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Micro-computed tomography of false starts produced on bone by different hand-saws

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ABSTRACT

The analysis of macro- and microscopic characteristics of saw marks on bones can provide useful information about the class of the tool utilized to produce the injury. The aim of the present study was to test micro-computed tomography (micro-CT) for the analysis of false starts experimentally produced on 32 human bone sections using 4 different hand-saws in order to verify the potential utility of micro-CT for distinguishing false starts produced by different saws and to correlate the morphology of the tool with that of the bone mark. Each sample was analysed through stereomicroscopy and micro-CT. Stereomicroscopic analysis allowed the identification of the false starts and the detection of the number of tool marks left by each saw. Micro-CT scans, through the integration of 3D renders and multiplanar reconstructions (MPR), allowed the identification of the shape of each false start correlating it to the injuring tool. Our results suggest that micro-CT could be a useful technique for assessing false starts produced by different classes of saws, providing accurate morphological profiles of the bone marks with all the advantages of high resolution 3D imaging (e.g., high accuracy, non-destructive analysis, preservation and documentation of evidence). However, further studies are necessary to integrate qualitative data with quantitative metrical analysis in order to further characterize the false start and the related injuring tool.

1. Introduction

The tools used in post-mortem dismemberment produce characteristic witness marks on the body of the victim, commonly defined tool marks. The macroscopic and microscopic analysis of tool marks on bones plays a crucial role in forensic anthropology and pathology, providing useful information about the instrument used to cause them [1]. When saws are used to cut bones, they often leave specific saw marks, known as "false starts", which occur when the blade of the saw, during a stroke, hits the surface of the bone briefly and then restarts from another point, close to the initial point of cut. In the last decades, several techniques have been applied to the analysis of false starts on bones, including optical [2–4] and digital [5] microscopy, scanning electron microscopy (SEM) [6,7], environmental scanning electron microscopy (ESEM) and epifluorescence macroscopy [8].

Additionally, high-resolution radiological techniques (e.g., cone beam CT, micro-CT, peripheral Quantitative Computed Tomography – pQCT), especially suitable for bone evaluations [9–11], have been applied to investigate sharp force marks. Indeed, for instance, Gaudio et al. successfully assessed stab wounds on the cancellous bone of vertebral samples using a cone beam CT [12] and Rubinacci et al. applied pQCT to precisely characterize a single vertebral specimen with a sharp force injury [13]. Thali et al. described the potentiality of micro-CT for the assessment of stab marks on porcine pelvic bones [14]. Despite these highly promising evidences, however, to the best of our knowledge, a micro-CT based experimental study focused on the investigation of tool marks produced by different saws on human cortical bone was still missing. Micro-CT is a cross-sectional high-accuracy computed tomography with a spatial resolution of a few microns, which has recently opened the possibility of non-invasive high-precision analyses and reconstructions of bones and soft tissues, with several interesting applications also in the forensic field [15].

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The aims of our investigation were to test the potential utility of micro-CT for detecting and distinguishing false starts produced by different hand-saws and to correlate the morphological characteristics of the tool with the radiological features of the bone mark.

2. Material and methods

2.1. Bone samples

All the experiments were performed on human peroneal, metacarpal, metatarsal and phalanx bones, collected from individuals who donated their body to the University of Padua for research purposes [16]. The specimens were manually defleshed; skin and muscles were carefully removed with a surgical scalpel without damaging the surface of the bone.

2.2. Saw blades

The following four types of hand-saws were used for the experimental trials (Fig. 1a).

Saw n. 1: 5 teeth per inch (TPI) rip cut saw with alternating set;
Saw n. 2: 8 TPI crosscut saw with alternating set;
Saw n. 3: 10 TPI rip cut saw with alternating set;
Saw n. 4: 24 TPI rip cut saw with wavy set.

The above-mentioned tools were selected because easily available in all hardware markets, simple to use, and designed to cut through a wide variety of materials.

