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SMART BANDAGE FOR SPECIFIC WOUND HEALING

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ABSTRACT

A removable wireless monitor that attaches to patient and monitors blood pressure, cardiac rhythm & volume state. This type of smart bandage consists of electrically conductive fibers coated in gel that can be individually loaded with infection fighting antibiotics, tissue regenerating growth factors, painkillers or other medications. However, the smart bandage with flexible sensors will enable the real -time monitoring of the state of wound. The smart bandage prototype is controlled by a wireless device that sends voltage to a particular fiber in the bandage which heats the gel and then releases the medicine directly over the wound or affected area.

KEYWORDS: Wound healing, fibers, electronic connectivity, smart bandages, bio sensors.

INTRODUCTION

Wound is a type of injury which happens relatively quickly in which skin is torn, cut, or punctured (an *open* wound), or where blunt force trauma causes a contusion (a *closed* wound). In pathology, it specifically refers to a sharp injury which damages the dermis of the skin.[1] **Wound healing** is an intricate process in which the skin repairs itself after injury. Wound healing is depicted in a discrete timeline of physical attributes (phases) constituting the post-trauma repairing process. In undamaged skin, the epidermis (surface layer) and dermis (deeper layer) form a protective barrier against the external environment. When the barrier is broken, a regulated sequence of biochemical events is set into motion to repair the damage (fig: 1).[2]

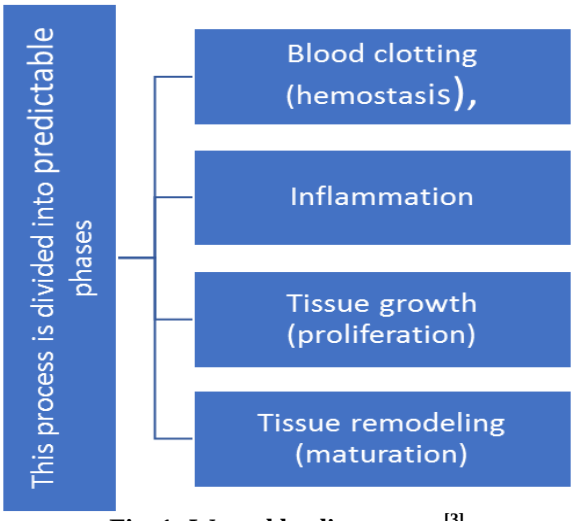

Fig. 1: Wound healing stages.[3]

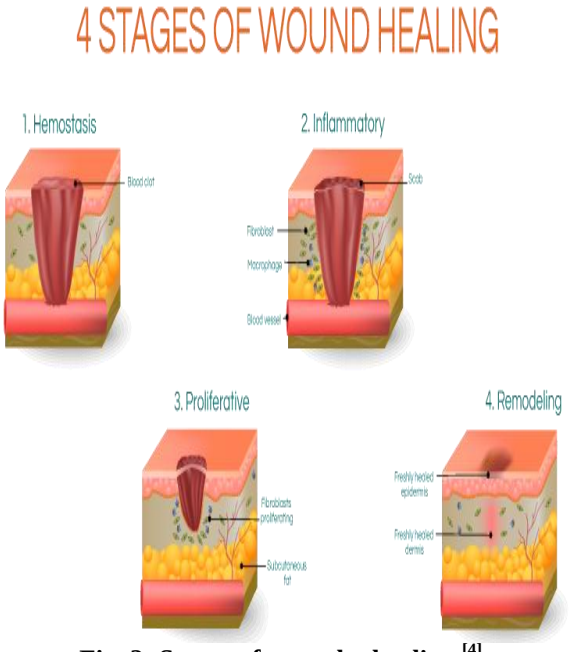

Fig. 2: Stages of wound n healing.[4]

Wound Dressings

Wound dressings have developed over the years from the crude applications of plant herbs, animal fat and honey to tissue engineered scaffolds. Many traditional medicinal plants used in Africa to treat wounds exhibit antibacterial activity.[5]

❖ Traditional wound dressing

Traditional wound dressing products including gauze, lint, plasters, bandages (natural or synthetic) and cotton wool are dry and used as primary or secondary dressings

for protecting the wound from contaminations. Gauze dressings made out of woven and non-woven fibers of cotton, rayon, polyesters afford some sort of protection against bacterial infection. Some sterile gauze pads are used for absorbing exudates and fluid in an open wound with the help of fibres in these dressings. Since traditional dressings fail to provide moist environment to the wound they have been replaced by modern dressings with more advanced formulations.

