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SMART CHROMIC DRESSING FOR NON-INVASIVE GLUCOSE MONITORING: A THEORETICAL DESIGN

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Abstract: *Diabetes is one of the most prevalent non-communicable diseases worldwide, with a rapidly increasing incidence that poses a serious public health challenge and economic burden. Current glucose monitoring systems, such as finger-prick glucometers and continuous glucose monitors (CGM), are often invasive, costly, and uncomfortable for patients, especially for long-term use. These methods also generate considerable medical waste, contributing to environmental concerns.*

This paper presents the theoretical design of a smart textile dressing for non-invasive glucose monitoring. The concept is based on a colourimetric response that indicates glucose concentration in sweat through a visible colour change. The dressing incorporates silk fibroin as the enzyme immobilisation substrate, glucose oxidase (GOx) as the active agent, and gold nanoparticles to enhance signal visibility. A cellulose acetate transparent film allows external colour assessment via the naked eye or a handheld colourimeter.

The proposed system offers multiple advantages over conventional glucose monitoring devices, including lower cost, greater comfort, and increased environmental sustainability. It also avoids skin puncture, improving usability for patients with diabetes who require continuous monitoring. This preliminary study sets the foundation for further research and prototyping of a low-cost, wearable biosensor that aligns with current trends in smart textiles and personalised healthcare.

Keywords: *biosensor, colourimetric, diabetes, disease, smart textile.*

1. INTRODUCTION

People with problems with blood glucose disorders require constant use of a glucose measurement system, usually the finger-prick glucometer. These devices come in different types and models but are generally small, portable, accurate, simple, and intuitive. However, they are pretty invasive, as they require a small blood sample for measurement, which is obtained by a tiny fingertip prick. These meters are composed of the glucometer itself, the lancet (the needle that performs the puncture to obtain the blood sample) and the test strips. Diabetes prevalence has been growing at an alarming rate worldwide. According to the International Diabetes Federation, approximately 537 million adults were living with diabetes in 2021, a number projected to rise to 643 million by 2030 [1]. Beyond the health burden, diabetes management generates a significant amount of medical waste and environmental impact due to the single-use nature of many monitoring systems [2].

The operation of this type of device consists of measuring blood glucose based on the intensity of an electrical discharge detected on the strip, which is produced when the blood comes into contact with the test strips; these have enzymes (molecules that catalyse chemical reactions) that oxidise the glucose with glucose oxidase (GOx) as a catalyst [3-5], when this oxidation occurs, electrons are released, generating an electrical microcurrent as a result. This reaction generates a glucose titration value within 5 to 10 seconds.

Continuous Glucose Monitoring systems (CGM) are used to monitor blood glucose levels. These devices are inserted under the skin to measure glucose in interstitial fluid. To reach the interstitial fluid, the device usually has an automatic lancing device, which, using a needle guide, inserts a filament under the skin to act as a sensor. This sensor must be appropriately attached to the skin to ensure it does not become detached. The placement of the sensor depends on the manufacturer's recommendation; the most common areas are the arm, the abdomen or the upper part of the buttock.

This study proposes the theoretical design of a textile-based chromic dressing for non-invasive glucose monitoring through sweat, based on enzymatic reactions, as an alternative to conventional and invasive CGM systems. To achieve this objective, current non-invasive measurement methods are studied to select both the measurement technique and the device's design.

2. DEFINED DESIGN ELEMENTS

2.1 Blood glucose measurement technology

A textile sensor exhibits high flexibility and lightness, which is a great advantage over commonly used sensor systems. Sensors for non-invasive glucose monitoring currently developed are mostly electrochemical or colourimetric. Electrochemical sensors could easily achieve continuous monitoring by transmitting the data in real time to wireless electronics. In contrast, colourimetric sensors could be read directly with the naked eye without the aid of additional equipment.

After analysing various measurement techniques in both fields, the study by Zheng et al. proposes a reflective optical sensor based on surface plasmon resonance and a reflective fibre structure. This system uses immobilised glucose oxidase; the enzymatic reaction between glucose oxidase (GOx) and glucose is used to measure glucose concentration through a change in refractive index, which implies a change in wavelength. This change is exposed by the influence of a gold film that assists the excitation of the optical sensor to reflect the light [6]. This change in reflected wavelength can determine the relationship of % reflectance to blood glucose concentration.

2.2 Device design

To begin to design the dressing, the technology on which it is based must be taken into account, and the aesthetic and shape requirements for the dressing are as follows:

- The colours are restricted to those defined by the enzymatic reaction that will produce the smart textile. These colours fall within the chromatic range from yellow to red through orange, with these changes occurring as the glucose level rises.
- The parts that make up the dressing must be: absorbent textile impregnated with the enzyme, gold particle spray film and film of transparent material that allows the change of colour to be visualised, as well as including an adhesive and facilitating perspiration by not allowing perspiration in the area of the textile.
- The textile size must be at least 8 mm in diameter, as this is the standard size of the measuring aperture of the colourimeters on the market.

