Open-source automated insulin delivery: international consensus statement and practical guidance for health-care professionals

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Open-source automated insulin delivery systems, commonly referred to as do-it-yourself automated insulin delivery systems, are examples of user-driven innovation that was co-created and supported by an online community who were directly affected by diabetes. Their uptake continues to increase globally, with current estimates suggesting several thousand active users worldwide. Real-world user-driven evidence is growing and provides insights into safety and effectiveness of these systems. The aim of this consensus statement is two-fold. Firstly, it provides a review of the current evidence, description of the technologies, and discusses the ethics and legal considerations for these systems from an international perspective. Secondly, it provides a much-needed international health-care consensus supporting the implementation of open-source systems in clinical settings, with detailed clinical guidance. This consensus also provides important recommendations for key stakeholders that are involved in diabetes technologies, including developers, regulators, and industry, and provides medico-legal and ethical support for patient-driven, open-source innovations.

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Introduction

Advances in treatments and technologies have notably improved care for people with diabetes. However, a substantial proportion of people with diabetes are still unable to reach the recommended treatment targets and frequently experience hypoglycaemia and hyperglycaemia, reducing their day-to-day function and exposing them to future medical and psychological complications. Automated insulin delivery (AID) systems, also called closed-loop or artificial pancreas systems, automatically adjust some aspects of insulin dosing by use of an algorithm in response to continuous data from a glucose sensor, data from an insulin pump along with additional information.[1] These systems are safe and effective in increasing time in range (TIR), minimising variability in glucose concentrations detected by continuous glucose monitoring (CGM) sensors and hypoglycaemia in people with diabetes of various ages under many conditions.[2–12]

Despite the notable research and commercial drives, given the lengthy and complex development and approval processes, few AID systems have been approved by regulators. These commercial systems are constrained by device ecosystem options and are not universally available, as approval, access, regulatory, and reimbursement policies for diabetes technologies vary considerably between countries.

Given these limitations, open-source automated insulin delivery (ie, open-source AID) systems have been co-created and supported by online communities who are directly affected by diabetes. Open-source refers to freely available software code. Although some people describe these systems as do-it-yourself, we prefer the term open-source, given the collaborative effort.

These communities have created accessible resources that provide detailed instructions for set-up and use. We estimate that over 10 000 individuals worldwide are using open-source AID systems, and uptake continues to increase globally.[13] Despite their increasing use, there is no professional guidance available for health-care professionals to support their use in clinical settings.[14] Although no evidence exists from randomised control trials (RCTs), real-world observational outcomes indicate effectiveness and safety for these systems,[15–21] with improved quality of life and sleep quality in people who use open-source AID systems.[18,22–26] Nevertheless, there are limitations in the evidence, with potential for selection bias, as detailed in this manuscript.

As with commercial systems, the control strategies that are used by open-source algorithms vary. Open-source AID systems are designed for considerable user customisation, making a direct comparison of the available systems challenging. Additionally, experts, patient organisations, and diabetes charity position statements from different regions provide variable opinions on the legal position of open-source AID systems for health-care professionals.[27–32] As a result, many health-care teams worldwide are uncertain how to best support people with diabetes who are using open-source AID systems in clinical care.

This international consensus statement and practical guidance review provides detailed recommendations for health-care professionals caring for individuals with diabetes who are using open-source AID systems. We consider evidence on effectiveness of AID systems, user-reported outcomes and lived experiences, safety aspects, potential limitations, and challenges that are associated with open-source AID systems; ethical and legal factors; and hands-on advice on how to provide support to health-care professionals in clinical practice. Although we do not universally recommend the use of open-source over

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commercial AID systems, we propose that the best interest of the individual should be balanced against the risks of using open-source AID systems.[19,23,33–39]

Methods

KB, RAL, and SH formed a steering and writing committee of health-care professionals (ie, endocrinologists, educators, exercise physiologists, and psychologists with clinical experience in open-source AID systems or publication track record on this topic) in February, 2020, to develop best practice guidance and statements that are up to date. An international group of 44 health-care professionals and four legal experts with clinical experience and expertise on the topic of open-source AID systems, from over 20 countries across several global regions, formed part of a large network of health-care professionals and a legal network. These networks provided a consensus of this guidance by use of online tools for remote collaboration and real-time feedback. Appraisal was also provided by professional diabetes organisations, including the International Diabetes Federation, International Society for Pediatric and Adolescent Diabetes, and other diabetes professional organisations.

Overview of open-source AID systems

For more on the **Loop algorithm** see https://loopdocs.org

For more on **OpenAPS** see https://openaps.org

See **Online** for appendix

For more on **AndroidAPS** see https://androidaps.readthedocs.io

For more on **Nightscout** see https://www.nightscout.info

Several open-source AID algorithms exist: oref0–oref1 and the Loop algorithm. OpenAPS implements oref0–oref1 in a program that runs on a Linux-based mini-computer (appendix p 5), whereas AndroidAPS executes oref0–oref1 on an Android app (appendix p 6) and FreeAPS X implements oref0–oref1 on an iPhone. The Loop algorithm is implemented in the iOS app Loop (appendix p 7, table).

The development of the first open-source AID system, OpenAPS, proceeded from the acquisition of CGM data (initially provided through Nightscout) and the ability to send remote commands to an insulin pump (ie, first shown on a Minimed pump in 2011 at a security conference). This ability to send arbitrary commands to a commercial insulin pump facilitated the development of algorithms that are focused on safety, which were initially designed to predict and then prevent hypoglycaemia. These algorithms eventually became OpenAPS, which aimed to reduce both hypoglycaemia and hyperglycaemia. When AndroidAPS and Loop became available in 2015, they shifted the user interface to smartphones. All three open-source AID systems were in use before the first commercial AID system received US Food and Drug Administration (FDA) approval in 2016.

Since then, open-source AID technology has kept pace with new CGM devices and is compatible with a broad range of insulin pumps, enabling a range of device options (table). The possible combinations are constantly growing and allow flexibility and customisation to users who might prefer (or require) interoperability that is not offered via current commercial systems. They also enable specific functionalities, real-time data sharing, use of smartwatches as user interfaces, and remote-control options, which can be particularly appealing to caregivers. Updates to the smartphone user interface might also improve engagement and allow integration with other smartphone features, such as personal calendars, Apple Health, Google Fit, mobile sensors (eg, global positioning system for location-based actions), and smart assistants. Such real-time, personalised, data-driven possibilities are integral to the current trends towards connectivity and data sharing, which can help to reduce the burden for people with diabetes and their caregivers.