❖ **Modern wound dressing**

Modern wound dressing has been developed to facilitate the function of the wound rather than just to cover it. These dressings are focused to keep the wound from dehydration and promote healing. Modern wound dressings are usually based on synthetic polymers and are classified as passive, interactive and bioactive products. These dressings act as a barrier against penetration of bacteria to the wound environment.

Classifications of modern wound dressing: described in table: 1

Table 1: Various types of modern wound dressings.

1) Semi-permeable film dressings	These dressings are composed of transparent and adherent polyurethane which permits transmission of water vapor, O_2 and CO_2 from the wound and it also provides autolytic debridement of eschar and impermeable to bacteria.
2) Semi-permeable foam dressings	Foam dressings are made up of hydrophobic and hydrophilic foam with adhesive borders. The hydrophobic properties of outer layer protect from the liquid but allow gaseous exchange and water vapor.
3) Hydrogels dressing	Hydrogels are insoluble hydrophilic materials made from synthetic polymers such as poly (methacrylates) and polyvinyl pyrrolidine. The high-water content of hydrogels (70-90%) helps granulation tissues and epithelium in a moist environment.
4) Hydrocolloid dressing	Hydrocolloid dressings are among the most widely used interactive dressings and are consist of two layers, inner colloidal layer and outer water- impermeable layer. Hydrocolloids are permeable to water vapor but impermeable to bacteria and also have the properties of debridement and absorb wound exudates.
5) Alginate dressing	Alginate dressings are made from the sodium and calcium salts comprising mannuronic and guluronic acid units. Once alginate dressings are applied to the wound, ions present in the alginate are exchanged with blood to form a protective film. It is suitable for moderate to heavy drainage wounds and not suggested for dry wound, third degree burn wound and severe wounds with exposed bone.

Disadvantages of Traditional Wound Bandages.[6]

(1) Permeability is too high, easily to wound dehydration;
(2) Adhere the wound, change can cause the mechanical injury again;
(3) The microbes are easy to enter, and the chance of the cross infection is high;
(4) Absorb the wound exudates and some toxic substances; Painful to remove, thus causing patient discomfort.
(5) Gauze dressings also provide little occlusion and allow evaporation of moisture resulting in a dehydrated wound bed.
(6) Another disadvantage applies to dressings containing fibres that are deposited in the wound and often have to be removed during dressing change.

These disadvantages are overcome by using smart bandages.

Smart Bandages

[7]Smart bandage can actually sense the state of wound & address the major medical challenge on how to treat hard to heal wounds. In addition to this, these smart bandage (with the help of electrochemical sensors) can detect the presence of potentially harmful bacteria present in the wound or cut & alert doctors. This is especially important for people with weakened immune system that are automated to be release in the presence of harmful bacteria such as salmonella, listeria, pseudomonas, E-coli.

The technology behind smart bandage

These new devices known as flexible electronics. Will do much more than just deliver medicine to the wound site. Flexible electronics is an emerging technology with revolutionary potential that encompasses the design and fabrication of electronic device and circuits combined with low production cost and environmentally friendly materials.

Some Smart bandages are

1. Smart Bandage for Real-Time Wireless Monitoring of Chronic Wounds.
2. Cohesive short-stretch bandages for venous leg ulcers
3. Four-layer bandages for venous leg ulcers
4. Smart bandage with wireless connectivity for uric acid bio sensing as an indicator of wound status
5. Paint-on bandage changes color as your wound heals
6. Smart Bandage Signals Infection by Turning Fluorescent
7. Bandage-Based Wearable Potentiometric Sensor for Monitoring Wound pH
8. Low Cost Inkjet Printed Smart Bandage for Wireless Monitoring of Chronic Wounds.
9. Smart Bandage Sounds Alarm When Wound Begins Healing Badly.

1) Smart Bandage for Real-Time Wireless Monitoring of Chronic Wounds.[8]

This smart bandage comprises two parts. The first part contains a disposable bandage with inkjet-printed sensors. The second part consists of a reusable electronic sensor. The first part is developed using commercially-available bandage strips. A carbon-based sensor electrode is printed on office paper and attached to the bottom side of the bandage. The reusable electronic sensor is developed using inkjet printing on adhesive kapton tape. The sensor circuit board, as well as the antenna and top sensor electrode, is inkjet printed on the tape. A double-sided circuit board is made on two sides of the tape. In order to connect both sides electronically, laser etching is used. As shown in fig 3.

