# Electrical stunning of pigs using high frequency electrical currents

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## Abstract
Generally, the preslaughter electrical stunning of pigs produces commercially significant levels of carcass damage. Typically this takes the form of broken bones, usually vertebrae and shoulders, and blood spots (blood splash) in muscle tissues. Less obviously, electrical stunning contributes to the severity of the pale soft and exudative condition (PSE) by accelerating the rate of post mortem pH fall. These damaging consequences of electrical stunning can be attributed primarily to the intensity of muscle contractions. Earlier work (Simmons, 1995), demonstrated that increasing the frequency of the stunning current, from the conventional 50-60 Hz, to more than 1000 Hz significantly reduces the intensity of the contractions and improves carcass and meat quality. However, convulsive movements after the stun are severe because high frequencies do not cause heart failure.

The objective of this project was to develop a method that would utilize the benefits of high frequency stunning currents while still controlling post stun movement. The approach was to combine a high frequency head stun with a second electrical circuit, localized near the heart and using 60 Hz, to produce cardiac arrest and control movement. The dual circuit stunning system significantly reduced, or avoided completely, broken bones, while measures of drip loss were significantly reduced when the heart circuit was positioned optimally. However, the current needed to ensure cardiac arrest was unexpectedly sensitive to electrode placement and the size of the pig being stunned. In commercial conditions of high throughput and variable positioning of the pigs in the restrainer, the sub-optimal positioning of the heart electrode necessitated an increase in the current level needed for the heart circuit, and this increase significantly compromised the meat quality benefits gained from the use of the high frequency. Therefore, while the dual circuit system has the potential to improve carcass and meat quality, further consideration is needed to ensure accurate placement of the heart electrode on the pig.

## Introduction
The pre-slaughter stunning of livestock serves a number of purposes. Producing unconsciousness during the act of slaughter, to ensure that pain is avoided, is a primary goal. In addition, stunning is used to control animal movement during the bleeding and shackling operation, to ensure operator safety, and is also vital to maintaining the high throughputs required of modern processing facilities. These objectives of pre-slaughter stunning need to be reconciled with the need to avoid detrimental effect on meat or carcass quality.

The normal procedure for pre-slaughter stunning of pigs in the U.S. is a cardiac arrest stun. This technique places one electrode on or near the head, to produce current flow through the head to ensure insensibility, and a second electrode is placed on the back or chest area to cause a current flow through the body and induce a cardiac arrest. Stopping the heart simultaneously with the stun suppresses post-stun convulsive activity and makes the subsequent handling of the carcass easier and safer. However, using a current flow through the body to produce a cardiac arrest also produces intense muscle contractions that contribute to quality defects in a number of different ways:

- They can directly cause bone fractures, particularly in the back and aitch-bone of the pelvis
- They can cause tearing of the muscle tissue, or separation of the attachments to bones, that result in bruises
- The muscle contractions cause blood pressure to increase in spite of lost heart function, which aggravates the bruising and contributes to blood splash
- pH decline is accelerated after slaughter, which contributes to the pale, soft and exudative (PSE) condition.

**High frequency electrical currents**

It follows from these observations that stun-induced damage should be minimised by reducing the intensity and duration of the muscle contractions associated with the stun. High frequency electrical currents (1000-10 000 cycles per second (Hz)) have been evaluated for their suitability for stunning livestock (Simmons, 1998). These studies demonstrated that high frequency currents reduce the force of muscle contraction, thereby avoiding broken backs when using a head-to-back electrode configuration. Also, stun-induced bruising is substantially reduced, and meat colour, water binding and tenderness are improved. However, although high frequency currents were shown to produce an effective stun, they cannot simply replace the conventional 60 Hz electrical stunning currents because they do not produce cardiac arrest. Consequently, convulsions following the stun are difficult to control.

**Dual circuit stunning systems**

A recent development in automated cardiac arrest stunning is to separate the electrical circuit used to stun the animal (the head current) from that used to produce cardiac arrest (heart current). The dual circuit system therefore requires two pairs of electrodes. The proximity of the body electrode to the heart means that lower currents can be used to induce cardiac arrest, and the force of contraction of muscles in the loin and shoulder muscles are reduced.

