Flexible Functional Composites for Athlete Health and Performance and Auxiliary Training Applications

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Flexible functional composites have great potential for a variety of applications in the fields of athlete health monitoring and auxiliary training. There are a few recent reports on various functional composites such as graphene-based composites, MXene-based composites, and polymer-based composites, *etc.* However, the applications of flexible functional composites for athlete health monitoring and auxiliary training have yet to be widely reviewed. This mini-review summarizes these three types of functional composites for the applications of athlete health monitoring and auxiliary training. The synthetic methods, structures, and properties of functional composites are reviewed *via* some typical examples. The authors focus on the properties of functional composites as sensors for health-monitoring. Moreover, future development directions are suggested based on the authors' knowledge. This review article demonstrates that these flexible functional composites can display excellent properties and promising potential for applications in athlete health monitoring and auxiliary training.

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INTRODUCTION

Recently, health monitoring is becoming extremely popular due to the real-time transmission of signals from individuals to medical institutions (Wang 2022). Health monitoring is the main way to obtain health-related information, which is of great significance for the early detection and treatment of related diseases. Athlete sports monitoring and data collection can effectively understand an athlete's health status, strengthen physical fitness, and improve competitive fitness level (Brancaccio *et al.* 2007; Kellmann 2010; Holzer *et al.* 2022). In recent decades, health monitoring has been widely used to collect athletes' medical information. For example, high-level professional athletes are monitored by a global positioning system (GPS) and accelerometer. The sensors can be used to collect heart rate, speed, strength, rhythm, distance, time, and provide real-time feedback to athletes, so that they can track and adjust their exercise level. The jump monitor, a wearable device launched by Vert Company, is small and can be easily installed at the waist of athletes (Manor *et al.* 2020; Damji *et al.* 2021; Piatti *et al.* 2021). It can monitor the height and number of jumps of an athlete in real time, as well as the amount of exercise to effectively prevent athletes from being injured. However, the realization of athlete health monitoring and auxiliary training will depend on the development of flexible functional materials, and flexible functional composites are promising candidates in these fields (Diamanti and Soutis 2010; Kinet *et al.* 2014). There are a few reports on various functional composites such as graphene-based composites (Cheng *et al.* 2015; Liu *et al.* 2016), MXene-based composites (Lei *et al.* 2019; Pu *et al.* 2019), and polymer-based composites (Ratna and Karger-Kocsis 2008; Amjadi *et al.* 2016). More recently, Su *et al.* (2022) reviewed the vital-sign and physiological-signal monitoring applications of flexible electronics, photoelectronics, and their integrated wearable devices. However, the applications of flexible functional composites for athlete health monitoring and auxiliary training have not yet been widely reviewed.

Herein, this mini-review summarizes these three types of flexible functional composites for the applications of athlete health monitoring and auxiliary training. The synthetic methods, structures, and properties of flexible functional composites were reviewed *via* some typical examples. Future research directions are suggested based on the authors' knowledge. These flexible functional composites will have promising applications potential in athlete health monitoring and auxiliary training.

GRAPHENE-BASED COMPOSITE FOR MOTION DETECTION APPLICATIONS

Novoselov *et al.* (2004) first separated graphene from graphite by micromechanical stripping. Graphene displays good optical, electrical, and mechanical properties, and it has wide application in energy, biomedicine, and drug delivery sectors (Stankovich *et al.* 2006; Castro Neto *et al.* 2009; Geim 2009). Graphene is also an ideal material for an electrochemical biosensor (Unnikrishnan *et al.* 2012). Meanwhile, the graphene sensor has good sensitivity in detecting dopamine and glucose in medicine (Thanh *et al.* 2016). The gold nanoparticle-anchored nitrogen-doped graphene nanohybrid modified indium-doped tin oxide electrode was obtained by placing gold nanoparticle-anchored nitrogen-doped graphene onto an indium-doped tin oxide-conducting glass substrate, which was used as the glucose sensor by using alkalized human serum samples. Graphene-based composites have also been developed for motion detection. For example, Jeong *et al.* (2015) fabricated the graphene foam/polydimethylsiloxane (PDMS) strain sensor with three-dimensional (3D) structure and percolation network as a health monitoring device. The strain sensor has sensitivity with a gauge factor (GF) of 15 to 29, stretchability over 70%, and durability over 10,000 stretch-release cycles. The strain sensor detected the elbows and fingers bending, and the pulse of the radial artery. Then, the graphene-paper pressure sensor with the optimization sensitivity and working range was reported for health monitoring and motion detection in the range of 0 to 20 kPa (Tao *et al.* 2017). All pulse detection, respiratory detection, voice recognition, and intense motion detections could be completed using this graphene-paper pressure sensor. After that, Song *et al.* (2018) reported a Janus graphene film pressure sensor with a wide sensing range, fast response time, and good stability for monitoring vital signs and cardiovascular assessment. The sensor monitors the vital signs of human body motion, breathing, and arterial pulse. Clearly, graphene-based composites have promising applications for motion detection.

