Title

Protocol for preparation of a textile magnetoelastic generator patch.

Journal

STAR Protocols, 5(3)

Authors

Tat, Trinny
Xu, Jing
Chen, Jun

Publication Date

2024-09-20

DOI

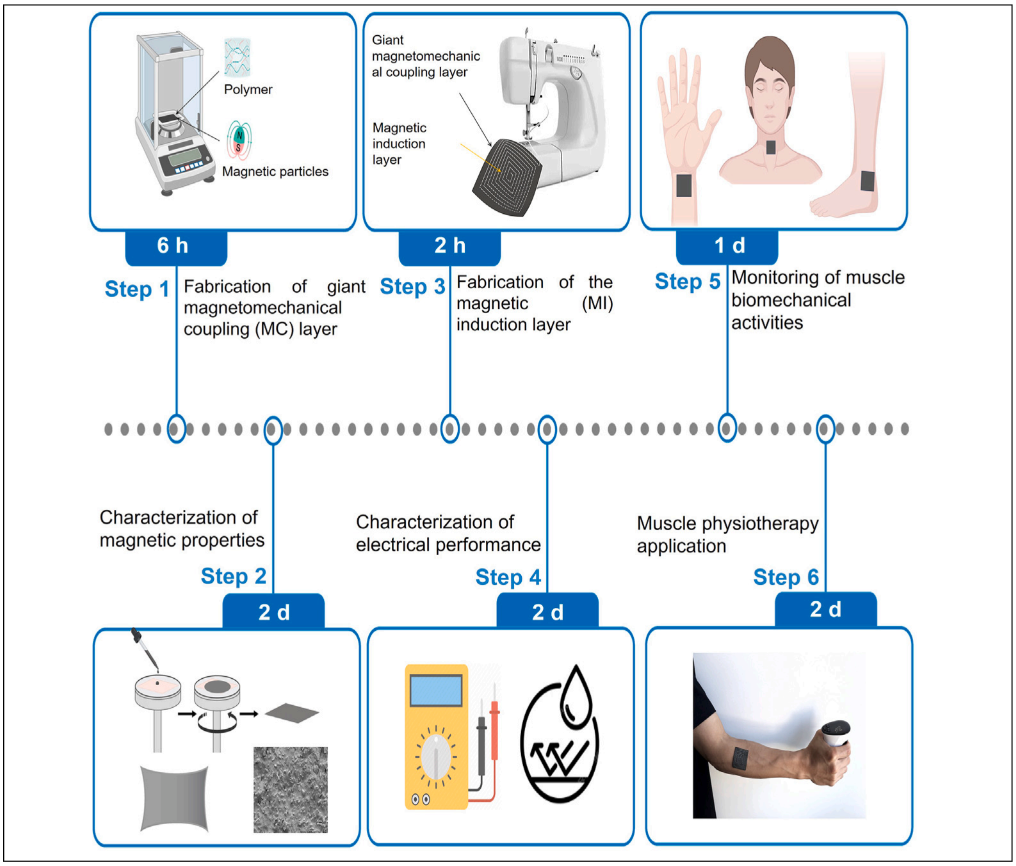
10.1016/j.xpro.2024.103289

STAR Protocols

CellPress
OPEN ACCESS

Protocol

Protocol for preparation of a textile magnetoelastic generator patch



The magnetoelastic generator (MEG) is a fundamentally new platform technology to convert mechanical motions into electrical signals for sensing, therapeutics, and energy applications. Here, we present a protocol for fabricating and characterizing the MEG for personalized muscle physiotherapy when integrated into a wearable textile patch. We describe the steps for fabricating such a textile MEG, including the magnetomechanical coupling (MC) and magnetic induction (MI) layers, and characterizing their magnetoelastic and electrical properties. We then detail procedures for monitoring muscle biomechanical activities and muscle physiotherapy application.

Trinny Tat, Jing Xu, Jun Chen

jun.chen@ucla.edu

Highlights

Fabrication strategy and structure characterization of a magnetoelastic generator

Examination of the electrical performance of the textile magnetoelastic generator patch

Application in monitoring muscle movements based on the produced electrical signals

Quantification of loading deficits and excesses based on the lab-scale equation

Tat et al., STAR Protocols 5, 103289
September 20, 2024
https://doi.org/10.1016/j.xpro.2024.103289

STAR Protocols

CellPress
OPEN ACCESS

Protocol

Protocol for preparation of a textile magnetoelastic generator patch

Trinny Tat,[1,2] Jing Xu,[1,2] and Jun Chen[1,3,4,*]

[1]Department of Bioengineering, University of California, Los Angeles, Los Angeles, CA 90095, USA

[2]These authors contributed equally

[3]Technical contact

[4]Lead contact

*Correspondence: jun.chen@ucla.edu

https://doi.org/10.1016/j.xpro.2024.103289

SUMMARY

The magnetoelastic generator (MEG) is a fundamentally new platform technology to convert mechanical motions into electrical signals for sensing, therapeutics, and energy applications. Here, we present a protocol for fabricating and characterizing the MEG for personalized muscle physiotherapy when integrated into a wearable textile patch. We describe the steps for fabricating such a textile MEG, including the magnetomechanical coupling (MC) and magnetic induction (MI) layers, and characterizing their magnetoelastic and electrical properties. We then detail procedures for monitoring muscle biomechanical activities and muscle physiotherapy application.

