The Fracture Energies of Acellular and Cellular Fishes

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Abstract

Acellular bone in more derived fishes has been observed withstanding higher stain rates than cellular bones in mammals. The fracture energy of a material can be calculated using an impact test. The opercles the great sculpin (*Myoxocephalus polyacanthocephalus*) and Chinook salmon (*Oncorhynchus tshawytscha*) were dissected, cut into uniform sizes with a laser, and subjected to a Chapry Impact test. The cross sectional areas of broken samples were used to calculate the fracture energy of the material. The mean of the no-bone trials was 0.8124 m with a standard deviation of 0.00176. . Maximum and minimum values for fracture energy of acellular bone were 2877.63 J/cm^2 and 1940.308 J/cm^2, respectively. Maximum and minimum values for fracture energy of cellular were 2643.25 J/cm^2 and 1663.49 J/cm^2, respectively. The fracture energies of the acellular and cellular bone were not significantly different (p=0.3483).

Introduction

Acellular bone is present in the highly derived fishes and is characterized by the lack of osteocytes embedded within the bone matrix (Moss, 1960). Even with a more laminar composition, acellular bone is not stiffer than cellular bone (Horton & Summers, 2009). Although, some fishes with acellular bone can withstand higher strain rates during suction feeding than in cellular mammalian locomotion (Lauder & Lanyon, 1980). This ability to withstand repetitive high strain rates could be related to acellular bone's toughness. An impact test is a quick and repeatable technique to measure a material's toughness through the use of a high-speed pendulum. The energy absorbed by the material can be determined by the difference in height of the pendulum before and after fracturing the sample (Hayward 2004). The purpose of this study is to use a Charpy

Impact Test to simulate a high-strain rate situation to compare the fracture energies of acellular and cellular bone.

Materials and Methods

Pendulum Construction

The pendulum consisted of three areas of construction: the base, the pendulum-releasing apparatus, and the pendulum (Fig. 1). Three 1 m beams of MISUMI Aluminum Extrusions were used to construct the base of the pendulum. One beam was cut into two equal parts using a chop saw. Two sample-supports were printed on a SeeMeCNC ORION Delta 3D Printer using PLA plastic. The pendulum-releasing apparatus consisted of a Tower Pro™ Micro Servo SG90 attached to a supporting structure also printed on a SeeMeCNC ORION Delta 3D Printer using PLA plastic and mounted on a 1 m beam of MISUMI Aluminum Extrusion. A 0.65 mm diameter hole was drilled through the beam to support a hollow aluminum pipe with a neodymium magnet attached to one end. Copper wire and duct tape were used to secure the servo to the aluminum pipe. An Arduino Uno microcontroller was used to program the servo to rotate 90°. A 1.85 mm diameter hole was drilled in another 1 m MISUMI Aluminum Extrusion support an iron rod with the pendulum attached. The pendulum was made of a hollow aluminum tube with a neodymium magnet attached to a ball-bearing ring. The bob of the pendulum was milled out of steel into a C-shape with a mass of 129.3 g.

