[1]Bone Fractures: Modeling with Candy Bars and a Bathroom Scale

Goals:

- Enable students to use a MODEL to conduct experiments, interpret results, and format hypotheses based on the verified results.
- Demonstrate that MODELS can be created to estimate phenomena that cannot be tested in the laboratory.
- Apply the Crunchie candy bar model results to human bones and compare results with known value ranges.

Motivation:

Using models to help predict and resolve actual physical phenomena is essential in science. Computer models, and the use of analogous materials for actual testing, can predict the behavior of phenomena without the use of human or other live models in some cases.

Regardless of the type of modeling (computer or physical) – one can learn much from applying the results of the models to the actual phenomena. One must always remember that models are created to mimic behavior and therefore depend heavily upon assumptions made during the modeling process. The fitness of the models to the actual phenomena may or may not be accurate.

In today's lab you will use an unusual candy bar with a honeycomb interior and outer chocolate as a model of human bone. The candy bar will be exposed to stresses. Your group will interpret the results of these experiments and make predictions about human bones from the model results.

Bones, Stress, and Strain:

On Blackboard, watch the short YouTube Video: Bones, Stress, and Strain. Write down the equations for both stress and strain for use during the laboratory. You will use the stress equation to calculate experimental values but the strain equation will only be used to hypothesize strain forces.

Look at Figure 1, an image of a cut Crunchie candy bar – along what axis does the candy bar have the honeycomb pattern similar to human bones[2] ? (Include a sketch

[1] Image from: http://www.ligorilaw.com/wp-content/uploads/2011/06/broken-bone.png
Lab adapted from http://www.nuffieldfoundation.org/print/2171

[2] http://www.britannica.com/science/compact-bone

in your group's report – showing the axis and therefore the direction of honeycomb pattern.

Using this knowledge – can you predict which orientation of the candy bar under stress will break first? Explain your reasoning referencing content from the video.

Figure 1: Cross-sectional cut of a Crunchie Bar interior

Now that your group has discussed and made your predictions – you need to test the hypothesis on the MODEL candy bar. From the results of experimentation, your group can compare initial hypotheses and determine if the results are a good MODEL for human bone AND thus, the MODEL is useful in understanding bones.

Procedure: Determining Compression Strength

To determine the accuracy of your group's prediction above – tests much be conducted. To do this you must cut your candy bar – be very careful cutting the candy bar as your group will want to conduct multiple tests and only have 1 candy bar. Therefore – no snacking!
To determine if your group's prediction was valid you need to test the stress level of the candy bar in both orientations – along the x and y axes shown in Figure 2.

Figure 2: Axes definition for Experimental Setup

How to do this without crushing the bar so quickly that no data is assembled is of great importance – be sure to read this procedure section in its entirety BEFORE conducting the experiment!

For the Force to compress along the X-axis, the bar must be oriented such that the chocolate sides are on the table and facing the bathroom scale.

For the Force to compress the Y-axis the bar must be oriented such that the cut surface is on the facing up toward the bathroom scale.

Yours or a group member's Force on the bathroom scale will register as weight in lbs. Have each group member practice turning ON the scale with pressure, and increasing the weight displayed on the scale by pressing down, as evenly as possible, hands on either side of the center point of the scale. Keep pressing down until the weight reaches about 40-50lbs. Note how the weight changed incrementally.

PRE_EXPERIMENT PROCEDURE – IMPORTANT!!
Repeat the process above (pressing down on the scale) a few times for each group member. Who had the most gradual change of lbs. displayed over the various trials? This person should conduct the experimental runs on the candy bar, as it is vital that the pressure is not placed on the candy bar all at once or else NO validation of predications can occur. **This is an essential step for good data collection!**

To analyze the experimental data – we must review units of FORCE and how the English units on the bathroom scale can be converted to Newtons the SI unit of force. Note the conversion is as follows: <u>1 lb. = 4.45 Newtons</u>.

Now that we have the experimenter selected and know how to convert experimental units into standard units – run the following experiments.

1. Saw 1 piece of candy bar about 1.5cm long for experimentation. Make sure the slice is as even as possible creating a rectangular piece. (Do not cut any additional pieces yet – the candy bar may get gooey and then change results.)

