Quest Journals
Journal of Medical and Dental Science Research
Volume 7~ Issue 9 (2020) pp: 01-11
ISSN(Online) : 2394-076X ISSN (Print):2394-0751
www.questjournals.org

Research Paper

Using a Case Study to Explore how to Evaluate Emerging Wearable Medical Technologies

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ABSTRACT
Nowadays, people are more prone to chronic diseases as age and health are proportional to each other. The purpose of this study is to analyze the sensor technology in smart clothing and discuss how to provide efficient health tracking service for elderly people and diabetic patients, meanwhile finding the suitability of different physiological fluids in glucose monitoring that could be used as sensors in smart clothing, finally summarize the future development of smart garment technology.
The study involves a series of steps to assess the commercialization of glucose monitoring smart clothing, the methodology used in this study are literature review, secondary data analysis, and a demonstration team review study, different types of sensor technologies with different physiological fluids are compared, reviewed and analyzed. It is found that some companies and research institutions began to propose different types of smart clothing with advanced technologies. The common point is the use of Nano-electromechanical systems (NEMS) technologies or nanomaterials to minimize the size of the sensor and energy consumption in order to embed the sensors into clothing. However, not all sensors can be embedded into the clothing, therefore, some sensor technologies have greater potential for development, and others don't. Nonetheless, with growing demand and scientific progress, the technologies will create more demand for applications, the results of this study suggests that the sensor technologies used in smart clothing will be used for a wide range of health monitoring or disease diagnosis, apart from glucose monitoring.
KEYWORDS:*Glucose Monitoring, Diabetes, Physiological Fluids, Smart clothing, Commercialization*

Received 10 December, 2020; Accepted 25 December, 2020 © The author(s) 2020.
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I. INTRODUCTION

With the arrival of aging society, the demand for medical services for elderly people is increasing rapidly, especially patients with chronic conditions. Diabetes is a common chronic disease around the world. As diabetes is not only popular among elderly people but also in younger generation, all kinds of research and developments have been made to accomplish efficient and effective diagnosis and monitoring.

Bruen, Delaney, Florea & Diamond (2017) provides a review that analyzed recent advancement towards non-invasive and continuous glucose monitoring wearables that contained the latest innovation of sensors with specific focus on glucose monitoring in different types of physiological fluids.Smart wearables for diabetes monitoring include smart clothes, contact lenses, foot wears, and smart wristbands (Davies 2016). Physiological fluids that can be used for glucose monitoring include blood, interstitial fluid (ISF), urine, sweat, saliva, ocular fluid (tears), and breath (Bruen, Delaney et al. 2017). Wearable technology includes devices or garments equipped with sensors and wireless communication technology monitor blood glucose levels, personalize treatment and connect to healthcare providers with information stored in cloud (Davies 2016).

The increasing need for long-term and frequent treatment to record the health status, which cause physical and psychological burden to themselves and their family members. Today, with the introduction of 5G technology, information can be transmitted to the cloud, turning smart textiles' manifold possibilities into actualities. From now on, a piece of wearable object won't be just a piece of wearable object: it may also be an entire sensor system which can continue to monitor the physiological device through electronic signal, and thus improve the quality of life of patients.Fears of needle stick infection and troubles of blood test are the major two reasons triggering patients to adopt this kind of technological invention. Advantages of the smart glucose

clothing also include timely monitoring which is particularly critical while people are in the circumstances where pretty low blood sugar might cause death accidents. Besides, sometimes the smart glucose clothing can monitor the diseases at any time for early prevention of illness worsening.
The purpose of this study is to assess the sensor technology's innovative development process in smart

