbreviations: ADRR, average daily risk range; BG, blood glucose; CGM, Continuous glucose monitoring; DM, diabetes mellitus; HBGI, high blood glucose index; HCP, health care professional; ISF, interstitial fluid; LBGI, low blood glucose index; MARD, Mean Absolute Relative Difference; RCT, randomized controlled trial; SMBG, self-monitoring of blood glucose; QoL, quality of life

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https://doi.org/10.1016/j.diabres.2017.08.005
0168-8227/

1. Introduction

Continuous glucose monitoring (CGM) is an increasingly adopted technology for insulin-requiring patients. CGM uniquely provides insights into glycemia that assist patients in managing their diabetes with appropriate lifestyle and medication adjustments. This article provides an overview of the technical aspects and clinical considerations for using continuous glucose monitoring.

2. Literature review

We reviewed articles in PubMed on continuous glucose monitoring from 1999 through January 31, 2017. We cross referenced the topics technology, lag, alarm, outcomes, glycemic variability, accuracy, and cybersecurity. We reviewed the latest practice guidelines regarding use of CGM from the Endocrine Society, the American Diabetes Association (ADA), and the American Association of Clinical Endocrinologists (AACE). Randomized controlled trials were referenced. We performed a search on Google for FDA-cleared CGM products that were available as of January 31, 2017.

3. Definition

A continuous glucose monitor is a wearable body sensor that automatically and repeatedly measures glucose at regular intervals (ranging from every 5 to 15 min) from a defined body fluid, such as interstitial fluid (ISF). A CGM usually consists of three components: (1) a wearable sensor; (2) a transmitter that wirelessly sends readings to (3) a receiver nearby that displays such readings to the user. Patients or their health care professionals (HCPs) utilize the glycemic patterns visualized by a CGM to make lifestyle or medication changes to best improve their blood sugar control (with confirmation by a capillary glucose test if this step is mandated on the product label).

4. Technologies

Currently approved CGMs use an enzymatic technology that reacts with ISF glucose molecules liberating an electron for each glucose molecule and transferring it (using Oxygen as a cofactor) to an electrode where an electric current is generated. This electric current (proportional to the glucose concentration) is then relayed from a transmitter attached to the sensor out to a reader (wirelessly) or a computer (via cable) which displays the data to the patient. The reader can display the results directly to the patient or can send the information wirelessly to the cloud for a patient, an HCP, or an authorized caregiver to view the results on a computer or a reader through a secure personal website.

Of note, the cofactors of glucose oxidase that are used by CGM compete with tissue oxygen and can therefore overestimate the glucose concentration in cases of hypoxia [1]. This vulnerability to hypoxia was formerly present in older blood glucose (BG) monitors in the 1990s, but more recent BG monitors utilize an enzyme and cofactor that do not require oxygen to accept electrons from glucose. These so-called second-generation sensors are not affected by hypoxemia, but their cofactors are toxic and cannot be implanted. Therefore, current CGMs continue to use first generation enzymes and cofactors. Third generation sensors are being developed that will not require any cofactor to accept liberated electrons, and such Oxygen- independent sensors could be implanted without toxicity or dependence on the ambient ISF Oxygen concentration [2].

Several additional types of long term implanted sensors are under development that measure ISF glucose through various enzymatic, optical, or osmotic technologies. Other researchers are exploring the possibility of non-invasively measuring glucose levels in tears and then converting the concentration to an estimated blood glucose level [3].