

Quiz

Wearables in Dermatology: Quiz on Next-Generation Technical Advances

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Wearables are skin-contact or skin-adjacent devices that continuously or intermittently monitor biophysical (e.g., photoplethysmography [PPG] for heart rate), biomechanical (e.g., motion, scratching) or biochemical (e.g., cytokines and electrolytes) signals. They use advanced sensors integrated into flexible, biocompatible materials to provide real-time health insights. Most rely on wireless connectivity for data transmission and analysis.^[1-11]

Wearable technologies are still emerging in dermatology, with limited clinical availability due to cost, validation requirements and accessibility issues. However, their potential for monitoring atopic dermatitis (AD), wound healing, ultraviolet (UV) exposure and stress biomarkers is significant, making them promising tools for dermatology research and future clinical practice.

Below are questions testing both the clinical and technical aspects of dermatological wearables.

1. Skin has inherent electrical properties that affect the accuracy of wearable biosensors. Which layer is primarily responsible for its electrical resistivity, thereby posing a major challenge in signal acquisition?
 - a) Hypodermis
 - b) Papillary dermis
 - c) Epidermis
 - d) Reticular dermis
2. Some advanced wearable sensors can operate without an external power source. Triboelectric nanogenerators (TENGs) achieve this by utilising which fundamental principle?
 - a) Piezoelectric effect
 - b) Electrostatic induction coupled with triboelectrification
 - c) Thermoelectric energy harvesting
 - d) Capacitive charge displacement
3. In designing wearable strain sensors, the choice of substrate material determines comfort and performance. Why is Ecoflex often preferred over polydimethylsiloxane (PDMS)?
 - a) Higher Young's modulus
 - b) Better adhesion to skin due to closer modulus matching
 - c) Greater electrical conductivity
 - d) Lower cost
4. Maintaining stable skin contact is critical for wearable sensor performance. Which factor poses the greatest hurdle for long-term adhesion of such sensors?
 - a) High elasticity of sensors
 - b) Stratum corneum regeneration every 28–50 days