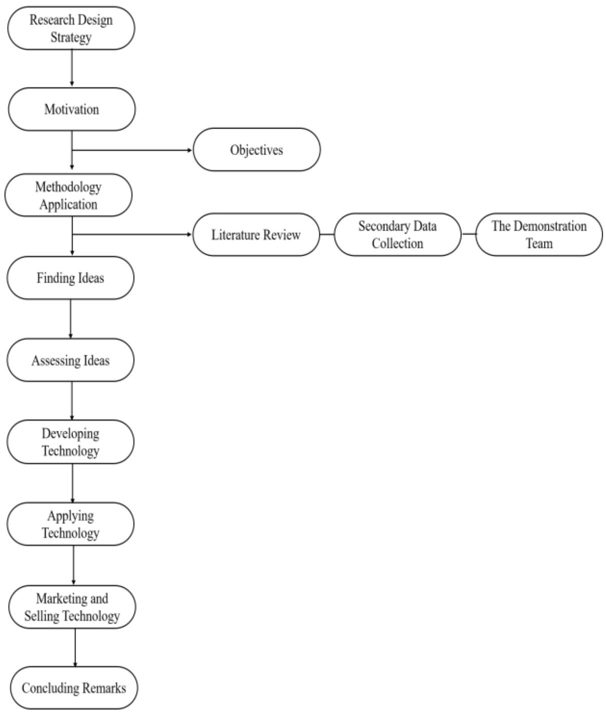


Figure 1: Research Structure

glucose clothing and discuss and explore how to provide good health tracking services for elderly people and diabetic patients. A step-by-step series of approach to an innovation, or an innovating technology is shown in Figure 1, which in this study, is the smart clothing for glucose monitoring, because it is critical in showing the life cycle of product innovation and the trends of introducing great ideas to the market (Touhill, Touhill & O'Riordan 2010).

This study has grasped one of the most novelist biological technology trends, analyzed and assessed a developing innovation device and conclude whether this emerging technology is competitive and indeed empirical for future marketing and commercialization in the society.

II. METHODOLOGY

2.1 Literature Review, Secondary Data Collection and Analysis

Literature review refers to the collection of academic writings on a subject (Galvan & Galvan 2017). The literature review of this study includes all peer-reviewed books, articles, journals, conference papers and dissertations of the area of research (Fink 2013), which is diabetes and smart clothing. The literature review in this research is generally using the systematic review, which basically focus on the research question by trying to identify, evaluate, select, synthesize and summarize all the research evidence related to this question. If the project has been evaluated to pass, then we shall pay loads of efforts in this regard. At this proposal stage we only plan some major directions in terms of literature review for the preliminary and future research.

Secondary data collection is the source that is obtained second-handed and is not the original work of the researcher. The secondary data is done by collecting other researchers or institutional data that is not carried out by the user (Schutt 2011). Secondary data includes existing data sets, reports and documents collected by other people or organizations. The sources of secondary data usually can be obtained from government documents, partner non-government organizations (NGOs), professional and academic institutions, and internet websites. This study uses mainly literature review and secondary data collection for comparison and review purposes of suitable sensors in smart clothing to monitor glucose levels.

2.3 Demonstration Team Engagement

This study also utilizes a demonstration team (innovation team) as a base to enhance the research. The team's application is used to experiment the whole process of this study.According to ScientiaGlobal (2016), Linh and his team are an innovation team that are creating a breakthrough in technologies of healthcare wearables. Bonbouton is a platform for smart clothes, powered by integrated graphene sensors that allows users to monitor their health comfortably and in an inconspicuous way (Bonbouton 2016). Some of the vitals that can be measured are body temperature, breathing rate, pulse, steps, and sleep. The team's objective is to improve the lives of people by developing connected technologies and preventing diabetic patients from foot amputation. Via a patented approach involving graphene inkjet printing, Bonbouton's team has created the ultra-thin and ultra-flexible sensing elements comprising heat, pressure, and potential sweat analysis, that can be embedded in clothing (ScientiaGlobal 2016).

Graphene technology used are nanomaterials that comprised single layers of strong-bonding carbon atoms that has high mechanical strength and flexibility properties, hence giving the ability of creating ultra-flexible and ultra-thin sensors that exhibits high electrical and thermal conductivity (ScientiaGlobal 2016).The team sees a bright future for diabetes management as they are creating their first product – a proprietary smart shoe insole that monitors foot temperature to detect and capture the early signs of foot ulcers of diabetes. The shoe insole will monitor foot temperature and pressure continuously and transmit this data to the Bonbouton's APP in real-time, which keeps all the data of that patient so that the patient, doctor, or caregiver can review.

This study aims to solve the problem of diabetic patients that have to undergo continuous glucose monitoring which leads to the motivation of this research. In the current study, alternative physiological fluids prior to blood glucose monitoring that is non-invasive to the body was reviewed and analyzed. Examples of companies and research institutes under each physiological fluid for glucose levels monitoring were also described. Physiological fluids that are suitable for textile-based or textile-integrated sensors were provided and were compared. From this comparison, the technology maturity and commercialization degree of each product is assessed.

