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The evaluation of two commercial electric sheep stunning systems: current applied and the effect on heart function

Running Title: ECG in Sheep

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Abstract

The maintenance of head-only minimum stunning currents for sheep to ≥1.0 Amp (EC Regulation 1099/2009) was examined in two trials in a commercial abattoir. In the first trial, a Jetco MS100 stunner failed to maintain the current to >1.0 Amp in 118 of the 228 sheep. In a second trial a Jetco MS105 delivered sufficient current in all sheep (n = 275) to meet the legislative requirement, apart from a single animal. Recorded electrocardiograms showed a regular heartbeat, with no evidence of ventricular fibrillation, in all animals in both trials following stunning and neck cut. Only one of the two stun units may therefore be considered to meet the requirements of EC 1099/2009 but both may meet the requirements for halal slaughter where pre-stun is considered acceptable.

Introduction

There are two types of slaughter of animals for food production from an animal welfare perspective, slaughter with stunning and slaughter without stunning. The derogation from stunning within current legislation (EC 1099/2009) permits religious groups to perform slaughter without stunning where their beliefs dictate. However, the requirements for Halal slaughter can be interpreted to permit the use of a stunning method provided the animals are slaughtered whilst healthy and alive and that the stunning method is recoverable (Fuseini et al 2016). Head-only electrical stunning is therefore accepted by many Muslim groups but any change in the applied electrical parameters, for example the requirements of EC Regulation (1099/2009) must be tested to show that there is no change in the animal's ability to recover after the stun.

Effective stunning can be produced when sufficient current is passed through the brain. The total impedance of the pathways between the electrodes will depend on the shape, size, material and cleanliness of the electrodes, tissue resistance, the pressure applied during stunning and the voltage used. The time taken to break down the inherent high resistance of living tissue is shorter when higher voltages are applied (Wotton & O'Callaghan, 2002). EFSA (2004) reported that when constant voltage stunners are used, the current starts to flow from zero to the maximum, which would be time dependent on the magnitude of the voltage. However, constant current stunners are designed and constructed in such a way that they anticipate high resistance in the pathway and hence start with the maximum available voltage. ~~which in the case of the Jetco MS105 studied in trial 2 was 474 Volts rms.~~ Owing to this, the target current is reached within the first few current cycles (within milliseconds of the start of current application) and the applied voltage may also be modulated according to the changes in the resistance. Therefore, constant current stunners are preferred to constant voltage stunners (EFSA 2004)

Stunning an animal prior to slaughter is defined in EC Regulation (1099/2009) as: "any intentionally induced process which causes loss of consciousness and sensibility without pain, including any process resulting in instantaneous death". The duration of this unconscious state must be long enough to prevent the animal from regaining consciousness before death occurs by exsanguination.

EFSA (2004) reported that cardiac ventricular fibrillation threshold testing in experimental models suggests that cardiac tissue is most sensitive to stimulation between 30 and 60 Hz of sine wave alternating current and increased stimulus duration increases the effectiveness of the application (Weirich et al 1983). However, the induction of cardiac ventricular fibrillation would depend upon the delivery of sufficient electrical current to the myocardium. EC Regulation 1099/2009 came into operation in January 2013 and specifies the minimum head-only electrical stunning current as 1.0 Amp for sheep. Previous Codes of Practice (HSA Guidance Notes 1999) had suggested 1.0 Amps for sheep and 0.6 Amps for lambs. Therefore, concern was raised within the Muslim population as to the effect an additional 0.4 Amp at 50 Hz AC could have on the potential for ventricular fibrillation (cardiac arrest) at stunning in lambs. The introduction of WATOK (2015) in England has permitted religious groups exemption from the minimum electrical parameters required for an effective stun as laid down in EC Regulation (1099/2009), Annex 1. Nevertheless, the application must render the animals unconscious as assessed by both the Official Veterinarian (OV) and the Animal Welfare Officer (AWO).

Previous research has demonstrated that head-only electrical stunning is fully recoverable (Velarde et al 2002; Cook et al 1995, 1996; Velarde et al 2000). However, Gregory and Wotton (1984) found that one sheep of a sample of 61 that received head-only stunning (3 s at 1 Amp, 50 Hz AC) showed ventricular fibrillation. Warriss and Wotton (1981) showed a similar occurrence with pigs, head-only stunned with 90 volts AC for 15 s. Therefore, there is a possibility that head-only electrical stunning at low frequency could affect the heart of some sheep. This trial was undertaken to determine whether the application of 1.0 Amp at 50 Hz AC to lambs and sheep would result in a ventricular fibrillation and hence the death of the animal, contrary to halal requirements.