**Strategy**

Developing a dual-circuit electrical stunning system provides an opportunity to introduce the advantages of high frequency electrical stunning while removing some of the deleterious effects of conventional 50-60 Hz currents. The high frequency current can be used for the head stun, while a low amplitude 50-60 Hz current (optimal frequencies to produce cardiac arrest), can be applied to the area of the heart to induce cardiac arrest and control post stun convulsions. The benefits of this stunning procedure are compared with conventional 50-60Hz frequencies, and with a 500 Hz waveform, the highest frequency able capable of producing cardiac arrest at the current amplitudes used for the pre-slaughter stunning of pigs.

## Preliminary assessments of alternative stunning procedures.

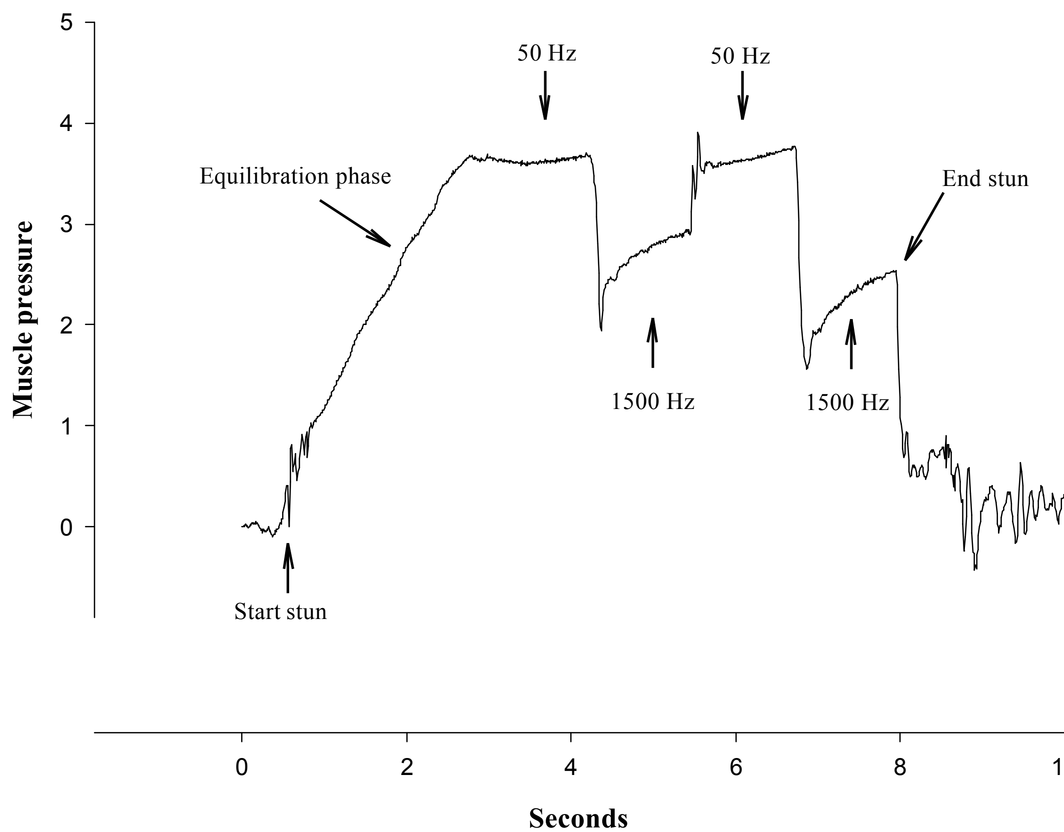
**Loin muscle pressure during electrical stunning**

Since stun damage can be attributed directly to the force of contraction, the direct measurement of such forces will provide an effective method of evaluating the likely impact of a stunning procedure on stun-induced carcass damage. Although carcass damage can be used as a direct end-point measure to compare different stunning methods, it is clear from commercial experience that susceptibility to stun-damage differs widely between pigs and that the incidence of damage is highly variable. Therefore, very large numbers of animals are needed to evaluate alternative stunning methods using these direct endpoints. To overcome this, we have developed a procedure to measure directly the force of muscle contraction and compare the forces generated using different stunning regimes. This procedure is based on measuring the intramuscular pressure, which gives a good index of force of contraction (Styf & Korner, 1986).