Summary of existing evidence

The current scientific literature on open-source AID systems is mainly based on evidence in the real world, which might include different software versions running on a variety of hardware.[40] In addition to glycaemic improvements, there is preliminary evidence that open-source AID systems can have a positive effect on quality of life, sleep quality, fear of hypoglycaemia, and on other aspects of everyday life.[18,22–26] A multinational survey assessing motivations for building an open-source AID system found that improving glycaemic and long-term health outcomes, reducing diabetes distress and burden, and improving sleep quality (especially for caregivers) were almost universal motivators.[25] Lack of access to approved technologies and frustration with available therapies were frequently mentioned. Peer support and mentoring by the community were sources for both technical and emotional support.[24,25,41] Most encounters between users of open-source AID systems and health-care professionals are perceived positively or neutrally, although clinicians might have concerns about the legal aspects of recommending open-source AID systems.[24]

The algorithms that are used in open-source AID systems have been tested in silico[42] with the UVA/Padova type 1 diabetes simulator in different scenarios (eg, with bolus overestimation and underestimation and anticipated and late bolus) and with different glycaemic target settings and features of the open-source algorithm enabled (eg, advanced meal assist and microboli). These few in-silico studies are indicative that open-source AID systems are safe and effective for glycaemic management in most predictable settings. The different open-source algorithms have also been tested against each other in pigs for unannounced meals (ie, where the system is not informed of the food consumed), showing more TIR with comparable hypoglycaemia for AndroidAPS using microboli and unannounced meals than with Loop with integral retrospective correction.[43] Generally, the TIR for open-source AID systems appears to be at least similar to commercially available systems; however, to the best of our knowledge, no head-to-head randomised clinical trial has been conducted against any commercially available systems.

	Open-source AID systems			Commercial AID systems				
	OpenAPS	AndroidAPS	Loop and FreeAPS	Medtronic 670G/770G	Medtronic 780G	Tandem Control IQ	Diabeloop DBLG1	Cam APS FX
Type of closed loop	Hybrid to full	Hybrid to full	Hybrid	Hybrid	Hybrid	Hybrid	Hybrid	Hybrid
Type of algorithm	Heuristic*	Heuristic*	MPC	Proportional-integral-derivative and insulin on board	Basal rate modulation: proportional-integral-derivative, insulin on board; corrections: fuzzy logic	Predictive control (ie, Kalman filter with prediction)	MPC	MPC
Licence status	Open source	Open source	Open source	US FDA and CE mark (for people aged ≥7 years)	CE mark	US FDA and CE mark (for people aged ≥6 years)	CE mark (for people aged ≥22 years, total daily dose <90 units per day)	CE mark (for people aged ≥1 years)
Availability	Worldwide	Worldwide	Worldwide	USA, Canada, Australia, some countries in Latin America, Middle East, Europe, South Africa, and Hong Kong	Some countries in Europe	USA, Canada, some countries in Europe	France	UK
Compatible CGM systems	Dexcom G4, G5, or G6; Medtronic Real-Time Revel and Enlite; other CGM systems and CGM-like devices (eg, FreeStyle Libre with MiaoMiao or BluCon) via Nightscout	Dexcom G4, G5, or G6; FreeStyle Libre (via MiaoMiao, BluCon, or Bubble); FreeStyle Libre 2; Eversense; Medtronic Guardian 2 (via 600 series pump); Medtrum A6; PocTech; Gluco24	Dexcom G4 (with share receiver), G5, or G6; Medtronic Enlite; FreeStyle Libre (via Spike)	Medtronic Guardian 3	Medtronic Guardian 3 and future generation sensors	Dexcom G6 and future generation sensors	Dexcom G6 and future generation sensors	Dexcom G5, G6, and future generation sensors
Compatible insulin pumps	Medtronic 512/712,† 515/715,† 522/722,† 523/723,‡ 554/754§	AccuChek Spirit Combo; AccuChek Insight; Dana R or RS; Medtronic 512/712†, 515/715†, 522/722†, 523/723‡, 554/754§; OmniPod Eros	OmniPod Eros; Medtronic 515/715†, 522/722†, 523/723‡, 554/754§	Medtronic 670G	Medtronic 780G	t:slim X2	Kaleido, AccuChek Insight	Dana RS, Dana-i
Compatible mobile phones	Optional (ie, Android and Apple)	Android	Apple	None for 670G; Apple and Android for 770G (view only, insulin pump cannot be remotely controlled)	Apple and Android (view only, insulin pump cannot be remotely controlled)	None	None	Android (ie, all models compatible with Dexcom G6 app)
Compatible smartwatches	Any	Wear OS by Google	Apple Watch	None	None	None	None	None
Connectivity	900 mHZ (between rig and pump)	BLE*, Bluetooth, RF2BT bridge, NFC2BLE bridge (depending on pump and CGM system)	BLE (between mobile phone and RileyLink), 916 MHz (between RileyLink and Medtronic pump), 433 MHz (between RileyLink and OmniPod)	2·4 GHz	BLE	BLE	BLE, mobile internet connection to cloud via virtual private network	BLE
Required additional hardware for use	Rig (eg, Raspberry Pi or Intel Edison, Explorer Board)	RileyLink (only for Medtronic pumps and Omnipod), otherwise none	RileyLink, EmaLink, OrangeLink, or similar	None	None	None	Dedicated handheld device	None
Required for setup	Any computer	Any computer, Android Studio software	Mac or virtual machine, XCode software, Apple developer licence	NA	NA	Any computer (only for updates)	NA	Compatible Android smartphone

BLE=Bluetooth Low Energy. CGM=continuous glucose monitoring. FDA=Food and Drug Administration. MPC=model predictive control. NA=not applicable. *The heuristic algorithm makes multiple predictions and delivery is altered to ensure that the lowest of these predictions falls in the target range for the individual. †Compatible with all firmware. ‡Compatible with firmware 2·4A or lower. §Worldwide Veo is compatible with firmware 2·6A or lower and Canadian or Australian Veo is compatible with firmware 2·7A or lower.

Table: **Device and ecosystem selection of open-source and available commercial AID systems and their characteristics.**

To date, no safety and efficacy data are available on open-source AID systems from RCTs. A single-centre clinical trial in Poland showed safety and efficacy of the AndroidAPS algorithm used with the Dana Diabecare RS insulin pump (SOOIL, Seoul, South Korea).[44] Further clinical trials are testing open-source AID algorithms that have now been adopted in commercial product development with the intention to obtain regulatory approval.[45,46]

Real-world studies have shown that open-source AID systems are widely used in various regions of the world, including countries where the components of commercial AID systems are not available or are limited by cost or policy.[17,20,25] Observational studies based on user-reported outcomes,[17,20,25] device data,[13,15,16] and data provided by health-care professionals[16,26,47–51] have shown improvements in TIR and HbA_{1c} and a reduction in hypoglycaemia and hyperglycaemia throughout all age groups, including young children, adolescents, and older people (appendix pp 3–4). These studies are limited by the absence of a control group and the possible self-selection bias in the types of participants typically opting to use open-source AID systems (ie, potentially more technologically advanced, higher educated, or with a higher level of self-agency than the general population with type 1 diabetes). In keeping with these factors, a retrospective observational study emphasised higher levels of educational attainment, younger age, and lower HbA_{1c} among users of open-source AID systems than among users of commercial AID systems.[52]

With the right research question, inclusive recruitment, a proper comparator, and training and care that can be reproduced in real-world settings, RCTs can provide strong evidence for interventions. Many countries require national regulatory approval of protocols before conducting RCTs and further regulatory approvals for every device and software iteration. Additionally, RCTs are often expensive and time-consuming to conduct. These constraints make RCTs with open-source AID systems challenging, although some challenges have been overcome to allow a small RCT for one open-source system in New Zealand.[45] Both RCTs and real-world evidence have merits and disadvantages in diabetes research.[53,54] Limitations in population diversity that are imposed by RCT selection constraints and rigorous participant follow-up by investigators are not replicated in real-world clinical use. Therefore, our consensus group supports the view that real-world evidence should also be considered in regulatory decisions and assessing effectiveness and safety of diabetes technologies.

