REVIEW ARTICLE

Beyond Syringes and Pills: Advances in Drug Delivery Systems for Diabetes

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ABSTRACT

Diabetes is a chronic disease that affects millions of people worldwide, and its prevalence is increasing. The two primary subtypes, type 1 and 2, have different causes and mechanisms, but both result in abnormal glucose metabolism. The standard of care for diabetes includes insulin therapy, oral anti-diabetic medications, diet, exercise, weight loss, and frequent self-monitoring of blood glucose levels. However, these treatments have limitations that can lead to poor patient compliance and suboptimal outcomes. Alternative insulin delivery systems such as inhalers, patches, and oral sprays offer potential benefits such as increased convenience, reduced pain, and improved adherence. Non-insulin injectables, long-acting basal insulins, and GLP-1 agonists have also shown promise in improving glycemic control and reducing the risk of complications. Nanoparticle-based systems like SLNs are a novel approach that offers several advantages for diabetic management. They allow for targeted drug delivery, controlled release, and improved biocompatibility, enhancing drug efficacy and reducing side effects. SLNs have shown potential in animal models for reducing extracellular matrix degradation, inhibiting carbohydrate digestive enzymes, and enhancing the regeneration of insulin-producing beta cells. More studies are needed to validate their safety and efficacy in humans, but the potential benefits of SLNs make them a promising option for diabetes management.

Keywords: Diabetes, Oral insulin, Inhaled insulin, Solid lipid nanoparticles, Implants, Transdermal patches, Controlled release.

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INTRODUCTION

Diabetes emerges in perplexing and threatening forms, each more alarming than the last. The most well-known types, type 1 and type 2 diabetes, are merely the beginning of a treacherous progression. Type 1 diabetes, an autoimmune assassin, destroys insulin-producing beta cells without warning. Left without defense against high blood sugar, the body spirals into crisis, striking terror as it spares no one, its rampage ruthless and random. Type 2 diabetes, metabolic mischief, deceives subtly. Years of poor diet, obesity and inactivity allowed insulin resistance to develop stealthily while beta cells fatigued gradually. By the time this duo overran glucose control, the harm was irreversible. The greatest foe, type 2 diabetes is a cunning chameleon that camouflages until catastrophic damage results.[1]

Beyond these stand even stranger horrors. Gestational diabetes invades pregnant joy without notice, vanishing after delivery but securing an indelible stain. Latent autoimmune diabetes works covertly to destroy beta cells unnoticed by the body.[2] Type 3c diabetes, a mysterious misnomer, an umbrella term for less understood high blood sugar causes.[3] Diabetes emerges in disturbing forms at every turn, each more difficult to comprehend and conquer than the last. While its masked menaces continue to perplex and puzzle, diabetes remains an unrelenting villain robbing both life and liberty. Grasping its complex countenance is the key to any defense against this diabolical disease.

Pathogenesis

The origin and progression of diabetes is exceedingly complex and puzzling. The body sabotaging itself to destroy insulin's defenders (beta cells) or allow their insidious demise (glucose, insulin resistance) remains perplexing.

Type 1 diabetes sees the sinister autoimmune system destroy beta cell armies once valiantly controlling glucose and ensuring health. With defenses gone, the body succumbs to a pathological frenzy as glucose rises unchecked. Each falling beta cell only enrages the autoimmune beast, fueling ruthless ruin.[4] Type 2 diabetes sees treacherous metabolic betrayal allowing enemies (insulin resistance and less insulin) stealthy access. While beta cells compensate for years, exhaustion

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and damage inevitably cause decline. Causality remains obscure though irreversible.[5] Diabetes invades ruthlessly from childhood to age, striking freely with no reason. An incomprehensible force showing no mercy, annhilation or exhaustion, the ruin is total metabolic catastrophe.

Theories proposed and discarded, diabetes confounds with complex, controversial causality. Genetic fate or environment, virus or cytokines, insulin toxicity or lipotoxicity satisfy neither. Sinister, sickness left forever puzzling.[6] Current knowledge is insufficient, comprehension out of reach, perhaps conquering so illogical an illness. Diabetes pathogenesis an enigma, chaos and complexity shrouded. Any answers or remaining forever mystery, requiring relentless search.[7] Piercing this gloom, understanding may emerge of how the body turns so treacherously against health until comprehension renders defeat of this foe possible.