For complete details on the use and execution of this protocol, please refer to Xu et al.[1]

BEFORE YOU BEGIN

In 1865, Emilio Villari, an Italian experimental physicist, discovered the magnetoelastic effect, also known as the Villari effect, in rigid metals and metal alloys with an external magnetic field. It involves changes in a material's magnetic field under mechanical stress. However, this phenomenon has been overlooked in the field of soft bioelectronics for three primary reasons: (1) limited magnetization variation in the biomechanical stress range, (2) structural complexity and bulky structure induced by a required external magnetic field, and (3) a substantial mismatch in mechanical modulus, with up to six orders of magnitude difference between rigid magnetoelastic materials and soft human tissues. In 2021, Prof. Jun Chen's laboratory discovered the giant magnetoelastic effect in a soft materials system,[2] which was subsequently harnessed to create a magnetoelastic generator (MEG) as a fundamentally new platform technology for biomonitoring,[3–7] therapeutics,[8,9] and energy applications.[10–15] Through the synergy between the magnetoelastic effect and electromagnetic induction, MEG has emerged as an important platform technology, offering compelling capabilities for converting mechanical energy into electrical power with an intrinsic waterproof capability. It could even be made into a liquid bioelectronics format.[16,17] Based on that discovery, a textile MEG patch sensor was invented for muscle physiotherapy.[1] Fabrication of a textile magnetoelastic generator patch can be accomplished through a variety of materials for each of the following layers. This protocol uses neodymium-iron-boron micromagnets (NdFeB; MQFP-B-20076-088) and Ecoflex 00-30 part A and Ecoflex 00–30 part B for the magnetoelastic polymer or the magnetomechanical coupling (MC) layer, and 316L stainless steel (641, Adafruit Industries) as conductive yarn or the magnetic induction (MI) layer. Besides the fabrication, testing for the performance of its structure and ensuring its output performance is also important.

STAR Protocols 5, 103289, September 20, 2024

KEY RESOURCES TABLE

REAGENT or RESOURCE	SOURCE	IDENTIFIER
Chemicals, peptides, and recombinant proteins		
Ecoflex 00-30	Smooth-On	MFSOEcoflex30
Neodymium-iron-boron (NdFeB) micromagnets	Neo Magnequench	MQFP-B-20076-088
Software and algorithms		
LabVIEW	National Instruments	https://www.ni.com/en/support/downloads/software-products/download. labview.html#487445
Other		
Transparent medical adhesive patch	Smith and Nephew OPSITE Flexifix wound dressing	SG_B001SIYRO8_US
Sewing machine	Brother	XM2701
Isotemp 60 L oven gravity	Thermo Fisher Scientific	15103053
Scanning electron microscope (SEM)	ZEISS	SUPRA 40VP
Micro-computed tomography (micro-CT)	crumpCAT	Not avaiable
Superconducting quantum interference device (SQUID) magnetometer	Quantum Design	MPMS3
Digital gauss meter	TUNKIA	TD8620
Universal mechanical analyzer	Instron	5564
Low-noise voltage preamplifier	Stanford	SR560
Low-noise current preamplifier	Stanford	SR570
Function generator	Newark	AFG1062
Linear power amplifier	Labworks	PA-151
Electrodynamic transducer	Labworks	ET-126HF
Force meter	HYchuangan	HYPX-017-Z
Handheld force meter	Handeful	B0C6QW5JJN
KCl	Sigma-Aldrich	529552
NaCl	Sigma-Aldrich	746398
Na_2SO_4	Sigma-Aldrich	239313
$NaHCO_3$	Sigma-Aldrich	1613655
$NH_3 \cdot H_2O$	Sigma-Aldrich	05002
Urea	Thermo Scientific Chemicals	036428
Uric acid	Thermo Scientific Chemicals	A13346
1 M lactic acid solution	Thermo Scientific Chemicals	035628