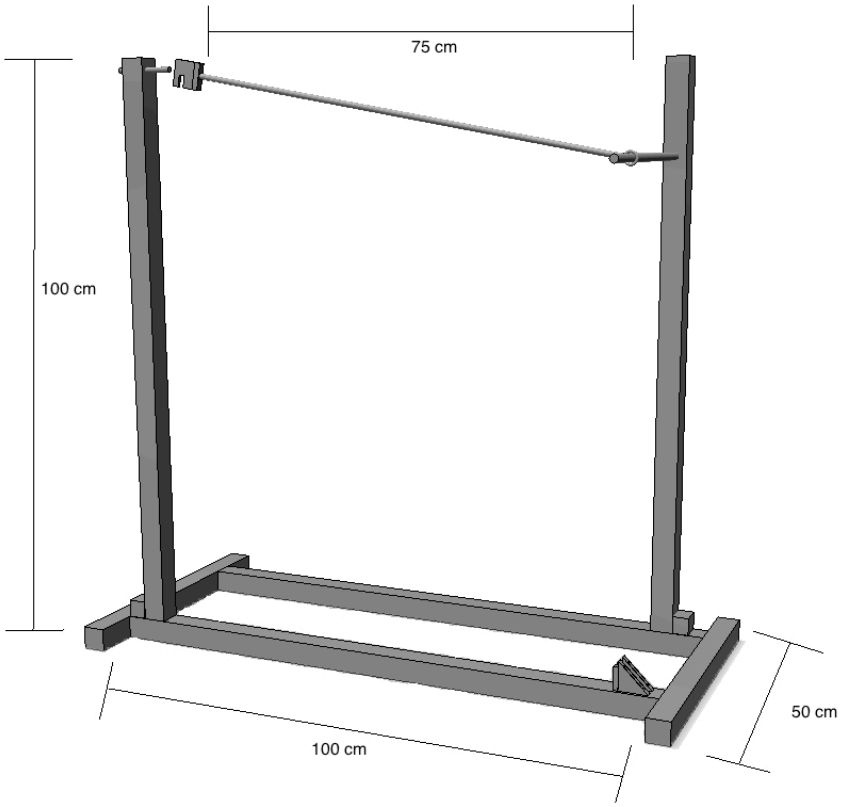

Figure 1. 3D representation of the entire pendulum apparatus. The base is comprised of two 100 cm and two 50 cm MISUMI Aluminum Extrusions. The pendulum and the pendulum-releasing apparatus are supported by 100 cm MISUMI Aluminum Extrusions. The rod of the pendulum is a 75 cm hollow aluminum tube.

Obtaining Samples

Three great sculpin (*Myoxocephalus polyacanthocephalus*) were obtained by seining Jackson Beach, Friday Harbor, WA, USA. All *M. polyacanthocephalus* were euthanized by administering a lethal dose of MS-222 (Tricaine methanesulfonate) and then bled out by a small incision at the base of the caudal fin. Both opercles were removed from each *M. polyacanthocephalus* and then placed in a SPT Ultrasonic Cleaner UC-0609 to help loosen and remove any remaining tissue. Each opercle was placed into a (size?) Hurricane Lasers – Ivan Category 2 to prevent any micro damages to the bone and to obtain a 4 mm x 15 mm sample. A 1mm x 1mm triangular notch was cut into the

center of each sample. The laser was set to cut at 100% power at 13 in/min. A scanning electron microscopy (SEM) was performed on a *M. polyacanthocephalus* opercle provided by Nicholas Gidmark to confirm this technique did not cause any damage. Dr. Adam Summers supplied this study with three frozen Chinook Salmon (*Oncorhynchus tshawytscha*) heads. The same procedures as the *M. polyacanthocephalus* were taken to obtain the opercle expect the speed of the laser was set to 10 in/min due to the greater thickness of the bone.

Impact Test

Fifteen trials without bone were performed to determine the variation in the pendulum swing. All bones samples were subjected to a Charpy Impact Test. The pendulum was released from 87.35 cm and the height after the sample was broken was recorded. All video data was recorded using high-speed video with a Casio-Exilim EX-FH20 at 420 fps. Photographs of the cross sectional area CSA) at which the bones broke were also taken with the camera and transferred to a Macintosh computer to take measurements. All high-speed video and CSA data were measured using the software ImageJ 1.48v. A t-test performed on the data was conducted using the software R 3.1.1.

Results

The results of the SEM showed that the laser did not cause any further damage to the bone. (Fig. 2). Maximum and minimum height reached for fifteen no-bone trials were 0.809 m and 0.816 m, respectively. Mean value was 0.8124 m with a standard deviation of 0.00176 (Fig. 3). Four samples were used in acellular bone data collection. Mean value was 2427.64 J/cm^2 with a standard deviation of 393. Maximum and minimum values for

fracture energy of acellular bone were 2877.63 J/cm^2 and 1940.308 J/cm^2, respectively. Three samples were used in cellular bone data collection. Mean value was 2035.14 J/cm^2 with a standard deviation of 530.96. Maximum and minimum values for fracture energy of cellular were 2643.25 J/cm^2 and 1663.49 J/cm^2, respectively (Fig. 4). There was not a significant difference in the fracture energy between cellular and acellular bone (p=0.3483).