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- c) Excessive sweat production
d) UV radiation exposure
5. Optical wearable sensors, such as those using PPG for heart rate monitoring, measure changes in light absorption through the skin. Which factor most significantly limits their accuracy?
 - a) Variability in melanin content across individuals
 - b) Excessive sweat production during exercise
 - c) Reflection of light at the stratum corneum-air interface
 - d) Scattering of light by collagen in the dermis
 6. What is the primary advantage of microneedles for interstitial fluid (ISF) extraction compared to traditional blood sampling?
 - a) Higher protein concentration in ISF
 - b) Minimally invasive with reduced pain
 - c) Faster glucose diffusion kinetics
 - d) No lag time compared to blood glucose levels
 7. Which of the following is a novel parameter measured by the miniaturised skin sensor developed for atopic eczema at the Technical University of Munich?
 - a) Serum immunoglobulin E (IgE) levels
 - b) Electrodermal activity (EDA)
 - c) pH levels
 - d) Trans-epidermal water loss (TEWL)
 8. How do wearables complement traditional dermatology practice?
 - a) By replacing physician diagnoses
 - b) Through continuous at-home data collection to enhance clinical assessments
 - c) By eliminating the need for biomarkers
 - d) Through direct administration of biologics
 9. Scratching at night is a hallmark of AD and a major cause of poor sleep. Which wearable technology has the strongest evidence for correlating with AD severity by measuring nocturnal scratching?
 - a) Devices measuring forearm muscle potentials
 - b) Wrist actigraphy
 - c) Microneedle cytokine detectors
 - d) Piezo-electric devices applied to the fingernails
 10. Smartwatches have been adapted to track scratching. What is a key limitation of smartwatch-based itch monitoring in AD?
 - a) Inability to measure daytime scratching due to movement artefacts
 - b) Overestimation of skin hydration
 - c) Requirement for blood sampling
 - d) Lack of correlation with eczema area and severity index (EASI) scores
 11. Which biomarker is NOT typically measured by current wearable biosensors for AD?
 - a) TEWL
 - b) Skin surface pH
 - c) Serum IgE levels
 - d) Stratum corneum hydration
 12. For wearable devices to be clinically useful in AD, their outputs must correlate with established disease severity measures. Which parameter is critical for validating wearable sensor data against clinical AD assessments?
 - a) Correlation with EASI or Scoring atopic dermatitis (SCORAD) scores
 - b) Patient self-reports alone
 - c) Device battery life
 - d) Sweat electrolyte levels
 13. What is the primary challenge of microneedle-based sensors in AD?
 - a) Inability to measure cytokines
 - b) Biofouling and short sensor lifespan
 - c) Lack of correlation with patient-reported outcomes
 - d) Exclusively nocturnal use
 14. Stress is a major trigger for many skin diseases. Measuring cortisol non-invasively, offers an objective biomarker for stress monitoring in dermatology. Which wearable technology noninvasively measures cortisol levels in sweat using a selective membrane?
 - a) Smartwatches with accelerometers
 - b) Cortisol-sensitive sweat sensors (Stanford/Karolinska)
 - c) Radio Frequency Identification-tagged bandages
 - d) Ultrathin pH patches
 15. Monitoring UV exposure is critical in skin cancer prevention. Which of the following statements best explains why N-doped carbon dots (C-dots) are superior for UV sensing in wearable devices compared to non-doped counterparts?
 - a) They are fluorescent under visible light, enhancing visibility in the dark
 - b) They show selective oxidation only under UVC radiation
 - c) Enable catalysis of 3,3',5,5'-Tetramethylbenzidine (TMB) oxidation across UVA, UVB and UVC spectra at near-neutral pH
 - d) They increase the durability of the hydrogel material in wearable devices
 16. Hydration is vital in dermatology, especially for conditions like eczema. Which of the following is a key advantage of graphene-based hydration sensors used in wearable technology?
 - a) Low cost and durability
 - b) Ability to detect dehydration only in elderly populations
 - c) Flexibility and precision in detecting hydration changes
 - d) Dependence on invasive sampling methods
 17. Which device is considered the standard for assessing stratum corneum hydration through capacitance, although it is not a wearable technology?
 - a) Capacitance sensor
 - b) Stratum corneum conductance sensor
 - c) Stratum corneum hydration sensor
 - d) Stratum corneum thickness sensor

- a) Korea Advanced Institute of Science and Technology smart patch
 b) Corneometer
 c) Gatorade Gx sweat-patch
 d) Piezoelectric nail sensors
18. What future development could revolutionise AD monitoring by wearables?
 a) Real-time detection of Interleukin (IL)-4/IL-13
 b) Hair growth tracking algorithms
 c) Nail plate thickness sensors
 d) Sebum secretion rate monitors
19. What is a major limitation of wearables in elderly dermatology patients?
 a) Inability to measure TEWL
 b) High cost of production
 c) Age-related barriers to technology adoption
 d) Lack of correlation with EASI scores
20. Wearable biosensors can convert mechanical forces acting on the skin into measurable electrical signals. Which of the following sensor types most likely uses this configuration [Figure 1] and works on the principle of converting mechanical deformation into an electrical signal?
 a) Optical sensor
 b) Triboelectric sensor
 c) Piezoelectric sensor
 d) Microneedle sensor
21. Prolonged UV exposure is a major risk factor for actinic keratoses and non-melanoma skin cancers, especially in elderly populations. Which wearable device has shown effectiveness in significantly reducing non-melanoma skin cancers in elderly individuals?
 a) Wearable blood glucose monitors
 b) UV dosimeters with real-time feedback
 c) Electronic thermometers
 d) Hydration wristbands
22. Wearable UV sensors are increasingly integrated with digital platforms to support personalised sun safety. What specific feature in UV wearables allows users to receive tailored advice for sun safety?
 a) Real-time blood test integration
 b) UV exposure alerts linked with smartphone apps
 c) Artificial intelligence-assisted camera image capture
 d) Integration with melanin measurement tools
23. How do 'smart bandages' advance AD management?
 a) By releasing topical corticosteroids in response to inflammation
 b) By measuring hair follicle density
 c) By detecting fungal biofilms
 d) By quantifying subcutaneous fat thickness
24. Nocturnal scratching is a key objective marker in AD and can be quantified using actigraphy. Figure 2 shows a representative actigraphy scratch trace recorded overnight. In the figure, the vertical peaks at 1–3 Hz