MATERIALS AND EQUIPMENT

Mechanical coupling layer mix of 60 wt %

Reagent	Final concentration	Amount
Ecoflex 00–30 part A	N/A	6 g
Ecoflex 00–30 part B	N/A	6 g
NdFeB micromagnets	N/A	18 g
Total	**N/A**	**30 g**

Mechanical coupling layer mix of 70 wt %

Reagent	Final concentration	Amount
Ecoflex 00–30 part A	N/A	6 g
Ecoflex 00–30 part B	N/A	6 g
NdFeB micromagnets	N/A	28 g
Total	**N/A**	**40 g**

Mechanical coupling layer mix of 80 wt %		
Reagent	Final concentration	Amount
Ecoflex 00–30 part A	N/A	6 g
Ecoflex 00–30 part B	N/A	6 g
NdFeB micromagnets	N/A	48 g
Total	N/A	**60 g**

Artificial perspiration		
Reagent	Final concentration	Amount
KCl	0.455 g/L	0.455 g
NaCl	1.55 g/L	1.55 g
Na_2SO_4	0.0583 g/L	0.0583 g
$NaHCO_3$	0.252 g/L	0.252 g
$NH_3 \cdot H_2O$	0.182 g/L	0.182 g
Urea	0.601 g/L	0.601 g
Uric acid	0.0092 g/L	0.0092 g
1 M Lactic acid solution	0.014 M	1.26 g
Deionized water	N/A	1 L

Calibration electrodynamic system consists of.

- A function generator (AFG1062, Newark).
- A linear power amplifier (PA-151, Labworks).
- An electrodynamic transducer (ET-126HF, Labworks).

STEP-BY-STEP METHOD DETAILS

Fabrication of the MC layer

Timing: 5 h

The first step of creating a magnetoelastic patch is to fabricate the MC layer. This magnetoelastic polymer layer allows for the mechanical-to-magnetic conversion. The second step is to sew the conductive yarn (MI layer) onto the magnetoelastic polymer (MC layer).

1. Prepare a mixture Ecoflex 00–30 part A, Ecoflex 00–30 part B, and NdFeB micromagnets (MQFP-B-20076-088) in concentrations of 60, 70, and 80 wt % (see the tables in materials and equipment).

   Note: A higher concentration of magnetic particles provides more electrical signals, but as a trade-off, would decrease the flexibility of the patch.[2] Xu et al. utilized 70 wt % for developing their textile magnetoelastic generator (MEG) patch.[1]

2. Mix with Ecoflex using a stirring rod for at least 10 min to introduce air bubbles in a one-directional, rotational motion at a speed of 2 rotations per second, producing a porous structure.

   Note: This duration applies to all the micromagnetic concentrations of 60, 70, and 80 wt %.

3. Immediately after stirring, spin-coat the mixture onto a transparent medical adhesive patch (Smith and Nephew OPSITE Flexifix Wound Dressing). The following steps provide instructions for the spin-coating process.
   a. Fix the 3 cm × 3 cm medical adhesive patch on a substrate made out of either glass or plastic.

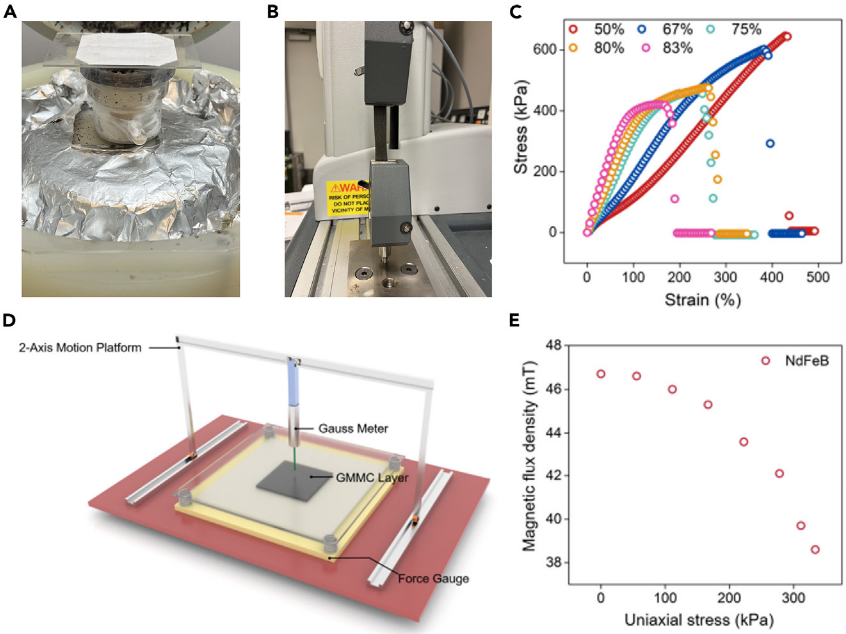


Figure 1. Characterization of the magnetoelastic properties of the textile MEG patch sensor

(A) Photograph of the spin-coater and the medical adhesive patch before applying the MC layer.