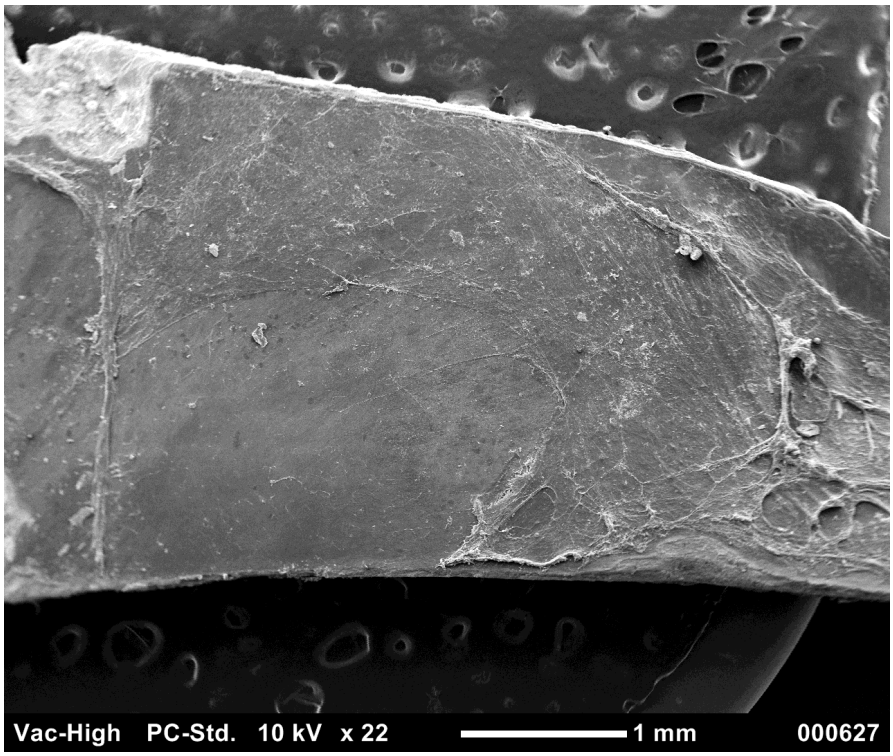

Figure 2. Scanning electron microscopy (SEM) of a laser-cut opercle of a *Myoxocephalus polyacanthocephalus* provided by Nick Gidmark. SEM reveals no micro damages across the bone after the laser cut it.

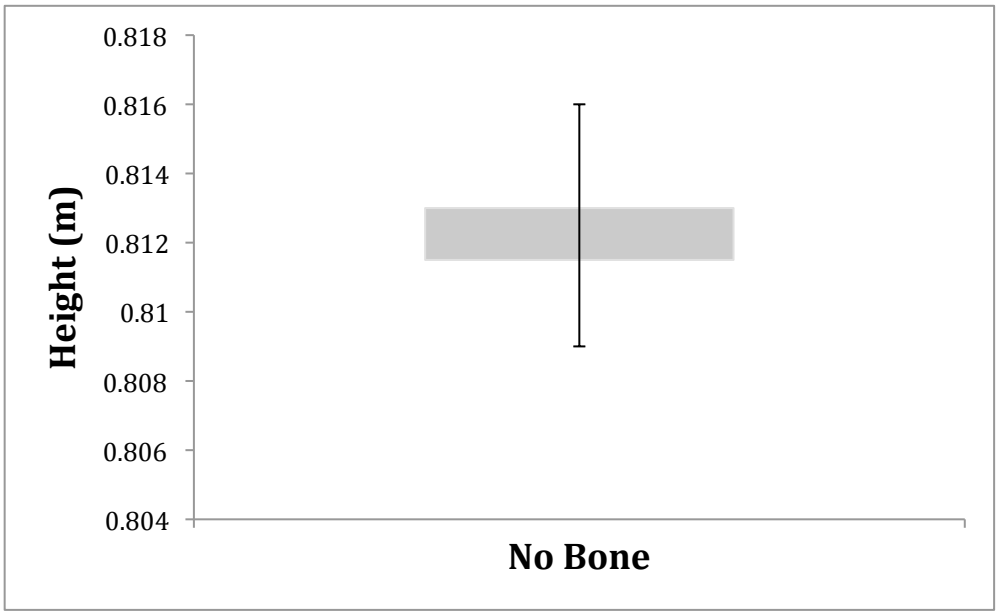

Figure 3. Fifteen no-bone trials to determine the swing variation of the pendulum. Maximum and minimum height reached were 0.809 m and 0.816 m, respectively. Mean value was 0.8124 m with a standard deviation of 0.00176.