Because of the movement of the skin relative to the underlying muscle at the outset of the stun, the recording procedure required that the electrode be inserted immediately after the start of the stun and during the current flow, once the animal was in a tetanised state. As a result, a pressure equilibration phase was needed before the recording period could begin (see Figure 1). The pressure recorded by this method is, to some extent, affected by the position of the needle in the muscle and its orientation relative to muscle fiber direction. In all recordings, a conventional 50 Hz and the experimental waveform were delivered sequentially, so that differences between the control and treatment waveforms could be expressed as percent changes.

Figure 1 demonstrates the changes in muscle pressure that occur when the frequency of the stunning current is altered sequentially from 50 Hz to 1500 Hz during the course of the stun, using a head-to-back electrode configuration. A series of these experiments on 32 pigs, found that the intramuscular pressure was reduced, on average, by 34.3% at 1500 Hz and 55% at 3000 Hz.

**Figure 1**. **Effect of stunning current frequency on muscle pressure.**



**Dual circuit stunning process**

A series of preliminary trials were carried out in a commercial abattoir to establish the baseline requirements of a dual circuit stunning system.

Cardiac arrest could be produced with frequencies up to 500 Hz, but higher frequencies were ineffective (Table 1). High frequencies delivered in the head-to-back configuration did not produce cardiac arrest but did offer a degree of movement control compared to head-only.

A current of 1.1A in the heart circuit produced heart failure in all pigs. Although a systematic assessment of the electrode position was not attempted, the results suggested that the optimal position was in the lower area of the chest, immediately behind the shoulder. Positions higher on the chest, or further towards the rear of the animal, reduced the chances ofstopping the ehart and increased movement after the stun. The success of the heart circuit did not appear to be particularly sensitive to the distance between the pair of electrodes in the cardiac circuit, although some loss of effectiveness was suggested with spacings of less than 5 cm. Arranging the electrodes in a vertical (dorsal-ventral) arrangement was more effective than a horizontal (rostro-caudal), mostly because it was easier to apply the electrodes in the optimal position.

**Table 1: Evaluation of head-to-back high frequency stuns**

| | 500 Hz (n=35) | 1500 Hz (n=12) | 3000Hz (n=12) |
|---|---|---|---|
| Mean movement score | 0.17 | 0.93 | 1.31 |
| Incidence of cardiac arrest | 98% | 0 | 0 |

The amount of current needed to induce cardiac arrest using a chest electrode was considerably greater than anticipated (Table 2). Movement was not fully controlled by a chest electrode combined with head-only stunning, but was controlled effectively when the chest electrode was combined with a head-to-back high frequency stun. This demonstrates that part of the suppression of post stun convulsions is produced by electrical stimulation of the thoracic region of the spinal chord, and that the final design of the stunning system will need to include this component.