Current Standard of Care

Diabetes management relies on a perplexing duo: injections and pills, painful and frightening modalities.[8] Insulin, a vital lifeline, delivers through piercing skin and muscle repeatedly, though crucial, creates fear, pain and psychological trauma through frequent stabbing. Each prick reminds of illness demanding this sinister sacrifice. Oral drugs promise control and normalcy but fail fully satisfy. Glycemic reign remains inconsistent and imperfect, the euglycemic holy grail out of reach. Losing power, others join a chaotic and confusing chemotherapeutic cocktail. Injections and pills, physiology guillotines slashing disease awry, advanced tools yet deeply flawed. Suppressing symptoms, not causes; creating the illusion of cure through coercion, prolonging life but not living. Lifestyle management, ignored first line, provides only solutions yet little practical power. Diet, exercise, weight loss, stress control - simply unachievable feats. Cycling between perplexing panaceas with little progress beyond palliation, diabetes prevails, ultimately conquering body and mind through sinister tentacles spreading ruin in every system.[9] Truly strange and stifling, limited and illogical, the approach contains complex catastrophe, each bizarre and bewildering option alike. The future alone can bring new hope of progress against this condition and its menace.

Insulin Delivery Systems

Insulin delivery systems like insulin syringes, pens, and pumps are the first-line treatment for the management of type I diabetes mellitus.[10] The advantages and disadvantages of insulin delivery systems are mentioned in Table 1.

Non-insulin/Oral Hypoglycemic Drugs

Oral medications for diabetes compose a bizarre and bewildering cocktail of chemicals, each with its own perplexing mechanism, inconsistent efficacies and intolerable side effects. They promise control and normalcy yet fail to satisfy, slashing symptoms while letting the sinister sickness thrive.[15] The oral hypoglycemic agents used in the management of diabetes mellitus are represented in Figures 1 and 2.
(DPP4- Dipeptidyl peptidase-4; GLP1- Glucagon-like peptide 1; SGLT2- Sodium-glucose Cotransporter2)

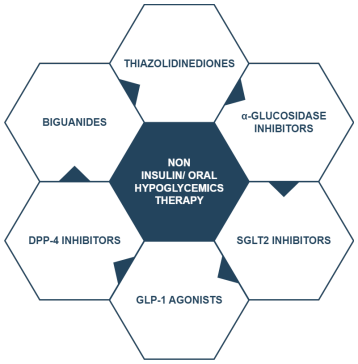

Figure 1: Non-insulin or oral hypoglycemics therapy

Biguanides	• Improves insulin sensitivity and reduces gluconeogenesis, but its Glycemic management remains imperfect. • Gastrointestinal side effects like nausea and diarrhea frequently emerge and may never abate.
DPP4 inhibitors	• Dipeptidyl peptidase-4 (DPP-4) inhibitors or "gliptins" apparently hinder the breakdown of GLP-1, but the benefits - if any - seem marginal at best. • They lead to upper respiratory infections, dizziness, headache and nausea. This drug class persists due more to corporate greed than medical gain.
GLP agonists	• Glucagon-like peptide 1 (GLP-1) agonists mime the effects of the incretin hormone, yet their control is inconsistent and costs unjustifiable. • As injections, they drastically surpass pill-based options in both efficacy and harm. Weight loss may emerge, but so do nausea, vomiting, diarrhea and pancreatitis.
SGLT-2 Inhibitors	• Sodium-glucose Cotransporter-2 (SGLT2) inhibitors allegedly reduce renal glucose reabsorption leading to loss of approximately 100 calories/day urination. • But urinary tract infections and genital yeast infections foil such calorific delight. Ketoacidosis seems poised to emerge as a looming threat.
α-glucosidase inhibitors	• Alpha-glucosidase inhibitors limit the breakdown of carbs, but provide little real-world benefit while producing oily diarrhea, abdominal pain and flatulence. • They remain popular mainly due to a lack of superior alternatives.
Thiazolidinediones (TZDs)	• Thiazolidinediones (TZDs) or "glitazones" operate by activating peroxisome proliferator-activated receptors, but prevalent edema, heart failure and bladder cancer render them too dangerous for wide use. • Their demise however lacked sufficient replacement.