Silver nanowires have excellent conductivity, light transmittance, bending resistance, and flexibility, which have applications as flexible and bendable LED display and touch screen. Chen *et al.* (2016) developed a crack-based silver nanowires/graphene strain sensor for electronic skins and health monitoring. The composites were pre-stretched at first to develop crack morphologies on the surface and then cut into rectangle strips (3 cm × 5 mm), attaching two copper wires to the two ends of the strip by conductive silver paste. A crack-based stain sensor was thus achieved with high GF, strain resolution, and working stability. The silver nanoparticles-bridged graphene strain sensor with high sensitivity and durability was also reported for detecting human motions (Yang *et al.* 2018b). The sensors were obtained using a polydimethylsiloxane film as the substrate, coating by Ag nanoparticles and reduced graphene oxide film, pasting two copper foils on the two ends of the film as the electrodes by silver paste, and covering with another polydimethylsiloxane film on Ag nanoparticles bridged graphene sheet composite as an encapsulate shell. It obtained a large GF of 475 and a strain range of > 14.5% for the strain sensor. The strain sensor detected both large-scale and small-scale human motions. More recently, Zhang *et al.* (2020) fabricated a silver nanowire-coated thiolated graphene foam and polyurethane elastomer self-healable strain sensor with high sensitivity, fast response ability, good stretchability, and durability. A silver nanowire@thiolated graphene foam-based strain sensor was prepared by, respectively, connecting with a thin copper wire at the two ends of silver nanowire@thiolated graphene foam as electrodes under the adhesion of silver paste. The 3D binary conductive-network silver nanowire@thiolated graphene foam-based strain sensor was obtained by placing the silver nanowire@thiolated graphene foam in a Teflon template, injecting tetrahydrofuran solution of functionalized polyurethane into the template to submerge the silver nanowire@thiolated graphene foam, and drying at room temperature for 48 h. It achieved a GF of 11.8 and response/recovery time of 40/84 ms. All the pulse beats, voice recognitions, various joint movements, and handwriting were detected based on strain sensor. The high conductivity of flexible silver nanowires favored the increase sensor property of graphene composites, including high GF and fast response/recovery time.

Carbon black also has received attention because of its large surface area (Lian and Xing 2017; Silva *et al.* 2017). Souri and Bhattacharyya (2018) reported wearable, stretchable, and durable yarns/graphene/carbon black strain sensors for human motion detection. The strain sensors had sensitivity with GFs of 1.46 to 5.62. All finger, wrist, and knee joint movements, pronunciation, breathing, and swallowing can be detected using these strain sensors. Moreover, Liu *et al.* (2021) applied wearable paper-based carbon black/graphene sensors for humidity and volatile organic compounds (VOC) detection. The sensors can detect relative humidity of 33 to 95% and VOCs of methanol, toluene, and petroleum ether with relatively short response time.

Molybdenum disulfide (MoS_2), a similar two-dimensional (2D) material with graphene, has an energy band gap of 1.8 eV. Kim *et al.* (2018a) reported a flexible MoS_2/graphene foam/ecoflex hybrid strain-pressure sensor with high sensitivity and durability. It achieved a sensitivity of 6.06 kPa^{-1} and good durability. The sensor can detect motion signals of neck bending and eye blinking. Furthermore, Chhetry *et al.* (2019) created a highly sensitive and reliable MoS_2-decorated laser-induced graphene piezoresistive strain sensor. It exhibited sensitivity with GF of 1242, a wide working range up to 37.5%, detection limit of 0.025%, and relaxation time of 0.17 s for the piezoresistive strain sensor. The sensor is used to detect the signals of phonation, wrist pulse, and large deformations.