(B) Photograph of the universal testing machine employed for stress and strain observation.

(C) Stress-strain curves of the sensor, with varying micromagnet concentrations, reveal noticeable trends. An increase in micromagnet concentration corresponds to the rise in both the magnetic flux density at the north pole's midpoint (from 7.9 to 54.2 mT) and Young's modulus of the soft system (from 177.99 to 692.23 kPa). Conversely, fracture strain decreases from 432.48% to 189.28%. Notably, even at 83 wt %, the soft system maintains mechanical softness similar to that of human skin and tissue, with a surface magnetic flux density of approximately 50 mT.

(D) The experimental setup for measuring magnetic flux density involves recording the vertical component of the magnetic field throughout mapping experiments.

(E) Changes in magnetic flux density under different uniaxial stresses are observed across various soft magnetic systems of the NdFeB material. Figure reprinted with permission from Zhou et al.[2]

⚠ CRITICAL: The glass/plastic should be bigger than the vacuum chuck whose diameter is 4.5 cm to ensure a complete vacuum (Figure 1A).

⚠ CRITICAL: The measurements of the glass should be bigger than those of the medical adhesive patch (3 cm × 3 cm).

  b. Place 1/8 teaspoon of the uncured mixture of MC layer on top of the medical adhesive patch.
  c. Run the spin-coater at 2000 rotations per min for 1–2 min until the MC layer is evenly coated.
4. Cure the combined adhesive MC layer at 70°C in the oven (Thermo Fisher Scientific) for 4 h.
5. After removing the MC layer from the oven, cut the MC layer into a 3 cm × 3 cm square. The MC layer does not need to be cooled down to room temperature before cutting.

Structural characterizations of the MC layer

⏱ Timing: 3 days

To gain comprehensive insights into the micromagnet structure, internal interactions, and the stretchability of the MC layer, the following structural characterizations can be performed.

6. SEM imaging.

  a. Prepare a sample of the MC layer in the size of 3 mm × 3 mm × 3 mm for SEM images (ZEISS Supra 40VP).

7. Micro-CT imaging.
   a. Prepare a sample of the MC layer in the size of 1.6 cm × 1.6 cm × 1.6 cm.
   b. Utilize an in-house micro-CT (crumpCAT) of the MC layer.
   c. Scan at 80 kVp/140 µA with 500 ms exposure.
8. Magnetic hysteresis loop.
   a. Use a SQUID magnetometer (Quantum Design, MPMS3).
   b. Set the scanning range to 3 T with a scan speed of 100 Oe/s.
9. Stress-strain analysis.
   a. Use a universal mechanical analyzer (Instron 5564).
   b. Prepare a sample of the MC layer in the size of 10 cm × 5 cm × 0.5 cm.
   c. Install the two specimen grips onto the tensile testing machine.
   d. Clamp the MC layer vertically between the specimen grips.
   e. Set the loading cell to 1 N.
   f. Adjust the distance between the clamps to allow the sample to be straight but not stretched out.
   g. Measure the distance between the two specimen grips and record it as length on the associated Instron software.
   h. Measure the thickness and width of the sample and record them on the associated Instron software.
   i. Set the tensile loading speed to 5 mm/min.
   j. After the sample breaks, save the data and record the stretchability of the sample. The data should consist of composite strain (mm/mm) on the x-axis and tensile stress (MPa) on the y-axis.
   k. Analyze the results by.
      i. Convert the composite strain into percentages by multiplying 100.
      ii. Convert tensile stress from MPa to kPa (Figure 1C).
10. 2D magnetic flux density mapping.
    a. Mount a digital Gauss meter (TD8620, Tunkia) on a two-axial motion platform (Figure 1D).

Note: The two-axial motion platform, designed in our lab, integrates stepper motors and servo motors to ensure precise control of the probe's movements.

Note: Linear rails and bearings are used to mount the probe. A microcontroller in the system sends signals to the motors, dictating their movements.

Note: This system can be programmed with specific instructions for the probe's path.

   b. Prepare a sample of the MC layer in the size of 3 cm × 3 cm × 2 mm.
   c. The calibration process is as follows.
      i. Turn on the Gauss meter and allow it to warm up.
      ii. Position the sensor probe in the air away from any magnetic fields and reset the meter to zero.
      iii. Use the Gauss meter mapping platform at room temperature to measure the flux density of a blank sample (no sample on the test platform) five times.