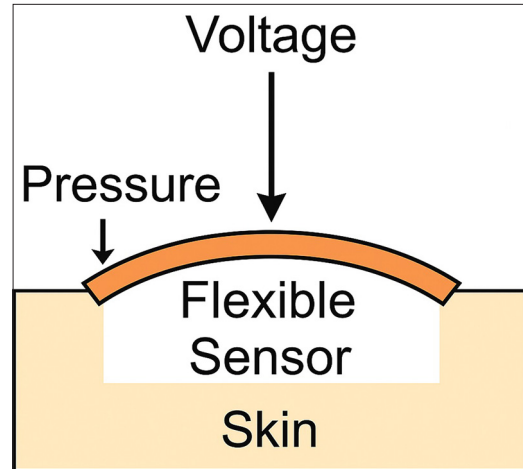


Figure 1: This sensor type operates on the principle of converting mechanical deformation into a measurable change in electrical signal.

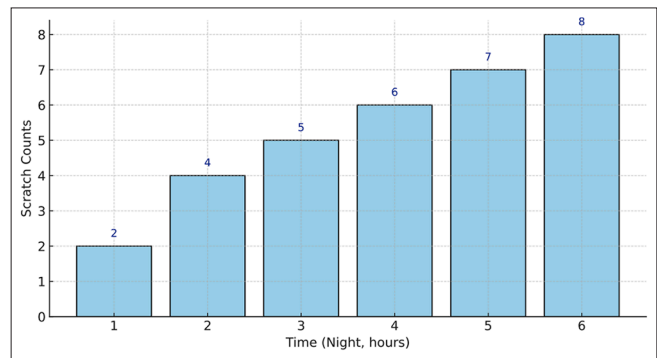


Figure 2: Actigraphy scratch trace. Peaks at 1–3 Hz correspond to scratch bouts.

most likely represent which clinical parameter?

- a) Random limb movements during sleep
 b) Scratch bouts characteristic of AD
 c) Periodic limb movement disorder
 d) Normal sleep architecture changes
25. Figure 3 illustrates two mechanisms: A TENG, which operates through contact–separation, and a piezoelectric film, which operates through pressure–strain. Based on the schematic, which statement most accurately distinguishes TENGs from piezoelectric devices in skin-wearable technology?
 a) TENGs require a crystalline material to deform under force, whereas piezoelectric devices require two different materials.
 b) TENGs generate current through contact–separation between dissimilar materials (triboelectrification + electrostatic induction), while piezoelectric devices generate voltage through direct mechanical strain of a single film.
 c) Both TENGs and piezoelectric devices require

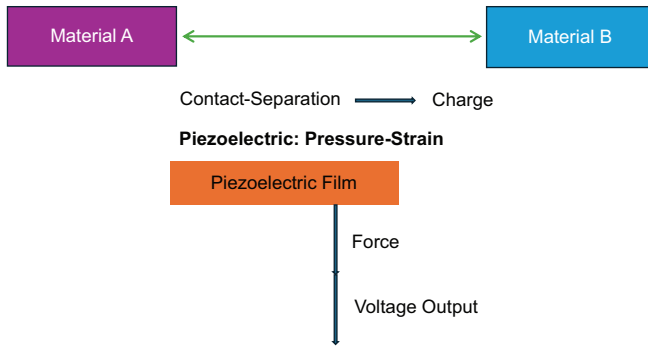


Figure 3: Triboelectric nanogenerator versus piezoelectric mechanisms.