Figure 2: Oral hypoglycemic agents used in the treatment of Type II diabetes[15,18]

Key Limitations of Standard Diabetes Treatment Approaches

Inconvenience

Diabetes treatment is inconvenient, tedious, and interferes with activities of daily living.[17]

Unpredictable and unstable blood sugar

Blood sugar levels remain unpredictable and unstable despite efforts.[16]

Side effects

Side effects include weight gain, low blood sugar, rashes, nausea, liver issues, bone loss, heart problems. Some medications can also produce allergic reactions in patients.[19]

Complexity and dependence

Regimens become overly complex with many drugs, doses, and checks increasing dependence on healthcare.[20]

High economic costs

Diabetes is expensive, imposing huge costs, including supplies, drugs, hospital care, lost productivity, complications, even death. Most patients find diabetes makes them poorer despite any insurance.[16]

Table 1: Insulin delivery systems

Insulin delivery systems	*Advantages*	*Disadvantages*	*Remarks*
Insulin syringes	Syringes provide precise insulin administration and dosage control. A range of short-acting, intermediate-acting and long-acting insulins can be delivered via syringe per the treatment plan. Syringe use allows for flexible and adjustable insulin dosing. Syringes have low upfront costs and are often covered under insurance.[11]	Insulin injections with syringes can cause pain, inconvenience, and poor compliance. Repeated injections can lead to health complications and psychological burden, resulting in non-adherence. Insulin syringes lack safety features, risking needle sticks, injury, and infection. Insulin vials' larger volumes and costs increase over time, producing waste. Traveling with syringes is complicated and costly. Disposable syringes have a large environmental footprint with limited recycling.[11]	Insulin syringes are still the most common method of insulin delivery They provide tight control and dosage flexibility However, they introduce several limitations and downsides Frequent injections, inconvenience, costs, safety issues, and psychological challenges hamper patient compliance Alternatives with fewer limitations and improved ease-of-use could significantly impact outcomes Better adherence to treatment is crucial for the effective management of diabetes.[10]
Insulin pens	Insulin pens offer more convenience than syringes They allow for faster and simpler insulin administration Insulin pens provide more consistent and accurate dosing compared to syringes Insulin pens offer safety features such as needle retraction and shields They reduce needle waste by using the same needle for multiple doses.[12]	Insulin pens still require multiple injections, leading to pain, inconvenience, and poor adherence. Insulin pens do not reduce the physiological or psychological burdens of insulin injections. Insulin pens have lower dosing flexibility, and adjustments require physician consultations. Insulin pens can be more expensive than syringes, adding to the economic toll of diabetes management and treatment. Storage requirements and temperature sensitivity remain the same as vials. Insulins in pens still need to be properly administered, rotated, and titrated based on blood glucose levels and effects, with close monitoring still essential.[12]	Automatic injection pens more convenient but also limited by multiple injections. While insulin pens improve convenience and safety to some extent, the frequent injections, financial burdens, psychological challenges and need for diligent self-management still limit their ability to significantly impact patient compliance and diabetes outcomes.[12]
Insulin pumps	Insulin pumps provide more precise control of basal insulin levels and respond faster to blood glucose fluctuations, reducing prolonged hyperglycemia and hypoglycemia. Insulin pumps offer greater flexibility in terms of sustaining any activity level and dietary choice, with frequent adjustments possible based on needs and changing circumstances. Continuous infusion of insulin on pumps more closely mimics the natural release of insulin from a healthy pancreas, improving insulin action and sensitivity over time. Insulin pumps have features that can automate adjustments and optimize control, reducing the need for manual calculations and determinations. Insulin pumps have safety features such as occlusion detection, negative order checking, priming detection, and maximum bolus limits, reducing the risks of over or under-delivery.[13]	Insulin pumps are significantly more expensive than insulin and syringes, with high upfront costs and recurring expenses. Inserting and changing infusion sets can cause discomfort, pain, bleeding, and infection. Technical issues can occur, requiring backup supplies and leaving patients vulnerable to pump failure issues. Insulin pumps cannot perfectly mimic the pancreas, and mealtime boluses still need to be determined and administered manually. Psychological factors such as anxiety and loss of control can result from constant insulin infusion and monitoring, leading to "pump dependence."[14]	Insulin pumps provide continuous subcutaneous insulin infusion for tight glycemic control through basal-bolus therapy. Insulin pumps have significant advantages in glycemic control and management flexibility. However, their high costs, complexities, technical issues, and psychological limitations restrict their feasibility and benefits for many with diabetes. To outweigh the cons, premium quality affordable pumps, easier usability, more automated features, and improved psychological acceptance would be required.[14]