Note: Choose a calibration location away from any magnetic materials or equipment that could interfere with the calibration process.

      iv. Use the average value of the measurements of the blank sample as background noise.
   d. Measure and record the real samples using the platform with the same settings (temperature, probe height, mapping speed, etc.) where the probe is programmed to move horizontally from left to right and vertically from up to down, covering a square area of ~ 5 cm × 5 cm.

   e. Subtract the final mapping results of the real sample from the background noise.
11. Magnetic field variation.
   a. Prepare a 3 cm × 3 cm sample of MC layer with various weight percentages.
   b. Use a Gauss meter (TD8620, Tunkia) to record the magnetic field while a force meter (HYPX-017-Z, HYchuangan) applies a force onto the sample (Figure 1D).

Fabrication of the MI layer to complete the textile MEG patch

Timing: 3 h

This section instructs how to develop the MI layer. This layer is used for magnetic-to-electrical conversion.

12. Use an industrial sewing machine or hand stitching.
13. Sew a stainless medium three-ply conductive yarn, made from 316L stainless steel (641, Adafruit Industries), onto the MC layer.
14. Form a square coil of six turns with even spacing.
15. Remove the insulator coat from the two ends of the conductive yarn using a razor.

Note: Exercise caution to avoid inadvertently cutting the tips during this process.

Electrical performance measurement of the textile MEG patch

Timing: 4 days

To test if the textile MEG patch can properly produce high-fidelity electrical signals, the following electrical performance characterization should be performed.

16. Voltage measurement.
   a. Connect the positive and negative ends of the conductive yarn to a Stanford low-noise voltage preamplifier (model SR560).
17. Current measurement.
   a. Connect the positive and negative ends of the conductive yarn to a Stanford low-noise current preamplifier (model SR570).
18. Waterproof and sweatproof capability assessment.
   a. Prepare a sample of artificial perspiration.
   b. Fully submerge the textile patch sensor in any position in a 400 mL beaker for 24 h (Figure 2).
19. Cyclic performance test for durability.
   a. Set the frequency of the calibration electrodynamic system (Figure 3) to 1 Hz.
   b. Measure the output performance using the Stanford low-noise current preamplifier (model SR570) from the negative and positive ends of the magnetoelastic textile patch and let the test run for 100,000 cycles.
   c. Set the three criteria for failure as follows.
      i. The textile MEG patch exhibits noticeable and irreversible damage in its shape and appearance.
      ii. A significant decrease in the device's output performance. Typically, a reduction exceeding 20% in the signal's amplitude, lasting for more than 1 min, will be considered a failure to maintain stable output performance during the cyclic task.
      iii. An obvious mismatch between the device's output signal and the stimulus. The stimulus in the cyclic performance test in this work involves a shaker-induced force with a frequency of 1 Hz. If the frequency of the device's output electrical signal deviates significantly from ~ 1 Hz, it indicates that the output signal is a false signal, and the test has failed.

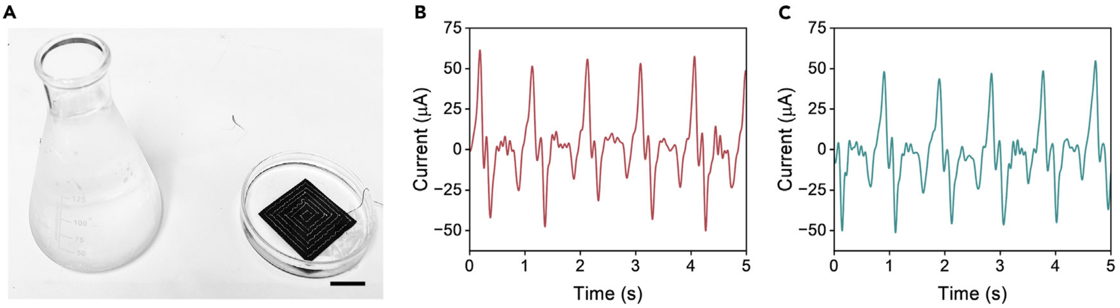


Figure 2. Electrical output of the device in response to perspiration

(A) Photograph of the laboratory-prepared artificial perspiration (left) and submersion of the textile patch sensor in the artificial perspiration for 24 h. Scale bar, 1.5 cm.

(B and C) Comparison of output current recorded by the textile MEG patch (B) before and (C) post-submersion in artificial perspiration. The output current remains similar, showing the device's anti-corrosion capability.

   d. To vary the frequency, set the frequency from 1 Hz to 10 Hz.

20. Response time calculation.
    a. Response time = $T_{\text{peak}} - T_{\text{initial}}$, where T_{peak} and T_{initial} are time points of the collected electrical signal when the signal reaches the peak value and back to the initial value (baseline), respectively.
21. Signal-to-noise ratio (SNR) of various frequencies.
    a. Determine the baseline noise of the current amplifier.
    b. Use the equation SNR = $20\log(A_{\text{Signal}}/A_{\text{Noise}})$, where A_{Signal} and A_{Noise} are the root mean square amplitude of collected signal and noise, respectively.

