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Development of Three-dimensional Cultured Skeletal Muscle Tissue and Its Application

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Abstract: Bio-hybrid robots embedded with three-dimensional cultured skeletal muscle tissue as an actuator have been developed. Three-dimensional cultured skeletal muscle tissue is composed of muscle cells and extracellular matrices. Animal skeletal muscle tissue is a set of uniformly oriented fibers formed by myoblast through proliferation and differentiation. For engineering of three-dimensional cultured skeletal muscle tissue, we care about cell orientation. Our previous study showed that our fabrication method (geometric constraints) could induce the orientation of muscle fibers. The quality of a three-dimensional cultured skeletal muscle tissue as an actuator is determined by its contraction force. Thus, in this study, we characterized our three-dimensional muscle tissue by measuring contraction force for robot application. Furthermore, we developed a 1-DOF robotic arm embedded with our three-dimensional muscle tissue. We applied electrical stimulation based on the functional analysis and observed that the robotic arm could be driven by our three-dimensional muscle tissue.

Keywords: Bio-hybrid robot, Artificial muscle, Three-dimensional cultured skeletal muscle tissue, Tissue engineering

1. INTRODUCTION

For human-robot symbiosis, robots need to be made of soft materials. Conventional rigid robots can perform with high speed and precisely under a certain environment, but they stop their manipulation when an accident occurs. On the other hand, living organisms can flexibly respond to changes in the environment. The development of robots using the cells that make up living organisms is expected not only to be soft, but also to get environmental adaptability. Therefore, bio-hybrid robots incorporating muscle cells as actuators have been developed [1]. Although several types of animal muscle cells exist, cardiac muscle and skeletal muscle have been mainly used. For cardiac muscle, they are arranged in a two-dimensional sheet form [2], [3]. For skeletal muscle, myocytes are mixed with extracellular matrix and cultured in three dimensions (three-dimensional cultured skeletal muscle tissue) and used [4], [5].

Animal skeletal muscle tissue is a set of uniformly oriented muscle fibres formed by myoblast through proliferation and differentiation [6]. Induction of cell orientation is an important issue in the construction of three-dimensional cultured skeletal muscle tissue. In our previous work, we showed that a fabrication method combining a mold and a petri dish with pins, geometric constraints, could determine the shape of three-dimensional cultured skeletal muscle tissue and induce orientation of muscle cells [7].

The quality of a three-dimensional cultured skeletal muscle tissue as an actuator is determined by its contraction force, which is an indicator of how forcefully it can pull objects. However, our previous study only analysed orientation of muscle cell and did not measure contraction force. In addition, it is necessary to understand the characteristics of a actuator for robot application. Animal skeletal muscles and conventional three-dimensional cultured skeletal muscle tissue are known to contract in response to external stimuli (e.g., neural transmission and electrical stimulation). Thus, we analysed contraction force of our three-dimensional cultured skeletal muscle tissue and developed a robot application.

2. METHODS AND RESULTS

Fig. 1 denotes the experimental flow of our study. First, we evaluated the performance of three-dimensional cultured skeletal muscle tissue by measuring contraction force. Next, we developed a 1-DOF robotic driven by our three-dimensional muscle tissue.

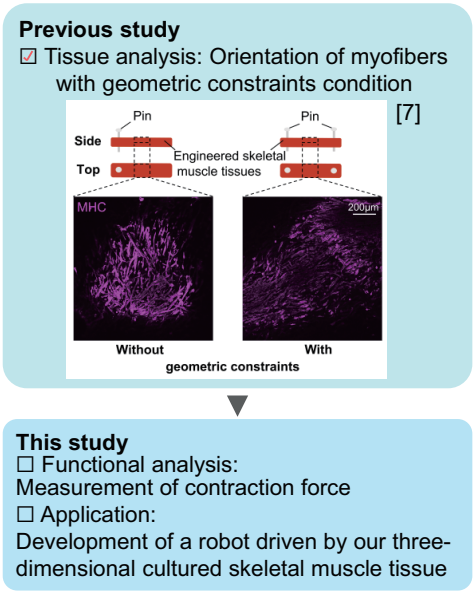

Fig. 1. Experimental flow in our study

† Hirono Ohashi is the presenter of this paper.

2.1. Measurement and analysis of contraction force

Contraction of our three-dimensional cultured skeletal muscle tissue (Fig. 2a) was induced by electrical stimulation. To measure contraction force, a micro force sensor (AE801, Kronex, CA, USA) was used. Electrical stimulation was given at different voltages (2–30 V), duration times (10–500 ms), and frequencies (1–8 Hz). As a result, we found that the contraction force in a voltage- and duration time-dependent manner. Higher contraction force was observed with 1 Hz electrical stimulation. The contraction force was comparable to that of three-dimensional cultured skeletal muscle tissue used in biohybrid robots.

2.2. Development of robot application driven by three-dimensional cultured skeletal muscle tissue

Next, we tried to develop a 1-DOF robotic arm driven by our three-dimensional cultured skeletal muscle tissue. Our culture method requires attaching the muscle to the robot after culturing. This causes problems such as losing the tissues when they are mounted on the robot and damaging them, thereby impairing their function as actuators. Therefore, we developed a culturing method of the tissue while it is attached to robot a part (Fig. 2b). Robot experiments were conducted under electrical stimulation conditions in which the most contraction force was obtained from the muscle tissue only and showed that the 1-DOF robotic arm was driven by muscle contraction.

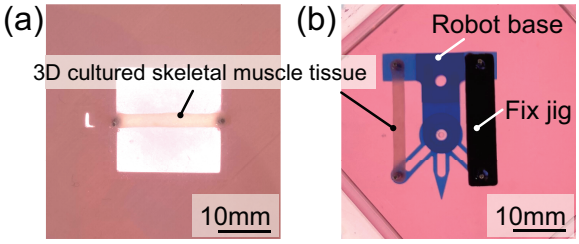

Fig. 2. (a) Our three-dimensional cultured skeletal muscle tissue. (b) A 1-DOF robotic arm driven by our three-dimensional cultured skeletal muscle tissue.

3. CONCLUSION

The aim of this study was the characterization of three-dimensional cultured skeletal muscle tissue for robotic applications. Characterization showed that contractile force increased in a voltage- and duration-dependent manner. When electrical stimulation was applied based on the muscle characteristics, the 1-DOF robotic arm was driven by our muscle tissue.

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