Textile strain sensors display the advantages of wearability and stretchability (Castano and Flatau 2014; Hamid and Debes, 2018; Seyedin *et al.* 2019). Yang *et al.* (2018a) reported a wearable graphene textile strain sensor with negative resistance variation for human motion detection. The sensor had high sensitivity, long-term stability, and great comfort. The sensor was reported for detecting both subtle and large human motions. After that, Chun *et al.* (2019) reported the graphene-coated fabric sensors for health monitoring and medical applications. The sensor monitored wrist pulse, electrocardiography, body motions, and speech vibrations. Liu *et al.* (2019) also developed semitransparent, ultrasensitive, and wearable graphene woven fabric strain sensors for human physiological signals monitoring. It obtained a high GF, a broad sensing range up to 30%, and linearity for strain sensors. These sensors can be applied in human motion detection and switch controls of LED lamps and liquid-crystal-display circuits. Recently, Zheng *et al.* (2020) prepared two kinds of graphene/cotton fabric strain sensors with high durability and low detection limit. It achieved linear current-voltage behavior, response time similar to 90 ms, and low strain similar to 0.4% strain for the two strain sensors.

In Wu *et al.* (2020)'s work, a flexible positive graphene pressure sensor was developed for real-time health and motion monitoring. The sensor achieved an ultrahigh sensitivity and a broad detection range, detecting varieties of physiological signals and human movements. Li *et al.* (2020) also prepared a flexible braided graphene belt/dragon skin strain sensor. The strain sensor had a sensing range up to 55.6%, high sensitivity of GF of 175.16, and low hysteresis, detecting the subtle actions and joint-related movements. Wang *et al.* (2022) presented a flexible tactile porous graphene/silicone rubber composite sensor with high sensitivity, good dynamic response, and repeatability for human motion and health monitoring. The composite's pressure sensor had sensitivities of 195 kPa^{-1} at 55 to 80 kPa. The sensor detected the distributed motion signals and pulse. An alginate/graphene aerogel pressure sensor with sponge-like structure was introduced for motion detection (Yue *et al.* 2021). It achieved an operation range of up to 1000 kPa with high sensitivity, low detection limit, and rapid response time for the aerogel pressure sensor. More recently, Li *et al.* (2022) also reported a compressible and sensitive graphene/wastepaper aerogel pressure sensor with 3D porous structure. The pressure sensor had a working range of 0 to 132 kPa, detection limit of 2.5 Pa, and sensitivity of 31.6 kPa^{-1}, detecting the pulse of the human body, cheek blowing, and bending of human joints.

Graphene oxide (GO) has more active properties than graphene because of its increased oxygen-containing functional groups after oxidation. Kafy *et al.* (2016) reported on a flexible cellulose nanocrystal (CNC)/GO composite film as a humidity sensor. The sensor had advantageous linear and fast response because of the hydrophilic functional groups in the composite. Kim *et al.* (2018b) fabricated highly durable and waterproof reduced graphene oxide (rGO)/single-walled carbon nanotube (SWCNT) hybrid fabric strain-pressure sensors for human-motion detection using a solution process. The device had water resistant properties because of its hydrophobic nature after 10 washing tests. The sensor-based motion glove indicated its practical applicability. Jiang *et al.* (2019) presented the flexible porous rGO fiber fabrics pressure sensor. The fabrics pressure sensor had a sensitivity of 0.24 to 70.0%, a GF of 1670, a detection limit of 1.17 kPa, and a response time of 30 ms. It reported the increased sensitivity due to the wrinkles on the rGO fibers surface. Lu *et al.* (2021) reported a flexible conductive rGO/polyurethane foam with an ultra-wide pressure detection range and high stability *via* freeze-drying and dip-coating method. The foam possessed the pressure detection range from 20 kPa to 1.94 MPa, sensitivity of 0.0152 kPa^{-1}, and response of 166 ms. Deng *et al.* (2021) fabricated functionalized Janus GO nanosheets/polypyrrole (PPy) and poly(2-(dimethylamino)ethyl methacrylate) (PDMAEMA)/guar gum-poly(acrylic acid) nanocomposite hydrogel strain sensors for human motion detection. It achieved a self-healing efficiency of 92.8%, a strength of 4.12 MPa, and a toughness of 874% for nanocomposite hydrogels. The hydrogel sensors can monitor a variety of human motions. Cheng *et al.* (2021) developed a poly (styrene-co-methacrylic acid)@PPy/rGO-decorated thermoplastic polyurethane electro-spun membrane piezoresistive sensor for health monitoring and motion detection. The pressure sensor can detect a small pressure of 0.94 Pa, with an operating voltage of 1.0 V, response time of 37 ms, and cycle stability over 1,650 cycles). The sensor monitors the human pulse, facial muscles, and joint movements. In view of the above reports, graphene-based composites have been applied as strain-pressure sensors for motion detection applications.