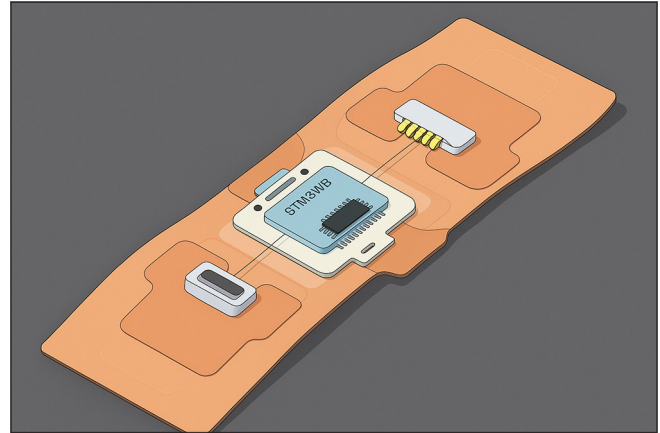


Figure 4: Smart and flexible wound dressing.

- battery assistance to function.
- d) Piezoelectric devices are unsuitable for measuring strain in dermatology wearables.
26. Advances in bioelectronics have enabled the creation of flexible wound dressings capable of both sensing the wound microenvironment and actively responding to pathological changes. These systems are being developed to provide dynamic, personalised wound management. What is the primary function of the bandage shown in Figure 4?
- To provide passive physical protection for superficial wounds
 - To continuously monitor pH and temperature of a wound and deliver antibiotics on-demand
 - To deliver systemic antibiotics through the bloodstream
 - To function as a cosmetic skin patch that releases moisturising agents
27. Psychological and physiological stress triggers complex changes in both sweat composition and skin physiology. Which biomarker is NOT included in the sweat analysis for long-term stress monitoring using electronic skin?
- Uric acid
 - Sodium
 - Cortisol
 - Lactate
28. Modern wearable sensors often generate large volumes of multimodal data that require advanced interpretation. What technology enables the stress-monitoring e-skin to distinguish between types of stressors?
- pH sensing arrays
 - Behavioural questionnaires
 - Machine learning algorithms
 - Visual colorimetric patterns
29. Traditional sweat-based wearables may fail in aquatic or high-humidity environments due to contamination and water interference. What technology do modern waterproof epidermal microfluidic devices employ to function accurately during aquatic activities?
- Metal coils to repel water

- Rigid plastic casings
 - Styrenic block copolymers and colorimetric assays
 - Bluetooth-linked hydration patches
30. Which of the following is a barrier to widespread adoption of wearable skin health technology in clinical settings?
- Limited manufacturing capacity
 - Overuse by elderly patients
 - Absence of standardised data interpretation protocols
 - Excessive radiation exposure

ANSWERS AND EXPLANATIONS

1. c

Explanation: The epidermis, particularly the stratum corneum, has very high electrical resistance due to its keratinised, low-water-content cells. This barrier property limits conductivity and complicates the acquisition of biopotentials [e.g., Electrocardiogram (ECG) and Electromyogram (EMG)] through wearable devices.^[1]

2. b

Explanation: TENGs operate based on the combined effects of triboelectrification and electrostatic induction. Triboelectrification occurs when two dissimilar materials come into frictional contact, such as through skin movement; one material donates electrons while the other gains them, generating opposite surface charges. Electrostatic induction arises when these charged materials are separated, creating an electric potential difference that drives electrons through an external circuit to balance the charge distribution.^[2,3] The self-powered nature of TENGs, along with their high sensitivity, durability, flexibility and comfort, makes them highly suitable for wearable skin devices.

3. b

Explanation: Successful attachment of sensors to the skin requires selecting a material with mechanical properties that closely match those of human skin. Silicone-based elastomers, such as PDMS, are commonly used as sensor substrates;

however, with a Young's modulus of approximately 3 MPa, PDMS is considerably stiffer than human skin, which can result in delamination.^[4] In contrast, softer elastomers like Ecoflex (Smooth-On), with a Young's modulus of around 125 kPa, more closely approximate the compliance of skin, allowing for better conformal contact and stable sensor adhesion.^[5]

4. b

Explanation: The major hurdle for long-term wearable sensor adhesion to the skin is the natural regeneration cycle of the stratum corneum, the outermost layer of the epidermis. The keratinocyte cycle (which includes the renewal of the stratum corneum) lasts between 28 and 50 days, depending on age. This continuous shedding and renewal process causes the outermost layer of the skin to slough off, leading to the detachment of sensors adhered to the skin's surface.^[6]

5. d

Explanation: The dermis contains dense collagen bundles and fibrils, which cause Mie and Rayleigh scattering of light, distorting optical signals.^[7] Scattering reduces the penetration depth and signal-to-noise ratio of reflected/absorbed light, complicating measurements like blood oxygenation or glucose levels.

