A preliminary study in to the viability of sponges as a proxy for *sus scrofa (domesticus)* lungs for ballistic evaluations.

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Abstract. While tissue simulants are considered best practice for ballistic evaluations, there is an ongoing debate about the use of tissue simulant and their relevance and there are calls to improve models by making them more anatomically relevant by the introduction of bony structures and organs. Therefore; the aim of this study was to try and determine if sponges and/or ballistic gelatin may be a suitable proxy to porcine lungs using 5.56x45mm (MK262-MOD1). Four sample groups consisting of 10% ballistic gelatin blocks, lungs embedded in gelatin, kitchen sponges and car sponge in gelatin were evaluated. Analysis included determining the onset of yaw, time from impact to the onset of yaw, temporary and permanent cavity characteristics and energy deposition. The results indicated that the kitchen sponge and car sponge may be a suitable proxy to porcine lungs, however there were significant differences between the lung model and plain gelatin blocks and additional work should be carried out to investigate the suitability of sponges as a proxy to porcine lungs further.

1. Introduction

Between 2003 to 2014, thoracic wounds represented 15% of gunshot injuries recorded in the UK Military Joint Theatre Trauma Registry (JTTR) In Iraq and Afghanistan (1), and represents 34-36% of civilian gunshot injuries (2).

The area of the body between the neck and the abdomen that contains critical organs for respiration and circulation such as the heart and lungs is known as the thorax (3). The lungs are enclosed by a serous membrane known as the pleura which consists of two layers, the visceral and the parietal pleura which forms the pleural cavity (3).

Previous research has concluded that ballistic trauma caused by projectiles depends on a number of factors such as impact energy, energy deposition and onset of yaw as well as wound location (4-9). Lungs have a low specific gravity and are highly elastic and therefore are fairly resistant to the damaging effects of high velocity projectiles, although it is not clearly understood how the alveoli and bronchioles within the lungs interact with projectiles.

Projectiles affect tissue by three different mechanisms, these are the formation of a temporary cavity and the subsequent permanent cavity and wound tract and generation of a shockwave, (10).

Physical models have traditionally been based on animals, but tissue simulants have been used as injury models. Tissue simulant used in the evaluation of wound ballistics include simulants such as ballistic gelatin and ballistic soap (5, 11-23).
Gelatin as a ballistic model was developed to replicate projectile behaviour within porcine hind limbs (6, 12, 13, 18); therefore using gelatin as a tissue simulant is best reserved for comparisons rather than using it as a surrogate.

While tissue simulant are considered best practice for ballistic evaluations, there is an ongoing debate about the use of tissue simulant and their relevance (19, 21) and there are calls to improve models by making them more anatomically relevant by the introduction of bony structures and organs (19).

Therefore; the aim of this study was to try and determine if sponges and/or ballistic gelatin may be a suitable proxy to porcine lungs.

2. Methodology

2.1. Ammunition

The ammunition used in this preliminary study was 5.56 x 45 mm MK262-MOD1 with a 77gr open tip match projectile. The projectile had an average velocity of 779±5m/s and was fired from 10m using a custom-manufactured action and barrel system with a 1 in 7 inch twist rate. The MK262-MOD1 ammunition was chosen for this study as it has a projectile which features in both civilian and military ammunitions.

2.2. Sample groups

Four sample groups were investigated, these were plain gelatin blocks as a control, porcine lungs, scrubber kitchen sponges (kmart, nz) and jumbo car sponges (OKS, china) (figures 1-4).

2.3. Ethical considerations

Although this study involved the use of animal tissue, ethical approval was not required as the tissue came from the food chain.

2.4. Sample Preparations

2.4.1. Ballistic gelatin. 10% gelatin (Gelita 250 Bloom Type A) blocks (250mm(W) x 250mm(H) x 450mm(L)) were manufactured in accordance with Defence Technology Agency (DTA) technical instructions (24). The gelatin was cured overnight at room temperature and subsequently moved to a chiller at 4°C for a minimum of 24 hours. The biomechanical properties of gelatin are affected by temperatures (25, 26) and therefore the models were shot within 10 minutes of removal from the chiller to ensure they remained at 4°C during testing, this was confirmed using a2024T Digitron probe thermometer (Digitron, UK).

2.4.2. Lung models. Pairs of lungs were acquired from a local abattoir and were inspected for damage, the lungs were then separated with the left lung being utilised for the study. The bronchial tubes were clamped off and a plastic tube was inserted in to the trachea and secured. The lungs were placed in water and were inflated with 3 litres of air and water displacement was used to confirm the amount the lungs were inflated by and the tubes were clamped off and sealed. The lungs were then placed in cool gelatin (approximately 45°C) and allowed to float to the surface, where they were then held 50 mm
below the height of the mould using a wooden brace held in place by a retort stand. The gelatin was topped up to 25 mm below the height of the mould and left to cure overnight. 24 hours later the retort stand and wooden brace was removed leaving the lung under a thin layer of set gelatin and a second pour of cool gelatin was used to fill the gelatin to the top of the mould. While the two-pour technique produces an additional interface within the gel block previous studies have showed that this interface does not interfere with temporary cavity or radial tear formation (22, 23). The blocks were stood on their end and backed by a second calibrated plain gelatin block and secured with straps (figure 5).

2.4.3. Sponge models. Sponge models were constructed by removing the scouring pad from the sponge, cutting a section of gelatin out of the block to allow the sponges to be correctly positioned at 50mm from the face of the block. The cavity created for the sponges provided a close fit, but did not cause the sponges to compress (figures 6-7).