MXENE-BASED COMPOSITE FOR MOTION DETECTION APPLICATIONS

MXene is a 2D inorganic material that consists of transition metal carbides, nitrides, or carbonitrides (Naguib *et al.* 2011, 2012), which have inherent electronic conductivity, excellent hydrophilicity, rich surface chemistry and layered structure. MXene has metal conductivity because of hydroxyl or terminal oxygen on the surface (Naguib *et al.* 2012; Ling *et al.* 2014). Yang *et al.* (2019b) reported a $Ti_3C_2T_x$ MXene nanoparticle-nanosheet hybrid network strain sensor with a high sensitivity and a wide sensing range for motion detection. It obtained a sensitivity of GF of 178.4, the detection limit of 0.025%, and a cycling durability over 5,000 cycles. In the review article, Yuan *et al.* (2020) introduced recent progress and challenges of MXene-based sensors to detect human physical signals (body motion and temperature) and chemical signals (body cancer biomarkers and small molecules). They provided a perspective about the applications of MXene-based sensors for seniors.

Rapid progress has been achieved on MXene/polymer composites for motion detection applications. For example, Song *et al.* (2019) fabricated flexible hollow MXene-PDMS composites as wearable and highly bendable sensors. The piezoresistive pressure sensor had a working range with bending angles of 0 to 180°, a reliability up to 1,000 cycles, a stable durability with a bending angle of 30°, and a detection limit of 10 mg for pressure detection. The sensor can be used for stereo sound and ultrasonic vibration monitoring, swallowing, facial muscle movement, and various intense motion detections. Yang *et al.* (2019a) also presented a wearable $Ti_3C_2T_x$/graphene/PDMS composite film strain sensor with high sensitivity and large range of linear response. The strain sensors had a GF of 190.8 in strain ranges of 0 to 52.6% and 1150 in strain ranges of 52.6 to 74.1%, a detection limit similar to 0.025%, a linearity of approximately of 0.98, and a cycling stability over 5,000 cycles. The authors indicated the different distinguished breathing patterns in yoga by the sensor. Chao *et al.* (2020) reported a flexible wearable MXene/polyaniline fiber nanocomposite strain sensor for broad-range ultrasensitive sensing. The nanocomposite strain sensor detected up to 80% strain of human motion with detection limit of 0.154% strain, and sensitivity of GF up to 2370.

One-dimensional (1D) CNTs were reported in composite 2D MXene for motion detection applications. Yang *et al.* (2021) reported a superhydrophobic MXene-coated carboxylated CNTs/carboxymethyl chitosan aerogel for piezoresistive pressure sensor. The pressure sensor had a response time of 62 ms, a detection range up to 80 kPa, as well as electrical stability and repeatability under humid and sweaty environments. The sensor monitors human motions including joint movements, walking, running, pronunciation recognition, and finger tapping. Moreover, Wang *et al.* (2021) developed a CNT/$Ti_3C_2T_x$ MXene/polyurethane strain sensor for the monitoring of human activities. The sensor had a working strain range close to 100% and a sensitivity as high as 363 simultaneously. The strain sensor detected joint motion, finger motion, and vocal cord vibration.

Various additives have been introduced into MXene to fabricate composites for motion detection applications (Nauib et al., 2014). Ma *et al.* (2020) developed a hydrophobic and multifunctional MXene ($Ti_3C_2T_x$)-decorated airlaid paper composite for motion monitoring. The composite exhibited good electronic/photonic/mechanical triresponsive properties. The sensor displayed high sensitivity and rapid response time of 30 to 40 ms, capturing a wide range of movements. Chao *et al.* (2021) presented a wearable MXene/protein nanocomposite-based pressure sensor with reliable breathability, biocompatibility, and robust degradability for human motion detection. The sensor had a sensing range up to 39.3 kPa, sensitivity of 298.4 kPa^{-1} for 1.4 to 15.7 kPa, response/recovery time of 7/16 ms, and cycling stability over 10,000 cycles, monitoring human psychological signals and wireless biomonitoring in real time. Li *et al.* (2021) fabricated MXene helical yarn/fabric tactile sensors with a GF of 715.94 for motions detection. The tactile sensors can recognize sign language, record middle and large human body motions, and detect walking postures and detect electric heating. Su *et al.* (2022) proposed layered MXene/aramid composite film with 10 μm thickness and flexibility for a sensitive pressure sensor. The sensor had a sensitivity of 16.7 kPa^{-1}, a detection range of > 100 kPa, and up to 10% stretchability. The sensor can be used in motion monitoring and human-machine interfaces. Zhang *et al.* (2022) prepared a cross-linked collagen fiber/MXene composite aerogel sensitive pressure sensor. The sensor exhibited a sensitivity of 62.0 kPa^{-1}, a response time of 0.30 s, a recovery time of 0.15 s, and a detection limit of 0.4 kPa.