Regarding the saw characteristics:

the TPI refers to the number of teeth present in an inch;
the "rip cut" shape corresponds to teeth which are not angled or filed, and form a flat chiselled face, designed to tear along the grain, acting like a miniature chisel, while the "cross cut" shape corresponds to teeth filed to an angle, with a design that allows each tooth to act like a small knife and slice through the wood;
the "alternating" set means that adjacent teeth are bent in an opposite direction, while the "wavy" set means that the teeth are laterally bent in groups [4].

2.3. Experimental trials

Thirty-two bone specimens were obtained by cutting the bones into sections of 2 cm in length. After immobilizing the bones using a metallic vice, all false starts were inflicted manually by the same right-handed male operator, in the middle of the bone section, holding the saw perpendicularly to the long axis of the bone and performing a single unidirectional stroke with an excursion of 15 cm in length, in order to simulate a false start. Each saw was used to produce a sequence of 8 false starts on 8 different bone sections. Speed and pressure of the saws were maintained as consistent as possible. The minimal and unavoidable variability of strokes served to approximate the variation that occurs in forensic investigations, since most traumas are not inflicted in a regular manner [17].

2.4. Stereomicroscopy

All samples were observed and photographed with a SZX12 Olympus Stereomicroscope, coupled with an Olympus DP50 digital camera.

2.5. Micro-CT

All specimens were analysed by an ex vivo high-resolution Micro-CT 1172 (Skyscan, Aartselaar, Belgium), with the following setting: 14 μm isotropic voxel size, 51 "kV" of Voltage, 194 μA of current, exposition time 6050 ms, rotation step 0.7, frame averaging 2, 1280 × 1024 pixel Field of View. The selected volume of interest (VOI side of 1 cm and height of 3.8 mm) was placed around the centre of the specimen aiming to include the entire false start. Hounsfield unit (HU) calibration was performed acquiring and reconstructing a water phantom with the same sample settings. Each scan required about 3 h. The acquired raw data were reconstructed with an N-Recon Software (Skyscan, Aartslaar Belgium). Subsequently, the bitmap files were converted in DICOM using the DICOM Converter® Software. Osirix (Open Source Software, Version 7.0.1) was used to elaborate the multiplanar (MPR) and the 3D volumetric reconstructions. The number of tool marks on bones was assessed on 3D and MPR images, while the features of each mark (quadrangular or triangular shape; flat or convex flour) and of the bone areas included between the marks (damaged or undamaged) were assessed on the sagittal plane and described in accordance to the general characteristics previously reported by Symes [4].

3. Results

3.1. Stereomicroscopy

All false starts were detected by stereomicroscopy and photographed (Fig. 1b). False starts produced by saws n. 1, 2, and 3 showed two parallel marks divided by a bone island. False starts produced by saw n. 4 produced a single mark.

3.2. Micro-CT

All false starts were detected by micro-CT. The integration of high-resolution 3D (Fig. 1c) and MPR reconstructions (Fig. 2) allowed the detection of the number and shape of each saw mark. False starts produced by saw n. 1 showed 2 marks of quadrangular shape and flat floor, divided by an area of undamaged bone. False starts produced by saw n. 2 showed 2 marks of triangular shape and convex floor, divided by an area of undamaged bone. False starts produced by saw n. 3 showed 2 marks of quadrangular shape and flat floor, divided by a bone area partially notched by the saw. False starts produced by saw n. 4 showed one mark of quadrangular shape and flat floor.

4. Discussion

In the last decade, micro-CT has frequently been used for forensic purposes, especially in wound ballistics for the identification of intermediate range gunshot wounds [18,19] and in forensic anthropology for sex determination and age estimation [20,21]. It has also been utilized for the analysis of tool marks on bones produced by hatchets and knives [14]. Pounder et al. [22] verified the potential utility of micro-CT to assess the striation patterns of stab wounds on porcine cartilages producing a 3D virtual casting of the walls of the stab track and fit-matching it with the scan of the blade of the knife. Capuani et al. [17] studied sharp force injuries on bones and observed that micro-CT is an appropriate tool to analyse bone marks produced by hatchets, but not to discriminate knife lesions, since 3D reconstructions led to smoothing of bone surfaces, preventing the differentiation between injuries produced by serrated and non-serrated knives. Aiming to overcome this disadvantage, Rutty et al. [15] suggested that the analysis of tool