Technicalities of open-source and commercial AID systems

Since the launch of Medtronic's 670G system in 2016, further commercial AID systems have been approved in selected countries (table). Having one company responsible for the creation of the CGM device, insulin pump, and algorithm is a challenging and expensive endeavour. Thus, the FDA has defined three interoperable components: integrated CGM (iCGM) device, alternate controller enabled (ACE) insulin pump, and interoperable automated glycaemic controller (iAGC) to accelerate the development pathway of AID systems. Although it is important to recognise that these designations enable different device manufacturers to work together, no authority exists to enforce cooperation. Without such enforcement, choice in device ecosystems is reduced due to device connectivity and data sharing capabilities (table). At present, commercial AID systems are restricted to particular pump and sensor combinations (table), which might not be covered by all health-care plans and could result in additional costs. As many commercial systems use the insulin pump for user interaction as opposed to a smartphone, they might not have the ability to connect with other devices, placing constraints on data sharing, user interface design, and software updates (table). CamAPS FX app, which received a CE mark in 2020, is the first commercially approved iAGC to use an Android-based smartphone as the interface. The next-generation Medtronic and Insulet pumps[55,56] can be used with the iAGC that is being developed by Tidepool, which uses the Loop algorithm on an Apple smartphone.

Open-source AID systems feature algorithm transparency and ability to rapidly iterate on the systems' technical design and features (eg, adding pharmacodynamic models of newly developed insulins). The ability to customise features related to algorithms and detailed variables offers additional benefits and personalisation. In commercial AID systems, there are constraints on the number of adjustable variables, such as target glucose and insulin absorption models. Although these constraints reduce complexity in system operation, which can reduce burden, they curtail the level of customisation for users who desire or need more flexibility (eg, for exercise, illness, pregnancy, and young children). The specifics of commercial algorithms are also not always detailed in the manufacturer's training materials. Algorithm transparency enables clinicians to assist people with diabetes to understand the risks and benefits, what they can change, and how the system responds to particular situations.

Access and availability

Open-source AID algorithms are available online and freely accessible on the software development platform GitHub. They can be set up on a variety of hardware that are available in a wide range of countries (table). Additional hardware might be needed depending on the particular set-up. A limitation of commercial systems is that their regulatory status and availability is limited to particular regions and groups. They may carry additional costs for the iAGC or require a pump upgrade. Hence, open-source approaches allow AID systems to be used by

people with diabetes who would otherwise be unable to benefit from them.

Safety

Living with diabetes and self-managing insulin therapy inherently carries risk, with both underdelivery and overdelivery of insulin posing potentially substantial health consequences. Existing AID systems, including open-source systems, are developed for optimisation of safety, with the algorithms prioritising avoidance of hypoglycaemia. Any users having problems with an open-source system can report the issue to the development team or community for support. For issues requiring notable code adjustments, new versions are released for general distribution only after thorough testing by the developer team, followed by the release of an experimental development branch to enable some community testing. This community model provides a transparent reporting culture and responsive iterative improvements to safety and effectiveness.

Safety and effectiveness of AID systems rely on accurate readings from glucose sensors.[57] Following a warning by the FDA regarding the use of unauthorised CGM devices in diabetes, we recommend that only sensors exceeding iCGM special controls should be used in the operation of AID systems[58] in regions where iCGM devices are available. Open-source AID systems also require the ability to send commands to insulin pumps, which might be out of warranty and not originally designed to accommodate communication from an external AID controller that is housed on a smartphone. Given the competing interests of security and openness, we recommend that manufacturers give users the option to execute remote commands securely on modern, in-warranty pumps.

All open-source AID algorithms make predictions about future glucose concentrations detected by CGM sensors, which depend on the accuracy of parameters, such as sensitivity factor, carbohydrate-to-insulin ratio, previous basal and bolus insulin delivery, meal specifications, and insulin models. As with any system, should these settings substantially differ from the needs of the individual and true physiology, inappropriate insulin delivery can result. Should the predictions be erroneous, there are several mitigation strategies that are used in open-source AID systems. Within the Loop algorithm, retrospective correction provides adaptation in the short term on the basis of prediction error, and suspend threshold prevents all insulin delivery once the actual or predicted glucose concentration detected by the CGM sensor falls below a specified threshold. In the latest iteration of OpenAPS, several predictions for glucose concentration detected by the CGM sensor are generated and the system acts to prevent the lowest prediction from falling below the target range. Additionally, OpenAPS uses a multitude of adaptive techniques and users can run an autotune program to optimise settings on the basis of model error.

Open-source AID algorithms rely on a model of insulin's effect on glucose (ie, pharmacodynamics) for accurate predictions. Therefore, the duration of insulin action or insulin model, should be set as a true reflection of pharmacodynamics. Some commercial AID systems provide a user-adjustable active insulin time, unique from the pharmacodynamic model, to prevent insulin stacking from repeated boluses. This value can be set to be unrealistically short to allow for aggressive insulin administration. Settings that reflect an individuals response to insulin allow an accurate estimate of insulin on board than do unphysiological settings (eg, a duration of insulin action that is too short), improving modelling and safety.[59]

Connectivity issues, algorithm controller (eg, smartphone or system on chip), and the insulin pump are among the most frequently reported concerns for open-source AID systems. Since insulin needs can change rapidly, poor or lost connectivity among these devices can jeopardise safety. However, open-source AID systems enact short (ie, 15–60 min) temporary basal rates or provide microboli and fall back to preprogrammed open-loop settings if wireless communication is lost.

Potential limitations and challenges

No AID system is perfect. Commercial and open-source AID systems share many common limitations. Health-care providers might have specific concerns regarding open-source AID systems (panel 1). Health-care professionals' experience and ability to support users might be limited. Open-source AID systems do not have regulatory approval, official onboarding programmes (ie, educational programmes for users, which are often provided by the manufacturers of commercial AID systems), or a customer helpline for users. Updates have to be performed manually by the user. Problems can be reported online and solved with online resources or experienced community support. Although open-source AID systems allow for wide customisability based on many flexible parameters, changing these parameters requires a level of understanding, time, and effort. These limitations require users of open-source AID systems to have a higher level of motivation, engagement, and health and digital literacy than do the general population.