6. b

Explanation: Microneedles produce almost no pain or very little pain because they penetrate up to where no large ending nerves are present and are minimally invasive.^[8]

7. b

Explanation: Researchers at the Department of Dermatology and Allergy, Technical University of Munich, are developing a miniaturised wristband sensor designed to provide personalised predictions for atopic eczema. This device measures EDA, which reflects the skin's electrical resistance and is influenced by the sympathetic nervous system and sweat gland activity, thereby correlating with stress levels. Previous studies have explored the utility of EDA as a diagnostic marker in other medical fields, including perioperative stress monitoring in surgical specialties and the assessment of severe depression in psychiatry.^[9,10]

8. b

Explanation: Wearables provide longitudinal at-home data, supplementing clinic-based evaluations without replacing physicians. It provides continuous data for a longer period, because of which we can objectively assess the pattern.^[11]

9. b

Explanation: Pruritus, or itch, is the primary symptom of AD and the main contributor to the reduced quality of life experienced by patients. Since the early 2000s, researchers have sought objective methods to measure scratching, employing technologies such as accelerometer-equipped watches, forearm electromyography, piezoelectric sensors on fingernails, sound recording devices and electromagnetic motion detection.^[12] Among these, actigraphy

has emerged as one of the most successful approaches, with recent technological advances making it precise, accurate and reliable for clinical use. A wrist actigraph, a portable device incorporating an accelerometer, measures wrist movements as a proxy for scratching.^[13] Studies have shown that wrist activity between 1 and 3 Hz during the first three hours of sleep serves as a meaningful indicator of AD severity in children.^[14] In addition to quantifying scratching, actigraphy provides valuable data on sleep disturbances in patients with AD.^[15]

10. a

Explanation: Smartwatch-based designs for measuring itch have certain limitations. They are primarily useful for monitoring nocturnal symptoms, as daytime movements can confound the measurements, and they cannot detect scratching performed with the arm not wearing the device – a limitation that is particularly relevant when eczema affects the wrist or arm wearing the watch.^[15] Despite these constraints, smartwatches have demonstrated the ability to identify nighttime scratching behaviour with over 90% accuracy.^[16]

11. c

Explanation: While wearable devices can measure physical parameters such as TEWL and skin hydration, they are unable to assess systemic biomarkers like IgE.^[17] To provide an objective evaluation of AD severity, epidermal probes – such as the Tewameter TM210 and Corneometer CM825 – have been employed. These devices measure TEWL to assess skin barrier function and the capacitance of the skin surface to evaluate stratum corneum hydration. Utilising such non-invasive measurements, the Objective Severity Assessment of AD score has been developed and demonstrated a strong correlation with the SCORAD index commonly used in clinical practice.^[18]

12. a

Explanation: Before wearable sensors can be widely adopted in clinical practice, it is essential to validate their readouts against established measures of disease severity. In the context of AD, this initial validation will likely involve cross-referencing sensor data with current clinical 'gold standards', such as the EASI or regional EASI scores.^[17]

13. b

Explanation: Reported challenges with subcutaneous sensors include their relatively short functional lifetime and difficulties with calibration. Another significant limitation is non-specific protein adsorption at the sensor-tissue interface when exposed to complex biological media, a process known as biofouling, which can reduce sensor performance. Currently, subcutaneously implanted sensors are primarily used for glucose monitoring, which may hold particular relevance for dermatological conditions associated with impaired glucose metabolism, such as psoriasis, acanthosis nigricans and hormonal acne. However, data on the use of subcutaneous sensors in skin diseases remain limited.^[19,20]