2. Look at the cross-sectional area of the candy bar piece. Since the first experiment examines the Y-axes compression strength– what area must be measured to calculate the stress on the bar? **Remember that Cross-Sectional Area measures the area of the sample surface being compressed by the bathroom scale**. Measure the length and width of this surface with calipers and record these values for future use.

3. Place a paper towel on the table surface – ensure that each time a candy bar piece is compressed that it is on the towel surface – get a replacement towel if needed throughout the experimental process. This is only to make clean up

easy – so much sure before you leave that your station is cleaned up for the next group, with no Crunchie crumbs left on the table.

4. With the 1.5cm long cut of candy bar – orient such that compression is along the Y-axis (Fig. 2). Place the scale on top of the bar and start pressing VERY LIGHTLY AND EVENLY ON THE SCALE TOP– increase the force on the scale until the bar begins to crack – NOTE THIS WEIGHT. Now continue until the bar fractures (but you have not smashed it into mush) – look at the fractured bar and take notes on HOW the Crunchie broke under pressure. Does your group believe this fractures appear similar to how human bones brake. (Look at the image on Blackboard of different types of long bone fractures.)

5. Repeat the entire process outlined in #1-#4 but orient the piece of candy bar such that the X-axis force is being measured. Remember that the cross-sectional area will have changed – be sure to measure the length and width of the new piece of candy before compression.

6. Now – to calculate the STRESS values for both orientations you must refer to the stress equation from the video and remember that FORCE must be in UNITS of NEWTONS and AREA in units of m^2. Complete all conversions using the data already collected. For simplicity in calculating the conversions – convert the 'mm' caliper measurements of length and width to 'm' BEFORE calculating the area. (1000mm = 1m).

$$\text{STRESS} = F/A$$

7. How did the two stress values compare? Did it match the video prediction of which orientation should be greater? Did it match your group's predictions? Explain Completely.

8. Compare your measured values with class results for both axes. (Write your measured values for both axes on the board – Your instructor will make two columns – Y-axis and X-Axis on the front board). Looking at all the measurements how did your group's values compare to other groups?

9. What is the average and standard deviation of the measurements?

10. Discuss the size of the standard deviation with respect to the average stress values calculated – what percentage of the class values fall within 2 stdevs of the averaged values? Hypothesize why your group believes there are variations in the values measured. (Think about inconsistencies that might arise using the same but different pieces of equipment by each group.)

