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## CASE REPORT

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## GENERAL

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## Introducing 3D Printed Models as Demonstrative Evidence at Criminal Trials

**ABSTRACT:** This case report presents one of the first reported uses of a 3D printed exhibit in an English homicide trial, in which two defendants were accused of beating their victim to death. The investigation of this crime included a micro-CT scan of the victim's skull, which assisted the pathologist to determine the circumstances of the assault, in particular regarding the number of assault weapons and perpetrators. The scan showed two distinct injury shapes, suggesting the use of either two weapons or a single weapon with geometrically distinct surfaces. It subsequently served as the basis for a 3D print, which was shown in court in one of the first examples that 3D printed physical models have been introduced as evidence in a criminal trial in the United Kingdom. This paper presents the decision-making process of whether to use 3D printed evidence or not.

**KEYWORDS:** forensic science, forensic imaging, microcomputed tomography, tool mark analysis, 3D printing, additive manufacturing, demonstrative evidence, court presentation

Technology advances rapidly in our modern society, and we are surrounded by it in our daily lives; it therefore seems strange that law enforcement agencies are notoriously slow in taking up these innovations. Courts in the United Kingdom in particular appear to be stuck in the past century with much of the daily court proceedings still involving paper hardcopies and printouts, in a time when the "outside" world is already looking into applications of virtual reality technology. While there are many practical and financial obstacles, which prevent courts from adapting to technological progress and limit the use of certain technologies, 3D printing is an excellent example of easily incorporated technological progress, which does not require major changes to existing court facilities. Three-dimensional printing is a general term encompassing a range of additive technologies which create physical models from digital files out of materials such as plastics or metal (1). The benefits of 3D prints in a courtroom have been demonstrated elsewhere, for example by Kettner et al. (2) in Germany. In the United States, justice personnel are more accustomed to seeing 3D printed evidence in court as litigation lawyers have recognized the potential thereof much earlier than those in criminal trials, and there is a plethora of commercial companies offering such services (for example Lazarus 3D, Houston, TX, or 3D Printed Evidence, Jacksonville, FL).

This paper reports on the use of 3D printed material as demonstrative evidence in a murder trial, one of the first such cases from the U.K. reported in the scientific literature, although some reference to 3D prints in the courtroom can be found in popular media outlets (3,4). It is not intended as a technical

paper on the process of 3D printing but as an example to demonstrate its application to raise awareness amongst legal practitioners.

### Case Background

The trial in question was a murder trial with two defendants who were accused of beating an individual to death. They were arrested following a police call-out by the victim's neighbor who reported sounds of a violent fight from next door. Upon entry to the house, police found a severely injured individual while the two other occupants of the house attempted to flee the scene. The victim was taken to hospital to undergo emergency cranial surgery, but later passed away from their injuries and a murder investigation was launched. A search of the property yielded a claw hammer and a spanner, which were thought to be associated with the assault (Fig. 1), and the two occupants were arrested on suspicion of murder. A section of the skull was submitted for micro-CT examination to help establish which implement had caused the injuries and whether both occupants or only one were involved in the attack. This was a central issue to the case as both defendants tried to shift the blame onto the other.

### Method/Workflow

The skull section was scanned using a Nikon XT225/320LC (Nikon Metrology, Tring, U.K.) micro-CT scanner at a resolution of 80  $\mu\text{m}$  (125 kV, 680  $\mu\text{A}$ , 354 msec exposure) to visualize the cranial injuries and provide measurements thereof, presented to the investigators in a written report.

The CT images were issued to the pathologist to assist with the analysis of the complex fracture pattern, which was visible in great detail on the scan, and a 3D print thereof was later requested by the Crown Prosecution Service (CPS) as further

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FIG. 1—Crime scene photographs of the hammer and the spanner thought to have been involved in the attack.

evidence to be shown to the jury at trial. In order to transform the CT data into a 3D print, the reconstructed 3D volume was converted into a surface mesh using Simpleware ScanIP 9.0.0 (Synopsis, Mountain View, CA, US) which was used to produce an original-scale 3D print at a resolution of 50  $\mu\text{m}$  using the Formlab Form2 printer (Formlabs, Somerville, MA, US) which is based on stereolithography technology (5). The overall workflow is visualized in Figure 2, which shows the outcome at each stage in the process.

## Discussion

Micro-CT has been demonstrated to improve forensic wound analysis (6,7), used in the present case to assist with the interpretation of the events surrounding the victim's death. The CT scan, shown in Figure 3, revealed two distinct fracture shapes, one being an elongated depression fracture and the other being a smaller square shape with rounded corners. It was concluded that these could have been made by two different weapons or a single weapon with two geometrically distinct impact surfaces.