No cure and false hope

Diabetes is rarely cured but may be "managed" temporarily, providing false hope. Underlying issues continue damaging health until complications become irreversible.[11]

Thus, it is evident that standard approaches are inconvenient, demanding, provide inconsistent results. They incur undesirable effects and costs, increase complexity and dependence, offer false hope, and rarely cure diabetes. It boils down to the fact that better solutions are needed for effective management of diabetes.

Recent drug delivery trends in diabetes management

Current diabetes treatments provide limited benefits while incurring high costs and harm. They fail to remedy the disease, merely suppressing symptoms by wearying the body and compromising health over time.[20] Strictly speaking, they do not actually "manage" diabetes but perpetuate danger.

If medications cured or controlled diabetes, they have utterly failed to satisfy. They continue struggling, unable to conquer diabetes without compounding issues. Success may come from needles or novel approaches but not from current pills.[21] Current innovations in medications meant for the management of diabetes mellitus are shown in Figure 3.

Oral Insulin

Developing oral insulin has proved immensely difficult, promising much but delivering little. Insulin cannot survive stomach acids and intestines, requiring modifications that reduce potency to permit passage. Each formula seems an invention transformed into failure, striking a balance between durability and effectiveness.[22] Many oral insulin options reached trials but none reached markets. Each had its own changes and benefits yet faced huge challenges: intestinal absorption and peptide integrity.[23]

Examples include insulin-chemokine fusions to help passage via chemokine receptors while protecting insulin. But fusions proved unstable, progressing no further.[24] Oral insulin sprays like exubera (pramlintide) reached markets briefly but offered limited benefits, withdrew due to poor sales, and patients still needed injections.[25,26]

Nitric oxide-releasing insulin to prevent degradation and promote widening showed promise but progressed no further. Tetrahydroxybutyl-insulin with modified bonds stalled in trials.[27] A topical insulin powder formulation completed phase 2 trials but disappeared, likely another failed hope.[27] Other approaches, including pH-sensitive peptides, fusogenic peptides, and intestinal transporters, continue research but progress remains elusive. Each iterative failure intensifies challenges rather than reducing them.[28]

Oral insulin has faced perplexing pitfalls despite tremendous efforts and advances. Each formula pushes possibilities but reaches hopeless ends. Though hope remains for eventual success, a viable oral insulin seems futile. The road to liberating diabetics from needles may be long, if passable at all.[29]