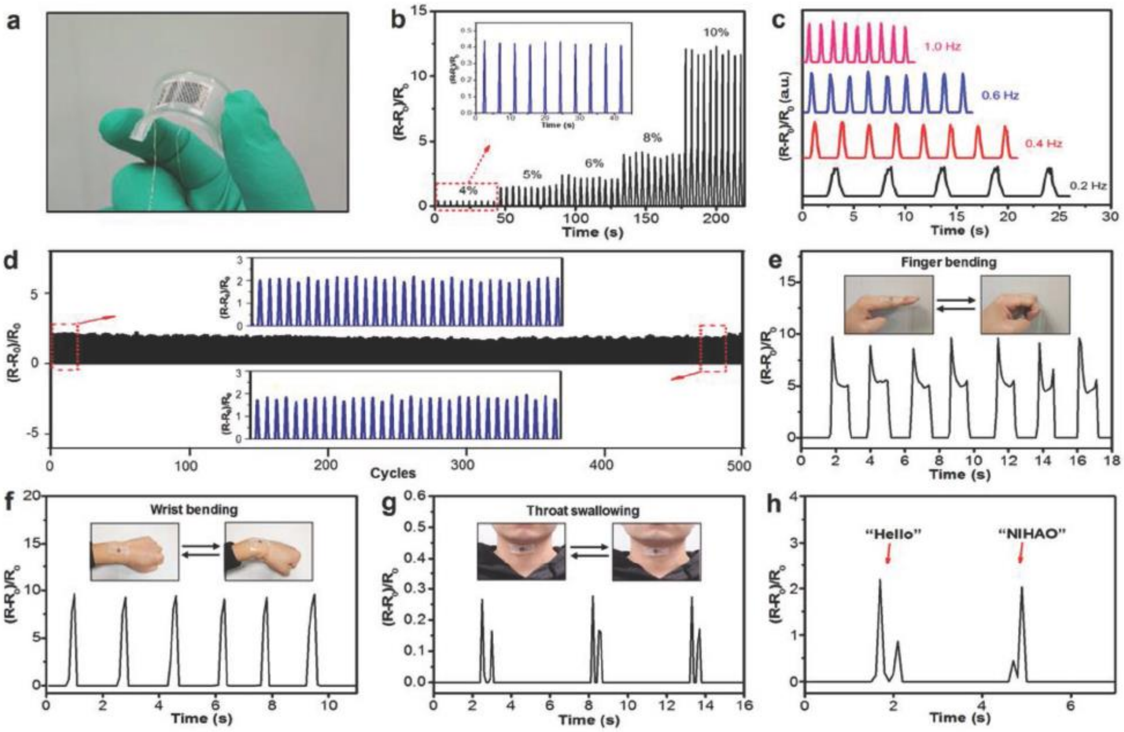

Fig. 1. Strain-sensing properties of the TOCNFs/Ti_3C_2 textile: a) The TOCNFs/Ti_3C_2 textile strain sensor; b) Relative resistance variation of the stain sensor under various cyclic strains; c) Relative resistance response of the stain sensor at different frequencies under 5% of stain; d) Relative resistance change of the stain sensor during 500 cycles of stretching and releasing between 0% and 5% strain at a strain rate of 1.3 mm s^{-1}. Relative resistance changes of e) finger bending, f) wrist bending, g) swallows of the throat, and h) speaking "Hello" and "NIHAO" (Cao *et al.* 2019)

Nanocellulose is extracted from natural fibers, which has renewable, biodegradable, and excellent mechanical properties. Cao *et al.* (2019) first synthesized flexible smart fibres and textiles using a 3D-printing process with MXene reinforced TOCNF inks for wearable heating textiles, health monitoring, and human–machine interfaces. TOCNF/Ti_3C_2 textile sensitive strain sensors displayed good responsiveness to multiple external stimuli (electrical/photonic/mechanical) (Fig. 1). Pi *et al.* (2021) developed robust and ultrasensitive CNC/MXene hydrogel sensors. The hydrogel exhibited excellent mechanical properties, conductivity of 0.4 S/m, and thermal conductivity of 0.38 W/mK.

Cao *et al.* (2020) developed a stretchable MXene liquid electrode triboelectric nanogenerator (TENG). The MXene-based TENG sensor was used to inspect the frequency and amplitude of various physiological movements (Fig. 2). After that, Sardana *et al.* (2022) synthesized an electrospun MXene/TiO_2/cellulose nanofiber (CNFs) heterojunction-based TENG sensor with reproducibility and high selectivity for detection of NH3. The sensor had sensitivity toward NH3 (1 to 100 ppm) along with a response/recovery time of 76 s/62 s at room temperature. Furthermore, Cao *et al.* (2022) achieved crumpled MXene film pressure and strain sensor as the single-electrode mode

TENG for wireless human motion detection. The sensor had sensitivity of 2.35 V kPa^{-1}, collecting complicated movement signals.