14. b

Explanation: A novel approach to measuring stress in the skin has been developed through a collaboration between research groups at Stanford University and the Karolinska Institute. They designed a sensor incorporating a specialised membrane capable of non-invasive detection of cortisol in sweat. In the absence of cortisol, the membrane remains permeable to ions; however, when cortisol is present, it blocks ion passage, which is subsequently detected by the sensor. The device demonstrated high reliability, with measurements unaffected by body temperature fluctuations, and showed specificity by not responding to structural analogues such as cortisone. Validation studies using both artificial and human sweat further confirmed its accuracy. Objective measurement of cortisol levels through such sensors offers valuable insight into patient stress levels.^[21]

15. c

Explanation: N-doped carbon dots function as photo-activated nanozymes, facilitating the catalytic oxidation of TMB across all three UV ranges (UVA, UVB and UVC), thereby overcoming the limitation of conventional systems that respond only to UVB and UVC. Importantly, they retain catalytic activity at near-neutral pH (approximately 6), ensuring safety and biocompatibility for wearable dermatological applications. This broad-spectrum responsiveness enables more comprehensive monitoring of UV exposure, which is particularly relevant as UVA constitutes the majority of solar UV radiation reaching the Earth's surface.^[22]

16. c

Explanation: Graphene-based sensors represent a state-of-the-art innovation for wearable skin hydration monitoring, owing to their lightweight structure, high flexibility and exceptional sensitivity to subtle physiological changes. Their ability to conform seamlessly to the skin's surface without causing discomfort allows continuous, real-time and non-invasive detection of minute variations in hydration and elasticity, making them particularly valuable for long-term dermatological monitoring.^[23]

17. b

Explanation: The Corneometer (CM 825, Courage + Khazaka) is widely used to assess stratum corneum hydration by measuring skin capacitance. Results are expressed in arbitrary units, with the final value typically obtained by averaging three consecutive measurements at the same site. This device provides an objective, non-invasive and rapid assessment of skin hydration levels. However, as it is not a wearable technology, its utility is limited to point-of-care or research settings rather than continuous monitoring.^[24]

18. a

Explanation: AD is characterised by immune-mediated inflammation and epidermal barrier dysfunction. Recent advances have demonstrated that key cytokines such as

IL-4 and IL-13 can be measured directly in lesional skin using biodegradable hyaluronic acid-loaded microneedle patches, with changes in cytokine levels broadly correlating with clinical improvement. This approach highlights the potential of microneedle-based ISF sampling for detecting inflammatory cytokines, offering a promising avenue for objective monitoring of AD.^[23,24]

19. c

Explanation: Age is often cited as a barrier to the use of wearable devices, as elderly patients may face challenges in adopting and consistently using new technologies.^[25,26]

20. c

Explanation: The image depicts a flexible piezoelectric sensor that generates an electrical signal in response to mechanical deformation such as bending, stretching or applied pressure. Utilising the piezoelectric effect, these sensors convert mechanical strain into electrical voltage and are commonly employed for monitoring arterial pulses, finger movements and respiration patterns. Unlike triboelectric sensors, which depend on friction between dissimilar materials and produce voltage through contact-separation cycles, piezoelectric sensors generate continuous signals under sustained pressure. In contrast, microneedle sensors penetrate the skin to access ISF, while optical sensors operate through light absorption, transmission or reflection, making them non-deformation-based modalities.^[6]

21. b

Explanation: A prospective randomised trial in elderly individuals with actinic keratoses demonstrated a 95% reduction in the incidence of non-melanoma skin cancers among those using UV dosimeters. These devices provided real-time feedback on UV exposure and delivered behavioural cues that encouraged protective measures such as timely sunscreen application.^[27,28]

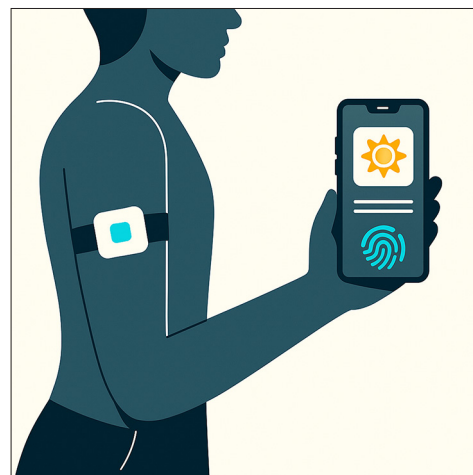


Figure 5: Ultraviolet wearables with smartphone apps that provide real-time exposure alerts.

