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A fully synthetic lung model for wound-ballistic experiments—First results

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ABSTRACT

Purpose: Today, synthetic models have all but replaced animal and corpse models in examining damage to soft-tissues and skeletal structures by ballistic trauma. As, however, non-solid organs such as the lungs, have not been able to be replaced by a fully synthetic model we attempted to create such a model.
Material and methods: 20% ordnance gelatine was frothed with a household mixer and cooled to stable foam. Several of these foam blocks were then stuck together with liquid gelatine and placed between 10% gelatine blocks. As controls, we embedded pig lungs in gelatine and compared the wound channels seen in computed tomography created upon shooting with 9 mm Luger.
Results: The fully synthetic models displayed radiological and physical densities comparable to real lungs. The wound profile characteristics of the fully synthetic lung models were very similar to the semisynthetic swine-gelatine models regarding the permanent wound cavity. Furthermore, in both semi- and fully synthetic models we detected a ring surrounding the permanent wound channel, most likely representing the remnants of the temporary wound cavity.
Conclusion: Our results indicate that this fully synthetic lung model is a viable substitute for ballistic experiments on lungs. We believe that further research on the temporary wound channel in lungs is possible with this model in order to provide more insight into the effect of ballistic trauma to the lungs not seen otherwise.

1. Introduction

Due to the complexity of bullet–tissue interaction, the field of wound-ballistics still strongly relies on experiments in order to understand the injuring capacity of a certain ammunition type, e.g. the wound profile. The wound profile refers to the penetration depth, the bullet deformation/fragmentation, the diameter of the permanent and the temporary wound cavity.

Fackler [1] noted that certain zones surround the permanent wound channel, namely a zone consisting of tissue damage as the innermost ring, followed by a zone of extravasation and then a zone presenting stretched but unharmed tissue. The volumes of these zones are proportional to the energy delivered by the bullet to the tissue.

Animal models have been used in the past (and are still used to a lesser extent still today) as a substitute for humans when performing such wound ballistic experiments. However, animal models have several drawbacks. Firstly, the killing of animals for the sole purpose of performing shooting experiments is ethically questionable. Secondly, although porcine tissue is believed to be comparable to human tissue in gunshot experiments [2–4] animals obviously do not mirror human anatomy. Especially the skeleton has major differences regarding thickness and length of the long bones, not to mention an entirely different skull shape than humans. Furthermore, animals – even from the same species and age – tend to differ significantly from each other, thus leading to different results despite otherwise identical experimental settings.

Due to the above-mentioned drawbacks, synthetic models have been implemented. One of the main advantages besides ethical issues is that synthetic models can be created identically, thus delivering very reproducible results. Synthetic soft tissue models have been used for a considerable amount of time. Either glycerine soap or ordnance gelatine is used as a soft-tissue substitute [5,6].

Agar has also proven to be a viable substitute for brain tissue [7]. Osseous structures have also been substituted, either as simple

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spheres or tubes, with or without latex covering mimicking the periosteum, or as highly complex anatomically correct skeletons made of polyurethane.

In order to simulate gunshots through osseous structures, synthetic models have been used in the past, usually in conjunction with soft-tissue simulants [8–11].

However, although soft-tissues such as the musculature and solid organs as well as the skeleton have been able to be substituted by entirely synthetic models, other intricate organs have to date not been able to be replaced. One of these organs is the lung. By virtue of its predominant anatomic build, namely alveoli, it is tremendously difficult to create a synthetic model mirroring injuries in real lungs for wound ballistic experiments.

One solution to this problem was delivered by Bresson et al. This group combined a soft-tissue simulant with real animal tissue – pig lungs – and by doing so delivered reliable results in the reconstruction of a fatal hunting incident [12]. However, this approach still relies on animal tissue.

We therefore asked ourselves how to create a wholly synthetic lung model for the reconstruction of bullet courses through the lung in order to study the interaction between the bullet and the lung tissue.