Considering these requirements and the fact that with this product, we are looking for total functionality, which will always prevail over aesthetics, we have designed a circular dressing. The shape was chosen to make measuring the colour with the colourimeter more intuitive since the measurement opening area is shaped like this.

Its size has been reduced as much as possible so that wearing it is of minimal inconvenience to the user, leaving a transparent film with a diameter of 20 mm on a textile with a diameter of 10 mm.

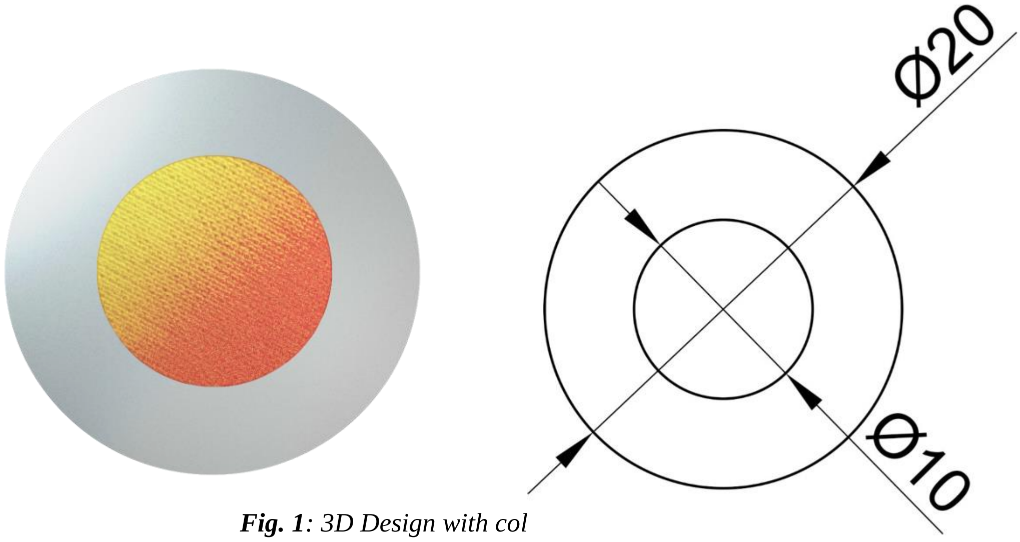

***Fig. 1**: 3D Design with col*

2.3 Materials

In order to choose the textile material that would make up the absorbent pad, a prior search was carried out to determine which textile materials had the greatest affinity for glucose, from this search, several articles were found that demonstrated the aptitude of silk fibroin to immobilise glucose oxidase, so this material was chosen to be in contact with the skin, which will be impregnated with the enzymes defined above and subsequently sprayed with gold particles on its surface.

To protect this material, a transparent film of cellulose acetate is adhered to, which allows the colour of the dressing to be measured using a small manual reflection spectrophotometer.

2.4 Instructions for the use of the device

Since glucose measurement will be defined by sweat, the area of the skin where the dressing is applied must have a certain amount of perspiration. The areas of the body with the highest concentration of sweat glands are, in descending order, the palm of the hand and the soles of the feet, the head, the torso and the extremities. Bearing in mind that for colour measurement, the dressing has to be placed in an accessible area that is not restricted by clothing, the palm of the hand could be considered a suitable location. However, it is a highly articulated and uncomfortable area, so it could easily become detached and, therefore, discarded.

With the aforementioned limitations, the most suitable part, although it is not so easy to sweat, would be the arm, specifically near the wrist, but without reaching the articulated area as shown in Figure 2, so that in the case of wearing long-sleeved clothing, it would only be necessary to roll up the sleeves a few centimetres to achieve accessibility to the reading with the colourimeter.

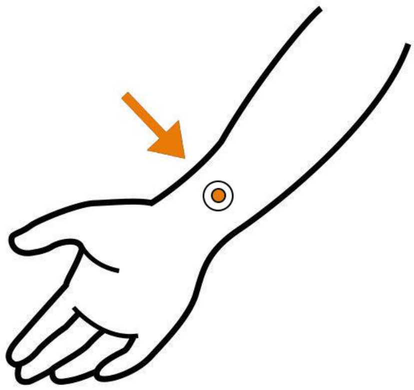

Fig. 2*: Placement area*

5. CONCLUSIONS

This paper presents the initial design of a non-invasive, low-cost glucose measurement dressing that provides a user-friendly and comfortable indicator for the user. Moreover, the proposed design contributes to sustainability by reducing electronic waste and promoting the use of biodegradable or recyclable materials. This study is the start of a larger project to prototype a device with a technology based on the colour change produced by the interaction of glucose with glucose oxidase enzymes and gold nanoparticles.

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