Review Article

Advanced Wearable Drug Delivery Systems for Enhanced Healthcare and Quality of Life

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ABSTRACT

The first wearable device applied to healthcare was the pacemaker, designed to control heart rhythm and significantly improve patient outcomes. This breakthrough marked the beginning of tremendous growth in wearable healthcare technology. A major challenge faced by many patients, especially those with chronic conditions like diabetes, dementia, or requiring long-term medication, is strict adherence to dosing schedules. Wearable devices address this issue by providing automated and continuous drug administration, improving patient compliance and quality of life. These devices integrate highly advanced materials and technologies, often requiring disposable components for safety and efficiency. Most wearable medical instruments are based on durable platform solutions, allowing them to be used in multiple applications. Common examples of wearable healthcare devices include insulin pumps, co-extruded tubing, drug reservoir plungers, microneedles, and wearable sweat patches. Insulin pumps, for instance, include components such as catheters and co-extruded tubes made from materials like polyethylene or polyurethane, chosen for their chemical compatibility with drug components, ensuring no adverse reactions. These materials and advanced sub-devices work synergistically to deliver precise and reliable drug administration. The development of wearable devices continues to evolve, focusing on enhancing patient convenience, treatment efficiency, and integration with digital health monitoring systems.

Keywords: Wearable healthcare devices, pacemaker, insulin pump, microneedles, drug delivery systems, co-extruded tubing, biomedical materials, patient compliance, continuous drug administration, digital health monitoring.

INTRODUCTION

The Wearable Technology was not created with a Healthcare field in mind. But The healthcare industry has always experienced staff shortages, and after past experiences it is more difficult to find and replace certified workers after the COVID-19 pandemic, especially registered nurses. In addition, the proportion is increasing worldwide, as is the frequency of chronic diseases, which is growing rapidly and shows no signs of slowing down. With the number of people able to provide care limited and the number of people needing care constantly increasing, change is necessary. The first device used in healthcare was a pacemaker in 1958. In recent decades, this technology has seen great advances. It is developed into watches, Bracelete and bands that can monitor vital signs, sensors that can be inserted or worn to track specific disorders or body levels, and many other concepts. Advances in the use of Wearables in the medical field are what must happen to help improve the current state of the field. Drug delivery devices, implantable devices, and combined wearable and implantable devices have recently emerged as patient-friendly concepts for the treatment of complex soft tissue pathologies that require repeated medical care and long term, such as diabetes, eye disease, cancer, wound healing, cardiovascular disease (CVD) and contraception. There is an urgent need to develop safer and more effectively drug delivery technologies to manage these conditions. Wearable Devices have previous been explored in the context of bioelectronics sensors and personalized health monitoring devices, but their application in drug delivery is evolving recently. These devices have mainly been explored to help with personalized health care, to monitor clinical parameters such as heart rate, blood glucose concentration, physical activity in patients and point-of-care disease care. However, the recent emergence of diagnostic and monitoring devices has faced many drawbacks, such as the need for repeated dosing, off-target toxicity, strict dosing schedule, etc. Often associated with traditional drug delivery approaches. The global portable injector market size is expected to grow from USD 4.3 billion in 2023 to USD 12.10 billion in 2035, representing a growth of 9 % during the forecast period 2023-2035. With the growth of the population, the incidence rates of various chronic diseases, such as diabetes, autoimmune diseases, cardiovascular diseases, oncological diseases, have an increasing trend. Pharmaceutical players have made extensive efforts in integrating innovative strategies and patient-centric approaches to address the growing burden of chronic diseases. Current treatment options include oral and parenteral administration of prescribed drugs. Among these options, parenteral drug administration is the most common method. However, it is impractical for the patient due to the need for frequent dosing and has other limitations, including dosing errors, the risk of microbial contamination and needless injuries. These factors have a significant impact on treatment compliance and therefore affect therapeutic outcomes; So, the Wearable Devices or Implanted Devices are included in this field to overcome such major problems and for the good quality of life for the patients refer (Table 1)[1-2].