Materials and Methods

Two trials were conducted at a commercial abattoir with a throughput of up to approximately 1,500 sheep per day, and a line speed of approximately one sheep per 4.5 seconds. The first took place on 4th February 2014, the second on 27th January 2015 following the installation of a new electric stunner. The abattoir used a single v-restrainer to move sheep from the lairage to the point of stunning and sticking, producing sheep acceptable to the halal market, but with all sheep receiving a pre-slaughter electrical stun. Sheep were supplied to the v-restrainer in batches of either ‘old season lamb’ (OSL) or of adult ewes from the lairage holding pens. No special arrangements were made for the trials regarding the sheep processed or their processing. The line ran as it would on any other normal day to ensure that the measurements made were representative of normal commercial practice.

Sheep were individually stunned at the head of the v-restrainer using a Jarvis Model 1J two-pronged handset (JETCO Jarvis Engineering Technologies, Auckland NZ), with a built-in water spray to help reduce contact impedance. The stunning system used in the first trial was a Jarvis Jetco MS100, manual, head-only electrical stunning system, designed to deliver a “choke limited” current of at least 1 amp, and set at 1.5A, 50Hz sine wave AC. In the second trial this was upgraded to a Jarvis Jetco MS105 current limited stunner, again set at 1.5A (stun current threshold), 50Hz sine wave AC. The Jetco MS105 included a light and alarm when the required stun duration was reached and a separate miss-stun signal that was initiated if the stun current threshold was not reached. After stunning, the sheep were rolled out onto a table where they were stuck and shackled to a conveyor line for further processing.

All electrical information was recorded onto an eight channel Vision Data Acquisition System (Vision XP-LDS Nicolet) with sampling rate set at 20KHz. The RMS current, RMS voltage and stun duration were later extracted from the recordings.

Stunning voltage was measured using a differential alternating current (AC) voltage probe (Elditest GE8115) across the electrical output from the stunner control unit to the stunning electrodes. The voltage probe measured AC voltage across the electrodes and produced a matching, low voltage waveform onto the Vision DAS. Stunning current was measured using an AC current clamp (Fluke i30s) around the positive electrical output from the electrical stunner to the stunning electrodes and was connected directly to the vision DAS.

Post-stun electrocardiogram profiles were recorded for the sheep sampled using a system specially designed to transfer electrocardiogram data onto the Vision DAS. Following stunning, shackling and neck cut, individual animals had fine needle electrodes in a bipolar apex lead array inserted sub-dermally. The needles were attached to leads of a sufficient length to allow time for the ECG to be recorded successfully as the animals travelled along the overhead rail during bleeding. The ECG signal was amplified using a Gould Bio-amp, set to filter out waveforms above 40 Hz (High pass) and below 2 Hz (Low pass). The signal was then passed through a Humbug 40/60Hz filter to eliminate background noise from the mains supply. The presence of ventricular fibrillation was assessed at the time of recording and verified retrospectively by examination of the ECG profile for a rhythmic QRS complex.

Due to the time constraints of recording individual animal details at stunning, and ECG as a sheep moved on the conveyor line, data were collected for approximately every 5th old season lamb (OSL) and approximately every 4th adult ewe. In the first trial only the electrical parameters of the stun were recorded and whether an animal was an OSL or ewe. In the second trial further details were recorded at the time of the stun: wool cover (on a scale of 1 to 5 (Figure 1)), the presence of horns, whether the animal was properly wetted prior to the stun, and electrode placement: in which position 1 was where the electrodes were placed in front of the ears; position 2, where the electrodes were placed in line with the ears and position 3, where the electrodes were placed behind the ears and towards the neck. This scoring system and the normal electrode placement positions were identified during a prior visit to the abattoir.

Figure 1 Here

To facilitate the further measurements taken and to match individual sheep to the electrical stun data, in the second trial the sheep to be sampled were marked across the shoulders with a coloured spray in the lairage section of the v-restrainer before stunning and were also identified on the Vision Data Acquisition System (Vision DAS) immediately after stun with a pulse marker triggered by the researcher recording the physical details of the sheep and the stunning process.

For both trials the cold carcass weights of all the animals within a batch were available. These were not matched to individual sheep but were used to calculate a mean weight for the batches from the lairage pens.

The study was approved by the University of Bristol's internal ethical review process.

Statistical Analysis

The percentage of sheep showing a 'normal' ECG following stunning and sticking is reported together with a 95% confidence interval for the estimate, calculated using Wilson's method (Altman et. al., 2000). Summary statistics are reported for the stun parameters. Additionally, general linear models were used to assess the effect of the sheep specific variables recorded in trial two on the RMS current achieved. The residuals from the model were assessed for normality and homogeneity of variance.

The ability of the two stunners to maintain a stun current above a threshold despite differences in resistance between individual sheep is of importance. The relationships between current, voltage and impedance for the individual stuns from both trials are presented as a series of graphs. The results of a bench test of the Jetco MS105 used in trial 2 are also presented.

