Design of a Device for Measuring Bulk Fluid Flow in Spine Segments under Tensile Loads

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Introduction: Intervertebral discs are avascular, and as such they have to rely on diffusion and fluid transport to receive nutrients. The mechanics of fluid movement in intervertebral discs and functional spinal units (FSU), which are comprised of an intervertebral disc with its neighboring vertebrae still attached, has been studied extensively under compressive loads because of its relevance to in vivo loading conditions. Fluid motion in an FSU under tensile loads also has relevance, but not been studied partially due to the difficulty of applying a tensile load on a FSU. A device has been designed that will allow for a 20 lbs tensile load on an FSU while submerged in an isotonic solution. This device is also MRI compatible. This device addresses the problem of generating tensile loads on the spinal unit, while allowing for in vivo conditions and real-time imaging of the FSU using advanced MRI techniques such as diffusion tensor imaging, UTE imaging, and sodium imaging.

Materials and Methods: Information from preliminary work showed that bulk fluid transport occurs in the first few seconds after the loading or unloading of the spine. Thus, an important design consideration was capability for real-time measurement of fluid movement during load application. To offset the well-known swelling behavior of disc tissue, the design also needed to keep the FSU immersed in an isotonic solution. In order to facilitate MRI compatibility, control of the device needed to operate remotely (e.g., from a nearby MRI control room), be comprised of non-magnetic components, and incorporate an FSU mounting paradigm that minimized imaging artifacts. A structured design process was followed to develop a device that met these requirements, while simultaneously allowing maximum freedom of load magnitude, FSU size, and testing configuration.

The device consists of two cylinders. The inner cylinder is used for the pneumatic control and the external cylinder contains the isotonic solution and the FSU mounting fixtures. A piston is used to transmit the load from the small chamber to the FSU. For non-MRI testing applications, the fluid motion is measured using a graduated tube and a video recording. This allows record both the instantaneous change of volume from the application of the load and measure the movement of fluid into and out of the disc. The device has also been designed to be used in an MRI, allowing for advanced 3D measurement of fluid transport throughout the FSU.

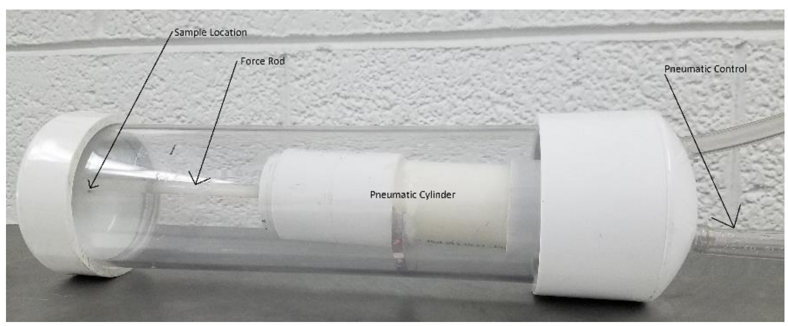

Figure 1 Image of Device

Discussion:
A pneumatic control system was chosen because it could be controlled from a distance. This was key because in order capture the fluid motion in the FSU, the device would have to be within the MRI while applying the load. It was also decided that the MRI data would be compared to volumetric measurements of the fluid motion.
To use the device, both vertebrae of the FSU are potted in resin. One end of the resin is secured to the cap of the cylinder, and the opposing ends attached to the piston rod. The piston was designed with a hose barb to allow the pressure on either side to be controlled, allowing both tensile and compressive loads to be placed on the FSU.

Conclusion: This device provides a novel method for mechanically testing FSU's under tensile loading, while simultaneously leveraging advanced MRI techniques. In so doing it opens the way to fully understanding how intervertebral discs receive nutrients and how we can optimize their nutrient flow. This device and the understanding of the fluid movement in intervertebral discs allow for the research into spinal therapies to help prevent and possibly reverse disc degeneration.

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