Lumbar arthrodesis or spinal fusion is usually performed to relieve back pain and regain functionality from degenerative disc disease, trauma, etc. Fusion is determined from answers to pain survey questions by patients, radiographic images (X-ray), computed tomography (CT) scans or magnetic resonant imaging (MRI), yet, all inspection methods are subjective methods of review.

Kanayama et al. observed that spinal rods fixated by the pedicle screws show a reduction of bending strain as the fusion mass developed. In addition histological and radiographic evaluations did not indicate complete maturation of the fusion mass even though mechanical data demonstrated that the bony union had achieved sufficient biomechanical integrity (Kanayama et al., 1997). Therefore, a progressive transfer of loading from the rods to the spine during the fusion process will result in a decrease in rod bending strain. An implantable monitoring system, which measures bending strain, would assist orthopaedic surgeons with the assessment of lumbar arthrodesis. A discontinuous change in bending strain could reveal either non-fusion or possible failure of the rods or pedicle screws. This data could diminish/eliminate costly exploratory surgeries where fusion is in question due to current subjective methods of review.

One important component of implantable monitoring system is a housing that will encase the strain sensor and telemetric components. The housing for the telemetric system has been developed with the prescribed conditions of long-term implantation, small size, 100% or more transfer of bending strain from the spinal rods to an internal strain sensor and ease of installation without the use of adhesives. To aid with design and development, Finite Element Analysis (FEA) using ABAQUS modeling software was employed. Metallic materials were not considered since they would interfere with the telemetric components contained within the housing. Ceramics were also not deliberated due to difficulty of manufacture and attachment. Polyamides with a high modulus of elasticity and injection molded ability reduced the choice to a polymer with isotropic elastic properties of 0.4 for Poisson’s ratio and 4.09 GPa for Young’s modulus. A form of Polyetheretherketone (PEEK) named PEEK-Optima by Invibio was selected for its long term implantability.

A corpectomy model was used to simulate spinal loading and load application was modeled in ABAQUS software. Bending stress (σ) and strain (ε) are noted by the flexural formulae, σ = Mc/I, and, ε = Mc/EI, where M is the calculated moment, c is the distance from the surface of the rod to the neutral axis, I is the moment of inertia and E is Young’s modulus. Axial stress is defined as σ = P/A, where P is the applied vertical load due to body weight as seen in figure 1, and A is the cross-sectional area of the rod.

Calculations of bending strain and axial strain show that more than 90% of total strain developed is attributed to bending strain. Confirmation of these calculations is supported by Gibson. A corpectomy procedure was performed on an excised spine and supported the calculated results (Gibson, 2002).

The housing design was modeled using ABAQUS/CAE FEA modeling software version 6.3-1. Figure 2 shows the design conceived during the modeling process.

The housing is attached to the spinal fusion rod with the Atlas Cable System manufactured by Medtronic Sofamor Danek. The objective of the FEA model was to design a housing that would transfer 100% or more strain from the rod surface to the sensor surface of the housing. Figure 3 from the ABAQUS model shows a uniform magnitude of strain on the rod surface. Fluctuations in strain are noticed across the housing sensor surface, but the values are similar and amplified compared to the rod surface.

Once satisfactory results were obtained with the finite element model, the housing was fabricated from virgin PEEK material. To facilitate ease of installation the housing was manufactured as one piece with a large side opening to allow sufficient room for the spherical bearings of the Atlas cable system. To simulate a continuous strain across the rod surface between the two pedicle screws four point bending was arranged in a Materials Testing Machine (MTS 810). Figure 4 shows that the housing strain is slightly larger in magnitude than the rod strain and does mimic the rod strain with a small amount of amplification. Exponential decay of the strain signals at the beginning of the graph data are due to strain hardening.

Dynamic testing results from figure 4 confirmed the performance of the housing to transfer strain to its components and affirmed the FEA modeling results.


Gibson, H. Spinal Fusion Rod Strain Measurement and Prediction by FEA. Department of Mechanical Engineering, Speed School of Engineering, University of Louisville. May. 2002.