**Table 2: Evaluation of different cardiac arrest circuit currents in combination with 1500 Hz head-to-back**

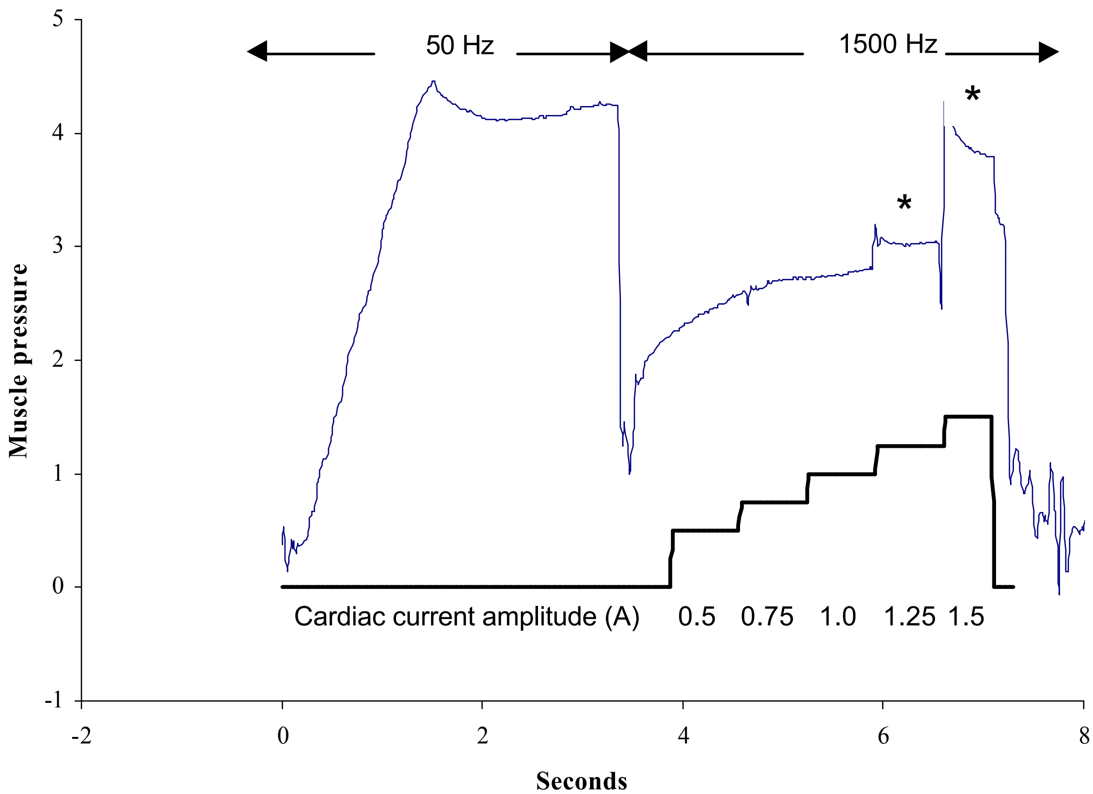
| | 0.5 A (n=12) | 0.8 A (n=12) | 1.1 A (n=35) | 1.5 A (n=35) |
|---|---|---|---|---|
| Mean movement score | 0.79 | 0.44 | 0.14 | 0.09 |
| Incidence of cardiac arrest | 27% | 69 % | 100% | 100% |

**Muscle pressure during dual circuit stunning**

The preliminary trials demonstrated that a head-only high frequency stun would not produce sufficient movement control, and that the dual circuit system would need to comprise a head-to-back high frequency circuit combined with the local cardiac circuit. An evaluation of the impacts of the cardiac circuit on the loin contractions was used to predict the likely effect of this system on stun damage.

The head to back stun was started with 50 Hz to provide a control muscle pressure response, and then switched to 1500 Hz. The current flow through the head-to-back circuit was between 1 and 1.3 A, produced from 250 V. During the 1500 Hz cycle, the cardiac circuit was initiated, and the current level stepped from 0.5 to 1.5 A in 0.25 A increments (Figure 2). Changes in muscle pressure were expressed as a percentage of 50 Hz pressure.

**Figure 2. Loin muscle pressure during dual circuit stunning.**




* : Response of the loin to applied cardiac current and 1.25 and 1.5 amps.

When using a head-to-back 50 Hz current throughout the stun, the heart circuit did not affect muscle pressure when using currents of up to 1.5 A. In effect, the 1 A heart-to-back current appeared to produce a near maximal activation of the loin muscle. In contrast, combining the heart circuit with a 1500 Hz head-to-back current did produce an increase in muscle pressure. Based upon recordings from 8 pigs, the current flow through the heart circuit did not affect loin muscle pressure until 1.1 A, when a small physical response could be seen in the pig, together with a small response in the pressure recording. By 1.5 A, the response to the cardiac current produced a muscle pressure that averaged 93% of the 50 Hz control pressure.

Electrodes arranged in a configuration either perpendicular or parallel to the axis of the body were compared. Although the current needed to induce cardiac arrest was unaffected, significantly less muscle pressure response was recorded in the perpendicular configuration.

## Commercial trials of dual circuit stunning

## New Zealand trials

One day a week for 6 weeks, a control stun and two experimental treatments were applied to a batch of 60 pigs (20 in each group). These pigs were all from the same producer and were of a similar weight and age although they were a mixture of boars and gilts. The stun current was applied using a standard head-to-back electrode configuration with a separate electrode for the cardiac arrest cycle. This was manually applied by placing the electrode on the side of the animal in the appropriate region.