How It Works?

The smart bandage is part disposable and part reusable.

- The sensors used to detect bleeding, pH levels and external pressure on the wound are located on a disposable bandage whereas the electronics on the flexible kapton tape can be detached and reused multiple times.

The capacitive sensor detects bleeding, as well as pressure levels on the wound. A resistive sensor detects pH levels on the wound. The changes in capacitance and resistance are processed by the electronics, and the information is sent in a wireless fashion. The wireless communication is done through an inkjet-printed loop antenna that is integrated with the circuit as shown in fig (2). This data can then be sent to remote health care providers using either the mobile network or the internet.

Benefits

- Reduces healthcare costs for patients, hospitals and insurance providers.
- Detects infections in a timely manner.
- Better wound management.
- Reusable electronics can be used on multiple disposable bandages.
- Pressure sensors can alert patients and help them avoid pressure ulcers.
- Provides dressing alerts for patients.
- Hassle free wireless and real-time monitoring.

There are currently no commercially available wireless devices to continuously monitor the wound-healing process. The proposed smart bandage, for the first time, provides a complete wearable system to wirelessly monitor chronic wounds in real-time.

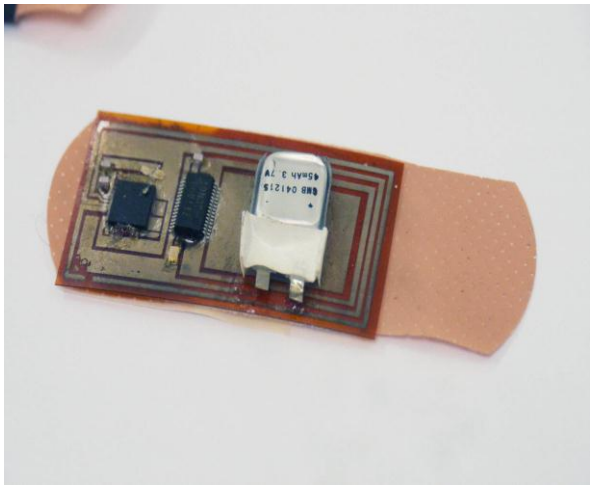

Fig. 3: (real time wireless monitoring bandage).

2) Cohesive short-stretch bandages for venous leg ulcers.[9]

Short-stretch/cohesive short- stretch bandaging SSB is the commonest form of treatment for venous ulceration on the continent (Ellis, 2004). However, it is now being used more readily in the UK. It works in a very different way to the four-layer system. It provides a tube-like structure on the limb, compressing the limb. Once the calf muscle is activated it rebounds against the bandage causing blood flow back to the heart.

Advantages	Disadvantages
Only Two layers, so less bulky than four Can be more comfortable to wear at rest for the patient Quicker than 4LB to apply, so less risk of back injury or strain to nurse, Same bandage is usable for all limb sizes, Reduced risk of over-compression, as the bandage is applied at full stretch. Potential margins for error are lower than 4LB, Has similar healing rates as 4LB, SSB can be washed and reused (CSSB cannot), Is a cheaper system than 4LB even when bandages are not reused.	May need a new training program to be put in place, as can be an unknown system to many nurses. However, the manufacturing companies will often assist. Further RCT studies would be advantageous totally immobile patients are usually not suitable for this system.

3) four-layer bandages for venous leg ulcers.[8]

This method of bandaging was developed at Charing Cross hospital in the early 1990s and since then has been accepted as the 'gold standard' in the treatment of venous leg ulcers (Moffatt, 2004a). The bandage works by applying a continuous level of sustained compression on the limb. 4LB forms an elastic cylinder around the leg. This expands and contracts with the calf muscle, which acts on the venous system by creating increased force in the leg, thereby reversing venous hypertension.

Advantages	Disadvantages
There is an abundance of literature and several RCTs to support its use and safety. It is possible to gradually increase bandage pressures so that patients can adjust to the system w Pressures are adjustable by the use of a combination of layers so the system is usable for mixed aetiology as well as venous ulcers. Most community nurses and all leg ulcer specialist nurses know how to apply the system, so training is not an issue and supervision of new practioners is readily accessible.	The system is bulky, meaning patients are restricted with their footwear and clothing. It can be an expensive option when compared to other systems available Sub-bandage pressures can be too high or too low and achieving the correct tension is not an exact science, margins for error are potentially high risk. The time spent on application of 4LB can put a lot of strain on the nurses' backs, particularly in a community setting.