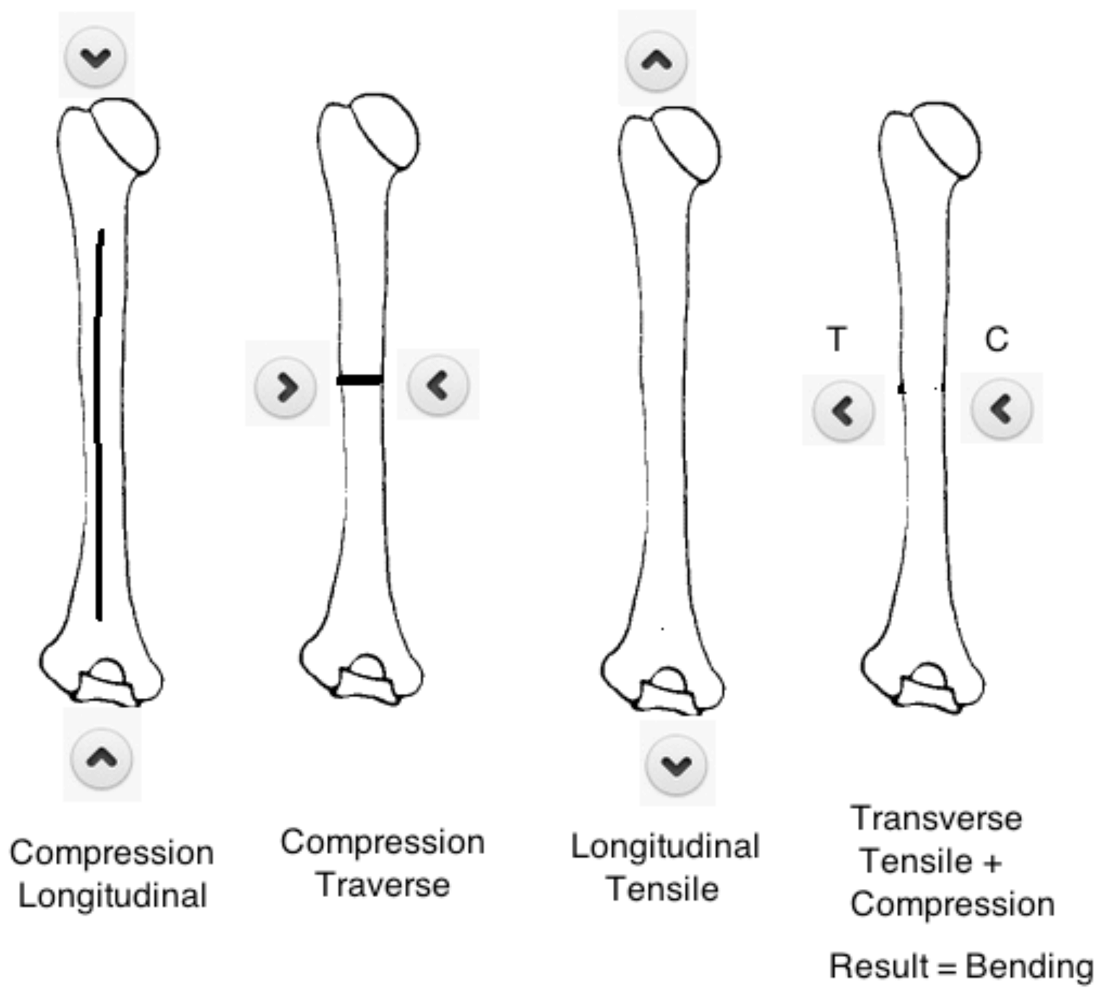

Figure 3: Compression and Tensions applied to bone

11. Now, look at these measurements and compare with the stress measurement of the human femur bone can endure before fracturing. View Figure 3 to make sense of the stress values given below.

Human Femur	Stress (N/m^2)
Compression Longitudinal	205×10^6
Compression Transverse	131×10^6
Tensile Longitudinal	135×10^6
Tensile Traverse	53×10^6

a. Remembering stress is defined as (Force)/(cross-sectional Area) = (F/A), calculate the ratio the compressional stresses of the human femur bone to the compressional stresses determined for the Crunchie bar.

b. Using these ratios, state how much stronger the compressional stresses for the human femur bone are than the Crunchie bar?

c. Using the skeleton in the room – choose two bones of the human body and take measurements of the bone with calipers to estimate the X-Axis and Y-Axis cross-sectional areas. Note that this is an estimate – so explain reasoning in the area value produced in your group's write up.

d. Now, using the ratio determined (a) and the Area from (c) – determine the estimated compression forces of the two different human bones (assuming that the bone structures are similar to the femur). **Remember that the cross-sectional areas for various bones differ – your group must make measurements of the skeleton bones and use values measured to predict the new cross-sectional area as requested in step (c).** (It is known that the bone densities vary – this is an estimate only!)

e. Hypothesize – looking at the forces determined in (d) for your group's chosen bones – does it make sense to you that the forces are larger or smaller than the femur bone values provided in the table? Explain your group's reasoning. Therefore – do you think the assumptions and MODEL used in today's lab is sufficient for comparisons of bones of the human body?

f. Does your hypothesis in (e) seem to imply that the bone densities in (c) differ greatly from the femur? Explain. How could the MODEL be used accurately? What limitations must be placed on using the ratio in (a) to make predictions on other human bones?

g. Your group does not have the sufficient tools to test tensile stress of the Crunchie candy bar, only compression stress with the bathroom scale. But, what if the compression ratio of Crunchie bar to human bone ratio determined in (a) is close to the tensile stress ratio, how could you predict the tensile stress of the Crunchie bar? Explain and provide your group's predictive values.