Six stunning procedures were compared
*Control* – 50 Hz, 300V, head-to-back, 5 seconds duration
*Treatment 1* 500 Hz, 300V, head-to-back, 5 seconds duration
*Treatment 2* 1500 HZ, 300V, head-to-back, 5 seconds duration
*Treatment 3* 3000 Hz, 350V, head-to-back, 5 seconds duration
*Treatment 4* 1500 Hz, 300V, separate cardiac arrest current, 5 seconds duration (cardiac arrest cycle 2 seconds duration running concurrently)
*Treatment 5* 3000 Hz, 300V, separate cardiac arrest current, 5 seconds duration (cardiac arrest cycle 2 seconds duration running concurrently)
*Treatment 6* 5000 Hz, 300V, separate cardiac arrest current, 5 seconds duration (cardiac arrest cycle 2 seconds duration running concurrently)

Results of the different stunning procedures on bone breakages and meat quality are shown in Tables 3.

**Table 3: Effects on dual circuit stunning system on carcass quality**

| Bone breakages | Broken Back | Broken Pelvis |
|---|---|---|
| Control | 10 | 3 |
| Treatment 1 | 1 | 0 |
| Treatment 2 | 2 | 0 |
| Treatment 3 | 0 | 0 |
| Treatment 4 | 2 | 0 |
| Treatment 5 | 0 | 0 |
| Treatment 6 | 0 | 0 |

Broken vertebrae were prevalent in the 50 Hz treatment groups, and 3 broken aitchbones were also recorded (Table 3). The incidence of breaks will depend on the breeding of the pigs and production methods, and the line of pigs used in this work was deliberately chosen for their susceptibility to these problems. Also, the use of a back electrode positioned on the midline, where a high level of direct stimulation of the loin occurs, increases the incidence of breaks. However, the results clearly show that high frequencies reduce the incidence of breakage and, where they occur, the severity is less and often limited to bleeding in the intervertebral discs rather than obvious fractures to the bone. The use of the cardiac circuit had no measurable effect on the incidence of breakage.

**Table 4: Effects on dual circuit stunning system on meat quality**

| | $pH_{30}$ | $pH_u$ | Drip % | L | a* | b* |
|---|---|---|---|---|---|---|
| Control | 5.91 | 5.61 | 1.7 | 53.87 | 9.25 | 6.02 |
| Treatment 1 | 6.12 | 5.60 | 0.9 | 53.26 | 9.51 | 5.01 |
| Treatment 2 | 6.17 | 5.59 | 1.1 | 53.17 | 10.03 | 9.92 |
| Treatment 3 | 6.22 | 5.69 | 1.0 | 51.24 | 9.18 | 4.82 |
| Treatment 4 | 6.11 | 5.73 | 0.9 | 50.29 | 9.87 | 5.87 |
| Treatment 5 | 6.23 | 5.61 | 0.9 | 51.88 | 10.53 | 5.38 |
| Treatment 6 | 6.18 | 5.79 | 0.8 | 51.08 | 9.14 | 9.51 |
| Significance | $p<0.01$ | ns | $p<0.001$ | ns | ns | ns |

A significant slowing in the rate of pH decline was evident in all the high frequency treatment groups, although ultimate pH was not affected (Table 4). Drip losses, measured as fluid absorbed in cotton plugs inserted into the LD during overnight chilling, were also significantly reduced by the use of high frequencies. The use of the cardiac arrest circuit maintained the improvements in the rate of pH decline and the increased water holding capacity found when using high frequencies alone.

## US commercial operations: Plant 1

Trials at a US plant were intended to compare a conventional 60Hz stunning system with potential high frequency, dual circuit alternatives. Applied Control Electronics provided the equipment used in these trials, which was a system that produced current controlled outputs of the required frequencies.

Plant 1 used an electrode arrangement based on head to contralateral side, to a position immediately behind the shoulder. Bleeding was carried out on a horizontal bleeding table, typically within 5 seconds from the end of the stun. The stun duration was on average 2.5 seconds. A dual circuit stunning system and a 500 Hz waveform were evaluated. The latter was chosen because it is the highest frequency that could produce cardiac arrest.

A total of 100 pigs were assessed in each treatment group. The pH was measured on line at approximately 1 hour post-mortem in the mid loin area, then again at 24 hours to determine ultimate pH. Colour was measured with a Hennessey grading probe at 24 hours post slaughter, and again using a Minolta Chromameter from the thoracic end of the loin, after boning. A portion of the loin was vacuum packed for 21 days, after which purge losses and colour were measured. The loins were subjectively assessed for the presence of stun damage, graded as 0=absent, 1=mild or 2=severe.

