TISSUE ENGINEERING
Volume 11, Number 5/6, 2005

Commentary

In Vitro-Cultured Meat Production

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INTRODUCTION

ALTHOUGH MEAT has enjoyed sustained popularity as a foodstuff, consumers have expressed growing concern over some consequences of meat consumption and production. These include nutrition-related diseases, foodborne illnesses, resource use and pollution, and use of farm animals. Here we review the possibility of producing edible animal muscle (i.e., meat) *in vitro*, using tissue-engineering techniques. Such "cultured meat" could enjoy some health and environmental advantages over conventional meat, and the techniques required to produce it are not beyond imagination. To tissue engineers this subject is of interest as cultured meat production is an application of tissue-engineering principles whose technical challenges may be less formidable than those facing many clinical applications.

CULTURED MEAT PRODUCTION

Most edible animal meat is made of skeletal muscle tissue. The idea that skeletal muscle tissue-engineering techniques could be applied to produce edible meat dates back at least 70 years,[1] but has been seriously pursued by only three groups of researchers. Their efforts can be divided roughly into scaffold-based and self-organizing techniques.

In scaffold-based techniques, embryonic myoblasts or adult skeletal muscle satellite cells are proliferated, attached to a scaffold or carrier such as a collagen mesh-work or microcarrier beads, and then perfused with a culture medium in a stationary or rotating bioreactor. By introducing a variety of environmental cues, these cells fuse into myotubes, which can then differentiate into myofibers.[2] The resulting myofibers may then be harvested, cooked, and consumed as meat. van Eelen, van Kooten, and Westerhof hold a Dutch patent for this general approach to producing cultured meat.[3] However, Catts and Zurr appear to have been the first to have actually produced meat by this method.[4]

A scaffold-based technique may be appropriate for producing processed (ground, boneless) meats, such as hamburger or sausage. But it is not suitable for producing highly structured meats, such as steaks. To produce these, one would need a more ambitious approach, creating structured muscle tissue as self-organizing constructs[5] or proliferating existing muscle tissue *in vitro*.

The latter technique was employed by Benjaminson, Gilchriest, and Lorenz, the first researchers to have applied tissue-engineering techniques to meat production.[6] They placed skeletal muscle explants from goldfish (*Carassius auratus*) in diverse culture media for 7 days and observed an increase in surface area between 5.2 and 13.8%. When the explants were placed in a culture containing dissociated *Carassius* skeletal muscle cells, explant surface area increased by 79%.

Explants have the advantage of containing all the cells that make up muscle in their corresponding proportions, thus closely mimicking an *in vivo* structure. However, lack of blood circulation in these explants makes substantial growth impossible, as cells become necrotic if

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