III. ASSESSMENT STEPS OF GLUCOSE MONITORING SMART CLOTHING FOR DIABETIC SELF-CARE

3.1 Finding Ideas

3.1.1 Coming Up of an Idea

There are four crucial factors in making a commercialization of good ideas successful which are teamwork, planning, discipline, and perseverance.An innovation team that aims to commercialize an innovative technology contained four uniquely different individualities whom are, the inventor or the innovator, the investor, the technologist, and the entrepreneur (Touhill, Touhill et al. 2010). However, some innovations do not satisfy users' requirements in terms of cost and performance, therefore, a portfolio mission statement is needed to attract innovators, or inventors so that they understand the type of ideas. Next, the specific criteria that includes key features of eye-catching ideas has to be formulated, such as the criteria needed for a smart clothing to monitor glucose levels. The criteria will be the requirements needed for a continuous glucose monitoring of smart clothing.

3.1.2 Ideas Must Be Consistent with The Overall Plan

The idea of the using smart clothing to monitor diabetes must be pursued carefully and is consistent with the overall plan, which is the goals, target market, budget and so on. Hence, a member of the innovation team is assigned as the governor, who is the person to keep focus on the plan and stay discipline. And it helps to have an estimate of cost and time for the whole process, and of what would be needed to accomplish success.(Touhill, Touhill et al. 2010).

3.1.3 Smart Clothing to Monitor Diabetes

Smart clothing is considered a revolution to healthcare practice, and with hopes that the extensive use of clothing to monitor health or help treat it can reduce the reliance on expensive equipment and burdened healthcare systems. Smart clothing can be defined as new apparel features which provide interactive responses via signal sensing, data processing and responses actuating (Tao 2001).

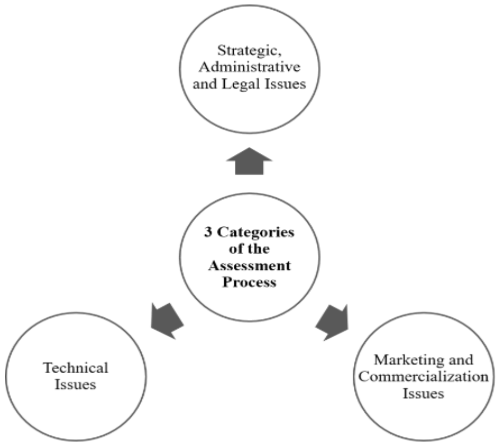
Smart clothing is perceived as an approach to create value, enhance health awareness, and reduce costs because it can track chronic conditions, has a critical benefit to the growing aging population, make patients' stay at a hospital more comfortable, and offer more convenience and flexibility to patients (Brown, 2018). The emphasis of smart clothing is found on the seamless integration between the fabric and the electronic components that combines these two together such as cables, microcontrollers, sensors and actuators (Barhanpurkar, Joshi& Kumar 2015).For healthcare function, it is to insert conductive fibers into fabrics so that healthcare monitoring such as heart rate, respiratory rate and so on can be monitored anytime, and with embedded wireless communication device, the information could be transmitted to healthcare center or hospital(Deng & Cui 2016).

The medical and healthcare sectors are a significant and growing part of the textile industry. The market is driven by several factors which include population growth, the aging of population, increasing standards of living, increasing concerns towards health, and technology advancement (Horrocks& Anand 2016). Thus, a whole new range of materials is needed for the future of smart textiles. For example, conductive polymers, metallic, optical fibers are materials that can be incorporated into textile, hence, providing electrical conductivity, sensing capabilities, and data transfer (Syduzzaman, Patwary, Farhana & Ahmed. 2015).

The BIOTEX project developed textile-based sensors for non-invasive continuous monitoring of health during daily activities. The sensors offer monitoring using sweat which is placed on the lower back using a waist-band, also electrocardiography (ECG), respiration, and pulse oximetry sensors are available with a separate garment (Coyle, Lau,Moyna, O'Gorman, Diamond & Francesco et al. 2010). With more and more institutes that are keeping putting efforts in researching sensors technology, the performance requirements of sensor, such as size, power consumption, weight, water-resistant, flexible, and cost, will be met in the near future.