Monitoring muscle movements

Timing: 3 days

Once the textile MEG patch is examined to provide high-fidelity electrical signals, we proceed to apply the device toward the application of monitoring muscle movements for physiotherapy.

22. Throat movement monitoring.
    a. Place the textile patch on the frontal neck at the throat and begin drinking water consistently for at least 20 s.
    b. Record the associated current output using the textile MEG patch and the Stanford low-noise current preamplifier (model SR570).

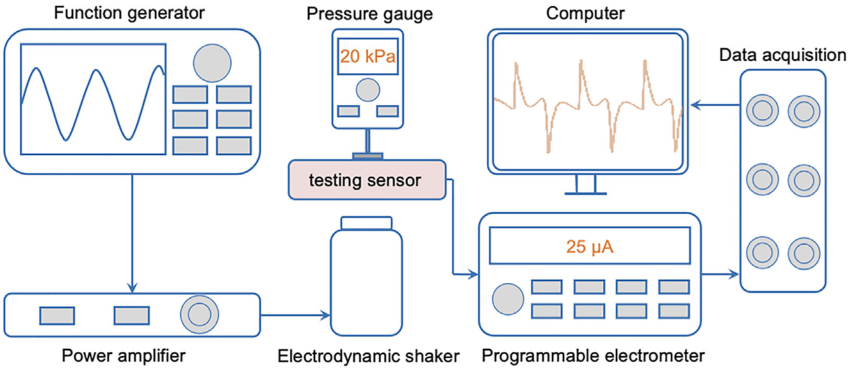


Figure 3. Schematic illustration of the experimental setup for sensing performance characterization

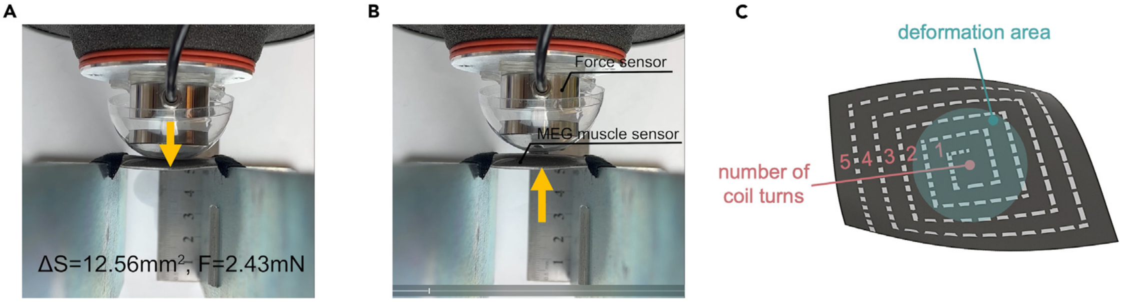


Figure 4. Self-powered monitoring of muscle biomechanical activities

(A and B) Use of an electrodynamic transducer to induce increasing force and surface area on the sensor.

(C) Illustration depicting the structure of coil turns and the area of shaker-induced deformation for standard tests.

23. Wrist pulse monitoring.
    a. Place the textile patch on the inner/flexor wrist and measure the pulse for at least 5 s.
    b. Record the associated current output using the textile MEG patch and the Stanford low-noise current preamplifier (model SR570).
24. Ankle movement monitoring.
    a. While walking at a normal pace (3 mph), place the textile patch at the ankle where the lateral malleolus is located.
    b. Measure walking for at least 15 s.
    c. Record the associated current output using the textile MEG patch and the Stanford low-noise current preamplifier (model SR570).
25. Muscle-induced deformation simulation.
    a. Affix an acrylic hemisphere with a diameter of 3 cm to the front of the force meter to simulate muscle-induced deformation on the textile MEG patch (Figure 4).
    b. Record the associated current output using the Stanford low-noise current preamplifier (model SR570).
26. Arm bending measurement.
    a. Place the textile patch on the biceps to measure the angle from parallel to the ground toward where the lower arm bends up.
    b. Apply a user loading of 10 lbs.
    c. Record the associated current output using the textile MEG patch and the Stanford low-noise current preamplifier (model SR570).
27. Gripping force measurement.
    a. Utilize a commercial handheld force meter (Grip Strength Tester, Handeful Store) in the range of 0–250 N.
    b. Record the associated current output using the textile MEG patch and the Stanford low-noise current preamplifier (model SR570).
28. Quantification of loading deficits and excesses.
    a. Calculate a scoring scale between the setting goal and the training goal using the laboratory-invented equation.
        i. Score = $| P_s - P_m / P_s | \times 100$, where P_s is the standard peak value and P_m is the measured peak value.