Results

In trial one electrical stun parameters and ECG were recorded for 228 sheep (144 OSL, 79 ewes and 5 rams). The mean duration of current application was 3.9s (± 0.544 sd). All 228 sheep showed continued heart function following stunning and sticking and no animals displayed ventricular fibrillation in their ECG. An example of an electrocardiogram recorded within the trial is shown in Figure 2 and summary statistics for the trial are shown in Table 1.

Figure 2 Here

Table 1 Here

It can be seen from Table 1 that the minimum RMS current recorded was 0.42A. One hundred and eighteen of the 228 sheep (52%) received an RMS current that was less than 1.00 A. The distribution of RMS current recorded is shown in Figure 3.

Figure 3 Here

In trial two electrical stun parameters and ECG were recorded for 275 sheep (225 OSL, 50 ewes). In trial two, the mean duration of current application was 3.42 seconds (± sd = 0.062 sd) for OSL and 3.44 seconds (± 0.023 sd) for adult sheep, respectively. All 275 sheep showed continued heart function following stunning and sticking and no animals displayed ventricular fibrillation in their ECG. Summary statistics for the trial are shown in Table 2.

One animal received a RMS current of less than 1A. The distribution of RMS currents seen in trial two is shown in Figure 4.

Table 2 Here

Figure 4 Here

Across both trials 100 per cent of animals showed continued heart function as demonstrated by ECG. A 95% confidence interval for all animals in the trial is 99.2 to 100%, for OSL alone 99.0 to 100%, for ewes 97.1 to 100% and for the 5 rams the 95% confidence interval is 56.6 to 100%.

Using data from trial 2, a general linear model was used to test for an effect of stun order, electrode placement, carcass weight, the presence of horns, and degree of wool cover on the RMS current achieved. All predictive variables bar 'the presence of horns' and 'electrode placement' were treated as continuous variables. There was a highly significant relationship between the order in which the sheep were stunned and the RMS current ($p < 0.001$), with a mean decrease in current of 2.05×10^{-4} (se 0.433×10^{-4}) A per sheep recorded throughout the study (note that approximately every fifth animal on the line was recorded). There was a trend for an effect of wool cover which failed to reach statistical significance ($p = 0.083$), in which each unit increase in wool cover score was associated with a 5.87×10^{-3} (se 3.376×10^{-3}) A decrease in RMS current ie only approximately 6mA decrease in current for every unit increase in wool cover.

The output of the Jetco MS105 was bench tested to measure the effect of increasing impedance on voltage and current output using the stunner's 1.5 Amp setting. The bench test results of the Jetco MS105 are shown in Figure 5.

Figure 5 Here

Figure 6 shows a plot of the sheep impedances, (calculated from the RMS voltage and RMS current using Ohm's law) against the applied RMS voltage recorded from the two different stunners in trials one (Jetco MS100) and two (Jetco MS105). The results from the Jetco MS105 bench test are also superimposed as a solid line. For further clarification of the performance of the two stunners, Figure 7 shows the relationship between impedance (calculated) and the measured RMS voltage for each animal in the two trials. The results from the Jetco MS105 bench test are superimposed as a solid line and the theoretical relationship that would be seen with a constant voltage source of 320 V is given as a dashed line.

Figure 6 Here

Figure 6. The relationship between sheep impedance, (calculated from the RMS voltage and RMS current using Ohm's law) and the applied RMS voltage from the two different stunners in trials one (Jetco MS100) and two (Jetco MS105). The results from the Jetco MS105 bench test are superimposed as a solid line.

Figure 7 Here

Figure 7. The measured RMS current output of the two stunners tested in trials one (Jetco MS100)1 and two (Jetco MS105)2 plotted against the impedance (calculated) of the individual sheep. The MS105 bench test results are shown as a solid line and the theoretical relationship (V = I x R) for the current given a constant voltage of 320 V is shown as a dashed line.

Discussion

Heart Activity: The halal requirement for the stunning method to be recoverable and therefore for animals to be alive at the time of slaughter was met with every stunning application in both trials (n = 503). The recorded ECG demonstrated continued heart function following stunning and sticking and no animals displayed ventricular fibrillation in their ECG. The amount of current delivered will depend upon the voltage and total impedance in the pathway (between the electrodes). It is possible that with very long application times at low frequency (50 Hz) the current field developed by a head-only application could have spread sufficiently to affect cardiac tissue and induce ventricular fibrillation, but in practice this~~ese~~ was shown not to occur. The average stun application time was <3.5s during both trials which was insufficient to result in a ventricular fibrillation in any of the animals recorded. Further insurance against the induction of ventricular fibrillation would be to increase the frequency of the stunning current ~~but this~~which would significantly increase the threshold current required for fibrillation (Weirich et al 1983).