4) Smart bandage with wireless connectivity for uric acid bio sensing as an indicator of wound status.[10]

Advanced wound care technologies need to evolve in response to the growing burden of chronic wounds on National healthcare budgets and the debilitating impact chronic wounds have on patient quality of life.

- Here a new type of smart bandage for determination of uric acid (UA) status, a key wound biomarker, formed by screen printing an amperometric biosensor directly on a wound dressing.
- Immobilized uricase, paired with a printed catalytic Prussian blue transducer, facilitates chronoamperometric detection of uric acid at a low.

Working potential

- The smart bandage biosensor interfaces with a custom designed wearable potentiostat that provides on-demand wireless data transfer of UA status to a computer, tablet, or Smartphone by radio frequency

Identification (RFID) or near-field communication (NFC)

- The analytical performance of the smart bandage—Sensitivity, selectivity, operational stability, and mechanical robustness—is described.
- Application of these Bandages will provide insight into wound status and may reduce the frequency at which dressings are changed, Allowing for healthcare cost savings and a reduction in patient stress and pain.

5) Paint-on bandage changes color as your wound heals[11]

Also known as a liquid bandage

A smart liquid bandage glows to reveal the amount of oxygen the wound underneath is getting, and that could help doctors help us heal.

Monitoring wounds meant removing bandages to observe their progress, potentially aggravating the vulnerable areas and exposing them to harmful bacteria. An international team of researchers led by Professor Conor L. Evans at the Wellman Centre for Photo medicine of Massachusetts General Hospital and Harvard Medical School, has come up with a unique "paint on" bandage that would eliminate the need to remove it to check oxygen levels.

The bandage is impregnated with phosphors -- chemicals that absorb light and then release it by glowing (think glow-in-the-dark watch). The phosphors are designed in such a way that they glow red when a wound isn't getting enough oxygen, and green when it is.

The glowing effect of the bandage is triggered by a light source the researchers have also developed, which they say can be captured using the camera on a smartphone.

6) Smart Bandage Signals Infection by Turning Fluorescent[12]

Bacterial infection is a fairly common and potentially dangerous complication of wound healing, but a new "intelligent" dressing that turns fluorescent green to signal the onset of an infection could provide physicians a valuable early-detection system. as shown in (fig 3). Researchers in the United Kingdom recently unveiled a prototype of the color-changing bandage, that shows in (fig:4) which contains a gel-like material infused with tiny capsules that release nontoxic fluorescent dye in response to contact with populations of bacteria that commonly cause wound infections.

It could be used to alert health-care professionals to an infection early enough to prevent the patient from getting sick. In some cases, it may even be able help avoid the need for antibiotics.

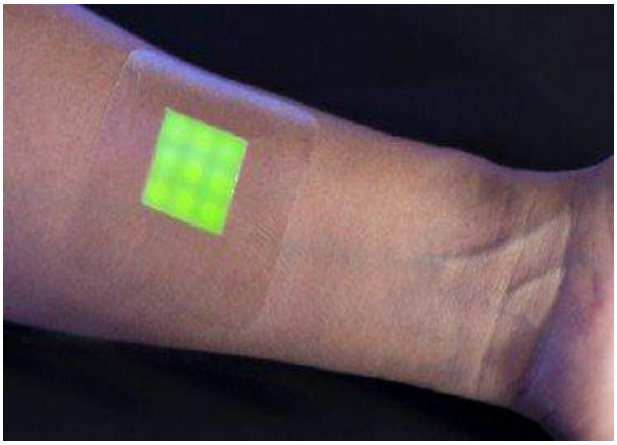

Fig: 4.

An infection-detecting bandage could prevent this by reassuring parents and doctors when a wound is in fact not infected. They would also be useful for monitoring surgical wounds as well as those that result from traumatic injury.

All wounds get colonized by bacteria, often including pathogenic species, but small populations are generally not harmful, and the immune system can clear them. In some cases, though, a population of harmful bacteria grows too big for the immune system to handle, and clinical intervention is needed to clear it.

"We believe that this transition normally happens several hours, if not longer, before any clinical symptoms become evident."

Earlier detection might give doctors time to head off the infection even before such symptoms arise. The transition is "almost certainly" associated with the formation of a so-called biofilm, a layer of microbes that work together and secrete a slimy substance to defend the colony against the immune system. At a high enough population density, the bacteria film switches on the production of toxins. The new dressing works because the outer layer of the dye-containing capsules is designed to mimic aspects of a cell membrane. Toxins puncture the capsules like they would cells in the body, releasing the dye, which fluoresces when it is diluted by the surrounding gel.