Types:

Table 1: Various types of wearable devices used in drug delivery.

Name	Diseases in which devices are used	Material	Type
Microneedles	Skin Diseases (cancer, skin infection, etc.)	Polymers, Silica glasses, Ceramic, steels	1) Solid Microneedle 2) Coated Microneedle 3) Dissolving Microneedle
Insulin Pump	Insulin supplier (Diabetes)	Durable Plastic and metal, Cartridge, worm screwing	1) Conventional Pump Patch Pump
Wearable Sweat Patches	Electrolytes and Component Monitize (continous detection of sweat analytes)	Microfluidic sweat collection, sweat sensor	1) Sweatbands 2) Skin Patch 3) Textile Patch
Eluting Catheters	Nausea, low immunity (intravenous device; in veins by tube or needle)	Catheter, tubes, plastic, stick gum attached	1) Normal Saline Lactated Ringers
Blood Pressure Monitor	Blood Pressure (Pulse waves analysis)	Lithium ion, plastic, monitor	1) Aneroid Barometer 2) Pieoelectric Sensor 3) Mnometers

APPLICATIONS

1. Microneedles:

In recent years, microneedle devices have attracted the attention of the medical and scientific community due to their ability to pierce the stratum corneum, forming microchannels that facilitate the passage of lipophilic and high molecular weight molecules. Implementation of a portable microneedle-based on sensor array for monitoring multiple biomarkers in intestinal Fluids have lacked system, integration, and evidence of assay performance. Development and testing of a fully integrated wearable array of microneedles for the wireless and continuous real-time sensing of metabolites (lactose, glucose, alcohol). A microneedle device consists of a series of microneedles that can have different properties depending on their application. For example, the length of microneedles is related to their specific function and intended application. They can range from 100 to 3000 µm, with the most common size ranging from 250 to 1500 µm.

By forming micron-size pores on the surface of the skin, microneedles allow the penetration of macromolecular drugs into the stratum corneum in a minimally invasive way, increasing the efficiency of penetration and facilitating the direct administration of drug molecules into the dermis. The application of Microneedles has been extended to skin disorders including superficial tumors, wounds, skin infections, Skin inflammatory disease and abnormal skin appearance. Microneedling strategies can be broadly divided into various categories such as to Improve drug delivery efficiency by optimizing the composition of Microneedles; Syringes and microneedles have been used to deliver drugs to patients for over 160 years and are still the most common and effective way[3].

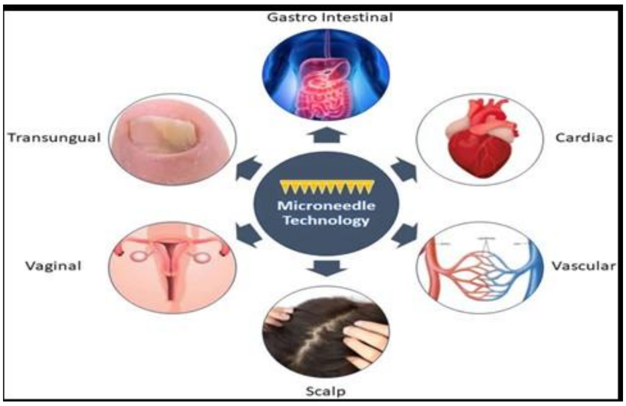

Figure 1: Application of Microneedle

The study presents the application of microneedles in the mucosa of the mouth, eye, vagina, gastric mucosa, nails, scalp and vascular tissues for the delivery of vaccines, biologicals, drugs and diagnostic agents. Technology has created easy access to poorly accessible segments of the eye to facilitate the delivery of monoclonal antibodies and therapeutic agents in the management of neovascular diseases. Microporation has been reported to significantly improve drug delivery across the poorly permeable nail plate. Curved microneedles and microneedle handles designed in space have been shown to deliver stem cells and therapeutic macromolecules directly to cardiac tissue and vascular smooth muscle cells, respectively[4-7].