Trial 1. Jetco MS100: The requirement of a minimum current of 1.0 Amp for all classes of sheep (EC 1099/2009) was not achieved during trial one using the Jetco MS100 stunner. The voltage range produced of 213 to 404 V (Figure 6 and Table 1), did not maintain the current above the chosen setting of 1.5 A. It can be seen from Figure 7 that in reality the output current produced by the Jetco MS100 was little better than would have been achieved by a constant voltage of 320 V and therefore this stunner showed little if any current control.

Trial 2. Jetco MS105: The Jetco MS 105 delivered sufficient current to meet the legislative requirement of 1.0 A (EC 1099/2009) for all except one of the 275 animals in trial two, for which the current was 0.97 A. The limiting factor with all electrical stunning equipment that employs some form of current control is the maximum voltage that the output can reach when applied across the impedance of the animal's head. The maximum voltage produced by the Jetco MS105 when tested in the laboratory was 474 V RMS and the maximum impedance above which the stunner will not deliver 1.0 Amp was 380Ω (Figure 5). Figure 7 demonstrates how the current changes in response to changes in impedance. However, the use of a current limiting choke to control the output voltage dependant on the impedance of the animal's head within the design of this stunner resulted in better current control, but current was not limited to the legislative requirement of 1.0 Amp. Table 2 Shows the range of currents produced from 0.97 to 1.38 Amps. It is possible that the higher currents could affect both heart function if applied for an extended application time and/or produce deleterious meat quality (Gregory 1998).

The statistical analysis showed an effect of order on the current applied to each animal. The current applied decreased slowly but steadily. This effect was most likely due to a gradual build-up of dirt on the electrode tips, perhaps combined with operator fatigue. There was also an effect of decreased stun current in the sheep with the greater wool cover. The decrease in current of approximately 6mA for every unit increase in wool cover would have been inconsequential in terms of stun efficacy.

Electrode design can have a large effect on the magnitude of the current flow by changing the electrode/skin contact impedance (Sparrey & Wotton 1997). The design of the pin electrodes on the stunner handset, used in both trials, results in a very small area of contact with the animal's head, but is required to ensure that the wool is penetrated and contact is made with the skin. It is recommended that the design of the electrodes should be modified to increase this area of contact, possibly by increasing the number of pins, which would help maintain the impedance to current flow below 380 Ω when using the1.5 A setting, thus maintaining a current level of ≥1.0 A. It is also important to ensure that the water jets are directed onto the tips of the electrodes to minimise contact impedance.

Animal Welfare Implications and Conclusions

EC (1099/2009) regulates the minimum current for effective head-only electrical stunning for sheep at 1.0 A. The operation of stunning equipment with some form of current ~~limitation~~ regulation has welfare advantages by ensuring the applied current is greater than 1.0 A. However, the equipment is limited by the maximum voltage that can safely be manually applied in an abattoir, as determined by the Health and Safety Executive within the UK.

~~The study was approved by the University of Bristol's internal ethical review process.~~

Acknowledgements

We are grateful to the abattoir and abattoir staff for their help and enthusiasm in carrying out the study. The work was funded by AHDB Beef & Lamb.

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Table 1. Summary statistics for the stun parameters and sheep weights from trial one (n = 228).

	Min	Max	Mean	SD
Stun duration (s)	2.52	9.96	3.90	0.54
RMS current (A)	0.42	2.85	1.07	0.43
RMS voltage (V)	213	404	334	44
Cold carcass wt (kg)	9.50	36.50	19.38	3.96

Table 2. Summary statistics for the stun parameters and sheep weights from trial two (n = 275).

	Min	Max	Mean	SD
Stun duration (s)	3.04	3.46	3.42	0.06
RMS current (A)	0.97	1.38	1.25	0.06
RMS voltage (V)	117	415	270	45
Cold carcass wt (kg)	17.33	23.20	19.51	2.39