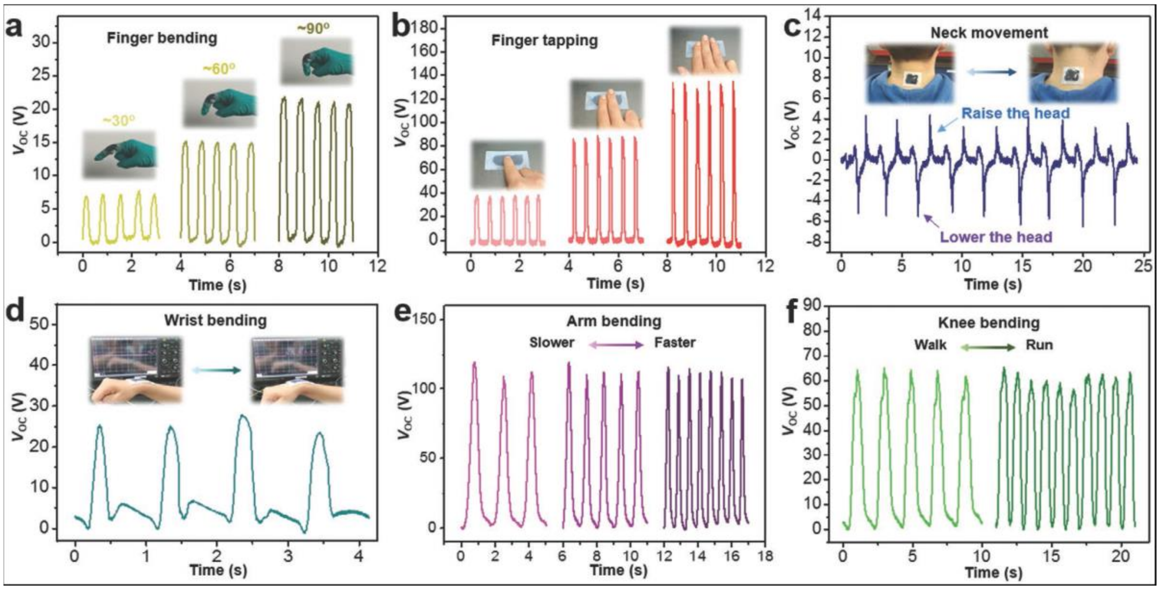

Fig. 2. CM-TENG-based self-powered biomechanical sensor for monitoring human body movements: a) finger bending, b) finger tapping, and c) neck movement. Generated VOC of the CM-TENG under different bending frequency of d) wrist, e) arm, and f) knee (Cao *et al.* 2020)

POLYMER-BASED COMPOSITE FOR MOTION DETECTION APPLICATIONS

Traditional rigid inorganic integrated devices cannot be closely fitted and integrated with the flexible tissue of the human body, so they cannot be accurately monitored. Fabbri *et al.* (2011) explored poly(ethylene oxide)-silica hybrids entrapping sensitive dyes for biomedical optical pH sensors. The pH optical sensors were used for the fast detection of biomedical parameters of fast esophageal pH-monitoring. Someya *et al.* (2016) published the article "The rise of plastic bioelectronics," indicating that plastic bioelectronics combined the inherent properties of polymers and soft organic electronics for the applications in the fields of wearable and implantable devices. Yan *et al.* (2018) developed the stretchable graphene/poly(glycerol sebacate) nanocomposite piezoresistive sensor for motion detection. The nanocomposite sensor had high sensibility for all the processed strain gauges. The sensors were applied to monitor the bending movement of the finger. Hu *et al.* (2018) reported a polyvinylidene fluoride (PVDF) piezoelectric thin film sensor for wrist motion signal detection. The sensor had sensitivity of 3.10 pC/N with the excitation signal exceeding 15 Hz. The wrist motion sensor was small in size, flexible, and sensitive, detecting the wrist motion signals with weak amplitude, low frequency, strong interference, and randomness. He *et al.* (2021) prepared a flexible porous CNT/graphene/PDMS nanocomposite strain sensor. The strain sensor had GFs of 182.5, 45.6, 70.2, and 186.5 in the 0 to 3, 3 to 57, 57 to 90, and 90 to 120% strain regions. It had a detection limit of 0.5% strain, a response time of 60 ms, stability and durability of 10,000 cycles. The porous strain sensor detected wrist bending, finger bending, elbow bending, and knee bending.

