Introduction: Focal cartilage defects can lead to progressive joint degeneration and osteoarthritis. Current repair procedures have had limited success in treating these cartilage defects. Cartilage-engineering techniques that utilize bioresorbable scaffolds to support the newly generated tissues have shown promise in resurfacing damaged joints. Scaffolds provide a structure to incorporate materials that encourage both bone and cartilage growth. Strain gauge sensors can be attached to scaffolds (creating a sensate scaffold) to measure deformation and subsequently derive joint pressures, which can be used to determine biological triggers that affect cartilage cell maintenance and matrix proliferation. The purpose of this study was to utilize scaffolds with sensors to determine the joint pressures and to assess the influence of the scaffold on pressures in the canine femoral condyle both on the bench top and in vivo.

Methods: Three strain gauges were attached around the circumference of 8 mm (radius) cylindrical PBT porous scaffolds. Gauges were calibrated and tested at various alignments to determine reproducibility of strain gauge measurements. Both hind limbs of nine large hound dogs (29-35Kg) were removed and mounted on an MTS leaving the capsules and soft tissues in the region of the joint intact. Low pressure, high sensitivity Fuji film was placed into both medial and lateral compartments of the menisco-femoral joint and loaded to 100 N at 30°, 50° and 70° flexions simulating paw strike, stance and toe off during gait at a rate of 200 N/s. Scaffolds were surgically implanted into the medial condyles of each femur on the bench top. Fuji film placement, loading and impression analysis was repeated before and after scaffold implantation to determine the biomechanical influence of the implanted scaffold.

Six tall male hounds weighing between 29 and 35 Kg were selected for implantation surgery. The NIH Guide-lines for animal care and use were observed during animal experiments. Following preparation of one hind limb of each of six hounds, an incision was made exposing the bones were dehydrated, embedded and sectioned using a published in vivo monitoring, bones were explanted and loaded using an MTS bench top loading system. Finally, bones were dehydrated, embedded and sectioned using a published undecalcified tissue-embedding technique. Histomorphometry was used to assess bone growth.

Results: Strain vs. load curves for gauged scaffolds were consistently linear throughout the range of loads applied during the calibration process. Similar peak contact surface pressures, measured using pressure sensitive film, were obtained before and after scaffold placement (Table 1). Strain measurements of both cyclic and sustained loads were acquired from all strain-gauged scaffolds at loads as small as 2.5 N. At a peak joint load of 142.84 N to the femur, loads of 37.399 ± 3.5 N passed through the sensate scaffold.

In vivo strain patterns were similar to patterns collected directly from strain gauges attached to the mid-diaphysis of the femora of dogs during earlier in vivo studies. Each gait cycle contained a low strain swing phase that was assigned the zero strain value and peak strains during the strike and toe-off phase (Figure 1). Loads converted using strain calibration curves indicated peak loads ranging from 80 to 120 N during gait representing approximately 35% of the dog’s body weight. During two-legged stance, peak loads increased by 250%. All scaffolds were securely fixed by bone in-growth with no visible adverse reaction to the scaffold material.

Discussion: Fuji film studies indicated that scaffolds caused only small changes in joint surface pressure. The reliability and reproducibility of the bench top strain gauge measurements indicates that these scaffolds could be used in vivo to detect real-time joint loading. Real-time monitoring of joint loading will provide important clinical diagnostic information such as a complete joint loading history during the post surgery period by detecting joint loads that are damaging to both healthy and tissue-engineered cartilage. Additionally these scaffolds have the potential to add fundamental insights into the native environment of cartilage. This will significantly aid physicians in determining appropriate rehabilitation therapies and will be paramount in the development of a functional engineered cartilage tissue.

Load measurements collected from strain gauged scaffolds were in general agreement with visual observations that dogs loaded at most 2 legs (one front and one back) simultaneously during gait at this speed. Results were also in agreement with evidence showing that, during stance, 40% of the dog’s body weight is carried on the hind limbs. Telemetry was noted to function well when the exciting coil was accurately aligned with the subcutaneous transmitter but stopped transmitting when the power coil was slightly misaligned. Monitoring of telemetry output over a period of several days provided a consistent output suggesting that this system could be used over an extended period even though fluid infiltration was likely to incapacitate the system eventually.

Ongoing studies using cartilage covered “sensate” scaffolds are evaluating the effect of a tissue engineered cartilage layer. Development of better waterproofing coatings for connections between gauges and lead wires, and between lead wires and transmitters is expected to increase the length of time that these systems are able to provide measurements.

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