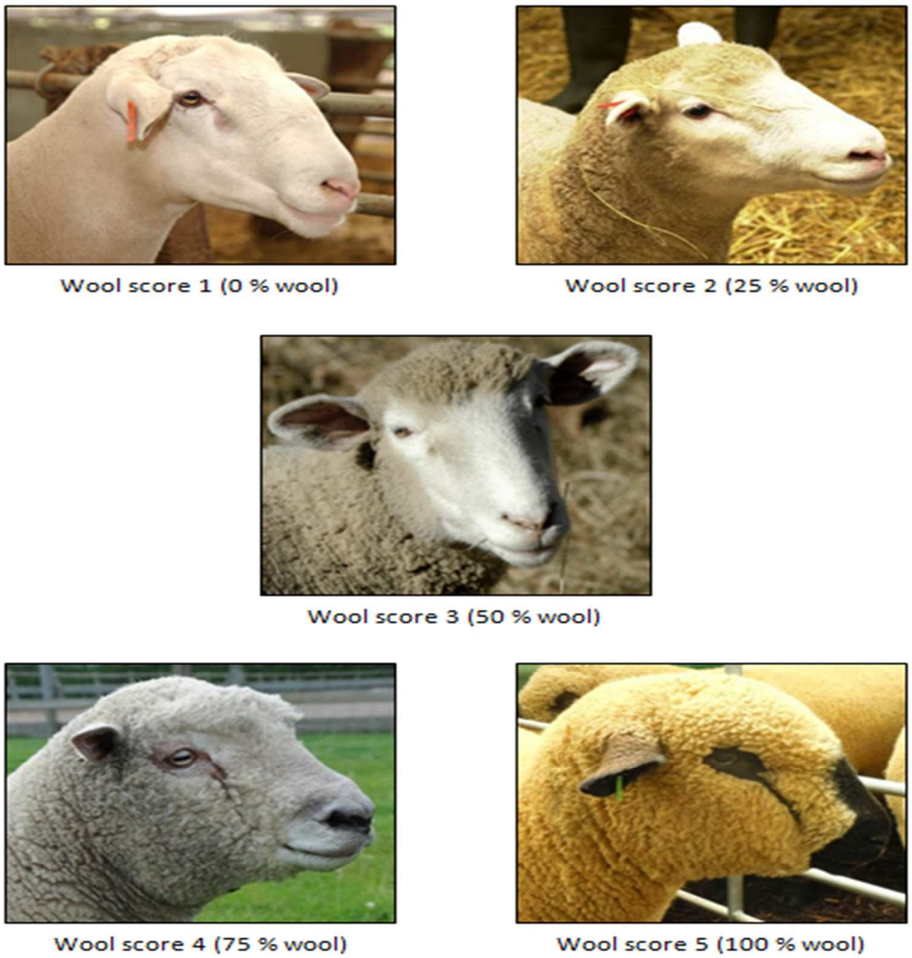


Figure 1. Wool cover scoring system.

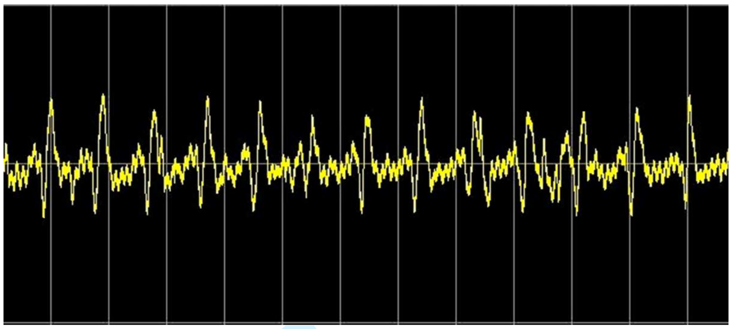


Figure 2. Normal electrocardiogram recorded from a sheep post-slaughter (Divisions are at 200 millisecond intervals).