2. Insulin Pump:

An insulin pump is a portable medical device that delivers a continuous flow of fast-acting insulin under the skin. Most pumps are small, computerized devices about the size of a pumpkin orchard stock. Insulin pumps are an alternative to multiple insulin therapy (syringe or pen injections) for people with diabetes who need insulin to manage their disease. Insulin pump technology is developing rapidly. All pumps available in the US today include CGM (continuous glucose monitoring) technology and offer the ability to automatically adjust your insulin needs based on your current glucose level. Each insulin pump is approved by the Food and Drug Administration (FDA) based on the age at which you can use it. Some insulin pumps are approved for children up to 2 years old. Most other pumps are approved for people 7 years and older. Insulin pumps are an insulin treatment option for diabetes management. Studies have shown that an insulin pump can improve diabetes control and reduce the risk of hypoglycemia. Many people find that they have more flexibility in choosing meal times and exercise when they wear an insulin pump. Sharing your insulin pump data with your healthcare team between office visits helps you make the most of the time you spend with them during your appointments. Downloading your pump reports allows the care team to track trends and adjust your care plan if necessary. Candidates for insulin pump therapy receive several insulin injections each day, check their blood sugar several times a day, are motivated to use the pump, and have good problem-solving skills Open communication between the pump user and their diabetes care team is essential.

Figure 2: Application of Insulin Pumps[8]

Although it is available from different manufacturers, insulin pumps are always designed in the same way: an ampoule contains insulin that enters the body as needed for a battery pump through a caterer and a cannula. A small motor pushes the cap of the insulin ampoule forward through the threaded stem, causing the insulin to be released. The motor has extremely high requirements: to reduce the weight of the portable device, the motor must be compact, and its diameter must generally not exceed about 10 millimeters. The motor must be reliable and accurate, because too little or too much insulin is harmful to the patient. A man's life may also depend on the reliability of the engine used. Because insulin must be injected into the body every few minutes, the motor must start and stop at regular intervals. In addition, the engine should work very efficiently thanks to the operation of the battery[9].

3. Wearable Sweat Patches:

Wearable sweat sensing system typically consists of Microfluidic structure for sweat collection, sweat sensors. Microfluidic Structures based on Flexible Materials can provide conformal contact and stable interfaces between skin electronic devices. It also enhances sweat capture efficiency and reduces the evaporation for improved detection accuracy. Wearable devices are releasing the patient's friendly concept for treating soft tissue They need repeated and long-term medical care, such as diabetes, eye diseases, cancer, wound healing, cardiovascular disease (CRDs) and monitoring. These devices help to personalized health care, for the monitoring of clinical parameters, such as cardiac concentration, physical activity in patients for diagnosis. In early 1983, An artificial pancreas with an endocrine needle coated with the microcomputer and the sensor module and Pump also helps to maintain the daily glucose level in diabetics in the range of 7 days. Wearable sweat sensors have two main applications: direct measurement of various sweat components or power generation from human sweat. Until now, more attention has been paid to the detection of sweat, in line with the significant research in specific detection techniques. Prototypes of different wearable sensors have been used to detect different components of sweat, such as glucose, lactate and different ions. Wearable sweat sensors have attracted considerable attention due to their non-invasive mode of operation, real-time availability, and broad application prospects in the fields of health and energy. In the last decade, great consideration has been given to the construction of wearable sweat sensors with the ability to collect, detect and visualize sweat[10].

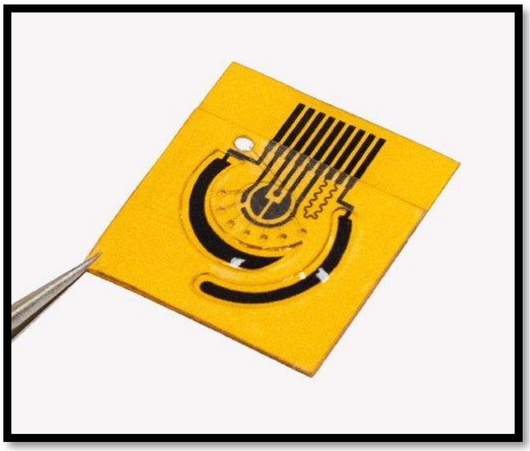

Figure 3: Application of Wearable Sweat Patches

There are many notable studies on wearable biosensors and their applications in a variety of biological fluid matrices such as blood, sweat, saliva, urine and tears[11-13].