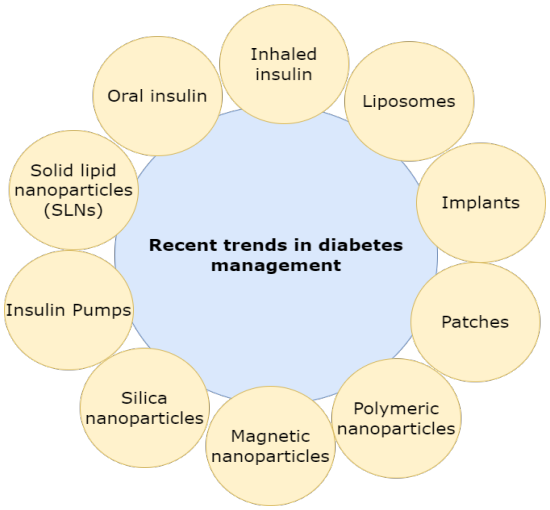

Figure 3: Recent trends in diabetes management

Inhaled insulin

Inhaled insulin promised revolution through control and normalcy but delivered frustration instead. Supposedly absorbing faster into bloodstreams through lungs, inhaled insulin allowed quicker, tighter control of post-meal spikes and flexibility. Meal calculations could determine perfect inhalations to cover carb content, enabling more physiological management. However, devices for inhaled insulin delivery metered dose inhalers and dry powder inhalers introduced complex challenges.[30] They required skill and coordination but still had major limitations. Lung function and technique impacted effectiveness and safety.

Pulmonary side effects also emerged swiftly with inhaled insulin. Bronchospasm, coughing, and wheezing threatened each inhalation. Concerns over long-term lung damage and studies showing insulin-treated lung cancers in animals raised dire warnings, halting progress.[25] The only approved inhaled insulin product was Afrezza, an ultra-rapid-acting insulin for post-meal use. It reached markets but lacked interest, now discontinued.[31,32] Other inhaled insulins from Novo Nordisk, Sanofi and Exubera reached phase 3 trials before failing or ending development.[33]

Perplexing pharmacokinetic differences, device difficulties, respiratory risks and preference for safer subcutaneous options plagued every attempt. Potential control and side effect benefits seemed outweighed by delivery perils. Each product positioned to transform management instead introduced more complexity and compromised safety. Inhaled insulin representedan unfulfilled promise, thwarted by practical hurdles. Devices, dosing, lung limits, pharmacokinetics, side effects, costs and risks combined disastrously.[27] Though its demise remains somewhat puzzling, inhaled insulin's failure seems comprehensible in hindsight.

Nanoparticle-based systems

Nanoparticles hold tremendous promise for advancing diabetes management through improved drug design. By modifying solubility, enabling sustained release and facilitating targeted

delivery, nanoparticles could revolutionize treatment by increasing effectiveness, decreasing harm and eventually enabling cure.[30]

Nanoparticles modify solubility by encapsulating hydrophobic drugs in lipophilic cores, allowing dissolution in aqueous media. Poorly soluble drugs can now be formulated into viable treatments. Sustained release also becomes possible through controlled breakdown of polymer matrices or lipid bilayers. Drugs can be released gradually over hours, days or longer, reducing dosing frequency and maintaining steady therapeutic levels.[29]

Targeted delivery allows nanoparticles to concentrate in specific tissues like the pancreas, liver or gut, limiting distribution throughout the body. Fewer drugs reach unintended targets, reducing side effects. Some nanoparticles even enable theranostic approaches, providing both treatment and monitoring capabilities.

Several Nanoparticle Types are Explored for Diabetes Applications

Liposomes

phospholipid bilayers encapsulating hydrophilic and hydrophobic drugs. Lead candidates include NN414 reducing liver enzymes and LONPES delivering pioglitazone.[34,35]

Polymeric nanoparticles

polymers like PLGA form nanoparticles for sustained release. Exenatide-PLGA shows promise for diabetic neuropathy pain relief.[36]

Magnetic nanoparticles

responsive to magnetic fields, enabling MRI-guided targeting and controlled release. Iron oxide nanoparticles deliver insulin and C-peptide, reducing hyperglycemia.[37,38]

Silica nanoparticles

Porous silica allows large drugs to be loaded for targeted delivery. Silica nanoparticles loaded with vitamin D help maintain pancreatic beta cell function.