3.2 Assessment Ideas

3.2.1 The Assessment Process



As diabetes is a specific disease, smart clothing

Figure 2: The Three Categories of the Assessment Process
Source: Touhill, Touhill et al. (2010)

that detects diabetes has to be a wearable that can come in contact with the physiological fluids when the user wearing it. Theimprovement on the key elements of the smart clothing is obvious from the literature survey, to grasp the market opportunity, three Categories of the assessment process are demonstrated in figure 2. The innovation team members can consult and refer to during the assessment process. (Touhill, Touhill et al. 2010).

3.2.2 Strategic, Administrative and Legal Issues

Smart clothing alone is a great idea, but the different physiological fluids' detection sensors have their pros and cons to be embedded into clothes. The concept of using sweat to monitor glucose fits within the scope of strategic plan. However, the concept has already been patented (Potts, Moyer, Yanazawa, Finkelshtein & Ye.2010). Hence, it may face problem in the technical issue aspect. Nevertheless, it is probably not so suitable for urine to be tested in textile-based sensor because urine usually comes in larger volume. At the moment, Interstitial Fluid (ISF) requires needles to go under the skin (Diabetes.co.uk 2018) and it might not be too strategic as people will feel reluctant to use this product. Saliva requires spitting of sample or inserting biosensor into the mouth, while tears are not possible to be in contact with body sensor of textile.

3.2.3 Technical Issues

There is currently no body sensor in textile for urine and tears sample to detect diabetes. The current devices for interstitial fluid detection too are bulky with large batteries although the results could be transmitted to smartphones (Diabetes.co.uk 2018). Unless measurements are done by a miniature device and consuming much less battery power, a garment with bulky device is obviously not useful and inconvenient.The measurement technology by using ISF has to be further improved for applying to the smart clothing. Currently, there are devices which use saliva to detect glucose, but there is no textile-based or textile-integrated sensor that uses this fluid. Sweat sensor can be easily incorporated into a garment as the skin will produce sweat and clothing is the directly in contact with our skin.

3.2.4 Marketing and Commercialization Issues

Patients with diabetes will find this innovation of glucose monitoring using smart clothing useful in the long-run as they can monitor the glucose level anywhere, at any time. Sweat might be the easiest to commercialize since it looks the most promising. While GlucosAlarm for monitoring glucose in urine is a great invention but it's currently not a wearable device but a sensing device. There is also tattoo printed sensors for teeth that may fulfill the requirement of the smart clothing, and further research is still required as to how the user collect the saliva sample to be tested by sensors in the garment because saliva cannot be in direct contact with body sensors of textile.

Regarding the invention of Google (Duffy 2014, Legraien 2017) for monitoring glucose in tears, the contact lens which directly detects glucose has a growing potential because contact lens is the easier possible way to detect glucose from tears. For the innovation to be marketed and commercialized, the best channel is through hospitals, with the support of doctors and medical professionals because they can be a good example and testimony when promoting the product. Also, by collaborating with research and pharmaceutical companies such as Abbott and Hexoskin can be another good option to commercialize the product.

3.3 Developing Technology

In this stage, the idea is all set for the development phase. The technologist will lead the way and the entrepreneur is also relatively active in this phase. The main task of the development phase is to gain adequate information so that products can be designed and built through the development effort.

3.3.1 The Goal of Development is the Basis of Design

The role of the inventor, or innovator is significant in the assessment and evaluation phase of the research because they have to deliver the idea clearly to technologist and the other team members so that the team has a clear understanding of the whole idea (Touhill, Touhill et al. 2010).Then The innovation team has to address challenges that are ahead (Filho, Tahim, Serafim & de Moraes 2017). By developing the technology, there should be an innovation product in the making. Therefore, each physiological fluid is reviewed and assessed with current wearable devices.

3.3.2Physiological Fluids That Measure Glucose and Smart Wearables — The Current Status

Blood

By using blood glucose meter, blood is the most reliable body fluid for diagnosis of blood glucose levels. However, blood test is accurate but the testing procedures and testing time is far more strenuous compared to the others. Patients who intend to self-monitor their glucose level will have to suffer many times a day pricking fingers to get the blood sample which result in people are getting tired of this conventional testing method for glucose monitoring. because of the invasive sampling techniques, other physiological fluids are taken into account for non-invasive and continuous monitoring (Coyle, Lau et al. 2010). Thus, the intrusive sampling technologies are not included for further discussion here.