The focus of this paper, however, is the presentation of the 3D printed model in court, as this constitutes the main innovation. This discussion section aims to elaborate on the decision-making process, which involved carefully weighing all advantages and disadvantages against each other. The three major decision points in this case were whether using a 3D print is appropriate, if yes, what print properties to use, and finally how to present the print in court. In order to submit evidence to court, it must adhere to certain standards; scientific evidence in particular is subject to intense scrutiny under Criminal Procedure Rule (CrimPR) 19 (8), which outlines the admissibility criteria for expert evidence. Alongside the general criteria of helpfulness and nonprejudicial effect, it provides a scientific reliability assessment of the methods used to create the evidence. In this

case, the three-dimensional model served as demonstrative evidence as defined by Harston (9) but was introduced by the metrology expert and therefore CrimPR 19 must be met. It is sometimes argued that purely demonstrative evidence is subject to less strict standards (10,11), but even if the evidence only serves an illustrative purpose, it still needs to be an accurate representation of the facts. Silva et al. (12) have demonstrated that 3D printed models generally adequately represent anatomical features, although not sufficiently accurate to take measurements directly on the model. However, additive technologies have developed steadily since their study in 2008, now able to produce higher accuracy models, possibly enable direct measurements in the near future.

### Step 1—Deciding to Exhibit 3D Print

Using such replicas of medical evidence in lieu of the original solves several problems. The first problem is the health hazard this biological tissue could pose (13); the second issue is the potential damage excessive handling could cause the object; and the third issue—perhaps the most significant challenge—is the emotional and moral effects handling actual human remains could have on both the fact finder and the victim's family (14). The first two issues can be mitigated by careful packaging, but the plastic alternative can be directly handled without any risk to jurors' health or the evidence itself and even if it does get damaged it can be reprinted indefinite times. This was used by the expert witness testifying on the scanning and printing technology who used a separate, annotated copy of the model as visual cue for their testimony.

The fact that 3D prints can be handled directly without protective packaging allows the jury and the judge to examine the part and the three-dimensional relationship between the injuries more closely with the potential to better understand the testimony