Metallic nanoparticles

gold nanoparticles reduces inflammation and rescues beta cells from apoptosis. Silver nanoparticles have antimicrobial effects against bacteria linked to poor wound healing in diabetics.[39]

Solid lipid nanoparticles

Solid lipid nanoparticles (SLNs) are lipid-based nanoparticles with a solid lipid core rather than the phospholipid bilayer of liposomes. They are composed of lipids that are solid at room temperature, such as triglycerides, partial glycerides, and fatty alcohols. SLNs offer several advantages over liposomes and other nanoparticle types for drug delivery.[40]

SLNs could revolutionize diabetes management by enhancing effectiveness, decreasing harm and enabling cure. A solid lipid core can encapsulate both hydrophobic and hydrophilic drugs, increasing versatility. Compounds for treatment, prevention, complications can be formulated into SLNs. Controlled release provides sustained drug delivery over extended periods. This could improve insulin, glucagon-like peptides, antioxidants and other therapies while reducing dosing frequency.[41]

Lipid based SLNs have several advantages over traditional drug delivery systems. They are biodegradable and biocompatible, meaning that they can be broken down naturally without causing harm to the body. This reduces the risk of toxicity and allergic reactions, making SLNs a safer option for drug delivery. In addition, the surface modifications of SLNs allow for targeted delivery to specific tissues, improving the treatment's efficacy while minimizing side effects. Encapsulation of drugs within SLNs also offers several benefits. The lipid matrix shields the compounds from degradation and inactivation, allowing for improved bioavailability of the drug. This means that more of the drug will have an effect, reducing the required dose and potentially minimizing side effects. Furthermore, SLNs can be used to co-load multiple drugs, leading to synergistic benefits and reducing the risk of drug interactions or side effects.[42]

SLNs can be administered through various routes, including oral, intravenous, cutaneous, and pulmonary delivery. This versatility allows for more flexibility in treatment options and could eventually lead to non-invasive diabetes management through inhalation or transdermal applications. Despite the potential benefits of SLNs, developing them for insulin or oral antidiabetics delivery has been challenging. Issues such as aggregation, leakage, and rapid/incomplete release have complicated their development, and success has remained elusive.[43] However, researchers continue to advance SLN technology through complex formulations, surface modifications, and alternative routes of administration.

SLN vaccines, in particular, have shown promise in combating diabetes by rekindling broken immune systems and regaining the ability to produce vital insulin. Encapsulation of antigens within SLNs allows for sustained release, enhancing and prolonging immune responses.[44] The potential candidates for the development of SLNs are listed in Table 2. However, the complexity and cost of SLN vaccines have hindered their development, and evidence of their effectiveness has remained elusive.

SLNs have the potential to revolutionize diabetes management by increasing effectiveness, decreasing harm, and enabling a cure. However, hurdles remain in their progress, and success is not guaranteed. Further research and development are needed to overcome the challenges of developing SLNs for insulin and oral antidiabetics delivery and to fully realize the potential of SLN vaccines.

Implantable and transdermal delivery systems

Insulin and hormone implants could theoretically reduce glycemic variability and enable tighter control by delivering treatment continuously over extended periods. Rather than multiple daily injections, an implant releases its payload slowly and steadily, maintaining relatively stable basal levels.

This could eliminate dangerous drops and spikes in blood glucose that lead to complications while reducing hassle, pain,

Table 2: Promising clinical candidates for SLNs

Clinical candidate	*Characteristics*
Insulin-SLNs	Provided sustained release and reduced insulin requirements/injections but definitive proof of benefit has remained limited and complex. Further research needed.[45]
Metformin-SLNs	Showed extended release, lowered blood glucose and reduced side effects versus free metformin. However, A1C/HbA1c changes were minimal and development stalled, likely due to cost/complexity issues.[46]
GLP-1 agonist-SLNs	Reportedly enhanced stability and potency, but definitive proof of benefit was lacking, and synthetic issues may have hindered progress. Cost is also potentially prohibitive.[47]
Combination therapies	Insulin-metformin co-SLNs offered theoretical advantages but lacked proof of enhanced efficacy/ease of use beyond individual components. Complexity increased while evidence did not.[48]

and user error. Consistent basal insulin or incretin support may even permit some patients to only transition from injections to pills. For other individuals, implants could serve as an adjunct enhancing efficacy.[49]

Types of Implants Developed or Under Development Include

Insulin implants

Insulin is released from biodegradable polymer matrices over weeks to months. Insulin implant use led to A1C reductions of 1–2% and 50% lowering of insulin doses in trials. Patient preference and costs remain hurdles to approval and wide adoption.[50]