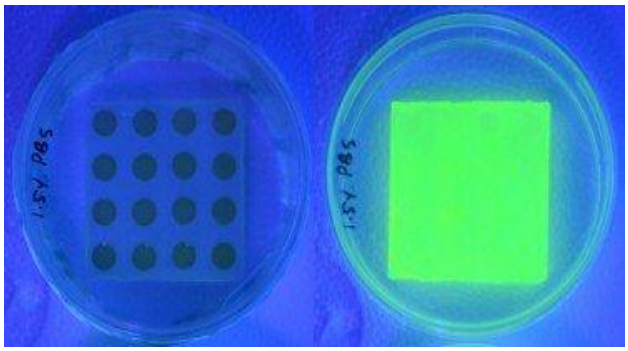

Fig: 5.

- The image (fig: 5) on the left shows a bandage before it contacts bacterial toxins.
- The one on the right shows how it looks when activated.

Though the clinical utility of the color-changing dressing has yet to be proven, it is "undoubtedly a step forward" from today's medical microbiology techniques.

In a recent demonstration prototype bandages turned fluorescent shortly after coming into contact with biofilms of three separate species of pathogenic bacteria but did not change color after contacting biofilms of non-pathogenic species.

How this color changing Smart bandage works?[13]

All wound tends to get colonized by bacteria and larger growth in harmful bacteria can make it difficult for the immune system to handle. This transition usually takes hours to become evident for the physicians but color changing can denote this change in bacterial information by changing its color. When bacterial population grows in the density then it starts production of toxins.

This color changing bandage has an outer layer of dye containing capsules which gets punctured by this toxin and starts to release the dye which fluoresces when it gets diluted by the surrounding gel present in bandage. This glowing bandage can give a timely indication of the spread of bacteria in the wound and it can help physicians in providing right course of treatment. One of the biggest challenges in medicine is to accurately diagnose the wound infections. This color changing dressing bandage offers some great insight but its clinical utility is yet to be proven.

The smart bandage that turns yellow to provide an early warning of infections.[14]

- The bandage can give an early warning of injuries going septic.
- This could have the potential of preventing overuse of antibiotics.
- Bandages that glow bright yellow if the wound underneath has been infected have been developed by British scientists.
- The invention is intended to give an early warning of injuries from burns or scalds going septic under the dressing.

How does it work?

• The bandages work because they contain tiny 'Nano capsules' that contain fluorescent dye. When they come into contact with chemicals produced by disease causing bacteria, the capsules break open, releasing the dye. The capsules are not affected by ordinary bacteria found on the skin. When they come into contact with chemicals produced by disease causing bacteria, the capsules break open, releasing the dye.

The capsules are not affected by ordinary bacteria found on the skin.

Bandages Made of Crab Shells Could Help Wounds Heal Faster

- Plasters and bandages could soon be fitted with the shells of crabs to help cuts and scrapes heal faster. The key ingredient in the dressing is a mineral called chitosan found in crustacean shells.
- It is known for its healing properties as well as its ability to kill bacteria and has been used in China to treat battle wounds for centuries.

A new "smart bandage" could serve as an early detection system for wound infections.

7) Bandage-Based Wearable Potentiometric Sensor for Monitoring Wound pH [15]

A new wearable electrochemical sensor for monitoring the pH of wounds is introduced. The device is based on the judicious incorporation of a screen-printed pH potentiometric sensor into bandages.

- The fabrication of this sensor (fig :6), which uses an electro polymerized polyaniline (PANi) conducting polymer for pH sensing, combines the screen-printing fabrication methodology with all solid-state potentiometry for implementation of both the reference and the working electrodes.
- The pH bandage sensor displays a Nernstian response over a physiologically relevant pH range (5.5–8), with a noteworthy selectivity in the presence of physiological levels of most common ions.
- The bandage-embedded sensor can track pH fluctuations with no apparent carry-over effect. The sensor displays good resiliency against mechanical stress, along with superior repeatability and reproducibility.
- The in vitro performance of the device was successfully evaluated using buffer solutions emulating the composition of a wound. The novel pH-sensitive bandages facilitate new avenues towards the realization telemedicine.