22. b

Explanation: Many modern UV wearables are integrated with smartphone applications that deliver real-time exposure alerts [Figure 5] and personalised recommendations, such as reminders to reapply sunscreen, hydrate or seek shade. By providing tailored feedback, these devices enhance user engagement and improve adherence to sun safety behaviours.^[23,29]

23. a

Explanation: Smart bandages incorporating continuous temperature and pH sensors have been tested for monitoring the healing of chronic wounds. In one design, the sensor was integrated into a closed-loop system that released drugs through a thermally responsive carrier embedded within a hydrogel patch whenever real-time measurements indicated inflammation or infection.^[17,27]

24. b

Explanation: Actigraphy captures accelerometer-based movements. Peaks in the 1–3 Hz range correspond to the rhythmic frequency of scratching during sleep in AD patients. Unlike random limb movements, these repetitive bouts correlate with disease severity and sleep disturbance, and they have been validated against clinical scores (EASI, SCORAD).^[16]

25. b

Explanation: TENGs operate through repeated contact and separation of two dissimilar materials, generating surface charges through triboelectrification and producing current through electrostatic induction, whereas piezoelectric devices rely on a single material that generates charge directly when mechanically stressed, producing voltage. Both mechanisms are exploited in dermatology wearables for self-powered strain sensing, motion detection and skin-mounted electronics. Clinically, TENGs are particularly attractive for ultra-light, flexible patches, while piezoelectric sensors are widely used for monitoring physiological signals such as pulse and respiration.^[2,3]

26. b

Explanation: The image depicts a smart, flexible wound dressing designed for real-time monitoring of the wound environment and on-demand antibiotic delivery. This bandage integrates pH and temperature sensors to detect early signs of infection, typically indicated by elevated pH and temperature levels. Upon detection of abnormal values, an embedded microheater activates thermo-responsive drug carriers within a hydrogel layer, releasing antibiotics – such as cefazolin – directly into the wound. These carriers, composed of PNIPAM particles, undergo a physical transformation in response to heat, enabling precise drug delivery. The system operates in a closed-loop manner and supports wireless communication, facilitating remote monitoring and individualised treatment protocols. Such intelligent design makes the bandage particularly suitable for managing chronic wounds, where traditional dressings cannot provide dynamic feedback or controlled drug release.^[27]

27. c

Explanation: The advanced electronic skin developed for stress monitoring simultaneously measures pulse waveform, galvanic skin response and temperature, along with six key sweat biomarkers: Glucose, lactate, uric acid, sodium, potassium and ammonium. Notably, cortisol – a widely recognised stress hormone – is not included among the monitored markers in this system.^[30]

28. c

Explanation: The stress-monitoring electronic skin employs machine learning to analyse multimodal data from physiological signals and sweat biomarkers. This enables the device to distinguish between different types of stress with high accuracy (98%) and predict psychological stress with 98.7% confidence, offering the potential for personalised feedback and interventions.^[31,32]

29. c

Explanation: Waterproof epidermal microfluidic devices are engineered to operate effectively in aquatic environments, such as swimming, or during high-sweat activities. They utilise soft elastomeric materials, including styrenic block copolymers, which prevent contamination from external water while enabling accurate sweat sampling. Embedded colorimetric assays allow real-time quantification of sweat biomarkers, such as chloride concentration, facilitating precise hydration assessment even under challenging conditions.^[33]

30. c

Explanation: A significant barrier to clinical adoption of wearable skin health technologies is the absence of standardised frameworks for interpreting continuous sensor data. Variations in device hardware, software and output hinder uniform clinical application, limiting diagnostic consistency and integration into routine dermatological practice.^[23]

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Editor Query???

EQ1: Kindly check and confirm the edits