Interstitial Fluid (ISF)

Interstitial fluid (ISF) makes up approximately 40% of water in the body and hence plays a significant role as it contains glucose, salt, fatty acids, calcium, magnesium and potassium (Diabetes.co.uk 2018). Abbott Inc., Dexcom Inc. and Medtronic MiniMed are some of the companies which sell products for glucose monitoring available in the market. ISF could be monitored by a subcutaneous sensor, which need for hypodermic needle inserted under skin. This method is considered a semi-invasive monitoring AND causes less pain compared to finger pricking test and possesses application potential for smart clothing. As a result, this technology is considered in this study.

Saliva

As a small amount of saliva sample is needed without penetrating under the skin, this method is considered non-invasive and could be useful in CGM. Saliva has to be sampled by spitting or inserting device into the mouth for sampling. Some products available in the market are iQuickIt Saliva Analyzer by iQuick, and ADOUR Glucometer by Indiegogo. The iQuickIt Saliva Analyzer simply uses saliva specimen to measure glucose. A small amount of saliva sample can be taken using a one-time use strip and immediate testing can be obtained by placing the strip in the analyzer. The data results can be sent automatically in real-time via wireless communication to a smart device so that they can be shared and monitored by caregivers or medical professionals (iQuick 2015). The ADOUR Glucometer application is similar to that of iQuickIt Saliva Analyzer, what's more, the size of the iQuickIt Saliva Analyzer and ADOUR glucometer are slightly smaller than a palm (iQuick 2015, Indiegogo 2018).

Other kind of saliva-sensing, such as tattoo printed onto a tooth, and monitor respiration and bacteria, gives us hope that teeth integrated devices for CGM is has great potential for further growth. However, it is necessary to pay attention to the validation of such systems that saliva glucose value have a statistically significant correlation with blood glucose and it can be obtained only after fasting measurements and at least 2 hours postprandial (Newman & Turner 2005).

Urine

Urine contains many types of metabolites such as glucose, proteins, nitrates, and some other dissolved salts such as sodium and potassium. Although this sensing method is non-invasive, it may not be suitable for CGM as the human body cannot produce urine continuously and the result can be less accurate than blood monitoring. However, the presence of high uric glucose concentration is identified as a risky condition, this could mean that the individual is diabetic (Makaram, Owens & Aceros 2014). Thus, patients can monitor their glucose levels at home a few times a day and share it with their doctors or caregivers through wireless communications (Hodsden 2015).

Rather than conventional type of urine test, which is to collect a small volume of urine in a small cup, the GlucosAlarm shows glucose testing via urine inside the toilet bowl. The device uses a light sensor that detects and measures the frequency of glucose present in urine with only one drop of urine needed. The sensor has to be activated before using the toilet and aiming a small amount of sample into the device. The GlucosAlarm is reasonably affordable with one test costing less than 17 cents US dollar and the results are able to be kept in a smart device via wireless communication (Hodsden 2015).

Ocular Fluid (Tears)

Tears have three layers and they are not constant in their composition. The three layers of tears are an outer hydrophobic oily layer that prevents tears from evaporating, a middle aqueous layer that carries vitamins, salt, and other minerals to the cornea, and a mucous layer that helps tears stay on the eye (Helmenstine 2016)

Google made a prototype smart contact lens to measure glucose concentrations in tears in 2014. It uses a transparent biosensor that can be integrated into contact lens (Duffy 2014). The sensor detects pH, acidity levels, and measures the glucose levels in tears. It provides information to patients for self-monitoring and lets them keep track of their glucose levels from their smartphones. As much as this development sounds promising, the prototype can only test for glucose levels at the moment and is still undergoing laboratory test for other medical conditions diagnosis such as cystic fibrosis and cancer detection (Legraien 2017). The latest technology using tears to detect glucose levels is by using contact lens with a microchip sandwiched between two layers of soft lens. The wearer will not notice any difference while wearing the contact lens. Contact lens is appropriate for CGM with fresh amount of tears replenished for accurate glucose monitoring throughout the day (Bruen, Delaney et al. 2017).