4. Eluting Catheters:

Eluting Catheters is also called as Intravenous Devices Intravenous devices are used to give drugs by intravenous injection or infusion into a vein in the body with a tube or needle. They are commonly used in situations where it is essential to control the medication in the body or when the patient needs to get the drug into the blood quickly, such as in an emergency or when oral medications break down during metabolism There are several types of IV, and the most common is the standard IV, which is used in short-term situations, such as pain relievers, antibiotics and anti-nausea medications. With the standard intravenous route, a needle is usually inserted into a vein in the wrist or the back of the hand. Then, a catheter is pushed over the needle, then the needle is withdrawn, while the catheter remains in the vein. Pulsatile IV devices are another type of device used for intravenous infusion, or injection directly into a vein in the body with a syringe. On the other hand, a catheter is a long tube that delivers medicine from a vein near the elbow, chest or neck to a vein near the heart Additive intravenous devices are focused on the development of customized catheters for local drug delivery Insertion of an intravenous catheter is a routine procedure for most veterinarians and clinical nurses. It is essential for the administration of medications in emergencies and routine surgical procedures, as well as for many routine treatments. Although IV catheter placement becomes second nature over time, it is a skill that requires concerted effort to perfect. In this article, I provide an overview of the types of catheters, The key principles of catheter care, and a step-by-step guide to placement. Placement of an intravenous catheter is recommended for any anesthetic to maintain intravenous access in case of emergency[14-17].

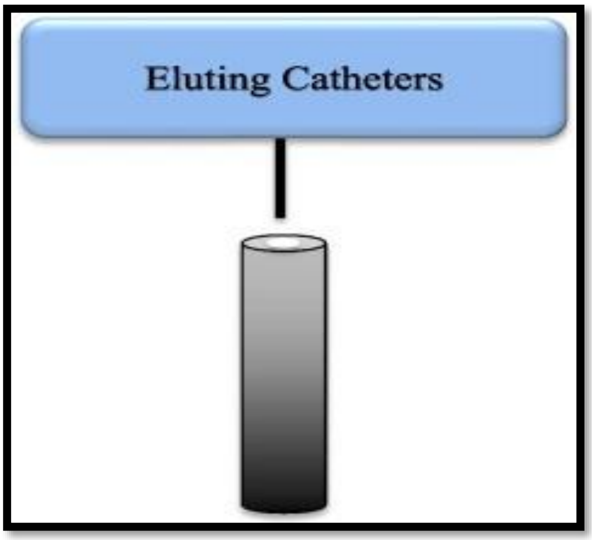

Figure 4: Eluting Catheter

Table 2: Marketed Examples

Brand name	Company name	Price of the brand name
Niscomed syringe pump (Insulin pump)	SP-6	14,784 RS
Micro-Needling Infusion (Microneedle)	GHAR Soaps	2,399 RS
Dermadry Total 877067 (Wearable Sweat patch)	DERMADRY	42,4999 RS
Blood Pressure Monitor	Grin Health	6,900
Plenumtech Crest Syringe (Infusion Pump)	Plenumtek Medical	35,000

CONCLUSION

Drug delivery devices and Implanted delivery devices have created new opportunities in healthcare technology by providing user-friendly, long-acting, self-administering and affordable drug delivery platforms. The evolving concept of devices such as Microneedles, Insulin Pumps, Wearable Sweat Patches, Intravenous tubes, etc has addressed many of the challenges associated with conventional drug delivery approaches, such as repeated dosing, nonselective targeting, uncontrolled drug delivery, and off-target toxicity. These Devices has various application in their fields; such as accurate dosing , easy to use, automatic systems are included and many more Wearable Devices and Implanted Devices have various Implementation according to their functions and working.

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