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Original communication

# Three-dimensional imaging of human cutaneous forearm bite marks in human volunteers over a 4 day period

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ABSTRACT

*Introduction:* Human bite marks are often sustained during sexual, domestic or child abuse. Currently, analysis of these marks involves digital photography techniques along with an expert forensic odontologist opinion. Photographs often focus closely on the bite mark and give little context to the anatomical location of the injury. Due to variation in camera models and expertise of the photographer, photograph quality can affect its interpretation. Additionally, it can sometimes be days between injury and examination, allowing the injury pattern and colour to alter, making it harder to analyse.
*Aim:* To investigate if a 3D imaging technique, creating a time-lapse image of a bite mark in three dimensions, can provide context to the injury in terms of nature and location, and also allow analysis of the change in appearance of a bite mark over time.
*Method:* Participants had an experimental bite mark produced on their forearm by dental casts mounted on a dental articulator. The forearms were photographed immediately following the bite, and at intervals of 3, 6, 24, 48, 72 and 96 h. A DI3D® (Dimensional Imaging 3D) photogrammetry system and Autodesk Maya 2015® software was used to create a 3D animation from the images obtained. The clearest, long lasting bite mark injuries were selected for animation, enabling the 3D imaging technique to be used optimally.
*Results:* 3D time-lapse animations were successfully created with the ability to be viewed on most electronic devices. With further refinement this technique could be valuable in a number of areas. We anticipate animations produced in this way to have significant benefit to the presentation of photographic evidence in a court setting, and in age estimation of injuries.


## 1. Introduction

Documentation of injuries is a significant component of the forensic workload. Current practice involves simple sketch drawings and 2D digital photographs, albeit with a variety of photographic techniques often employed.[1,2] Interpretation of any injury seen in a photograph is unavoidably restricted by the limitations of 2D space, and the appearance of the injury at that one point in time. However, the art world has pushed the boundaries beyond sketches and photographs to create a multitude of methods of visualisation. The use of 3D technology in particular is ever increasing in medicine, for example surgeons print pre-operative models for surgical planning, and anatomy teaching includes 3D images. This is only possible with the aid of computer graphics and animation, or photogrammetry; the reconstruction of 3D models, using exact measurements from a series of photographs. If this technology exists in a medical capacity already it should be incumbent on forensic departments to evaluate and if appropriate adopt such techniques. Human beings are three dimensional; therefore, logically the most accurate representation of human injuries is one in 3D. The beauty of our healing processes is that we recover from damage with time, so by recording just one point in this sequence with a drawing or photograph, the potential for elucidating vital evidence reduces and learning opportunities diminish.

The aim of this study is to investigate 3D time-lapse imaging of experimentally produced bite marks, using pre-existing software commonly employed for facial recognition work to develop a reliable procedure for recording injuries. It also aims to determine whether this type of imaging could play a significant role in the future of photographic documentation of any injury in a living victim.

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## 2. Materials & methods

Participants for this study were recruited through the Centre for Forensic and Legal Medicine. Before recruiting began, approval was sought from The University Ethics Committee and granted. All volunteers were given a Participant Information Sheet and Study Protocol detailing the aims, methods and risks of the study. They were also asked to complete a medical questionnaire to assess their suitability. Bleeding disorders and anti-thrombolytic medications were amongst the exclusion criteria. Each volunteer who met the criteria for the study gave fully informed written consent in line with the most recent Supreme Court ruling on the updated UK law on consent.[3]

Before receiving the bite mark, a control image of each forearm was captured to give a baseline image of natural skin pigmentation, musculature, hair distribution, and any other unique features which would be present in all images. The purpose of having this image was to show contrast between undamaged skin, its immediate response to injury, and then track its healing process accurately.

Each participant had an experimental bite mark produced on their forearm, by dental casts mounted to a dental articulator. Dental casts were produced in die stone (Shera premium, Sherawerkstoff-technologie®, Lemforde, Germany) using impressions of the lead author's dentition. The casts were articulated on a semi-adjustable articulator (DenarMK II®, Prestige dental, Bradford, England, UK) and placed within the mechanical apparatus. This consisted of a metal frame which supported a central vertical rod and loading platform. The study utilises similar apparatus and techniques for causing a bite as previously described by Chinni and Forgie.[4]

Previous studies in Western populations have shown the average maximum bite force in the anterior region to be 120–350 N.[5] Therefore, the participants each received a bite at approximately 60% of an average maximum human anterior bite force.