Sweat

Sweat might be the easiest physiological fluid to obtain access to for sampling from human bodies. It can provide lots of information by biomarkers such as glucose, amino acids, proteins, and other metabolized molecules. Researchers from the University of California-Berkeley and the Stanford University (Dusheck 2017) are collaborating to develop a wristband-type wearable sweat sensor that could diagnose diseases such as cystic fibrosis and diabetes. Sweat sensors can detect chlorine ions and glucose in sweat by electronically transmitting the information in real-time to a server that can analyze the raw data (Cooper 2016). High level of chlorine ions indicates cystic fibrosis, and level of glucose in sweat is comparative to that in blood, which indicates diabetes for high blood glucose levels (Muanya 2017).

BIOTEX project funded by the European Union (EU) intended to develop textile-based sensors to measure physiological parameter and chemical composition of body fluids, with a specific focus in sweat (Coyle, Lau et al. 2010). Maldarelli (2016) demonstrates a wearable patch that uses sweat to monitor blood glucose levels (Legraien 2017). This patch led by Kim, D. H. from the Institute for Basic Science in Seoul, South Korea have designed and created a dual patch that can monitor blood glucose levels and supply insulin to reduce high glucose levels when they occur (Maldarelli 2016). The technology uses a strong and flexible material made of graphene, with added gold particles. The patch has sensors that will sense sweat’s temperature and pH alterations of high glucose levels that will trigger heaters in the patch to dissolve a coating layer that expose microneedles to discharge metformin drug to regulate high glucose levels (Cho, Lee& Cho 2016). The results are sent automatically to a smart device for monitoring and can also be shared with caregivers and medical professionals.

3.4 Applying Technology

3.4.1 Off-The-Shelf Suits Has to Alter

In many cases, ready-made suits do not fit exactly right off the shelf. The situation of innovation of glucose monitoring smart clothing is the same as the suit pants, it does not fit perfectly off the rack. Hence, we have to alter the product into a manner that will meet customer or user requirements (Riedl, Howell &Waco

2017). This can be done by doing a full marker research and using the results obtained to design the product, which allows potential scope of alterations that are possible to be needed by users based on understandings of industry needs (Touhill, Touhill et al. 2010). The enhanced product performance has to be evident to demonstrate the cost-effectiveness and upside return on investment of the alteration so that customers are aware of the cost of the product and they can see the improved performance for themselves (Blank 2006).

3.4.2 Needs, Perception, and Acceptance of Users

Accuracy and reliability of wearable sensors is one of the most significant barriers in wearable sensing smart clothing (Such & Muehlsteff 2006). The balance of sensor signal quality and human comfort is a key barrier to various smart clothing applications (Dunne & Smyth 2007), which will decrease users' confidence in smart clothing.Beside the technical issue, development groups often find it challenging to increase acceptance rates of smart clothing by the public. Perry, Malinin, Sanders, Li & Leigh (2017) showed that 97.5% of participants had never purchased smart clothing and 53.8% of participants had never heard about smart clothing.

It is mainly because the user needs have not been identified, which include the difficulties in specifying apparel function and appearance (Ariyatum 2005). According to Bergmann&McGregor (2011), clinicians and patients want medical body wearable with embedded sensor systems that are easy to function and maintain, with no effects on day-to-day behavior. Caregivers of elderly people, on the other hand, want smart clothing more reliable, fashionable, easy to maintain, and with an affordable price (Park, Harden, Nam, Saiki, Hall & Kandiah 2012). On contrary, youngsters such as college students preferred smart clothing solar-powered with good functions and fashionable (Hwang, Chung & Sanders 2016).