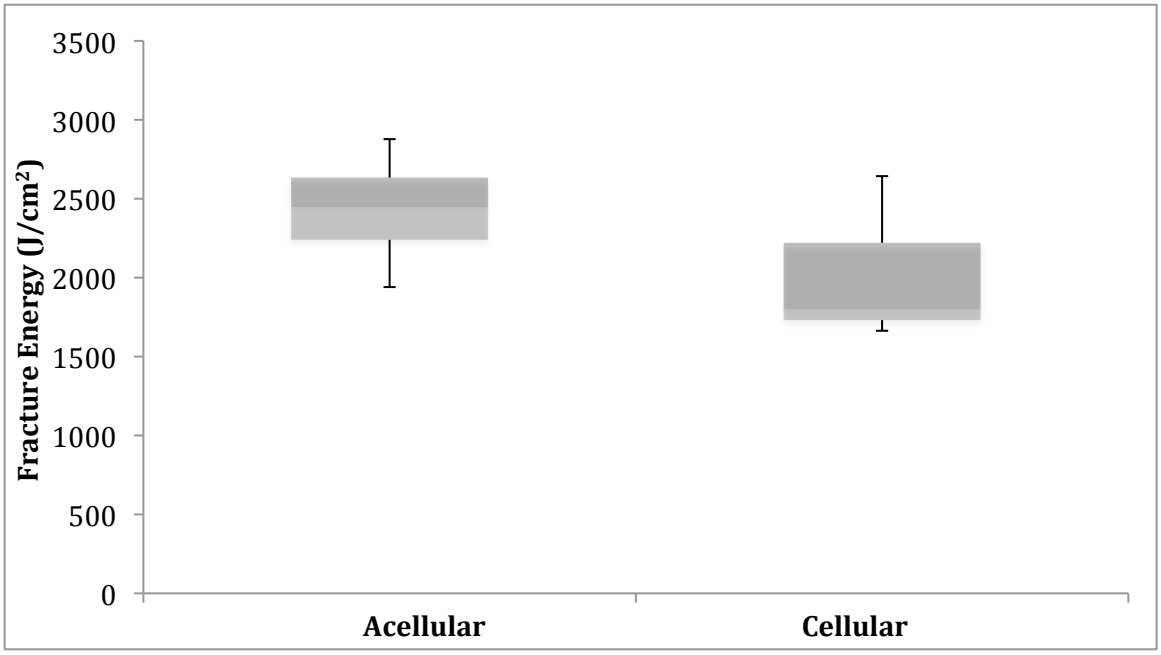

Figure 4. Box plots of the fracture energy (J/cm^2) of acellular (n=4) and cellular bone (n=3). The minimum values for acellular and cellular were 1940.308 J/cm^2 and 1663.489 J/cm^2, respectively. The maximum values for acellular and cellular were 2877.634 J/cm^2 and 2643.254 J/cm^2, respectively. P=0.3483.

Discussion

The SEM results did show there was not further damage to the acellular bone, but the cellular bone seemed to have been slightly burnt around the edges since it was thicker than the acellular bone and required a slower cut speed. The laser did not cut through one of the cellular opercles and was therefore removed from the sample size. Another cellular bone sample had to be removed from that sample size because it was broken during a cycle in the ultrasonicator. This might be the result of the notch being cut too deep by the laser. More trials on cutting thicker materials with the laser cutter must be performed to determine the optimal speed and power.

The impact test environment was not ideal for collecting data. Two acellular and one cellular bone sample were not retrieved after being broken by the pendulum bob. The small area in which the sample rested may have caused fractured samples to hit edges and travel in unexpected directions. A system for collecting fractured samples must be taken into consideration due to the samples moving quickly after being struck by the pendulum's bob.

The fracture energies of the different species' opercles were determined to not be significantly different, but that may be due to the low sample size of each. Collect more samples would give a better understanding how different or similar these bones are handling high-strain rates. More research needs to be conducted on variety of different fishes with acellular and cellular to determine if it changes with each species.

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