GLP-1 agonists

An implant delivers exenatide or liraglutide, stimulating insulin secretion and suppressing glucagon release. According to studies, it provided comparable A1C control to daily injections with fewer side effects. Development continues toward safety/efficacy for approval.[51]

Somatostatin analogs

Implants release somatostatin to inhibit glucagon, reduce gluconeogenesis and suppress appetite. According to trials, they lowered blood glucose, A1C, weight and appetite/eating. Therapy remained limited by short duration of effect, high costs and lack of definitive proof in diabetes populations.[51]

Glucose-responsive insulin

Insulin is deposited around sensing electrodes, releasing in response to interstitial fluid glucose concentration changes. These "artificial pancreases" remain limited by foreign body reaction, inflammation, short duration and lack of FDA approval. They highlight promising possibilities yet saddled with complex problems.[52]

While insulin and other hormone implants theoretically enable the holy grail of continuous treatment and optimal diabetes management, progress to widespread clinical use has confronted considerable complexities. Costs, duration of effect, side effects, lack of definitive proof, patient preference for existing options and regulatory difficulties have posed barriers.

Transdermal patches

Transdermal patches could theoretically enable sustained medication delivery through the skin, reducing fluctuations while simplifying management. Insulin, anti-diabetics or GLP-1 agonists deposited in patches could maintain consistent basal levels or enhance/prolong effects.[53,54] However, progress has proven limited and perilous, running aground on numerous complex challenges.

Some Leading Candidates and Their Current Status Include

Inslin patches

Insulin release from microneedle patches or hydrogel patches lowered blood glucose and A1C over 24 to 72 hours according to studies. However, insulin tended to degrade or cluster during storage, the patches were difficult to apply/remove without pain, and proof of efficacy/cost-benefit beyond short-term use remains lacking.[55] Development continues amid numerous struggles.

Metformin patches

Metformin hydrogel patches decreased blood glucose and A1C levels over 48 to 96 hours with less GI side effects versus pills. Need for frequent reapplication, skin irritation issues and lack of definitive proof in diabetics prevented approval.[56] Limited evidence suggests costs and complexity may also impede adoption if approved.

Exenatide patches

Exenatide microneedle patches boosted C-peptide levels without severe nausea. However, A1C/fasting glucose changes remained minimal and duration short (24–48 hours) without proof of usefulness for multiple dose management.[57] Regulatory concerns over microneedle use also slowed progress.

Combination patches

Some studies combined insulin, pramlintide, exenatide or GLP-1 agonists within single transdermal patches. Synergistic benefits were hypothetical but evidence too limited for

Figure 4: Novel Insulin products (# Candidates in clinical trials or the names of the manufacturing company)

meaningful conclusions or development progression. Practical challenges likely outweigh theoretical advantages.[58]

While transdermal patches for diabetes management spark hopes of remedying the limitations of needles and pills, progress has stalled at every turn. The short duration of effect, complexity/cost issues, lack of definitive proof, regulatory difficulties, skin irritation concerns and practical challenges of introducing microneedles have thwarted approval and adoption. The current novel trends in diabetes management are summarized in Figure 4.

CONCLUSION

In conclusion, while standard diabetes treatments have led to improved outcomes, they are still limited by issues like poor patient compliance, inconvenience, pain, and suboptimal glycemic control. Alternative and emerging therapies may help address these limitations and provide additional benefits. Insulin delivery systems like inhalers, patches and oral sprays offer increased convenience and reduced pain. Newer medications such as non-insulin injectables, long-acting insulins, and GLP-1 agonists have shown promise for improving glycemic control and reducing complications. Nanoparticle platforms such as SLNs represent an innovative approach with significant potential advantages for diabetes management, including targeted drug delivery, controlled release, enhanced drug efficacy and reduced side effects. Although SLNs have only been tested in animal models, their possible benefits warrant further research to determine their safety and efficacy in humans. Traditional treatments are expected to remain the basis of diabetes care. However, alternative and developing therapies have the potential to be useful add-ons or even eventual substitutes that can assist in achieving optimal diabetes management.

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