Results of the stunning trials are shown in Table 5. Overall, relatively few differences were evident between the control and experimental stunning systems. It was apparent from the behaviour of the animals following the stun that cardiac arrest was not produced consistently following the 500 Hz treatment, and this may have contributed to the increased incidence of stun damage.

**Table 5: Summed values for stun damage in loins.**

| | Sum of stun damage scores | Broken backs/aitch bone |
|---|---|---|
| Control | 6.3 | 0 |
| Dual Circuit | 8.0 | 0 |
| 500 Hz | 8.8 | 0 |

The pH responses of the pigs to all three stunning systems were similar (Table 6). The pH values at 45 minutes were above 6, and the ultimate pH averaged around 5.7. As a consequence, the colour and drip values were in an acceptable range. The absence of any clear distinction between the three stun treatments suggests that all three systems were producing comparable effects at all ageing timepoints (Table 7).

**Table 6: Mean (SD) values for 24 hour meat quality measurements**

| | pH 45 min | pH 24 hr | L | a* | b* | Hennessey probe value |
|---|---|---|---|---|---|---|
| Control | 6.09 (.17) | 5.72 (.16) | 42.17 (2.7) | 2.71 (1.3) | 9.22 (1.3) | 78.26 (14.8) |
| Dual circuit | 6.12 (.17) | 5.71 (.17) | 42.31 (3.6) | 2.67 (1.4) | 9.14 (1.5) | 80.70 (15.4) |
| 500 Hz | 6.06 (.16) | 5.73 (.19) | 42.25 (3.6) | 2.94 (1.4) | 9.43 (1.5) | 77.98 (14.9) |

**Table 7: Mean (SD) values for meat quality measurements after 21 days of ageing.**

| | pH | Purge (%) | L | a* | b* |
|---|---|---|---|---|---|
| Control | 5.75 (.13) | 1.50 (1.3) | 45.71 (4.2) | 2.35 (1.4) | 12.22 (1.8) |
| Dual circuit | 5.75 (.15) | 1.23 (1.0) | 44.40 (4.6) | 2.51 (1.48) | 12.24 (1.7) |
| 500 Hz | 5.78 (.16) | 1.51 (1.2) | 42.17 (2.7) | 2.38 (1.72) | 12.06 (1.7) |

**Conclusions**

Overall, the performance of the control stunning system was very good. The incidence of stun damage was minimal and the meat quality indices were good. Unexpectedly, the electrical stunning device used at this plant had high frequency components in the waveform, and this may have contributed to the good result, and the absence of any significant differences between the control and high frequency treatment groups.

## Plant 2

Since the control stunning system in plant 1 was not representative of commercial electrical systems, a second trial was arranged. The dual circuit system could not be used at the second plant because of the arrangement of the restrainer, and the comparison was limited to the 500 Hz waveform.

The control stunning system used a head to side electrode arrangement, applying the stun for 1.8 seconds. The waveform was a constant voltage, 60 Hz sinusoid, and produced a current flow during the stun of, typically, around 2 A.

The experimental animals, 290 in total, were chosen from the same producer and slaughtered on two consecutive days, using both control and treatment groups on each day. Carcass loin pH was measured in the chiller at 3 hours post-mortem and repeated the following day before boning for ultimate pH. A Hennessey probe colour measurement was also made at this time. As the muscles were boned, they were assessed for stun damage, using the following scheme:

*Dorsal surface:*
Blood speckle in the subcutaneous fat
Blood splash in the cap muscle

*Ventral surface*
Diffuse speckled blood splash
Bruise damage at the muscle attachments to the vertebrae
Bruising at the muscle attachments to the ribs

In each case, the severity of the condition was judged subjectively using the scores: 0= none, 1 = mild, 2= severe.

After boning, the cranial ends of the loins were subjectively judged for colour (1-6 score) and firmness (1-3 score), measured for L*, a* and b* values and assessed for drip. Drip measurements were measured as weight loss from muscle samples over a 24-hour period.