Each participant placed their forearm against a custom made arm board (Fig. 1) within the mechanical apparatus and loosely gripped a hand hold. In this resting position the dental casts made light contact around the anterior aspect of the forearm. 20 kg weight was placed on the loading platform for 15 s after which it was immediately removed. The second photograph, at a time of 0 h post-injury, was taken to show the immediate inflammatory reaction with 2 further photographs at 3 and 6 h. The remainders of the photographs were taken at 24, 48, 72 and 96 h post-injury. During the photography sessions, the arm board was bolted to the top of a standard photography tripod for continuity of forearm positioning. In line with best practice in photographic documentation of injuries, a combination ABFO #2 scale and colour chart was present in all of the images.[6]

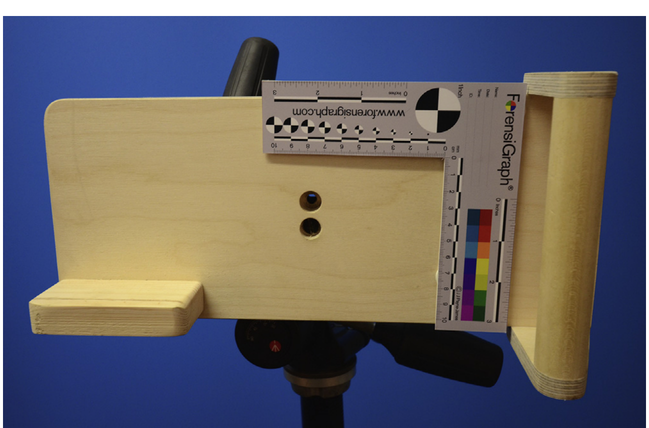


**Fig. 1.** Custom designed arm board.

The images were captured using a passive stereo photogrammetry system, designed for high resolution 3D facial image capture. We used a DI3D® (Dimensional Imaging 3D) photogrammetry system (High Fidelity 3D Facial Image Capture, DI3D System®, Dimensional Imaging, Glasgow, Scotland, UK), with a set-up of 6 cameras (Canon EOS 60D®, Canon Inc., Tokyo, Japan) angled to each capture a different view of the target object[7] (Fig. 2). The photogrammetry system combines these 6 photographs to create a surface model using its software algorithms (Fig. 3). The surface model typically contains several hundred thousand individual points which were triangulated and reconstructed using the views of those points from each camera. The points were then joined together to create a mesh of small polygons giving the model a solid appearance, in line with the nature of the arm (Fig. 4). In areas which are not fully imaged by any of the cameras, such as the top of the forearm, these polygons can become stretched as the system attempts to fill in the gaps. This surface distortion is present in the animations, however it had no impact on the findings since it only affects the extremities of the 3D models. The cameras were aligned to focus centrally on the bite mark, achieving maximum detail capture over the area of interest. If necessary, the cameras can be recalibrated using a different focal point in order to take photographs of other areas such as the lower limb or torso. A photo-realistic texture was then applied to the 3D surface model using the best view of each polygon from the 6 photographs (Fig. 5). The application of this texture ensures that the virtual model is as close to the photographed arm as possible. At each time period, for each participant, the DI3D photogrammetry system outputs a textured 3D model which corresponds to that particular time. This gave us 8 models, and 48 individual photographs, per participant over the course of the study.

To create the animation the complete set of models from a participant were loaded into one scene in Autodesk Maya 2015®. Firstly, where necessary, position adjustments for each model were made to ensure all 8 models were aligned using the constant position of the tripod and common skin landmarks where present. A keyframe animation technique was used to produce a short video showing each of the 8 models in sequence, from the control model through to the final 96 h post-injury model. Virtual camera movements were added to direct focus towards the bite mark. This allows a viewer to observe the final animation not just as a sequence of static images but with a changing viewpoint arcing from left to right during the transition between each model. Rendering was completed using the Software Renderer in Autodesk Maya®, to create a series of finished high-resolution images suitable for creating an output video.

Supplementary video related to this article can be found at http://dx.doi.org/10.1016/j.jflm.2016.02.003

Adobe Photoshop CS6® was used to create a series of images depicting a progressing timeline. This extra 2D imagery was added to the animation using Abode After Effects CS6® to indicate the transition between models and act as a marker for each model's place in the sequence. The completed animation was exported as a video in MP4 format ready for presentation. Throughout these processes there were no changes to the geometry, texture, lighting or colour of the original images in order to preserve the original photographs and present the injuries accurately. For legal purposes, an audit trail can be obtained from all of the software packages used.

## 3. Results

10 participants took part in this study, 5 of whom were male and 5 female. All participants were young adults in good general health.