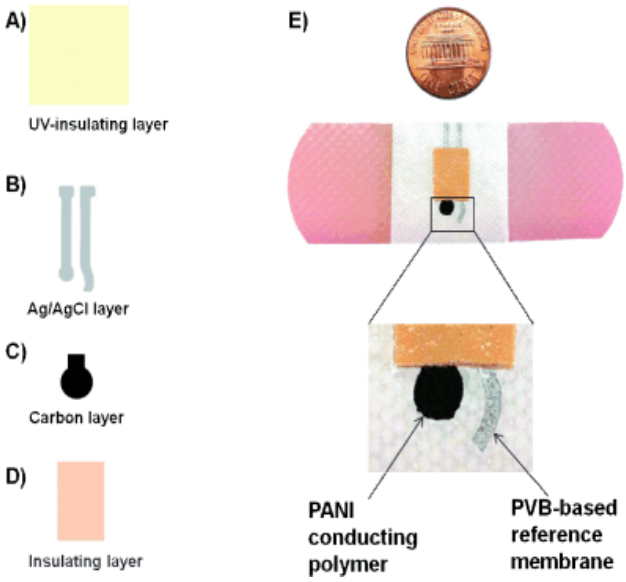

Fig. 6: Fabrication process to create the pH sensitive bandage.

A–D) UV-insulating layer is printed, followed by an Ag/AgCl and a carbon layer, and finally an insulating layer with skin-like color. E) Images displaying the printed potentiometric sensor on an adhesive bandage. Electro polymerization of PANi onto the printed carbon working electrode (circle) and deposition of PVB-based reference membrane.

8) Low Cost Inkjet Printed Smart Bandage for Wireless Monitoring of Chronic Wounds[16]

In this smart bandage an unprecedented low cost continuous wireless monitoring system, realized through inkjet printing on a standard bandage, which can send early warnings for the parameters like irregular bleeding, variations in pH levels and external pressure at wound site. In addition to the early warnings, this smart bandage concept can provide long term wound progression data to the health care providers. The smart bandage comprises a disposable part which has the inkjet printed sensors and a reusable part constituting the wireless electronics.

This work is an important step towards futuristic wearable sensors for remote health care applications.

System Design and Operation

The system level design is depicted in Fig. 7. As mentioned above, the system has been designed as a combination of a disposable part and a reusable part to reduce the cost.

- The sensors to detect bleeding, pH levels and external pressure on the wound are realized on a disposable bandage whereas the electronics are integrated on a flexible kapton tape which can be detached and reused multiple times.
- Two types of sensing mechanisms are used. A capacitive sensor detects bleeding as well as pressure levels on the wound. A resistive sensor detects the pH levels on the wound. The changes in

capacitance and resistance are processed by the electronics and the information is sent in a wireless fashion using IEEE 802.15.4 standard that operates around 2.4 GHz. The detachable electronics comprise a transmitter with an embedded.

Microcontroller, a capacitance to digital converter (CDC), an LED to inform the patient about the status of the bandage and a battery to power the system.

The wireless communication is done through an inkjet printed loop antenna that is integrated with the circuit. The smart bandage can wirelessly communicate with a personal smart phone to provide wound progression data in a patient's personal environment. This data can then be sent from the patient's smart phone to remote health care providers using either the mobile network or the internet.

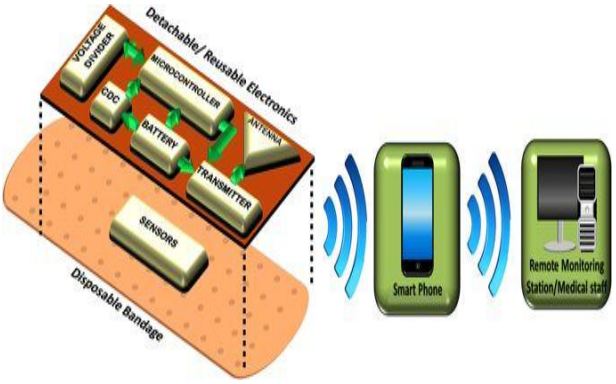

Figure 7: System design.

The smart bandage assembly comprises two parts

1) Disposable part
2) Reusable part, the sensors are printed on a disposable bandage strip that can be disposed off after use.

The wireless electronics which include inkjet printed circuit board and antenna are made on a kapton tape that can be detached and reused on another bandage. This approach reduces the cost of the system and maintains disposability of the bandage which has been in contact with the wound.

The bandage can communicate wirelessly to a patient's smart phone which can then connect to remote health care providers over the mobile network or the internet.