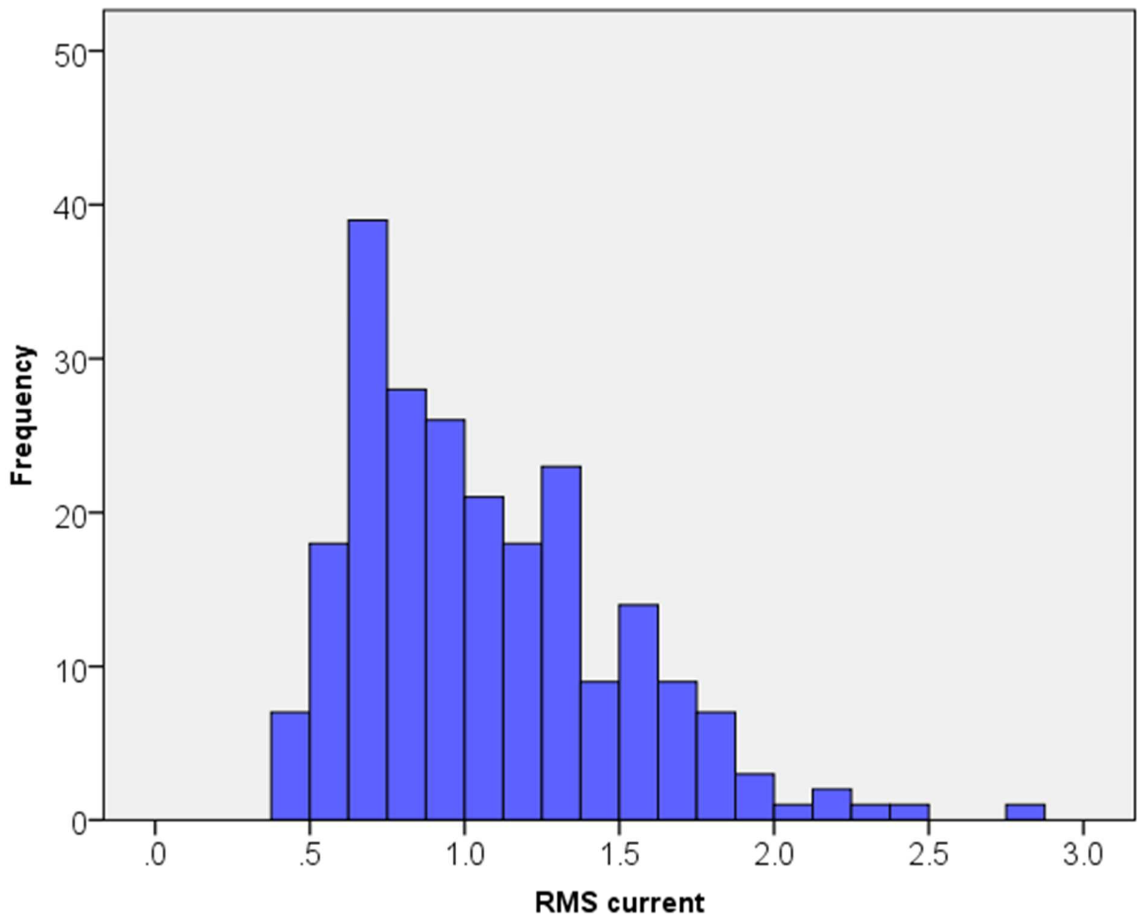


Figure 3. Histogram showing the distribution of the RMS stunning currents received by individual sheep within trial one.

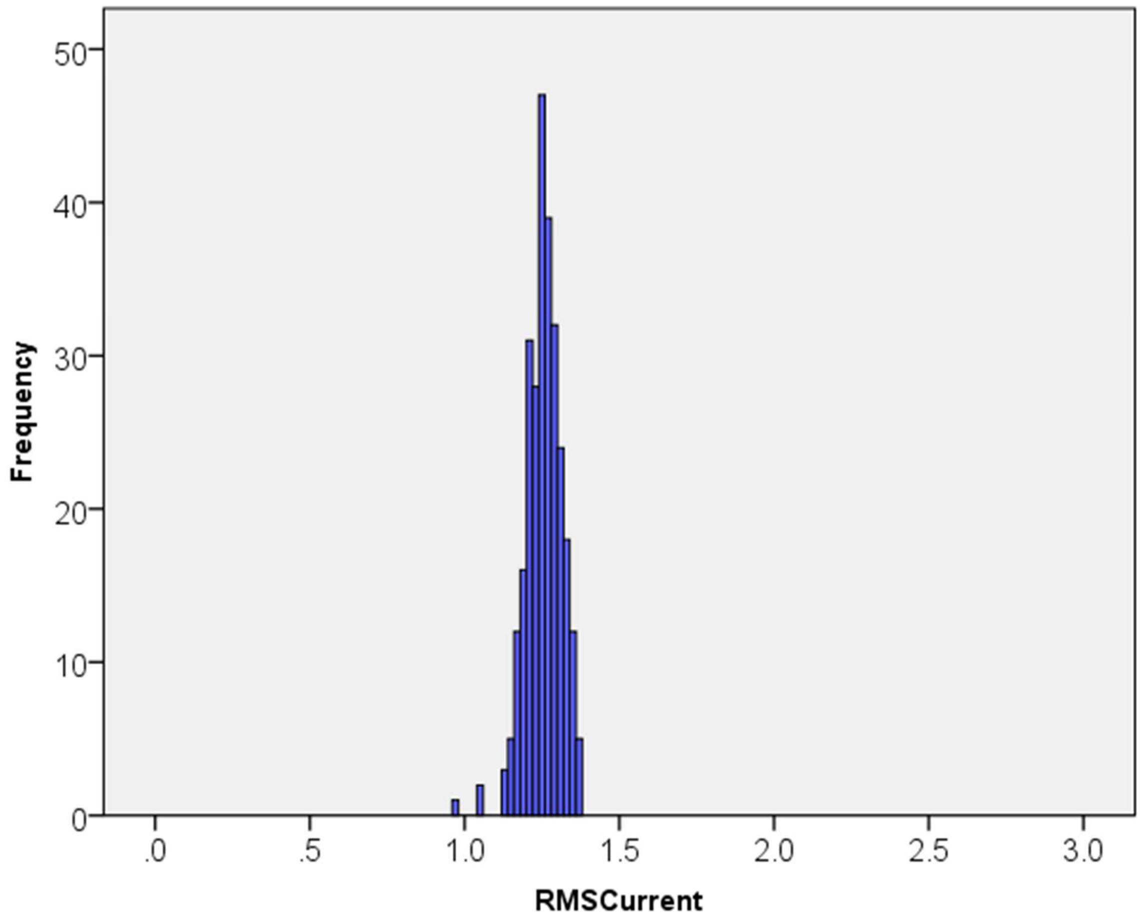


Figure 4. Histogram showing the distribution of the RMS stunning currents received by individual sheep within trial two.