3.4.3 Discrepancy and Suitability of Textile-Based Sensors in Smart Clothing

Table 1: Summary of Physiological Fluids Suitable for Textile-based Sensor in Smart Clothing

Physiological Fluid	Discrepancy	Suitability
Blood	Invasive, non-CGM (Yilmaz, Foster et al. 2010)	No
ISF	Semi-invasive (Diabetes.co.uk 2018), bulky device (Diabetes.co.uk 2018)	More research efforts are required
Saliva	Cannot be in direct contact with body sensors of textile, bulky device (iQuick 2015, Indiegogo 2018)	More research efforts are required
Urine	Bulky device (Hodsden 2015), inconvenient collection of sample (Healthline 2018), non-CGM	More research efforts are required
Ocular Fluid (Tears)	Cannot be in direct contact with body sensors of textile (Duffy 2014, Legraien 2017)	Not necessary.
Sweat	Can be in direct contact with sensors of textile (Coyle, Lau et al. 2010, Maldarelli 2016)	Yes (Already available)

Source: Bruen, Delaney et al. (2017), Organized by this study

Sweat sensors have already been embedded into textile, while the ideal status would be measuring glucose and other physiological parameters for healthcare monitoring using smart clothing as everyday outfit. Currently, there is only urine sensing device, since urine can be monitored a few times daily, it can be incorporated into garment such as a smart underwear with urine sensor, though it is non-continuous. Other physiological fluids are currently not appropriate measured by textile-based sensors directly, ISF and saliva needs further research to improve in collecting samples. Tears, however, will probably be better operating in a stand-alone mode. Table 1 shows the summary of physiological fluid suitable for textile-based sensor in smart clothing.

3.4.4 Ideal Smart Clothing

Smart clothing is able to read physiological parameter via textile-embedded sensors, which is a basic self-monitoring medical wearable. The ideal

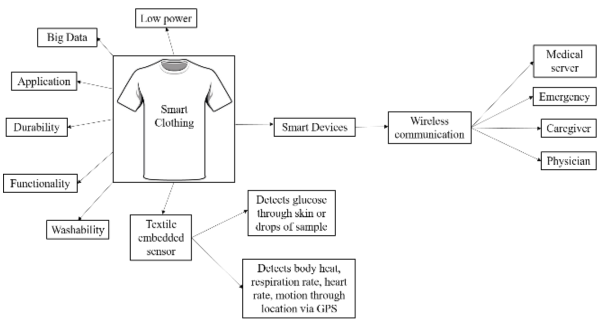


Figure 3: Requirements of Smart Clothing for Glucose Monitoring
Source: Cho, et al. (2009), Jovanov, Milenkovic, Otto & de Groen (2005)

smart clothing for diabetes should combines functional textile, sensors, distributed computation, and an extremely low battery-powered transmitter into single unit that connects in real-time to a smart device, and the data results can be shared with medical servers during an emergency, while the caregiver and physician can monitor the patient's condition without space limitation or can even located precisely where the patient is. In order to have a continuous detection monitoring diabetes, smart clothing should meet the requirements portrayed in Figure 3.

3.5 Marketing and Selling Technology

3.5.1 The Difference Between Marketing and Selling

Marketing and selling are two different activities that have indivisible relation, with marketing being an overall process, while selling is the purpose of the marketing plan. Marketing is necessary to turn a device or service into something valuable and has its own personality (that is now a product) that will attract customers so that the product has sale (Michalowicz 2013). The team needs knowledge on the product, what it does and how it can fulfill the customer's need, and any sales materials such as manuals, samples, brochures, demos, and supporting literature will be needed to close the sales (Touhill, Touhill et al. 2010). Hence, a marketing plan is required to identify the target customers.

3.5.2 Selling Value, Not Cost

If most of the targeted customers have not seen, heard, and used smart clothing for monitoring glucose before, it means the product is indeed innovative, and the team should tell customers the value of this product instead of looking at its cost by emphasizing saving customer's budget (Touhill, Touhill et al. 2010). Because the price of smart clothing mainly depends on the quality of the material used, the fabric used, the technology used for monitoring and keeping the clothes durable while washing.

The timing of market launch is important to determine whether customers trust the product or not. Announcement before market launch is also crucial to hype up the market anticipation towards the new product launched. Although arriving the market to attempt pioneer advantage is beneficial to the innovation, it is rather important that the product is completely developed when it reaches the market to ensure the product works properly (Frattini, De Massis, Chiesa, Cassia & Campopiano 2012). The communication campaign should highlight the technical contents of the innovation, which is the key aspect in stimulating early customers' adoption. Furthermore, an early preannouncement of innovation and its innovative features available helps foster early market interest in new technologies and influence their adoption decisions. Frattini, De Massis et al. (2012) provided an complete dimension of commercialization in high-tech innovation as presented in Table 2.