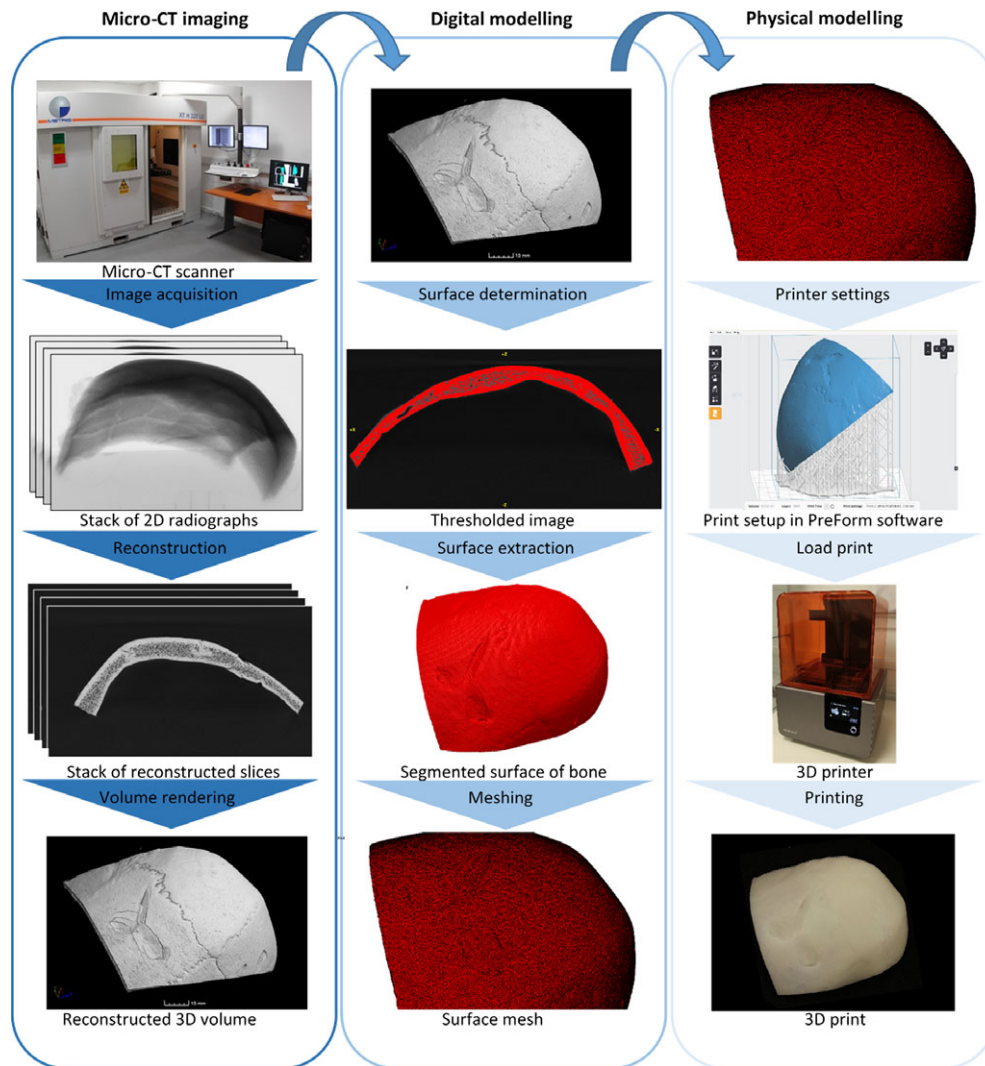


FIG. 2—Schematic representation of the workflow followed in this case, starting with a micro-CT scan of the sample and finishing with the physical 3D printed object. All steps were conducted in-house.

given by the pathologist. This meant that the model could be easily made available to the jury during their deliberation without concerns for anyone's safety.

The third issue is the most problematic one and the major limitation for using actual biological material as evidence, which is only justifiable if it contributes information not otherwise obtainable. Presenting human tissue in court could cause distress due to ethical, religious, or cultural reasons, in particular, for the victim's family who wish to bury their loved one.

Additionally, providing a detailed physical representation of the victim's injuries—both original and replica—potentially introduces subconscious bias amongst jurors who, in light of the horrific injuries, might see the defendants less favorably (15). The risk of bias is more likely to result in an inadmissibility ruling and possibly is the reason why there is little evidence for the use of 3D prints in U.K. courts as barristers might be reluctant for fear of rejection. It therefore needs to be ensured that the probative value of using 3D printed evidence outweighs the potential prejudice and that admission guidelines are followed. In the present case, it was felt that the complex pattern of overlapping fracture lines could be best represented on a three-dimensional model. As the blunt force injuries lay at the center

of the controversy of who attacked the victim and with what implement, trying to reduce confusion surrounding this aspect with all resources available outweighed the potential risks.

#### Step 2—Print Properties

The wide range of materials available in additive manufacturing offers the choice between a realistic and a more abstract representation. This decision was important from a legal perspective as the look of the object might have influenced the judge's decision on its admissibility. At one end of the scale lies the most realistic appearance, but it has been shown by Bright and Goodman-Delahunty (15) that graphic depictions of injuries, for example, can have a strong emotive impact on jurors, therefore threatening the fairness of the trial proceedings. At the other end lies the more abstract representation option, which potentially violates the requirement for the evidence to be an accurate resemblance of the facts. In the present case, the model was produced to be as closely resembling the original as possible as it consisted of only a small section of the skull, which is not immediately recognizable as such, therefore limiting an emotional response. A white resin was chosen as the material to

