The Physics of Cutmarks
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ABSTRACT
Cutmarks are the most direct evidence of faunal butchery by humans; however, understanding the physical properties associated with their creation is critical when interpreting the archaeological record. By quantifying the minimum amount of force required to cut through soft tissue and the minimum amount of force required to produce a visible cutmark on the surface of bone, and then correlating those values with the maximum amount of force exerted by a human butchering with a stone tool, archaeologists will better understand the conditions conducive to creating cutmarks. A precise metalurgical served as the specimen for the cutting experiment, while obsidian and chert flakes, and a scalpel blade were used as the cutting tools. Axial force was measured with a dynamic loading cell, accurate to the nearest Newton. Cutmarks were replicated with rubber latex and were analyzed using a scanning electron microscope at varying degrees of magnification, and depth was measured to the nearest micrometer. Twenty adults (10 male and 10 female) volunteered to perform an experiment measuring the maximum amount of force that could be exerted in a kneeling position while holding a small fish and a large bifur. Force was measured using a digital scale accurate to the nearest tenth of a kilogram. Results have shown that less force is required to cut through soft tissue using obsidian as opposed to chert flakes, and the amount of force required to produce a visible cutmark on bone is context, and that an average male can exert a greater maximum force using both hand and small stone tools than females.

INTRODUCTION
In the effort to increase the accuracy of their interpretations, archaeologists employ the use of experimental actualistic studies to better understand the functional processes that result in the evidence observed in the archaeological record. Actualistic studies follow the principle of uniformitarianism, in that contemporary processes are representative of those that may have occurred in the past. The most direct evidence for butchering of faunal remains are cutmarks that are left on the cortical surface of the bone as a result of cutting tools. Much research has been conducted to increase understanding of the subsistence strategies of prehistoric humans, including experimental butchering techniques that work to create cutmarks viewed on an archaeological fauna. However, until the physical properties of the butchering process are understood, it will remain difficult to formulate accurate interpretations of the behavior of the butcher associated with the cutmarks on the bones. Therefore, the goals of this research project are as follows:

• Determine:
  - the minimum amount of axial force required to cut through muscle tissue
  - the minimum amount of axial force required to develop a cutmark on a bone
  - the maximum amount of axial force exerted by a person with varying stone tool sizes

MATERIALS AND METHODS
Cutting Force Measurements
A domestic pig (Sus scrofa) left hind limb served as the specimen for the muscle tissue and bone for the cutting-force experiment (Figure 1). The limb was approximately one week post-mortem and was at room temperature during the time of cutting. It was mounted in a wooden platform and then placed on a dynamic force cell that is accurate to the nearest Newton (Figure 4). The cutmark was tracked as the muscle tissue was cut through a number of 10 scalpels, an obsidian flake, and a chert blade (Figure 3) with the minimal amount of force required to create a cut. After the muscle tissue experiment was complete, the muscle tissue was removed to expose the number four metatarsal (Figure 2), the anterior portion of which was then cut with the same scalpel blade and flake three times in series. Data was recorded automatically from the force cell in a predesigned Excel program, and the graph in the force vs. time data was observed as a downward spike (Figures 5-8). The bone was then removed to expose the number four metatarsal (Figure 2), the anterior portion of which was then cut with the same scalpel blade and flake three times in series. Data was recorded automatically from the force cell in a predesigned Excel program, and the graph in the force vs. time data was observed as a downward spike (Figures 5-8). Obsidian and chert experiments were repeated three times in series. Data was recorded automatically from the force cell in a predesigned Excel program, and the graph in the force vs. time data was observed as a downward spike (Figures 5-8).

Cutmark Analysis
A rubber latex mold of the cutmarks formed by the stone tool flakes was created and was analyzed in a scanning electron microscope at varying magnifications. Depth of the cutmark was determined using a digital micrometer. The amount of force required to produce a visible cutmark on bone is context, and that an average male can exert a greater maximum force using both hand and small stone tools than females.

RESULTS AND DISCUSSION
The following results were obtained from comparing the minimum amount of force required to cut through muscle tissue in relation to the amount of force required to produce a visible cutmark on the bone:

- Minimum Force to to Cut Soft Tissue Form a Cutmark on
  - Scalpel = 11N Bone
  - Obsidian = 10N
  - Obsidian = 11N

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Maximum force measurements were converted to Newtons by multiplying the kilogram quantity by 9.8 m/s², as this is the force due to gravity. These values were then plotted on a graph of the mass of the individual and force exerted in Newton. The graphs are observed as a downward spike (Figures 5-8). Maximum force of large or small stone tools exceeds minimum force to cut through muscle tissue and produce a visible cutmark on a bone by:

- 13 times for small stone tools (total individual)
- 22 times for large stone tools (total individual)

- 1.65 times more force can be exerted with large stone tools than small stone tools (total individual)

- Males generally exert greater forces with both large (110%) and small (84.8%) stone tools than females

- Females have a more positive correlation between body mass and maximum force exerted than males

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REFERENCES