Ethical considerations

Intensive insulin therapy and self-management are the basis of optimal glycaemic outcomes.[61] The daily tasks that are required to reach these outcomes by people with diabetes or their caregivers can represent a substantial challenge. For many people, limiting access to treatments or constraining current treatments exacerbates this burden and adds unnecessary psychological distress.[62,63]

One of the fundamental driving principles of diabetes care is respecting people with diabetes, and where relevant their caregivers, autonomy, and individual treatment choices.[28–30] The health-care professionals'

obligation is to respectfully support such autonomy, while ensuring that people with diabetes and their caregivers have the capacity to make informed choices and understand the risks and benefits of their chosen option. For open-source AID systems, previous position papers have used this obligation to provide justification for health-care professionals supporting open-source AID systems. The four principles of biomedical ethics

Panel 1: **Potential limitations of open-source AID systems**

Getting started or updating

Building and using open-source AID systems are two separate processes requiring different skill sets. Detailed guides exist to set up each system; however, some people opt to have others help to build the system (eg, a friend, experienced user, or physician), which can be done remotely. Given the time and effort that are needed for a first-time user to set up the system, getting help from others can substantially reduce burden. Having health-care professionals available who have experience in physiological settings is of particular importance with open-source AID systems. There are frequently more challenges that are associated with initial set-up than with continuous use.

Settings

Open-source AID systems have more adjustable settings than many commercial AID systems. Additionally, the systems use physiological settings to predict future blood glucose concentration. Guidance for some settings are provided in this consensus statement and new formulas developed from the Loop observational study have been reported in abstract form.[60] However, understanding the guidelines requires a particular level of health literacy and engagement, given the time and effort needed, and might mean that not all users of AID systems can derive optimal benefits. Health-care professionals' support can be valuable in improving health literacy and engagement.

Component connectivity

For any system, the greater the number of connected components, the more challenges with maintaining connectivity and powering devices. Commercial systems generally have between two and three components communicating wirelessly, and open-source AID systems have between three and four components. Should disconnection occur in open-source AID systems, the individual using the system is returned to baseline risk (ie, the risks associated with the sensor and pump, without the closed-loop algorithm dosing the insulin) following resumption of programmed open-loop settings. For systems with more components, connection issues can be a common source of frustration.

Support

Limitations exist for all AID systems. Each component might require specific techniques for troubleshooting. Commercial support for pumps and sensors already exists through the manufacturers. Industry expends substantial effort developing troubleshooting guides and processes, including helplines for some systems. Despite these efforts, users can have long hold times, speak to staff who are inexperienced with diabetes, and be given unsatisfying solutions. Open-source AID systems do not offer call-in helplines, but there are extensive online resources, a large and growing community of knowledgeable users, and developers who can assist. However, searching for the correct resources and support online can be a daunting task for some users.

Selection bias

Unfortunately, disparities in study recruitment exist for most clinical diabetes research, and often people who are willing to participate in observational studies in the long term have the time, energy, and resources to devote. Major weaknesses in all clinical trial recruitment include the scarcity of underserved people with diabetes (eg, people with low socioeconomic status, people of ethnicities other than non-Hispanic White, people living with clinically significant mental illness, and young or older people with diabetes) and selection bias. Randomised controlled trials provide strong evidence but require the right question, inclusive recruitment, a proper comparator, and training and care that can be reproduced in a real-world setting. Commercial AID systems have received regulatory approval without control groups. Additionally, the level of training that is delivered by study personnel frequently exceeds the commercially used training materials. Finally, care provided to study participants far exceeds the standard-of-care visits every 3–4 months. As a result, in this context, prospective observational trials in the real world can give a more realistic view of system performance.

Provider knowledge

Industry provides training for health-care professionals on commercial AID systems, which engenders familiarity, but these discussions do not provide full insight into algorithm details. Providers might understandably feel uncomfortable caring for someone who is using a system with which they are unfamiliar. Open-source AID systems require active learning by users, caregivers, and providers, including staying on top of developments and software changes for multiple systems.

Reporting adverse events

Adverse events in the context of open-source AID systems can be reported via the same channels that are used for commercial systems (eg, the US Food and Drug Administration and the UK Medicines and Healthcare products Regulatory Agency). Online reporting systems also exist to allow users to emphasise errors to a responsive community of volunteers. However, with commercial adverse events, the manufacturer is frequently the first to hear about an adverse event and is obligated to forward a report to the government agencies.

provide a good starting point for thinking about the wide ethical issues (panel 2).

In competent adults, given the ethical implications of withholding information on effective treatment options, we support health-care professionals discussing these systems as a treatment option with people with diabetes who might benefit from AID systems. We note that additional challenges might apply to vulnerable populations, such as adults without capacity, children, and adolescents, compared with competent adults within the same legislative jurisdiction, and clarity should be sought regarding these challenges.

Legal challenges

Reverse engineering (eg, understanding how system components communicate[65]) is explicitly permitted in Europe.[66] However, the use of open-source AID systems is not approved by regulatory bodies.[36,39] Substantial variation exists between different countries and regions in regulatory approval processes and potential legal consequences for health-care professionals supporting the use of unregulated systems. Regulatory approval does not preclude liability. Health-care professionals might be concerned about the potential legal implications of supporting people with diabetes who are using unregulated systems,[35] which should be balanced against allegations of a breach of duty of care (ie, negligence) and professional guidance. The quandary is further complicated by uncertainties with respect to accountability if adverse events occur. The chain of accountability could include regulatory institutions, device manufacturers, clinical institutions, health-care professionals, algorithm programmers, and people with diabetes or their caregivers. At present, no precedents exist, understandably creating a dilemma for health-care professionals and their organisations when supporting the use of these systems. Local policy varies and is impossible to outline for every jurisdiction. We do not recommend that any health-care professional should violate local law or organisational governance; however, if ethical and effective treatment is either deemed to be unlawful or occupies an uncertain and problematic regulatory position, then the regional policies should be questioned or clarified. We encourage the authorities and representative organisations of health-care professionals in countries or regions for which ethical and effective treatments could be considered unlawful to explore legal interpretation or update legal frameworks.

Children and adolescents

At least 20% of users of open-source AID systems are children or adolescents (ie, aged 19 years or younger).[13,17,25] Frequently changing insulin requirements, diurnal variability in counter-regulatory hormones (particularly during puberty), and unpredictable activity make children and adolescents ideal candidates for AID systems. The uptake of diabetes technology is particularly high among young children in countries where these treatment

Panel 2: **Application of the principles of biomedical ethics to open-source automated insulin delivery (AID) systems in the relationship between health-care providers and patients**

Autonomy

Respecting the autonomy of people with diabetes requires the user to have a thorough understanding of risks and benefits of the system. With this information, they can choose their own method of insulin administration. An individual's considerations might include cost, availability, evidence for safety and efficacy, system flexibility, ease of use, transparency, and regulatory approval. Open-source systems provide algorithm transparency, facilitating greater autonomy in operation. The algorithms that are used in some commercial systems are not as transparent, decreasing the ability of health-care professionals to discuss operation and reducing the autonomy of people with diabetes.