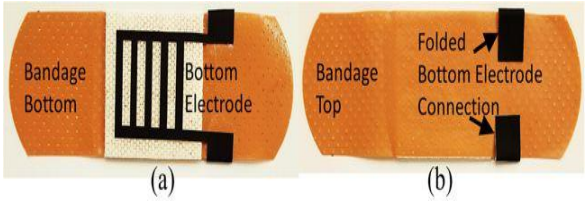

Fig: 8 (fabrication and assembly steps).

(a) Bottom side of the bandage showing printed carbon-based sensor electrode.
(b) Top side of the bandage showing folded connection of the bottom electrode.

9) Smart Bandage Sounds Alarm When Wound Begins Healing Badly[17]

This way, even chronic wounds could be monitored at home.

Using a UV lamp, the pH level in the wound can be verified without removing the bandage and the healing process can continue unimpeded.

A novel bandage alerts the nursing staff as soon as a wound starts healing badly. Sensors incorporated into the base material glow with a different intensity if the wound's pH level changes This way even chronic wounds could be monitored at home.

When wounds heal, the body produces specific substances in a complex sequence of biochemical processes, which leads to a significant variation in a number of metabolic parameters. For instance, the amount of glucose and oxygen rises and falls depending on the phase of the healing process; likewise does the pH level change. All these variations can be detected with specialized sensors.

A high pH signals chronic wounds

The pH level is particularly useful for chronic wounds. If the wound heals normally, the pH rises to 8 before falling to 5 or 6. If a wound fails to close and becomes chronic, however, the pH level fluctuates between 7 and 8. Therefore, it would be helpful if a signal on the bandage could inform the nursing staff that the wound pH is permanently high.

This smart bandage can heal wounds three times faster[18]

The bandage constitutes of electrically conductive fibers coated in a gel that can be individually filled with infection-fighting antibiotics, tissue-regenerating growth factors, painkillers or other medications.

A micro-controller the size of a quarter which can be activated by a smartphone or any other wireless device, releases small amounts of voltage through a selected fiber. As show in below picture (fig: 9).

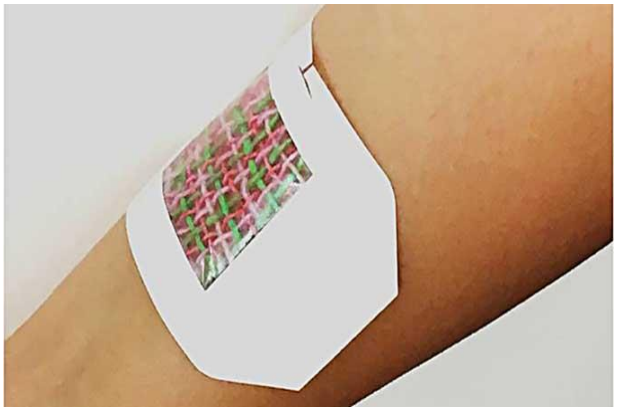

Fig: 9.

- Each bandage can be equipped with multiple medications meant for a specific or variety of injuries while giving precise control over dosages and delivery schedules. The blend of customization and control could substantially improve or accelerate the healing process.

This is the first bandage that is capable of dose-dependent drug release (fig: 10). You can release multiple drugs with different release profiles. That's a big advantage in comparison with other systems. What we did here was come up with a strategy for building a bandage from the bottom up.

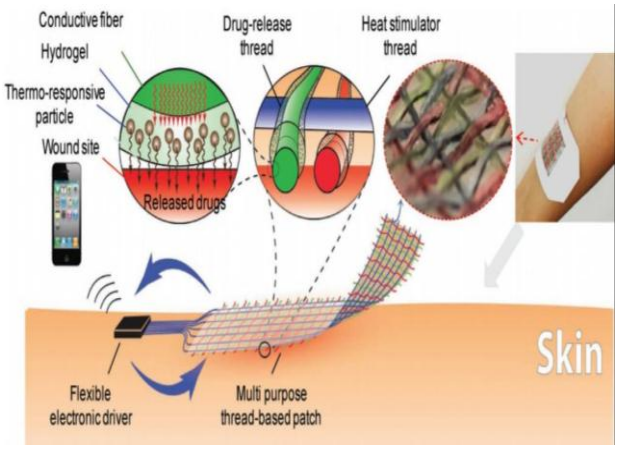

Fig: 10: (smart bandage drug release mechanism).

This is a platform that can be applied to many different areas of biomedical engineering and medicine."

The bandage is loaded with infection-fighting antibiotics, tissue-regenerating growth factors, painkillers or other medications.