EXPECTED OUTCOMES

In this protocol, the primary experimental variable influencing the electrical performance of the textile MEG patch is the fabrication of the MC layer. With an increase in magnetic nanoparticle concentration, the electrical performance improves, albeit at the expense of a decrease in stretchability and flexibility. The MC layer with 70 wt % shows optimal performance. Thorough mixing to evenly distribute the magnetic nanoparticles throughout the Ecoflex is also important to provide consistent outcomes. Repeated measurements, whether on a single sample or multiple samples processed with the identical protocol, should yield similar performance results.

LIMITATIONS

In this protocol, the most important focus resides in the meticulous fabrication of the MC and MI layers. These steps should remain consistent to yield multiple samples of similar performance. Another limitation lies in the inability to test the device in real medical scenarios, particularly in the context of muscle physiotherapy with body biomechanical motions, which may induce motion artifacts and adversely affect measurement accuracy and stability.[18] Despite the current challenges, our endeavors have been directed toward emulating medical applications within the scope of this study.

TROUBLESHOOTING

Problem 1

Due to gravity, the magnetic powder may sediment during the curing process, causing uneven distribution of the inner magnetic particles at different levels.

Potential solution

After mixing Ecoflex with magnetic powder, place the mixture in the oven and preheat it for 5 min. After that, take the preheated mixture out and mix it thoroughly with a stirring rod again to make sure that the magnetic particles are evenly distributed. Then put the mixture back in the oven and finish the rest of the entire curing process.

Problem 2

The MC layer's soft and sticky nature poses challenges in smooth movement and directional control during stitching with the sewing machine.

Potential solution

Coat the conductive yarn with biocompatible materials, like polydimethylsiloxane (PDMS), before sewing it onto the MC layer.

Problem 3

The conductivity of the yarn used as the MI layer in our design may be compromised by water or sweat, affecting the device's durability, and introducing unwanted noise signals.

Potential solution

For optimal performance, when using a laptop, remove the power cord to minimize signal interference. A desktop computer is highly recommended. Also, coat the conductive yarn with biocompatible materials, like PDMS, before sewing it onto the MC layer to safeguard against the influence of moisture on conductivity.

Problem 4

How to collect the signals from the voltage and current amplifiers?

Potential solution

Resources and LabVIEW software to collect the voltage and current signals can be requested by contacting the lead contact personnel.

RESOURCE AVAILABILITY

Lead contact

Further information and requests for resources and reagents should be directed to and will be fulfilled by the lead contact, Jun Chen (jun.chen@ucla.edu).

Technical contact

Questions about the technical specifics of performing the protocol should be directed to and will be answered by the technical contact, Jun Chen (jun.chen@ucla.edu).

Materials availability

This study did not generate any new unique reagents.

Data and code availability

The code supporting the current study has not been deposited in a public repository because they are a part of another ongoing research but are available from the corresponding author on request.

ACKNOWLEDGMENTS

The authors acknowledge the Henry Samueli School of Engineering and Applied Science and the Department of Bioengineering at the University of California, Los Angeles, for their startup support. J.C. acknowledges the Vernroy Makoto Watanabe Excellence in Research Award at the UCLA Samueli School of Engineering, the Office of Naval Research Young Investigator Award (award ID: N00014-24-1-2065), an NIH grant (award ID: R01 CA287326), the American Heart Association Innovative Project Award (award ID: 23IPA1054908), the American Heart Association Transformational Project Award (award ID: 23TPA1141360), the American Heart Association's Second Century Early Faculty Independence Award (award ID: 23SCEFIA1157587), the Brain & Behavior Research Foundation Young Investigator Grant (grant number: 30944), and the NIH National Center for Advancing Translational Science UCLA CTSI (grant number: KL2TR001882). J.C. and T.T. acknowledge the support from Caltech/UCLA joint NIH T32 Training Grant (award ID T32EB027629). The graphical abstract was created using Biorender.com.

AUTHOR CONTRIBUTIONS

J.C. conceived and supervised the project. T.T. and J.X. designed and performed all the experiments.

DECLARATION OF INTERESTS

The authors declare no competing interests.