Beneficence

Beneficence implies that the system is provided with the intent of doing good for the individual. Improving the lives of individuals with diabetes is the sole objective of the developers of open-source AID systems. Health-care professionals supporting people who could benefit from open-source AID systems are similarly trying to do good. The actual benefit of any AID system will be dependent on the individual's particular circumstances, but network meta-analysis suggests a significant improvement in glycaemic control for most people with AID systems versus other diabetes technology.[64]

Non-maleficence

Non-maleficence requires that a treatment does not harm. Open-source systems are designed with safety in mind and reasonable measures are in place to reduce risk, with evidence supporting their safety. Safety can be context-specific and person-specific and needs to be balanced with the risk of diabetes itself. If little knowledge on AID systems exists, then harm can unintentionally result.

Justice

Justice requires that the burdens and benefits of treatment should be distributed fairly among the population. Commercial AID systems are restricted geographically and, in some places, socioeconomically. Open-source software is freely available online and allows a wide population with diabetes to have access to and benefit from this technology.[25] Although equity in access to diabetes devices is not universal, equity in access to information regarding therapeutic options enables people with diabetes to make informed decisions for their care. Making these decisions might involve the initiation of discussions regarding open-source systems (eg, when considering future continuous subcutaneous insulin infusion or continuous glucose monitoring device options), if in line with local regulations.

Panel 3: **Recommendations for safe practice for health-care professionals**[19]

Discussing

- Ensure that discussions include approved technologies as an available option
- Explain that open-source systems are unregulated
- Ensure that the person with diabetes or their caregiver has a clear understanding of the benefits and limitations of all automated insulin delivery (AID) systems
- Ensure that people with diabetes and their caregivers are encouraged to inform their health-care professional regarding their preferred treatment, including technologies
- Consider initiation of discussion of open-source AID systems with people with diabetes or their caregivers, depending on local legislations

Supporting

- Respect the individual's right to choose how they prefer to manage their diabetes or of the person that they care for
- Continue to support and provide access to regulated devices (eg, continuous subcutaneous insulin infusion, continuous glucose monitoring systems, or intermittently scanned continuous glucose monitoring) to meet reimbursement criteria, even if people with diabetes or their caregivers intend to pursue open-source AID systems
- Provide support with reviews of glucose concentrations detected by CGM sensors and insulin dosing adjustments
- Provide guidance on optimising open-source AID system settings, if experienced, or refer to appropriate health-care professionals who can support this aspect
- Provide information resources for people with diabetes or their caregivers to research

Documenting

- Ensure clear documentation of discussions with people with diabetes or their carers
- Disclaimer statements for open-source systems can include confirmation that the user understands that the system is unregulated; the health-care institution, clinic, or health-care professional cannot take any responsibility for the system; the handling of data might not conform to local data protection requirements; and there is an ongoing need for the user to research extensively when using these systems.

Reporting

- Report any adverse events to local health or regulatory institutions

modalities are accessible.[67] However, not all commercial AID systems have been approved for children aged 6 years or younger or individuals with low insulin requirements, and the efficacy of AID systems is controversial for these groups,[3,68,69] although children show similar improvements to adults with open-source AID systems.[13,17,25] For many families, use of an AID system facilitates improved and uninterrupted sleep overnight.[18,24,25] Caregivers frequently mentioned the possibility of remotely monitoring and remotely controlling their child's AID system as an important reason for choosing open-source AID systems,[24,25] although remote monitoring has become available on some commercial AID systems. The child's welfare should always be considered by health-care professionals and by caregivers who are setting up open-source AID systems for their children, with the child's assent and engagement.

Psychological aspects

Meeting glycaemic targets should always be balanced against treatment burden and its effect on emotional wellbeing. Extensive research and clinical experience show the bidirectional link between psychosocial functioning, defined as a person's thoughts, feelings, and behaviours, and diabetes management and outcomes. The need for attention to psychosocial functioning from the health-care professional is emphasised in therapy guidelines[70,71] and is also essential when considering support of open-source AID systems.

Research suggests that some people with diabetes are concerned about the psychosocial effects of diabetes devices and these effects can be barriers to uptake and continued use.[72–75] Psychosocial research regarding open-source AID systems is emerging and evidence is scarce; therefore, it is unclear whether people considering open-source AID systems might have similar concerns. Building, setting up, and running an open-source system might be more demanding on time, cognitive workload, or social resources than the use of commercial systems, and this burden should be discussed.

The scientific literature on commercial AID systems reports several psychological benefits, including reduced anxiety, improved sleep, reduced burden, and greater flexibility with daily life.[76–84] It is reasonable to expect that these benefits are similar for users of open-source AID systems. Nevertheless, gaps in the evidence base need to be addressed with further studies to improve our understanding of open-source AID systems on emotional wellbeing.

Best practice recommendations

Recommendations for safe practice

The evidence for safety and effectiveness along with ethical considerations provide a rationale for health-care professionals to consider supporting the use of these systems in their clinical settings. We advocate the use of evidence-based ethical treatments, where they can be used within purview of local and federal regulations. We also advocate that device manufacturers should offer transparency on the functional aspects of their products. Building on previous statements from diabetes organisations and health institutions,[27–32] we make recommendations for safe practice (panel 3).

Prerequisites

The decision to use open-source AID systems often begins with the people with diabetes or their caregivers. Real-world evidence from users of open-source AID systems shows a wide spectrum of ages, hormonal status, comorbidities, baseline glycaemic control, income,

Panel 4: **Common terms for customisable settings and parameters of open-source automated insulin delivery (AID) systems and their meaning**

Meals

Absorption time
For Loop users, the absorption time can be customised for every entered meal (ie, 30 min to 8 h; appendix p 8). We recommend choosing long absorption times (ie, 3 h) for large meals, foods with low glycaemic index, and foods with high fat content and for people with diabetes who have gastroparesis.

Advanced meal assist
Allows the system to quickly set a high temporary basal rate after a meal bolus, if carbohydrates are entered reliably.

Carbohydrates on board
Estimate carbohydrates that have not been absorbed yet and will most likely cause further increase in glucose concentration (appendix p 8).

Carbohydrate-to-insulin ratio
Grams of carbohydrates that are covered by 1 unit of insulin.

Unannounced meals
Feature that attempts to implement full closed-loop without meal announcements. This feature can produce postprandial hyperglycaemia, unless strict dietary protocols are followed.

Insulin delivery

Basal rate
Basal insulin delivery that should keep the glucose concentrations detected by the CGM sensors steady without any interferences (ie, a meal, activity, stress, bolus insulin, etc).

Correction or target (range)
The desired glucose concentration range detected by the CGM sensors or single value that the open-source AID should target (appendix p 8).

Insulin activity or absorption model
Used to estimate the timed effects of insulin on blood glucose concentration. An accurate model can help to prevent insulin stacking and enable safe correction treatments. AndroidAPS and Loop users can choose to implement a custom curve or various presets (appendix p 8).

Insulin on board
Estimated insulin in the body that has yet to act on blood glucose. This measure is sometimes expressed relative to the scheduled basal rate. If implemented in this way, then negative quantities indicate delivery below scheduled basal rate (eg, insulin suspension).