❖ **Implications for the smart bandage technology and future outlooks**

Current wound care or bandage technology is typically designed to protect the wound area. Intervene with the external conditions (e.g. infections) by delivering the medicine, detect the presence of harmful bacteria enable early detection of health condition (e.g.: ulcers) and communicate wirelessly with remote health care professionals.

CONCLUSION

Smart bandage is a relatively new concept in the area of medicine & are rapidly finding opportunities in the health care industry especially area of chronic wound care. Not only do these smart bandages have the ability to save lives, but they also have the potential to reduce complications speedup the healing process & save time and money.

The smart bandage is reliable, accurate, have a longer shelf life& ready to use.

REFERENCES

1. https://en.wikipedia.org/wiki/Wound.
2. The wound healing process: an overview of the cellular and molecular mechanisms.
3. Velnar T, Bailey T, Smrkolj V. https://www.ncbi.nlm.nih.gov/pubmed/19930861
4. http://www.shieldhealthcare.com/community/wound/2015/12/18/how-wounds-heal-the-4-main-phases-of-wound-healing/.
5. http://www.shieldhealthcare.com/community/wound/2015/12/18/how-wounds-heal-the-4-main-phases-of-wound-healing/.
6. Wound healing dressings and drug delivery systems: A review Joshua S. Boateng Kerr H. Matthews Howard N.E. Stevens Gillian M. Eccleston.
7. Wound dressings – a review Selvaraj Dhivya, Viswanadha Vijaya Padma, Elango Santhini.
8. ww.slideshare.net/SwathiAllada/can-smart-bandages-be-the-next-negativepressure-wound-therapy-market-insight?qid=93d35259-a7a5-4c17-aed5-02e85c49e0ed&v=&b=&from_search=1.
9. Smart Bandage for Real-Time Wireless Monitoring of Chronic Wounds, https://innovation.kaust.edu.sa/technologies/smart-bandage-for-real-time-wireless-monitoring-of-chronic-wounds/.
10. Cohesive short-stretch vs four-layer bandages for venous leg ulcers.Puffett N[1], Martin L, Chow MK. https://www.ncbi.nlm.nih.gov/pubmed/1683556.
11. Smart bandage with wireless connectivity for uric acid bio sensing as an indicator of wound status Electrochemistry Communications Volume 56, July 2015, Pages 6-10 PetarKassal[ab] Jayoung Kim[a]Rajan Kumar[a]William R.de Araujo[ac]Ivana MurkovićSteinberg[b] Matthew D.Steinberg[d] JosephWang[a] https://doi.org/10.1016/j.elecom.2015.03.018.
12. Paint-on bandage changes color as your wound heals: Bymichael Franco, 2014; 12: 08PM PDT Https://Www.Cnet.Com/News/Paint-On-Bandage-Changes-Color-As-Your-Wound-Heals/.
13. Smart Bandage Signals Infection by Turning Fluorescent by Mike Orcutt December 4, 2015.

https://www.technologyreview.com/s/544166/smart-bandage-signals-infection-by-turning-fluorescent.
14. Smart Bandage Signals Infection by Turning Fluorescent: http://www.prodigitalweb.com/smart-bandage-signals-infection-by-turning-fluorescent/.
15. The smart bandage that turns yellow to provide an early warning of infections.
16. http://www.dailymail.co.uk/sciencetech/article-3979080/The-smart-bandage-turns-yellow-provide-early-infection-warning-wouds.html By colin fernandez science correspondent for the daily mail Published**:** 16:40 BST, 28 November 2016 | **Updated:** 00:05 BST, 29 November, 2016.
17. Bandage-Based Wearable Potentiometric Sensor for Monitoring Wound pH:Tomàs Guinovart Francisco J. Andrade. Joseph Wang First published: 13 March 2014https://doi.org/10.1002/elan.201300558.
18. Low Cost Inkjet Printed Smart Bandage for Wireless Monitoring of Chronic Wounds 2016, Item Type: Article, Authors: Farooqui, Muhammad Fahad; Shamim, Atif, 6: 28949, DOI: 10.1038/srep28949.
19. https://www.mpo-mag.com/contents/view_breaking-news/2017-07-05/smart-bandage-sounds-alarm-when-wound-begins-healing-badly.
20. This smart bandage can heal wounds three times faster**:** http://dailyaccord.com/scientists-develop-a-smart-bandage-that-can-heal-wounds-three-times-faster/.