Poly(vinyl alcohol) (PVOH) is widely used to synthesize hydrogels. The Ag/tannic acid @CNCs/PVOH biomimetic hydrogels were obtained for artificial electronic skin (Lin *et al.* 2019). The multifunctional biomimetic skin hydrogel combined ultra-stretching (> 4000%), highly effective refolding self-healing (self-healing efficiency of 10 min up to 98.6%), compliance, and stress perception. The capacitive hydrogel sensor had good flexibility, high sensitivity, and wide detection range for accurate monitoring of human activities. Gao *et al.* (2020) constructed a multi-model PVOH hydrogel sensor with high toughness, fast self-recoverability, and excellent fatigue resistance for human-motion monitoring. It obtained ultra-stretchability (1120%) and supercompressibility (98%) for a hydrogel sensor. The sensor detected a large range elongation close to 900%, compression close to 70%, bend and pressure up to 4.60 MPa concurrently, as well as speaking, finger bending, and treading behavior. Yao *et al.* (2021) also fabricated a conductive PVOH/phosphoric acid gel electrolyte@PDMS composite for piezoresistive pressure sensor. The sensor had sensitivity of 0.1145 kPa^{-1}, response time of 70 ms, and durability for over 2,700 s. The sponge sensor detected vocal cord vibration, joint bending, respiratory rate, and pulse signal detection. More recently, a fully flexible polyaniline/PVOH/borax cellulose nanocomposite hydrogel sweat sensor was fabricated for self-powered health monitoring (Qin *et al.* 2022), which had tensile and electrical self-healing efficiencies exceeding 95% within 10 s, a stretchability of 1530%, and conductivity of 0.6 S m^{-1}. It achieved Na^+, K^+, and Ca^{2+} contents to sensitivities of 0.039, 0.082, and 0.069 $mmoL^{-1}$ for the sweat sensor, respectively.

Biomass is also used as an additive to fabricate polymer-based composites for motion detection applications. Liu *et al.* (2017) developed a wearable, self-healing, and elastic hydrogel strain sensor. The hydrogel had self-healing capability in only 5 min due to ionic coordination between CNCs and Fe^{3+}. The strain hydrogel sensor could monitor finger joint motions, breathing, and slight blood pulse. Qu *et al.* (2021) prepared lignin-reinforced poly(ionic liquid) hydrogel strain sensor with stretchability over 1425%, toughness over 132 kPa, and impressive stress loading-unloading cyclic stability. The strain sensor presented a high GF of 1.37, a response rate of 198 ms, and a low detection limit. The hydrogel can detect dual stimuli of strain and temperature. The CNC hydrogels were widely applied as strain sensors for detecting human motion. Moreover, the flexible conductive hydrogels sensors integrated with electrical conductivity of 2.58 mS cm^{-1} were made using PVOH, CNFs, and MXene (Zhang *et al.* 2021a). The sensors had sensitivity of GF of 2.30, response time of 0.165 s, working strain range of 559%, and operating temperature from −18 to 60 °C. The hydrogel sensors displayed the corresponding current signal for human motion detection, such as human swallowing, heart beating, wrist bending, and elbow bending. More recently, Guo *et al.* (2022) prepared the bacterial cellulose (BC)-based organohydrogels with tensile stress > 1.0 MPa and tensile strain of 1300% *via* microwave heating and acid catalysis method. It observed increased mechanical properties because of the hydrogen bond and the metal bonds with BCs-Ca^{2+} coordination. The flexible wearable sensors accurately monitor the large motion of fingers, wrist, elbow, and knee bend and walking and subtle physiological signals of the blink of an eye, and voice recognition (Fig. 3). Hemicellulose composite hydrogel sensors are also used for sports monitoring. The authors prepared multifunctional physical cross-linked hemicellulose/PPy composite hydrogels for sports monitoring, medical monitoring, and soft intelligent robots (Zhang *et al*. 2021b). It achieved the tensile strain of 1090%, stress of 481 kPa, compressive strength of 1790 kPa, and toughness of 2.82 MJ/m^3 for the hydrogels. The hydrogel sensors were reported to detect finger bending, wrist bending, and throat deformation during drinking and speaking. The sensors generated the corresponding signals during drinking water and speaking English words such as "sensor" and "hydrogel".