2.5. Gelatin Calibration
To calibrate the gelatin a 4.5mm copper-coated ball bearing (BB) was fired into the block from a Daisy Powerline air rifle (Daisy, USA) at two separate velocities. The depth of penetration was measured to the back of the BB using a Mitutoyo Absolute vernier calliper (Mitutoyo, Japan) (resolution of ±0.01 mm), and the diameter of the BB was then added. Blocks passed calibration if all spheres met the depth of penetration equation \( \text{DoP(mm)} = 0.584x - 20.12 \pm 5\% \) where \( x \) is in the impact velocity \( \text{(m/s)} \)(27).

2.6. Equipment Set – Up
A Photron SA-X high speed video camera (Photron, USA) operating at 30000 frames per second was used to record projectile and lung/simulant/gelatin interaction. Projectiles impact velocities were measured using an Oehler Model 36 Chronograph with three Model 57 screens (Oehler, USA) placed directly in front of the models.

2.7. Analysis
2.7.1. Model Analysis. The models were analysed to evaluate projectile fragmentation, energy deposition, onset of yaw, time of impact to the onset of yaw, depth to temporary cavity centre, temporary cavity area, and projectile tract diameter, depth to maximum gelatin disruption, and sum of the three largest shear planes, neck length, and projectile angle of deviation. Mathshop Expected Kinetic Energy (Mathshop, UK) software was used in conjunction with high-speed video (HSV) to determine overall velocity reduction, onset of yaw, time of impact to the onset of yaw, neck length and temporary cavity area and location. Neck length, temporary cavity area and location were calculated when the temporary cavity was at maximum expansion seen in the HSV (Figure 8).

The blocks were sliced into 20mm sections and inspected for projectile fragments and exiting fragments were collected. Both the retained and exiting projectile weight was calculated as a percentage of the original projectile weight and energy deposition was calculated using projectile impact and exit energy.

Projectile tract diameter, the sum of the three largest radial tears and the depth they occurred were measured where the greatest amount of gelatin disruption was visible (Fig. 9).

The impact position and the position of the projectile tract at the greatest amount of gelatin disruption was used to determine the angle of deviation in the plane that the projectile travelled.

![Figure 8. Temporary cavity](image1)
![Figure 9. Permanent wound channel](image2)

2.7.2. Statistical analysis. IBM SPSS Version 25 (IBM, USA) was used to carry out a Shapiro-Wilks test to confirm the normality of the data. Data with normal distribution, had a parametric One-way Analysis of Variance (ANOVA) and Tukey's multiple comparison tests performed. Where data did not have a normal distribution, a non-parametric Kruskal Wallis and Mann-Whitney U test were performed. P-values below 0.05 were deemed 'significant'.

3. Results and discussion
All blocks passed calibration before testing. Table 1 is a summary of the results with statistical analysis.

| Metric                          | Lung (n=3) | Gelatin blocks (n=5) | Small sponge (n=3) | Large sponge (n=4) |
|--------------------------------|------------|----------------------|--------------------|--------------------|
| Depth of the onset of yaw (mm) | 175±26     | 153±15               | 154±8              | 158±28             |
| p-value                        | 0.153      | 0.27                 | 0.302              |                    |
| Energy deposition (%)          | 99.7±0.4   | 92.4±6.0             | 99.9±0.2           | 99.7±0.6           |
| Metric                                      | Lung (n=3) | Gelatin blocks (n=5) | Small sponge (n=3) | Large sponge (n=4) |
|--------------------------------------------|------------|----------------------|--------------------|-------------------|
| of impact velocity) p-value                | 0.143      | 1.000                | 0.429              |
| Temporary cavity area(cm²) p-value         | 483±23     | 534±29               | 505±32             | 508±20            |
| Depth to temporary cavity centre (mm) p-value | 239±27     | 173±9                | 206±7              | 225±20            |
| Projectile tract diameter (mm) p-value     | 9±2        | 10±3                 | 8±2                | 10±1              |
| Sum of 3 largest shear planes (nearest mm) p-value | 177±10     | 186±11               | 188±26             | 190±12            |
| Depth to maximum gelatin disruption (mm) p-value | 205±15     | 178±28               | 195±9              | 246±99±2          |
| Neck length (mm) p-value                   | 102±21     | 153±15               | 79±9               | 106±9             |
| Time after impact to yaw (ms) p-value      | 0.2±0.03   | 0.1±0.02             | 0.2±0.01           | 0.2±0.04          |

Note: average mean±SD. *Statistical significant difference between groups (p<0.05)

There were no significant differences observed in any of the parameters evaluated between the porcine lungs and the kitchen sponges or the car sponges, this is despite the sponges being different thicknesses. This indicates that sponges may be a suitable proxy for lungs.

Significant differences were observed in neck length, time of impact to the onset of yaw and the temporary cavity location between the lungs and plain gelatin blocks. This increase in the time of impact to the onset of yaw, is likely to be responsible for the longer neck length and a later temporary cavity location. It is unclear as to why the plain gelatin block has a later time of impact to the onset of yaw, but it is thought that the projectiles interaction with the lung is likely to induce the onset of yaw earlier.
This study has a number of limitations. The sample sizes were small and only one nature of ammunition at one velocity was evaluated. Different types or ammunition design such as expanding ammunition may show different results.

Further work should look at additional testing of sponges as a proxy for porcine lungs, including testing other natures of ammunition. Other sponges may produce different results and should be validated.

4. Conclusions
The findings from this study indicate that both kitchen sponges and car sponges may be a suitable proxy for inflated lungs and further work should be carried out to increase the sample size and evaluate other ammunition natures to confirm this.

The findings also show that the plain gelatin blocks produce significantly different results to the lungs and therefore highlights that consideration of the results should be given when translating results from plain gelatin blocks into thoracic injury models.

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