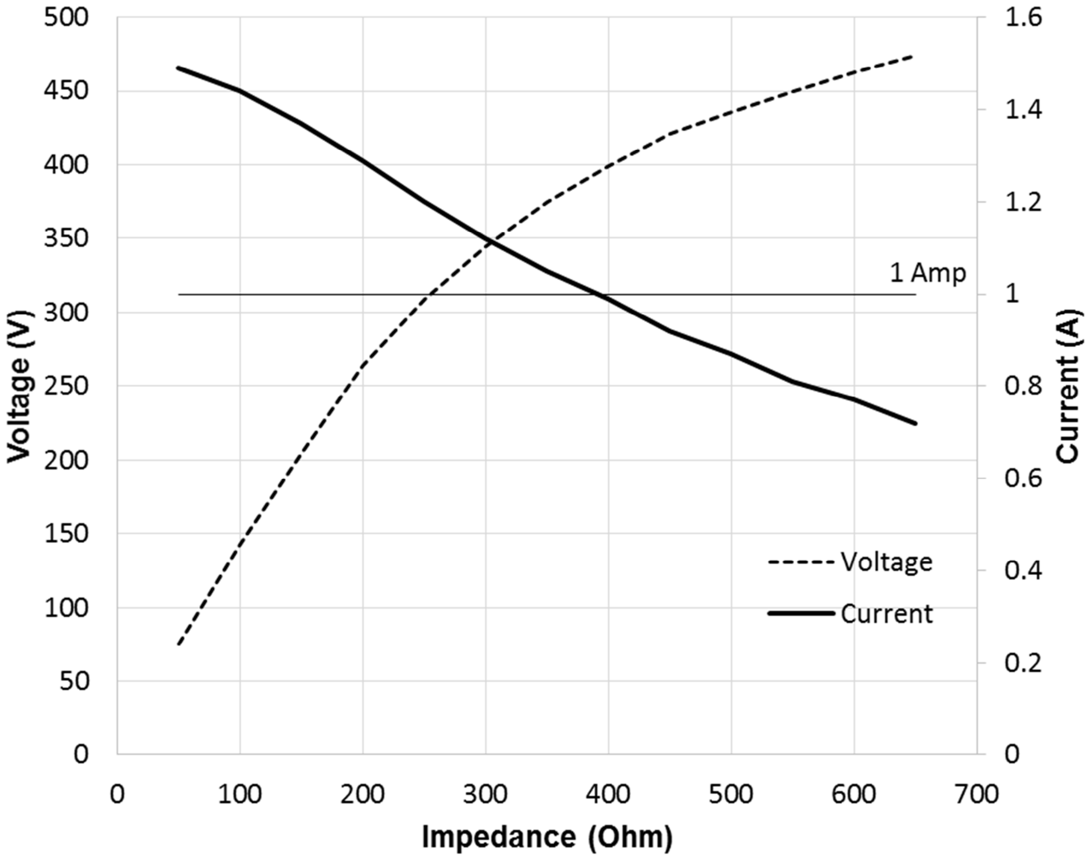
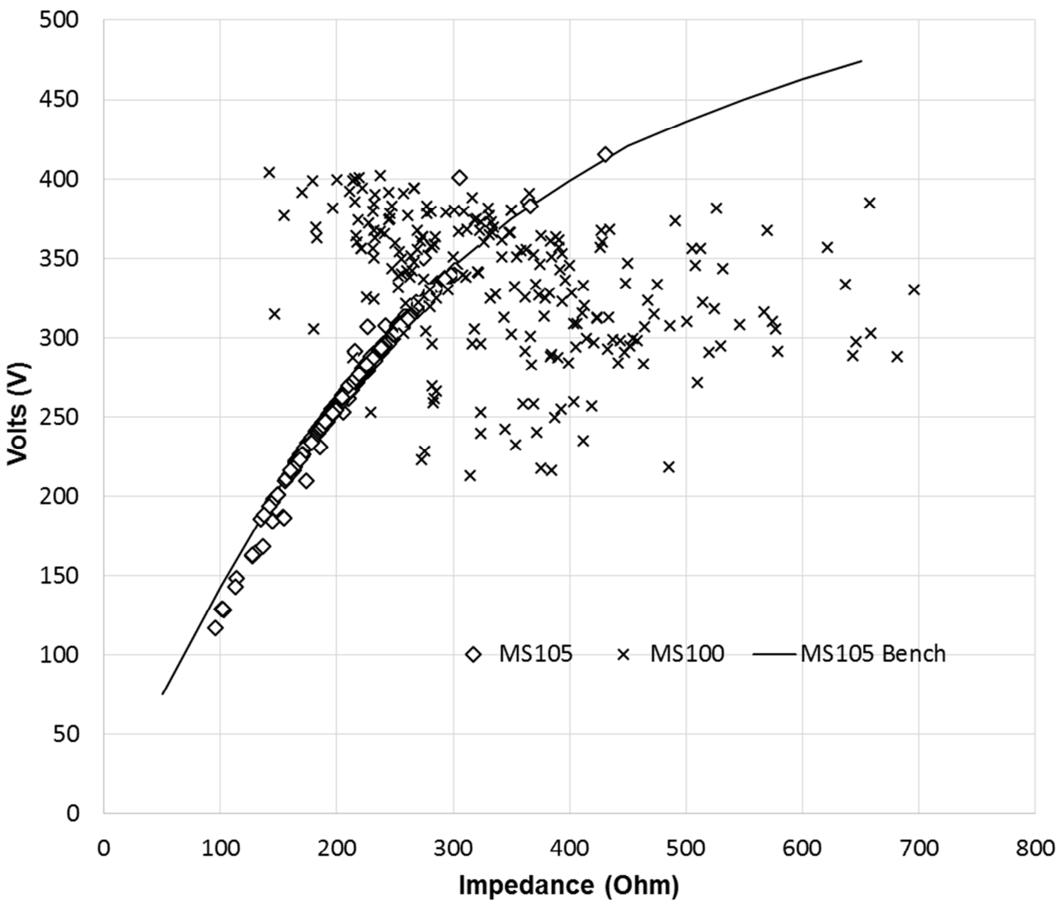


