Development of a New Synthetic Vertebral Cancellous Bone

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Statement of Purpose: Current mechanical models of human cancellous bone typically employ closed-cell rigid polyurethane foam. It has been shown that closed-cell foams have different dynamic failure mechanisms than open-celled foams; they also can't be used to study the effects of cement intrusion on implant fixation. Most current research requiring an open-celled structure utilizes aluminum foams (e.g., M-Pore, Germany). This foam offers an acceptable modulus of elasticity; however the compressive strength and ductility of the foam are not sufficiently representative of human bone. This report covers the development of open-celled foam to mimic vertebral cancellous bone. This foam will be implemented in the Analogue Spine Model (in current development by the co-authors) to provide a realistic vertebral body and failure mechanism for implants.

Methods: Compression tests (n=5) were conducted on four types of 14 ppi open-celled foam manufactured by Pacific Research Laboratories (Vashon Island, WA) and the current industry standard (aluminum foam, M-Pore, Germany) according to ASTM D1621-04a. Specimen volume and mass were recorded to calculate apparent foam density. Specimen ends were potted in 3 mm of Bondo. Specimens were tested in an MTS Mini Bionix (MTS, Eden Prairie, MN). After conditioning the specimens were compressively loaded to failure while recording the axial load and displacement. Following testing, specimen modulus of elasticity, and compressive strength were calculated.

Foam theory was then utilized to expedite foam development (Gibson and Ashby 1988). The four solid materials used to create the foam specimens and six additional materials were tested in four-point bending to determine materials parameters to be used in Foam Theory. Four-point bend tests were conducted according to ASTM D6272-02. Specimen volume and mass were recorded to calculate solid material density. Axial load and platen displacement were recorded and used to calculate modulus of elasticity and ultimate strength.

According to Foam Theory, the modulus of elasticity and compressive strength of human cancellous bone are functions of their relative density, and fall into a predictive envelope. The information obtained from the Four-Point Bend tests was used to generate the predictive envelopes for each type of foam, and compared to the experimental foam results to assess the validity of Foam Theory (figure 1). Finally, observations on the 6 additional specimens were made to determine which should be used to create the next generation of foams.

Results: After the initial foam testing, the modulus of elasticity and relative density of foams A and B were deemed adequate, but the compressive strength of all experimental foams were significantly lower than required. Foam B proved to be most similar to the aluminum foam. This foam also possessed increased ductility at yield, a drawback to using aluminum foam.

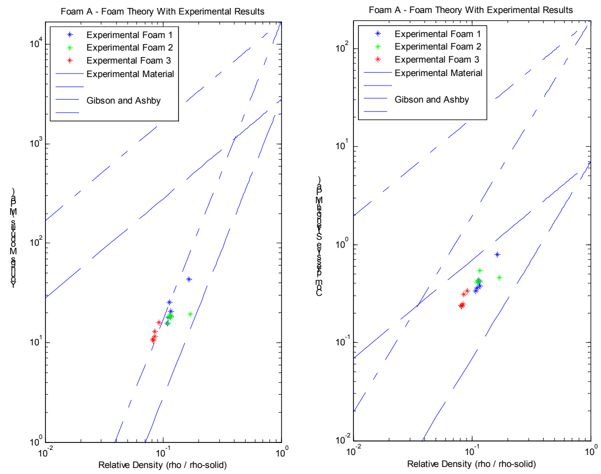

Figure 1: Predictive Envelopes with Experimental Results

Table 2: Experimental Foam Characteristics

	ρ/ρ_{solid}	E (Mpa)	σ_{Ult} (Mpa)
Gibson and Ashby	8% to 70%	10 to 1000	1 to 100
Foam A	9% to 12%	12 to 24	.27 to .45
Foam B	9% to 12%	6 to 50	.3 to 1
Foam C	14% to 20%	4.2 to 8.1	.09 to .19
Foam D	11% to 25%	8.3 to 27.2	.15 to .44
M-Pore Aluminum	8%	82.20	1.04

Finally, the 6 remaining materials were observed to see if their material properties were similar to the solid material properties assumed for cancellous bone. Similar to the experimental foam results, the materials possessed adequate modulus of elasticity, but compressive strengths that were an order of magnitude too low.

Table 1: Foam Theory Parameters

	E_{solid} (GPa)	σ_{Ult_solid} (MPa)
Gibson and Ashby	17.00	193.00
Material E	3.05	2.99
Material F	3.76	4.54
Material G	7.74	8.15
Material H	7.00	8.87
Material I	9.21	8.60
Material J	6.85	7.63

Conclusions: The progress made during this experiment has yielded promising results for the creation of a new open celled foam simulating cancellous bone. Open celled foams with properties similar to widely used aluminum foam were developed. Of critical importance to screw pullout tests, the foam has the same failure strength, and more representative ductility than aluminum foams. Finally, several potential foam materials were evaluated, and all indications are that they will produce superior foams compared to the ones already presented in this report. Future research will entail creating and testing the new foams to judge their effectiveness as models of human cancellous bone. Then these foams will be integrated into the Analogue Spine Model, to provide an even more accurate model of the human lumbar spine.

References: Gibson and Ashby (1988) Cellular Solids, Pergamon Press, NY.

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