Insulin sensitivity factor
Glucose-lowering effect of 1 unit of insulin. Insulin sensitivity factor is anchored from the value in the pump or device settings in the open-source AID system. For OpenAPS users, if autotune or autosens are used, then the insulin sensitivity factor value that is shown is what is being used by OpenAPS, as modified by the sensitivity ratio.

Sensitivity ratio
The ratio of insulin sensitivity or resistance compared with standard settings. For OpenAPS and AndroidAPS users, this ratio is calculated by autosensitivity, and this ratio is applied to both basal and insulin sensitivity factor to adjust accordingly. Less than 1·0 indicates sensitive and more than 1·0 indicates resistant. If the preferences allow it, sensitivity ratio can also be modified by temporary targets. For Loop users, sensitivity ratios can be applied with override presets in a proportion of original insulin requirement settings (ie, <100% is sensitive and >100% is resistant).

Super microbolus
A small portion of insulin that can automatically be delivered by the system in addition to, or instead of, basal rate changes. Super means that it can prepone basal insulin for faster insulin action than with a regular mealtime bolus on top of basal insulin.

Safety

Delivery limits
Maximum basal rate per h and maximum units of insulin for a bolus.

Maximum insulin on board
Maximum insulin on board that the system is not allowed to exceed as a built-in safety feature (ie, it will stop delivering any more insulin).

Suspend threshold
When current or forecasted glucose concentration at the sensor is below the threshold value, the open-source AID system will recommend insulin suspension.

Other feature

Autosens
Automatic weighting of past deviations (excluding carbohydrates and unannounced meals) to determine the insulin sensitivity factor.

Autotune
A tool to help to calculate potential adjustments to insulin sensitivity factor, carbohydrate-to-insulin ratio, and basal rates on the basis of model deviation. For OpenAPS users, autotune can be run directly on the rig. For users of other systems, it can be run via AutotuneWeb and the user's personal Nightscout profile.

(Panel 4 continues on next page)

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Deviation
The deviation from the expected rise or fall in blood glucose concentration based on calculated insulin activity and the actual rise or fall.

Temporary target
Allows the user to temporarily change the algorithm's customary correction range or target to adjust for factors, such as physical activity, illness, and stress.

Profile switch or override
Allows the user to temporarily change correction range or target and to apply relative changes to all insulin delivery parameters (eg, basal rate, carbohydrate-to-insulin ratio, and insulin sensitivity factor) at once (appendix p 8).

education, profession, technlogical literacy, geography, and diabetes pathophysiology.[24,25,85] Commercial AID systems are regulated and receive labels on the basis of safety and efficacy data for some patient groups, which does not apply to open-source AID systems.[24,25] User interfaces and online resources have been translated into many languages by volunteers from the community, and national subgroups exist to provide peer support. Additional support groups exist for caregivers of children, during pregnancy, and when tackling specific aspects regarding payers, access, or other regional specifics of health-care systems.

As detailed earlier, open-source AID systems have the potential for use by a wide range of people with diabetes. It is recommended for health-care professionals and people with diabetes to discuss, and where possible support, the prerequisites to ensure safe and effective use of these systems. People with diabetes or their caregivers should have the mental capacity to make an informed choice and decisions about their care; demonstrate understanding of functional insulin dosing, supported by direct attendance to a structured education programme or via interaction with health-care professionals; and have previous experience and feel confident with optimisation of pump therapy and use of CGM technology (for those who do not, it is recommended to learn about them first with HCP support, before integrating them into an AID system). As is the case with any potential treatment that could cause rapid glycaemic improvements in the setting of microvascular complications, we recommend consideration of additional retinal checks following initiation of an open-source AID system in this situation.

Supporting the initiation process

In addition to insulin, pump, CGM device, and associated supplies, people with diabetes might have to individually acquire additional hardware (eg, smartphone, computer, RileyLink, or OpenAPS rig) and set up software components (eg, Nightscout, xDrip+, OpenAPS, AndroidAPS, or Loop). Users should be made aware of the risks that are associated with obtaining and using second-hand medical devices should they or their caregivers choose to use these options. We recommend the use of medical devices that are within warranty, if possible.

Although open-source AID systems do not have a company-delivered training programme, they have various online resources to help with system set-up and use. Furthermore, there are peer-support networks in social media channels and via local meetups and gatherings. These networks enable new and experienced users to rapidly exchange from a wide pool of collective knowledge that is tailored to users' unique situations. In AndroidAPS, users are required to first fulfil a series of objectives that provide education and guidance through the features and settings over the course of several weeks. Advanced features are gradually enabled as these objectives are met. Further training and support should also be offered (appendix p 9).

Settings

Realistic measures of treatment effectiveness and holistic, individual goals should be identified before initiation. This process will help to frame specific settings and avoid over-reliance on numeric targets as the only focus.

Current understanding of optimal glycaemic targets to ensure minimal microvascular and macrovascular damage while avoiding hypoglycaemia has benefited from real-world and trial evidence.[61,86,87] The International Consensus on Time in Range[88] has offered a view on optimal glycaemic concentrations that can be determined from CGM measures, as described in this section. These recommendations should always be personalised depending on individual circumstances and goals. Importantly, optimal treatment goals that are detailed by the International Consensus on Time in Range (eg, a TIR of >70%) might be difficult to reach for many people with type 1 diabetes.[89]

We suggest considering targets according to the International Consensus on Time in Range.[88] Most users reach or exceed these targets (ie, TIR >70%, time below range [<70 mg/dL/3·9 mmol/L] as <4%, with <54 mg/dL/3·0 mmol/L as <1%, coefficient of variation <36%, HbA_{1c} ≤7·0%/53 mmol/mol) after commencing open-source AID.[15–17,25] Therefore, efforts can be focused towards other meaningful outcomes, such as minimising stress, emotional burden, and time spent on diabetes management.

We favour optimisation for hypoglycaemia prevention and gradually tightening the glucose target range, as is deemed safe. Algorithm glucose concentration targets at

Panel 5: **Practical scenarios and advice for use of open-source automated insulin delivery (AID) systems**

Carbohydrate consumption
Any carbohydrates consumed by the user (including those consumed to treat hypoglycaemia) should always be entered into the system.

Insulin bolus timing
As with conventional management, it is important to bolus ahead of the meal. Late boluses can cause the system to inappropriately increase basal delivery or administer a correction bolus, which can produce hypoglycemia when combined with the meal bolus.

Hypoglycaemia management
In keeping with advice for commercial AID systems, users might consider treating hypoglycaemia with less carbohydrates than usual if the system has suspended insulin delivery for an extended period of time.

Duration of insulin action
Users should be educated that the duration of insulin action that is used in open-source AID systems (ie, typically 5–7 h for rapid-acting insulin) is different to the active insulin time that is used in most continuous subcutaneous insulin infusion and commercial systems (ie, typically 2–5 h for rapid-acting insulin).