The results of the 500 Hz treatment on meat quality are shown in Table 8. There was a significant difference in the ultimate pH between treatments, but this is unlikely to be related to the stun, as there has never been any previous evidence to suggest that stunning frequency can affect ultimate pH. The statistical analysis in Table 8 has removed the pH effect and these corrected data show that colour was significantly improved by the high frequency waveform when expressed as chroma. However, subjective colour scores (2.5 vs 2.7) and Hennessey probe measurements (94.2 vs. 91.3), although following a similar trend, did not reach statistical significance. Firmness scores were the same (2.5) for both treatments although drip loss was significantly reduced by the use of high frequency stunning currents.

**Table 8: Mean (SD) values for 24-hour meat quality measurements**

| | Loin pH | L | a* | b* | Chroma | %Drip | Hennessey probe value |
|---|---|---|---|---|---|---|---|
| Control | 5.75 | 49.07 | -1.761 | 11.39 | 11.575 | 7.35 | 94.2 |
| 500 Hz | 5.68 | 47.73 | -1.742 | 12.16 | 12.361 | 6.52 | 91.3 |
| Significance | ** | ** | NS | *** | *** | * | NS |

The effects of stunning frequency on carcass damage were inconsistent (Table 9). The main differences were found in the speckle haemorrhages and vertebral bruises, improved by the high frequency in the former case and made worse in the latter. In both cases, the big differences were found on only one of the two days, so this effect was not consistent.

**Table 9: Mean scores for stun damage**

| | N | Bone breaks | Fat haemorrhage | Cap muscle | Speckle | Vertebral bruise | Rib bruise |
|---|---|---|---|---|---|---|---|
| Control | 150 | 0 | 11.3 | 32.7 | 34.6 | 23.3 | 29.5 |
| 500 Hz | 140 | 0 | 17.1 | 30.7 | 12.1 | 44.4 | 25.7 |
| Significance | | NS | NS | NS | ** | * | NS |

500 Hz was chosen because it can produce cardiac arrest, but it became apparent that this was not being accomplished consistently during the trial, based on the physical behaviour of the

pigs after the stun. Our subsequent work found that reducing the duration of a stun using 500 Hz to less than 3 seconds made the induction of cardiac arrest inconsistent. However, in spite of this, improvements in meat colour and drip losses were evident.

The carcass damage was, however, not improved. Also, the results of using 500 Hz in Plant 2 were significantly worse that Plant 1, where the incidence of carcass damage was minimal. An important difference in the procedures used between the two plants was the time interval between stunning and sticking: in Plant 1, this was consistently around 5 seconds, whereas the interval was closer to 15 seconds in Plant 2. This might be attributed to the failure to consistently produce cardiac arrest, so that the sustained blood pressure allows more infiltration of blood into the damaged tissues. Differences in pre-slaughter handling and the genetics of the animals are likely to have contributed also.

## Conclusions

The work reported here generally confirmed that high frequency electrical waveforms can reduce the incidence of stun-induced damage in pigs. However, a drawback of such currents is their inability to produce cardiac arrest, and therefore to control post-stun convulsive activity. In principle, cardiac arrest could be accomplished using a separate cardiac arrest circuit employing a conventional 50-60Hz waveform. However, our expectation that applying the electrodes near the heart would allow very low current levels to be employed were not realized: to ensure cardiac arrest reliably, the amount of current needed in the cardiac circuit was equivalent to that of a conventional head-to-back stun configuration.

In spite of this, the dual circuit system was successful in stunning and controlling movement, and produced significant improvements in carcass and meat quality when applied to the slower throughputs and lighter animal weights used in the New Zealand pig industry. Under the production pressures of the US industry, ensuring adequate placement of the heart electrodes was difficult to accomplish consistently in the conventional restraining conveyors. The concept of a manually applied, dual circuit stunning system that can replace existing manually operated systems is therefore unlikely to be successful. However, the fundamental benefits of this system may be worthy of further consideration, and methods of automating the application of the heart electrode to create the second circuit could be considered to develop this system further.

These studies also demonstrated that similar stunning system produced markedly different outcomes under different processing environments. One implication is that while the stunning method undoubtedly has an important role in producing carcass damage, other factors need to be taken into consideration. Likely contributing factors are pre-slaughter handling stressors and the time interval between stunning and sticking (bleeding).

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