REFERENCES

1. Xu, J., Tat, T., Yin, J., Ngo, D., Zhao, X., Wan, X., Che, Z., Chen, K., Harris, L., and Chen, J. (2023). A textile magnetoelastic patch for self-powered personalized muscle physiotherapy. Matter *6*, 2235–2247. https://doi.org/10.1016/j.matt.2023.06.008.
2. Zhou, Y., Zhao, X., Xu, J., Fang, Y., Chen, G., Song, Y., Li, S., and Chen, J. (2021). Giant magnetoelastic effect in soft systems for bioelectronics. Nat. Mater. *20*, 1670–1676. https://doi.org/10.1038/s41563-021-01093-1.
3. Zhao, X., Zhou, Y., Xu, J., Chen, G., Fang, Y., Tat, T., Xiao, X., Song, Y., Li, S., and Chen, J. (2021). Soft fibers with magnetoelasticity for wearable electronics. Nat. Commun. *12*, 6755.
4. Chen, G., Zhao, X., Andalib, S., Xu, J., Zhou, Y., Tat, T., Lin, K., and Chen, J. (2021). Discovering giant magnetoelasticity in soft matter for electronic textiles. Matter *4*, 3725–3740. https://doi.org/10.1016/j.matt.2021.09.012.
5. Zhao, X., Chen, G., Zhou, Y., Nashalian, A., Xu, J., Tat, T., Song, Y., Libanori, A., Xu, S., Li, S., and Chen, J. (2022). Giant magnetoelastic effect enabled stretchable sensor for self-powered biomonitoring. ACS Nano *16*, 6013–6022.
6. Zhou, Y., Zhao, X., Xu, J., Chen, G., Tat, T., Li, J., and Chen, J. (2024). A multimodal magnetoelastic artificial skin for underwater haptic sensing. Sci. Adv. *10*, eadj8567.
7. Xu, J., Tat, T., Zhao, X., Zhou, Y., Ngo, D., Xiao, X., and Chen, J. (2022). A programable magnetoelastic sensor array for self-powered human-machine interface. Appl. Phys. Rev. *9*, 031404.
8. Che, Z., Wan, X., Xu, J., Duan, C., Zheng, T., and Chen, J. (2024). Speaking without vocal folds using machine-learning-assisted wearable sensing-actuation system. Nat. Commun. *15*, 1873.
9. Libanori, A., Soto, J., Xu, J., Song, Y., Zarubova, J., Tat, T., Xiao, X., Yue, S.Z., Jonas, S.J., Li, S., and Chen, J. (2023). Self-powered programming of fibroblasts into neurons via a scalable magnetoelastic generator array. Adv. Mater. *35*, 2206933.
10. Chen, G., Zhou, Y., Fang, Y., Zhao, X., Shen, S., Tat, T., Nashalian, A., and Chen, J. (2021). Wearable ultrahigh current power source based on giant magnetoelastic effect in soft elastomer system. ACS Nano *15*, 20582–20589.
11. Zhao, X., Nashalian, A., Ock, I.W., Popoli, S., Xu, J., Yin, J., Tat, T., Libanori, A., Chen, G., Zhou, Y., and Chen, J. (2022). A Soft Magnetoelastic Generator for Wind Energy Harvesting. Adv. Mater. *34*, 2204238.
12. Ock, I.W., Zhao, X., Tat, T., Xu, J., and Chen, J. (2022). Harvesting hydropower via a magnetoelastic generator for sustainable water splitting. ACS Nano *16*, 16816–16823.
13. Xu, J., Tat, T., Zhao, X., Xiao, X., Zhou, Y., Yin, J., Chen, K., and Chen, J. (2023). Spherical magnetoelastic generator for multidirectional vibration energy harvesting. ACS Nano *17*, 3865–3872.
14. Ock, I.W., Zhao, X., Wan, X., Zhou, Y., Chen, G., and Chen, J. (2023). Boost the voltage of a magnetoelastic generator via tuning the magnetic induction layer resistance. Nano Energy *109*, 108298.
15. Ock, I.W., Zhou, Y., Zhao, X., Manshaii, F., and Chen, J. (2024). Harvesting ocean wave energy via magnetoelastic generators for self-powered hydrogen production. ACS Energy Lett. *9*, 1701–1709.
16. Zhao, X., Zhou, Y., Song, Y., Xu, J., Li, J., Tat, T., Chen, G., Li, S., and Chen, J. (2024). Permanent fluidic magnets for liquid bioelectronics. Nat. Mater. *23*, 703–710.
17. Zhao, X., Zhou, Y., Li, A., Xu, J., Karjagi, S., Hahm, E., Rulloda, L., Li, J., Hollister, J., Kavehpour, P., and Chen, J. (2024;). A self-filtering liquid acoustic sensor for voice recognition. Nat. Electron. https://doi.org/10.1038/s41928-024-01196-y.
18. Yin, J., Wang, S., Tat, T., and Chen, J. (2024). Motion artefact management for soft bioelectronics. Nat. Rev. Bioeng. *2*, 541–558.