Glucose targets
Glucose targets should be personalised. A range of approximately 0–20 mg/dL (6·0–6·5 mmol/L) can be a reasonable starting point, unless there are concerns about hypoglycaemia risk or other reasons for individualisation (eg, pregnancy).

Prandial insulin not delivered by pump
If subcutaneous or inhaled insulin is used to cover a meal and neither the carbohydrates or insulin are announced to the system, then the system might be able to modulate around some degree of mismatch or accept manual entry of carbohydrates that were consumed and insulin that was delivered.

Correction insulin not delivered by pump
If subcutaneous or inhaled insulin is used to treat hyperglycaemia without reporting, then the system will reduce its aggressiveness as an adaptation for the lower than predicted glucose concentration detected by the CGM sensors. If supported by the system, then we recommend entering information about exogenous insulin into the system.

Sick days
It is not necessary to stop use of AID systems during illness, assuming that the possibility of set failure has been considered and appropriately managed. Users should consider switching their profile, either up for illness leading to higher insulin resistance or down for illness that decreases hepatic glucose output. The advantage of the change is that the new profile can be set with different basal rates and carbohydrate-to-insulin ratio and insulin sensitivity factor.

Surgery
Many ongoing studies are examining use of continuous glucose monitoring systems in patients with diabetes who have been admitted to hospital, including during surgery. Continuous glucose monitoring systems will need to be validated in the setting of electrocautery and pharmaceuticals to ensure safe operation of AID systems.

Pregnancy
- Proportional decreases or increases in physiological settings should be considered for women with type diabetes to use or set up first trimester-specific override presets.
- First trimester: often a decline in insulin requirements between weeks 7–5.[90]
- Second and third trimester: insulin requirements continue to increase with substantial changes in the carbohydrate-to-insulin ratios that are required as the pregnancy progresses.
- Immediately before delivery: a small subset of women with type diabetes have a slight reduction in insulin needs. It is important to have safety settings should falls in glucose concentrations occur (eg, pre-pregnancy settings).
- Complicated delivery: factors might change too rapidly to compensate with subcutaneous insulin and preset settings; an intravenous insulin drip might be the preferred option, particularly during caesarean section.
- Post partum: a rapid drop in insulin requirements is often observed. It is advisable to have pre-pregnancy settings available, along with strategies for managing diabetes during nursing.
- Treatment target value or target range and hypoglycaemia threshold should be adjusted and revised according to tighter time in range recommendations during pregnancy.[91]

Exercise
Prolonged aerobic exercise:
- Set temporary target to at least 26 mg/dL (7 mmol/L) for activities that typically increase insulin sensitivity and the risk for hypoglycaemia (ie, extended aerobic activity). Change insulin profile to deliver approximately 50% less overall insulin during aerobic activity (ie, basal, bolus, and insulin sensitivity factor) than during no activity.
- Temporary setting changes should occur at least 60 min before the onset of exercise to allow insulin concentration to drop by exercise start time.
- Carbohydrate intake 5–90 min before the onset of exercise, even without an associated meal bolus, can elevate insulin concentration (ie, elevate insulin on board) during exercise and increase the risk of hypoglycaemia during the activity. Small amounts of carbohydrate immediately before and during exercise might be preferable to a pre-exercise carbohydrate load. Temporary settings might need to be cancelled or modified (ie, increased or decreased temporary targets) after exercise, depending on the type of exercise.

(Panel 5 continues on next page)

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- Swimming considerations: Bluetooth communication might be low under water and not all devices are waterproof. Changes in pressure when diving might affect device performance.

Anaerobic exercise:

- Glycaemic targets and profiles might not require any alterations from normal settings.
- Identify glucose concentration patterns detected by the CGM sensors with exercise, especially post-exercise hyperglycaemia.
- If post-exercise hyperglycaemia correction is insufficient, then glycaemic targets can be reduced.
- Increases in insulin profiles might also need to be set temporarily to avoid post-exercise hyperglycaemia (eg, 20%).
- Decreased glycaemic targets and increased insulin profiles might need to be continued for up to 3–4 h in recovery, unless there is a risk of post-exercise or nocturnal hypoglycaemia (eg, activity occurs in the latter part of the day). In this situation, the usual profile should be set after exercise is completed.

Infusion set failure

If there is a confirmed infusion set failure in which correction insulin was not successfully delivered, then the user can inject the undelivered insulin that the system believes itself to have delivered.

Ketosis management

General principles apply to managing high ketone levels, which require additional corrective insulin. Users should change infusion sets and insulin reservoirs or the patch pump as part of standard guidance. Manual insulin injections can be recorded in the AID system. The user can switch their profile to 30–200% until ketones are <0·6 mmol (ie, in the blood) or displayed as "++" (ie, in the urine) because of high insulin resistance during this period of time.

Low carbohydrate diet

People on a low carbohydrate diet have a lower total daily insulin dose than if they were eating more carbohydrates. A greater proportion of that total daily dose is typically made up of basal insulin than if the individual were eating more carbohydrates. If conventional equations are used for calculating carbohydrate-to-insulin ratio (eg, 450/total daily dose), then enough insulin will not be delivered.

Prolonged fasting

Prolonged fasts, such as religious fasting during Ramadan (ie, typically for >6 h in northern hemisphere countries), can be managed effectively and safely with open-source AID systems.[92] Profiles can include high targets during the fasting periods to avoid activity-induced hypoglycaemia and 30–50% profiles during termination of long fasts to overcome insulin resistance due to high concentrations of counter-regulatory hormones.

Insulin resistance

The equations that are typically used to calculate doses in people with type diabetes might need to be modified to account for changes in insulin resistance. By definition, insulin sensitivity changes inversely with insulin resistance. Greater insulin resistance should be met with a lower insulin sensitivity factor.

Cystic fibrosis-related diabetes

In people with cystic fibrosis-related diabetes, basal and insulin sensitivity factor needs are often lower than would be required in people with type diabetes. Carbohydrate-to-insulin ratio is proportionately more aggressive than are these other settings.

CGM sensors of approximately 110–120 mg/dL (6·0–6·5 mmol/L) can be a reasonable starting point.

Crucial safety parameters (panel 4) to establish include maximum temporary basal rates, maximum total insulin on board (ie, for OpenAPS or AndroidAPS), or maximum bolus and suspend threshold (ie, for Loop). The foundation of prediction-based AID is accurate settings on open-loop mode, including insulin sensitivity factor, carbohydrate-to-insulin ratio, basal rate, and insulin pharmacodynamics. We recommend using a well established pharmacodynamic model that reflects the peak and tail effects of current subcutaneous insulin. Work is being done to provide optimal settings on the basis of data from a large observational study,[13] and has been reported in abstract form.[60]

Before closing the loop, people with diabetes should have a clear understanding of what each setting means and how to evaluate them. Starting an AID system with incorrect settings can generate erroneous and potentially dangerous predictions. Notably, open-loop settings might not always reflect true physiology and one setting might be compensating for another (eg, an overly aggressive basal rate might compensate for an inappropriately weak carbohydrate-to-insulin ratio or insulin sensitivity factor, or both). Because most open-source AID systems rely on physiological settings, the same settings tend to work well in both open-loop and closed-loop mode. However, some users choose to use more aggressive carbohydrate-to-insulin ratios with AID systems than with other therapies, such as an insulin pump only or multiple daily injections, because the system can decrease basal rates when hypoglycaemia is predicted.