2. Method and materials

We created 5 semisynthetic and 5 fully synthetic lung models which were then shot at using 9 mm Luger full metal jacketed ammunition (9 mm Luger full metal jacket round head, mass 8 g, RUAG Ammotec Schweiz AG, Winterthur, Switzerland). The fully synthetic models were examined regarding their radiological density (Hounsfield Units, HU), their physical density and their texture, as determined by palpation by two board-certified forensic pathologists and a forensic autopsy technician who have performed many thousand autopsies and the energy transfer, as documented using light barriers.

The wound channels were examined with computed tomography (CT) with regard to permanent wound cavity and temporary wound cavity.

2.1. Model generation

2.1.1. Semisynthetic models

5 lungs from young adult pigs were obtained from a local abattoir and inflated by pumping air into the trachea. The trachea was then bound off and the inflated lungs were then set into buckets. Using ordnance gelatine powder (Type 3 Photographic Grade, GELITA AG, Uferstr. 7, 69412 Eberbach, Germany) we made 10% ordnance gelatine as described previously [6] which we then filled into the buckets containing the lungs, taking care to immerse the lungs completely. The thus created models were kept at 4–5 °C.

2.1.2. Fully synthetic models

We made a 20% gelatine–water mixture using ordnance gelatine powder (Type 3 Photographic Grade, GELITA AG, Uferstr. 7, 69412 Eberbach, Germany) and mixed this with a standard household mixer. The hereby produced foam was poured into a cast and immediately cooled down to 4–5 °C. The then solid foam supernatant was then cut off the solid gelatine beneath it. This procedure was repeated 4–5 times. The gelatine foam blocks were then stuck together using molten gelatine (10%) as glue (Fig. 1).

These glued foam blocks were then placed between two 10% gelatine blocks substituting the chest wall.

The phantoms were kept at 4–5 °C.

Fig. 1. 6 blocks of gelatine foam are stuck together.

2.2. Material testing

2.2.1. Physical impression

The fully synthetic lung tissue was judged physically by cutting, stabbing and squeezing by experienced forensic pathologists (SAB, SE) and an experienced forensic autopsy technician (SAP). These subjective impressions were compared to those of normal, non-congested human lung tissue as seen at autopsy.

2.2.2. Radiological density

In order to evaluate the radioopacity, i.e. the radiologic density of the fully synthetic model, we compared the Hounsfield values with those of healthy human victim's lungs without pulmonary pathology such as aspiration, emphysema, congestion, or oedema.

2.2.3. Physical density

The physical density of the foam of the fully synthetic models was calculated by determining the volume and the weight.

2.2.4. Shooting

All semi- and fully synthetic models were then shot at using a SIG Sauer P226 and 9 mm Luger full metal jacket (FMJ) round head ammunition from a distance of 370 cm from the models.

2.2.5. Energy transfer

The energy transfer was calculated by subtracting the pre- and post-phantom kinetic energies. To obtain these energies we documented the bullets velocities by light barriers in front (BMC12, Werner Mehl Kurzzeitmesstechnik, Schulweg 1, 91583 Diebach/Germany) and behind (BMC21a, Werner Mehl Kurzzeitmesstechnik, Schulweg 1, 91583 Diebach/Germany) the phantoms. Based on these velocities (v) and the mass (m) of the bullets (each 8 g) we calculated the kinetic energies as the result of 1/2 the product of the mass and the square of the speed ($E_{kin} = {}^1\!/_2 mv^2$).

Five measurements were performed on the fully synthetic phantoms and one measurement was performed on the semisynthetic phantom for comparison.

2.2.6. Imaging

CT imaging was performed using a 128 slice Dual-source Multidetector row scanner (Somatom Definition Flash, Siemens Healthcare, Erlangen, Germany).

The gelatine phantoms containing the projectiles were scanned on the CT at 140 kV using a tube current time product of 1200 mAs, a slice collimation of 0,6 mm, a rotation time of 1 s and a spiral pitch factor of 0,35 mm.