Table 2: The Dimensions of Commercialization in High-Tech Innovation

Variables	Description
Timing	•Timing of innovation launch into the market •Timing of innovation announcement before its launch
Targeting	•Target customer market for the innovation, (i.e. a group of customers who have similar needs and buyer behavior characteristics and who are responsive to the firm's offering)
Positioning	•Particular market position for the innovation, (i.e. how innovation is perceived by the customers, with respects to competitors and substitute innovations, on critical relevant attributes)
Distribution	•Type of channel to deliver the innovation •Critical functions
Pricing	•Pricing tactics •Pricing of the whole product configuration
Communication	•Type of channels •Type of message communicated
Whole Product Configuration	•Set of complementary products and services incorporated in the innovation basic offering
Partnerships and Alliances	•External organizations with partnership •Type of agreements signed with partners

Source: Frattini, De Massis et al. (2012)

3.5.3 Commercialization of Innovation as a Set of Interrelated Sub-Strategies

Frattini, De Massis et al. (2012) also suggested that an effective commercialization of technological

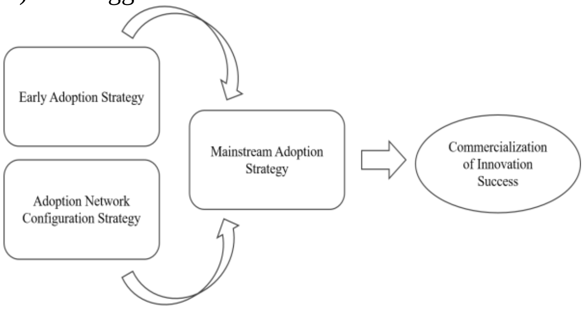


Figure 4: Commercialization of Innovation Success
Source: Frattini, De Massis et al. (2012)

innovation should comprehend a set of three interrelated sub-strategies, The early adoption strategy is a set of internal coherent commercialization decision designed to encourage the diffusion of innovation in the early market and encourage its members to establish a positive attitude towards it; The adoption network configuration strategy is designed to gain support, which is a necessary condition for supporting innovation in the mainstream market from the key players of this adoption network; Mainstream adoption strategy is designed to encourage the diffusion of the innovation in the mainstream market. The concept of the three strategies is depicted in Figure 4.

IV. CONCLUDING REMARKS

4.1 Summary

In this study, several sensing methods by using different physiological fluids for glucose monitoring are reviewed. However, it is found that only few of them can be incorporated for textile-based sensor in smart clothing in the application of diabetic self-care. Sweat sensor has the high potential to be integrated into clothing in the near future. ISF and saliva require further research, while urine is rather difficult due to sample collecting problem, but is still be possible with more research. Ocular fluid is better being in a stand-alone mode to monitor glucose. Overall, as demand grows and advances in technology, these technologies will gain more demand for applications.

It is significant to consider the commercialization of glucose monitoring smart clothing as a set of internal coherent of all the dimension variables (timing, targeting and positioning, whole product configuration, partnerships and alliances, communication, pricing, and distribution). Therefore, the innovation team should plan the commercialization of innovation at the beginning of the development process because the aforementioned strategic variables will affect a large part of the developmental activities.

In the future development, the study results indicate that the sensor technology, communication technology, local computing capability and artificial intelligence modelling used in smart clothing would be progress in a faster pace. Some of the ideas of diabetic monitoring involve socks that use temperature sensor to detect inflammation of diabetic patients in real-time (Buhr 2016). Currently, though sweat does look the most promising so far, it is difficult to point out which methods (ISF, sweat, tears, saliva and ocular fluid) will become the game changer for glucose monitoring using smart clothing.

4.2 Expectation of The Future

The future for smart clothing is still unpredictable, however since technology keep improving, smart clothing market will grow without doubt. Innovations in high-tech textile, and advances in micro- and nano-electronics are giving opportunities to many healthcare-related e-textiles, with monitoring diabetes being one of them (Brown 2018). In near future, the sensor size and power consumption will be significantly reduced. Meanwhile, the communication technology advancement is able to facilitate the instantaneous data communication for analysis. In addition, the power density of the battery is growing with the innovative development of the material. Regarding to local computing capability, central processing unit (CPU) will become very powerful because of the semiconductor manufacture process advancement.

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