Computer-Aided Tissue Engineering of a Human Vertebral Body

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"Tissue engineering aims to restore tissue function through the incorporation of biological materials such as cells, growth factors, and biopolymers. This approach is atypical of current reparative treatments, which focus mainly on drugs that encourage the body to battle disease on its own or to replace a damaged area using grafting."

- M.A. Wettergreen, B.S. Bucklen, W. Sun, M.A.K. Liebschner (1333).

The vertebrae are the bones that make up the vertebral column. The purpose of the spinal cord is to: support the spinal cord, nerves, and internal organs; provide a base for attachment for ligaments, tendons, and muscles; provide structural support for the body; aid in flexibility and mobility, including flexion, extension, lateral bending, and rotation. Current spinal fixation devices have limited longevity and joint function. Vertebrae are subject to many stresses and the demand for a design that can withstand these stresses can be achieved using computer-aided tissue engineering (CATE).

"The three important concepts encompassing the use of CATE are tissue modeling, tissue informatics, and scaffold design and manufacturing. The first step of the process involves obtaining a three-dimensional (3D) model of the tissue, either by extraction from imaging modalities or with CAD generation of a tissue model. Tissue informatics concerns characterizing native tissue properties using the tissue model or through the use of finite element models or assays that characterize the biochemical environment, such as gene analysis or microarrays. However, tissue informatics in its broadest definition defines compiling information about each tissue from organ to subcellular level but is most specifically referred to when analyzing the type and interaction of genes and proteins within tissues. The final step in the process is the design of a scaffold based on both the required location and the treatment type. Interplay between the three disciplines may yield a functional scaffold without ever breaking the skin before surgery." (1333-1334)

There are many steps to accomplish the manufacturing of a replacement for a vertebral body (VB). First is the generation of bone geometry. This is most efficiently completed using Dual Energy X-Ray Absorptiometry (DEXA) or Quantitative Computed Tomography (QCT). The benefits of using these methods is that they are non invasive and can obtain valuable information, such as intertrabecular distance. The next step is to estimate the material properties of the bone. QCT is successful in measuring bone mineral density. Computer programs are used to extract raw CT data and translate it into a model. Reconstruction projects the data into a 3D model; segmentation generates surface geometry information; volume creation determines density and porosity. Building blocks are then designed using the 3D models. The goal is to create a library of building blocks each with different properties to mimic a particular density and porosity of bone. The blocks can be used to assemble a 3D model of the vertebrae. The goal is to optimize the materials to display ideal biological and mechanical properties.

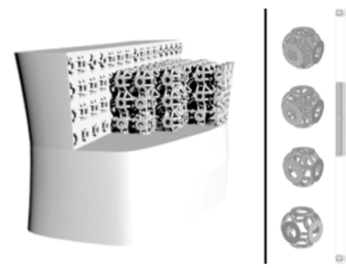

FIGURE 4. Using a library of building blocks to generate a global shape. The library at the right can be used in any location that is required to approximate the material demands of the vertebral body. The global shape approximates a vertebral body following the assignment of the building blocks to their respective locations.

Using Fused Deposition Modeling (FDM), a printhead deposits thermoplastic material in a 2D pattern. This pattern is a slice of the final model. Material selection is key to a successful transplant. Titanium products have been shown to have unexpected surface oxide reactions and preparation of biodegradable polymers involves toxic solvents that leave residue on the construct. Composites are a solution, since no one material possesses all the ideal properties.

In summary, the process to successful tissue engineering of a vertebral body is: CT Scan of patient, image reconstruction and material evaluation, arrangement of building blocks, rapid prototyping of mold, investment casting of mold with biomaterial, surgical implantation and integration with native tissue.

References:

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