

Lactate Threshold Monitoring with Wearable Graphene Sensor for Endurance Training

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Keywords: graphene, lactate threshold, wearable sensor

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INTRODUCTION

Lactate threshold, a critical indicator of endurance performance, is monitored during exercise to optimize training for athletes. Current lactate threshold monitoring method relies on invasive, discreet finger-prick blood test. One promising next-generation method that enables noninvasive, continuous monitoring is based on sweat lactate detection with on-skin sensor. The sensor performance is highly dependent on the electrode material. Graphene has proved to be a superior electrode for biosensors. Nevertheless, on-skin graphene sensors have only been developed for electrophysiological measurements (i.e., electrocardiogram, electroencephalogram, and electromyogram). In this project, we developed a graphene-based wearable sensor for continuous monitoring of sweat lactate profile, permitting accurate determination of the lactate threshold for optimal endurance training.

METHODS

Graphene grown on a copper foil was transferred to a tattoo paper by means of lamination (dry transfer using a commercial laminator; Fig. 1). The transferred graphene was drop-coated with 1-pyrenebutanoic acid succinimidyl ester and then lactate oxidase (Fig. 1). The lactate oxidase-functionalized graphene, bare graphene, and silver–silver chloride were applied to the upper arm, serving as the working, counter, and reference electrodes, respectively (Fig. 2). Electrochemical measurement (amperometry; +0.565 V was applied to the working electrode) was carried out with EmStat3 Blue potentiostat during cycling on a stationary bike (Fig. 2).

RESULTS AND DISCUSSION

Graphene was successfully dry-transferred to tattoo paper, which is much simpler, faster, and cheaper than the common wet transfer through solution-phase copper etching. Fig. 3 shows the current–time plot of the on-skin sensor during cycling. During the initial warm-up period (low cycling resistance and speed), the current signal remained stable at ~0.13 μ A. Shortly after increasing the cycling resistance and speed at 8 min, the current signal increased sharply, indicating the lactate threshold

(transition from aerobic to anaerobic exercise; above which muscle fatigue occurs). Two finger-prick blood lactate tests were performed during cycling (2.8 mM at the warm-up stage and 13.7 mM at the current-increase stage) to validate the accuracy of the graphene sensor. The results confirmed that the developed sensor is readily applicable to lactate threshold monitoring for endurance training.

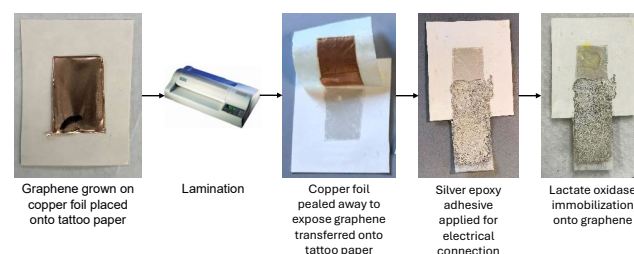


Fig. 1 – Fabrication process of the graphene electrode with lactate oxidase.

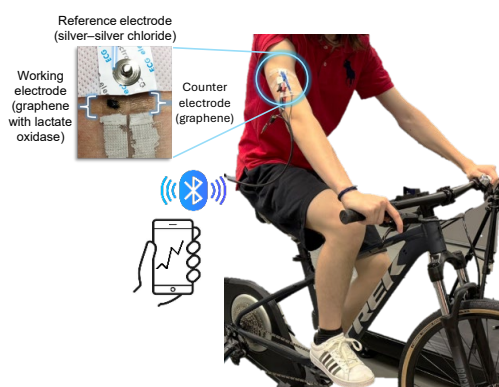


Fig. 2 – Experimental setup for lactate threshold monitoring during cycling with the wearable graphene sensor.

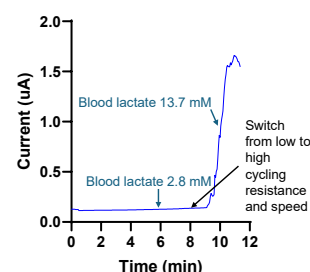


Fig. 3 – Current–time plot of the wearable graphene sensor during cycling.

ACKNOWLEDGEMENT

This project was funded by the Research Institute for Sports Science and Technology (RISports) at PolyU (project number: P0043690).