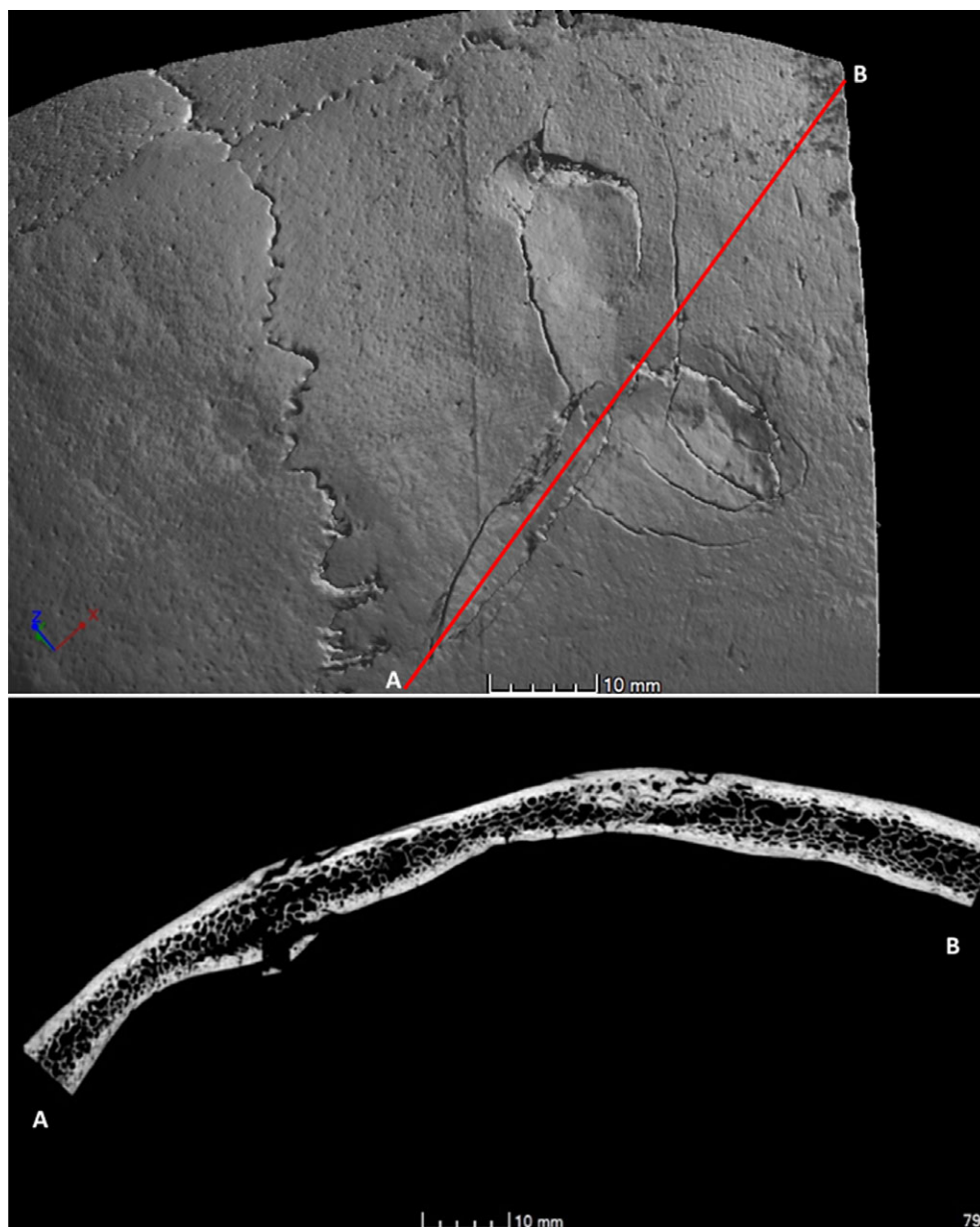


FIG. 3—Some of the injuries observed on the micro-CT scan are shown as the volume-rendered model (top) and as 2D section (A, B) through the bone (bottom).

represent the color of bone, but with an obvious plastic appearance and feel. The print resolution was higher than the original scan resolution; all detail was thus retained. This fine balance between realism and “sanitizing” was struck in this case as the model was admitted without objections from either party.

### Step 3—Presenting the Print

Once the evidence had been admitted, the CPS had to decide who should appear in court to give evidence in support of the model? It was agreed that an expert in metrology and measurement systems who was involved in the scanning and production of the print would be the most suitable choice for confirming the originality of the print and the processes involved in its creation. With the originality and accuracy of the evidence confirmed, the pathologist could then relate to the model and the CT images when testifying on the postmortem findings, and the jury was

able to refer to 3D evidence to better understand the medical evidence. Recent debate in the field of jury research appears split on the question whether jurors are capable of understanding and assessing complex medical or scientific evidence (see for example [16] for an argument for jury competence and [17] for a more sceptical view). Regardless of whether they are competent or not, visual and haptic evidence has the potential to improve understanding as it addresses the different learning styles encountered amongst the jurors (18) and maximizes the retention of information in the memory (9,19) by actively engaging them in the trial. Upon observation, the jury in this case appeared interested and attentive, taking extensive notes, during the presentation of the 3D print, a major benefit of demonstrative exhibits in general (20). Improvement in these areas is likely to contribute positively to the decision-making process of the jury deliberation by providing them with the necessary tools to reach a qualified and competent verdict. With trial by jury still at the

heart of our justice system, maintaining high quality of this stage is central to the overall functioning of the system.

## Conclusion

Digital 3D evidence is a powerful instrument to add clarity to expert testimony and reduce possible confusion surrounding scientific or medical evidence, thus equipping the jury with the best possible means to reach a well-informed verdict. Using a 3D printed object as demonstrative aid in a homicide trial, the barristers in the case presented here succeeded in keeping the jury's attention during a long, at times dry trial, and possibly improving their understanding of the pathological facts. It further allowed the court to demonstrate it has arrived in the 21st century which maintains its credibility in the public perception. However, physical models should be used with caution and only where they add to the existing evidence to avoid the unjustified risk of cognitive bias. In the case presented here, both defendants were found guilty of murder and sentenced to life imprisonment, although it is difficult to determine the role played by the 3D print.

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