Open-source AID systems enable the user to feed in information regarding changes in insulin sensitivity. AndroidAPS users can quickly switch profile settings and Loop users can specify an override preset to scale basal rates, carbohydrate-to-insulin ratio, and insulin sensitivity factor by a uniform percentage (panel 5).

All data from open-source AID systems can be instantaneously made available to the health-care professional via Nightscout, a platform that provides logging and real-time monitoring of CGM data, insulin delivery, carbohydrate entries, predictions, and settings. Reports include daily and weekly overviews, sensor overlays, glucose distribution (appendix p 10), and percentiles. Loop users can also upload their data into Tidepool (appendix p 11), another open-source platform for data logging, via Apple Health. Alternatively, data from some CGM devices and insulin pumps can be extracted with the manufacturer software (eg, Medtronic CareLink or Dexcom Clarity). The International Consensus on Time in Range recommended visualising at least 2 weeks worth of data.[88] These reports enable people with diabetes and health-care professionals to discuss optimisation of therapy parameters and behavioural aspects.

Health-care professionals should be aware that some data systems may not comply with local data protection regulations. However, the principle of autonomy applies, with people with diabetes or caregivers choosing how they wish to use and share their data. Surveys have not identified local data protection regulations as an issue for open-source technology users; however, barriers often exist for health-care institutions.[93]

There are a multitude of physiological changes occurring in pregnancy, before and during delivery, and post partum. These changes can drastically alter insulin requirements. For open-source AID systems, it is crucial to anticipate these changes (panel 3).

Exercise can cause varying responses to glycaemia depending on the nature of the activity.[94] In situations where exercise tends to promote hypoglycaemia, such as with prolonged aerobic activities, temporary target setting and profile changes might need to be made at

For more on **Tidepool** see http://www.tidepool.org

Panel 6: **Summary of the international consensus on open-source automated insulin delivery**

(1) Scientific evidence exists from real-world data (based on self-report, physician-report, and device data), with support from in-silico data, that suggests that open-source automated insulin delivery (AID) systems are safe and effective treatment options for people with diabetes. Open-source AID systems can increase time in range while reducing variability in glucose concentrations and the amount of hypoglycaemia and hyperglycaemia in various age groups, genders, and socioeconomic communities.

(2) Open-source AID systems have the potential to help a wide population of people with diabetes alongside commercial AID systems, including individuals with suboptimal or optimal glycaemic control and people who are looking to ease their own day-to-day burden.

(3) Respect for autonomy, one of the fundamental practical, legal, and ethical tenets of medicine, includes supporting the right of people with diabetes or their caregiver's informed decisions about their own medical care. Health-care professionals should support people with diabetes or their caregivers who might choose to manage their diabetes with an open-source AID system.

(4) Health-care professionals should attempt to learn about all treatment options that might benefit people with diabetes, including available open-source AID systems. It is reasonable to provide a comprehensive overview of all available AID system options and educate people with diabetes and their caregivers on the availability and existing evidence, if the potential risks and benefits are clearly explained.

(5) Health-care professionals who are unfamiliar with the specifics of open-source AID systems, do not have resources to educate themselves, or have legal or regulatory concerns in their location should consider a cooperation with or a referral to other health-care professionals who can provide support for this aspect.

(6) All AID systems, including commercial systems, should fully disclose how they operate to enable health-care professionals, people with diabetes, and caregivers to make informed decisions and understand the benefits and limitations of all AID systems. Additionally, all users of continuous glucose monitoring should have real-time and open access to their own health data at all times.

(7) Benefits of open-source AID systems can include wide availability and access, device and platform interoperability, and customisability. However, these systems have not undergone the same regulatory evaluations as commercially available medical technologies. There is no commercial technical support, but extensive community support is available.

(8) Clarifying the user's goals and setting realistic expectations are crucial to the success of AID systems. To ensure maximum safety for people with diabetes, users of open-source AID systems should be guided to optimise their systems for hypoglycaemia prevention before pursuing tight glycaemic control.

(9) We do not propose that health-care professionals universally recommend open-source AID systems over available and accessible commercial systems. We also do not recommend that health-care professionals violate local law or organisational governance. However, if ethical and effective treatment is either deemed unlawful or occupies an uncertain and problematic regulatory position, then the regional policies should be clarified. We encourage the authorities and representative organisations of health-care professionals to help to apply professional consensus and evidence to update legal interpretations and frameworks.

(10) In view of the challenges of randomised controlled trials and the value of true user experience, real-world evidence should be considered by device regulators. Streamlined regulatory processes to evaluate and test algorithm updates should be adopted.

Search strategy and selection criteria

We identified references for this consensus statement through searches of PubMed for articles published between Sept 30, 1993, and June 30, 2021, by use of the terms "automated insulin delivery", "closed-loop insulin delivery", "artificial pancreas", "Do-it-Yourself artificial pancreas", "open-source AID", "OpenAPS", and "AndroidAPS". Additionally, we reviewed position statements and legal expert opinions regarding open-source automated insulin delivery systems or do-it-yourself artificial pancreas systems published by registered not-for-profit organisations and professional societies. We included articles published in English, Danish, German, and Polish.

least 30–60 min before starting exercise in any AID system (panel 3).[95] In situations where exercise tends to promote a rise in glucose concentration, such as with short-term vigorous competition, a different approach might be required (panel 3). Typically, most AID systems are effective in preventing nocturnal hypoglycaemia after sports, particularly if high temporary targets are set.[95,96]

Conclusion

Health-care professionals have an important role in facilitating and supporting people with diabetes to obtain beneficial outcomes from AID systems. Although we do not suggest that open-source AID systems be universally recommended over commercial options, strong ethical reasons support the use of open-source AID systems, with safety and effectiveness data derived from real-world evidence. This consensus guide (panel 6) provides an overview for health-care professionals to enable them to approach common situations. We recommend that local policies support the use of open-source AID systems as fostering ethical medical principles and evidence-based medical treatment. Further, we support policies that would require all AID systems, open-source and commercial, to fully disclose how they operate so that health-care professionals can have informed discussions with people with diabetes. Real-world evidence can also be powerful in reflecting the true user experience. We advocate that this evidence should be considered by regulators. Additionally, we recommend streamlined regulatory processes to evaluate and test algorithm updates. In this way, a large community can contribute to advancing diabetes care.

Contributors

KB, RAL, and SH led the consensus authorship group. All authors formed the steering committee and equally contributed to the manuscript draft. All contributors (ie, Outcomes of Patients' Evidence with Novel, Do-it-yourself Artificial Pancreas Technology [OPEN] International Healthcare Professional Network and OPEN Legal Advisory Group) critically reviewed the manuscript and provided comments to the authors. All authors reviewed and approved the final version of the manuscript.

Declaration of interests

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