Figure 5. The Jetco MS105 bench test results: the effect of increasing impedance on voltage and the current output (with the machine set at its 1.5 Amp setting).



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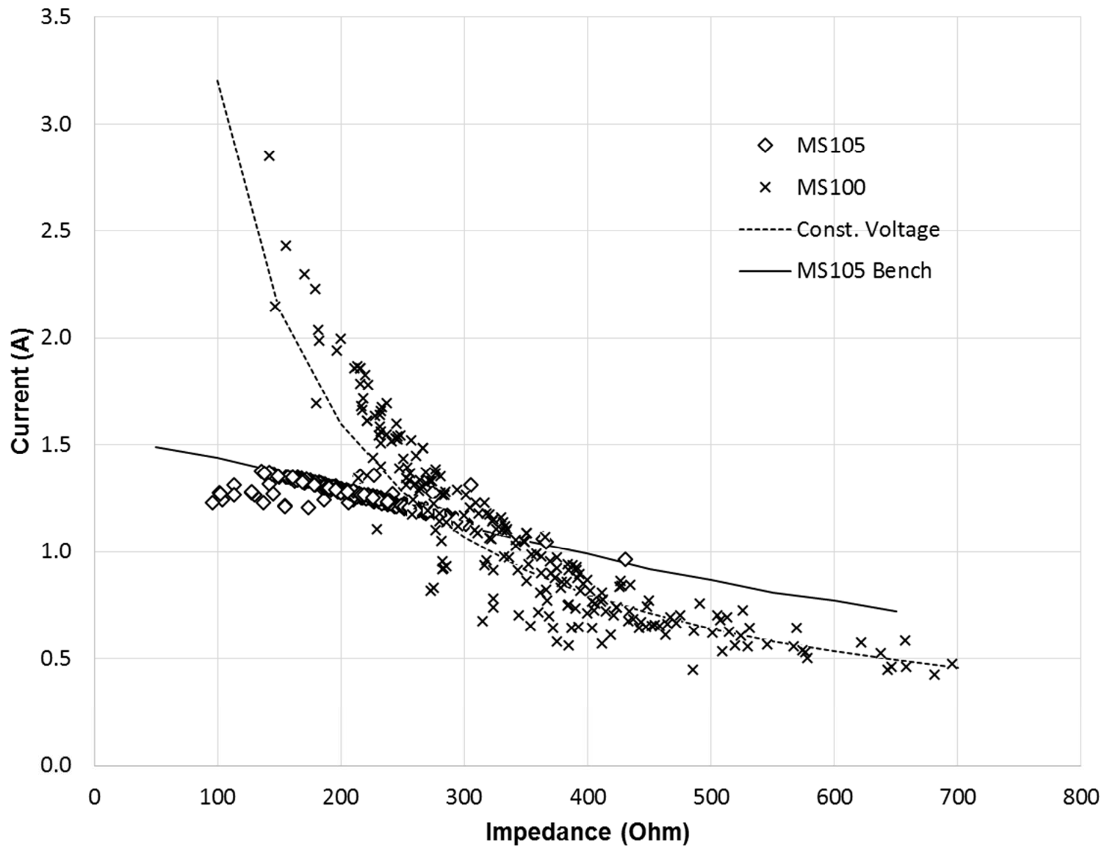

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