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Comparing the use of meat and clay during cutting and projectile research

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ABSTRACT

Diverse disciplines investigate how muscular tissue (i.e. 'meat') responds to being cut and deformed, however, large-scale, empirically robust investigations into these matters are often impractical and expensive. Previous research has used clay as an alternative to meat. To establish whether clay is a reliable proxy for meat, we directly compare the two materials via a series of cutting and projectile tests. Results confirm that the two materials display distinct cutting mechanics, resistance to penetration and are not comparable. Under certain conditions clay can be used as an alternative to meat, although distinctions between the two may lead to experimental limitations.

1. Introduction

A diverse range of disciplines investigate how muscular tissue (i.e. 'meat') responds to being cut and deformed under different experimental conditions. Animal products are primarily used in these studies, either as a substitute for human tissue, or when addressing questions relating to the butchery and processing of animal products in 'real-world' settings. Of note are ergonomic investigations examining how different cutting tools influence musculoskeletal stresses when processing animal carcasses within industrial settings, engineering and medical research investigating how cutting mechanics and tool use capabilities are influenced by varying cutting edge forms, and archaeological research interested in the relative ability of different artefact types and forms to be used during hunting and butchery activities.

The work of McGorry and colleagues are prominent examples from an ergonomic perspective [1,2]. In a series of publications examining the implications of blade sharpness, edge angle, and finish on grip forces and moments during modern industrial butchery settings, participants undertook the butchery of beef and lamb in diverse ways (e.g. shoulder boning, intercostal trimming, Y-cutting, shoulder fleecing) and on a relatively large scale (21 participants performed the shoulder fleecing and Y-cutting, for example). Szabo et al. [3] published similar experiments examining industrial poultry processing. Mechanical and medical engineering research has also examined how aspects of tool-form variation influence their ability to cut biological tissue, but instead often focus on how these variables influence their respective fracture mechanics. Shergold and Fleck [4], for example, used pigskin samples alongside in vivo tests on human skin when examining the relative performance (crack geometry) of sharp and flat-bottomed punches and hypodermic

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needles. Kasiri et al. [5] utilised bovine bones when measuring indentation and failure in cortical bone when cut with a surgical blade. Others have utilised processed meat foodstuffs when investigating the cutting mechanics of associated implements (e.g. wire band saw) in industrial or food preparation settings [6,7].

Archaeological research has heavily employed experiments that process animal tissues within two research themes. First, numerous publications have sought to replicate past butchery activities when investigating the relative ability of different tool forms to undertake butchery processes, the formation of cut marks on bones, and the processes leading to the development of microwear traces (e.g. [8–14]). Just as prominently, archaeologists have also long been concerned with the projectile technologies of past populations and have frequently undertaken replication experiments investigating form-function relationships and damage formation processes to both tools and targets (e.g. [15–18]). It is notable that Palaeolithic archaeology has a particular emphasis upon such experimentation [19].

All fields, however, face issues when using substantial quantities of animal materials in laboratory based experiments. These issues include the expenses of responsibly acquiring and safely disposing of animal tissues; a need for cold storage facilities; relevant health and safety concerns when processing and storing animal products; and the ethical concerns of utilising animal products. While these issues may be somewhat abated in studies of limited scale, they can pose substantial hurdles to large-scale quantitative studies. Further, differences and inconsistencies within animal tissues (muscle fibres, fat, connective tissue etc.) and between carcasses (size, muscle depth, time since death, etc.) may pose problems to studies of cutting mechanics at the micro-scale and comparisons between experimental subjects, respectfully. These concerns have previously been identified by researchers (e.g. [20]) and, at times, led to the use of industrially produced materials as animal product proxies in cutting and projectile experiments. Iovita et al. [21] and Wilkins et al. [22], for example, recently utilised ballistics gelatine instead of animal tissues when examining the functionality of stone tipped weaponry. Similarly, Key, Lycett and colleagues utilised neoprene rubber, polypropylene rope, polythene sheeting, and double-walled corrugated cardboard when testing the relative cutting capabilities of different stone tool forms [23–25]. While such materials may successfully examine the influence of external variables on tool-use capabilities, there are likely key differences in the resistance provided to cutting edges and how fractures initiate in these materials. Certainly, ballistics gelatine has demonstrated differences in the depth of penetration of projectiles and nature of the damage produced when compared to both pig and simulated thoraxes [26,27]. Moreover, cardboard and rope display distinct constitutive forms to bio-materials and do not display the typically J-shaped stress-strain curve of meat [28]. So, while such materials are useful and, dependent upon the hypotheses being investigated, are often suitable to be used as a standardised material to be cut, it would be useful to identify an alternative material that negated the above-mentioned problems and displayed similar resistance and fracturing properties to animal tissues.

Consequently, past research has both utilised materials that were thought to replicate the cutting mechanics of animal materials, and has directly tested their comparability against animal tissues. McCarthy et al. [29] and Schuldt et al. [7], for example, previously used polyurethane and ethylene propylene diene monomer rubber sheets (respectfully) when examining relationships between sharpness and cutting forces in metallic blades as these materials are considered to display similar fracture mechanics to animal tissues and other similar bio-materials. Marsot et al. [30], on the other hand, compared the shear strength of meat against a series of synthetic materials, and identified a relatively dense polyolefin-based foam as displaying both similar shear strength and cutting forces to meat. Shergold and Fleck [4: 841] went into much greater detail when outlining why silicone rubber may be considered as an "approximate substitute for human skin", providing a detailed review of the mechanical properties of both materials when being cut. Kalcioglu et al. [31] similarly examined the mechanical behaviours of animal tissues and industrially produced materials, but in this instance compared the penetrability, energy dissipation, and deformation mechanics of heart and liver tissues against a series of tissue simulant gels in projectile tests. Their results indicated that even the best simulant gel still exceeded the penetration depths of the animal tissues by at least ~15%.

As suggested by McGorry et al. [20,32], clay may also provide a suitable alternative to animal tissues during cutting experiments. In a study examining how task station and blade orientation variation influences gripping forces, cutting moments, and upper limb kinematics during a cutting task using a knife, they suggested that modelling clay provided cutting moments similar to "sirloin and London broil cuts of beef" [20:1644]. Others have utilised clay during controlled ballistics and cutting experiments when recording penetration levels when protected by different body armour fabrics [33] and deformation and failure rates in clay substrate when cut with tines [34] (although neither used clay as a direct proxy for biological tissues). While clay may intuitively appear similar meat in several important ways (e.g. resistance to a cutting edge), they represent two materials with very distinct compositions, with meat being a fibrous organic tissue and clay primarily being formed of silicate particles and trapped water. Moreover, there has yet to be a controlled experimental investigation specifically addressing the relative ability of clay to provide an accurate alternative to meat.

Here we redress this issue and assess the suitability of fresh potters clay to be used as an alternative to meat during cutting and projectile activities. Specifically, we undertake two rounds of experiments. The first examines the forces and deformation required to cut clay and meat of equal measure with a straight, homogeneous metallic blade. The second examines the ability of modern metallic composite arrows and Palaeolithic stone projectiles to penetrate clay and meat when fired at a controlled speed and distance. We conclude by discussing the nature of any similarities or differences in the two materials and the suitability of using clay as a substitute to meat in future archaeological, ergonomic, and engineering experiments.

2. Loading rates during cutting

The relative ability of sharp edged tools to initiate fractures in materials and permanently separate two or more of their aspects is of broad importance to many areas of research (see Atkins [28] and examples therein). Consequently, examinations into the forces required to cut materials with metal knives, stone tools, and other implements have taken many forms, including the use of pressure