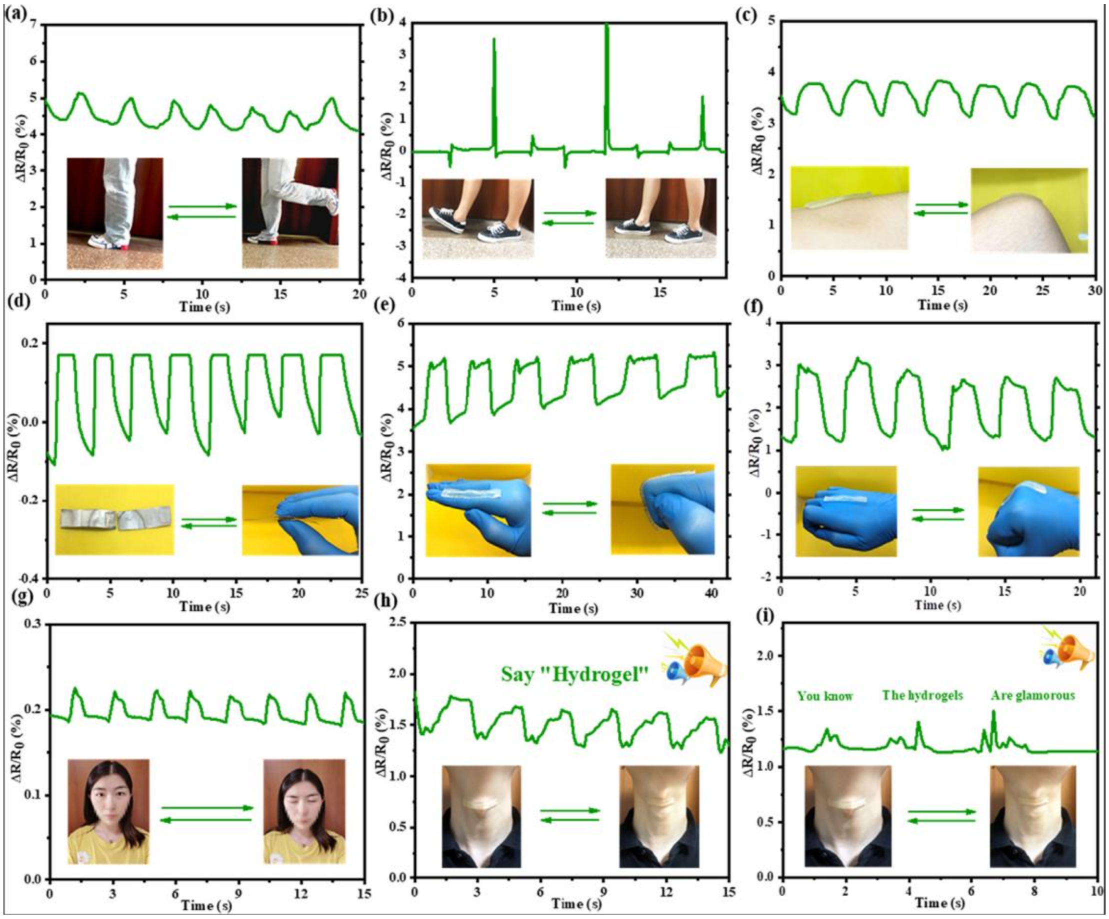

Fig. 3. The motion detection of C-Gly5 organohydrogels sensor: (a through f) walking, elbow and knee bending, pressing, finger and wrist bending; (g through i) blinking and speech (Guo *et al.* 2022)

CONCLUSIONS

In summary, this mini-review article described the recent development of flexible functional composites for health monitoring and auxiliary training applications. Especially, the synthetic methods, structures, and properties of functional composites, such as graphene-based composites, MXene-based composites, and polymer-based composites, were reviewed. As mentioned above, rapid progress has been achieved on these flexible functional composites. The flexible functional composites have promising applications potential as sensors in the health monitoring and auxiliary training fields.

Although the research on flexible functional composites for health monitoring and auxiliary training has made great progress, there are still some great difficulties and challenges, such as facile synthetic process, microstructure controllability, high efficiency, and industry applications. The future research trends and future research directions of the flexible functional composites for health monitoring and auxiliary training included the various flexible functional composites, composites sensors, and information system integration. The development of flexible composites sensors is still in its infancy and many problems need to be solved, such as signal interference, short continuous monitoring time, and poor durability.

Athletes' auxiliary training is a systematic system, which is complex and known to be sensitive to many factors interacting with each other. One of the challenges of auxiliary training monitoring is how to select suitable methods and technologies from a variety of sports evaluation methods and technologies. Monitoring methods can be simple and low-cost methods, or more complex and expensive methods, including the analysis of biochemical markers and the use of GPS and motion sensors to measure athletes' trajectory. It is expected that these flexible functional composites will have wider applications for health monitoring and auxiliary training in the near future.

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