# final report

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## The Potential of Very Fast Chilling for Processing

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# Abstract

Very fast chilling (VFC) is defined in the literature as reducing meat temperature to 0°C within 5 hours of slaughter. Previous research in Europe has demonstrated that VFC can result in meat of acceptable tenderness, but problems with consistency have prevented adoption by industry.

This project investigated ways to improve the consistency of tenderness from VFC. Findings suggest that consistent tenderness can be achieved using VFC and there are several options to do this. Cost benefit analyses showed that adoption of VFC is likely to be economically favourable and that more research into VFC is warranted to facilitate adoption by the Australasian red meat industry.


# 1 Executive Summary

## 1.1 Project Outline

- A study was undertaken to investigate the potential of very fast chilling (VFC) for the processing of red meat in an Australasian context. This study followed favourable findings from a literature review and a small pilot experiment conducted in 2007.
- Outputs from the 2008 study consisted of two experiments, a cost benefit analysis for the adoption of VFC in Australasia and an “industry update” document to report key findings of the experimental work to industry.

## 1.2 Experimental work

- For experiments 1 and 2, hot boned lamb loins were chilled in liquid immersion baths to investigate the source of previously reported variation in meat quality, due to variation in temperature conditions within the VFC range. The value of using post dressing electrical stimulation in association with VFC was tested in experiment 2. Meat quality was the basis of the measurements for experiments 1 and 2. For experiment 1 proteolysis was investigated using the Western blot technique and *post mortem* energy metabolism was investigated with high field Nuclear Magnetic Field Resonance (NMR) techniques.
- The results from experiments 1 and 2 confirmed literature reports that tender meat could be obtained with VFC and that this occurred earlier *post mortem*, (day 2) than with conventional chilling (day 5).
- However, the experiments also confirmed that VFC resulted in variable tenderness that could be explained by differences in minimum temperature and the rate at which this minimum temperature was reached within the VFC range.
- The best VFC regime was found to be a minimum temperature of -2°C (approximately) reached at 1.5 h *post mortem,* then held at -1.5°C in air until 24 h *post mortem*. This result was confirmed with the second experiment.

Hence, precise specification of the temperature conditions within the VFC range can reduce tenderness variation.

- Sarcomere shortening did not occur with the best VFC regime. Prevention of shortening either by sub-zero temperature and/or low pH 1.5-2 h *post mortem* can at least partly explain the tenderness results.

- An exciting finding was that – with the best VFC regime – the meat was tender early *post mortem* (5.3 KgF). There was no evidence that this result was due to accelerated proteolysis, indicated by western blot determination of Troponin T and Desmin products. Furthermore, tenderness improved and proteolysis continued with time *post mortem* (ageing) in a similar way to conventional chilling.

- Electrical stimulation altered the rate of pH change under VFC conditions and broadened the minimum temperature range (although still sub-zero) and the rate at which this minimum temperature was reached (1-2.5 h *post mortem*) at which tenderness was acceptable. This indicates that the rate of pH change may be important for optimal tenderness under VFC conditions, possibly through prevention of shortening.

- The relationship between pH/temperature and tenderness is different for VFC, hence conventional pH/temperature benchmarks do not apply to VFC.

- The NMR investigation provided evidence that VFC increased the rate of energy metabolism *post mortem* in support of the increased rate of change in pH. Concentration of lactate, glucose, and inositol were increased 5 h *post mortem* for VFC compared to control samples.

- Without precise control of the temperature conditions the risk of producing tough meat is high. While proteolysis and prevention of shortening play key roles, the early tenderisation due to VFC may not be explained by these factors alone.

## 1.3 Cost Benefit Analysis

- The cost benefit analyses identified that the most valuable benefits from VFC will be process efficiency gains due to reductions in chiller space and yield improvements. In the case of beef, efficiencies due to hot boning represent a large additional gain compared to the benefits obtainable for sheep meat for which hot boning is not essential to achieve VFC.

- With the assumptions used, cash flow was positive for the industry after 2 years and maximum benefits were reached 15 years after adoption of VFC was commenced.

- For sheep meat, the estimated cash flow gave a net present value (NPV) of NZ$75 million (or A$65 million at exchange rate of 0.87) and an internal rate of return (IRR) of 214%. For beef, the estimated cash flow gave a net present value (NPV) of NZ$63 million (or A$55 million at exchange rate of 0.87) and an internal rate of return (IRR) of 247%. These estimated returns are large

and suggest investment in VFC would be worthwhile given the assumptions used can be sustained under commercial conditions.

## 1.4 Recommendations

We recommend that the VFC research and development project be continued and should include the following components:

- A comprehensive consultation activity to publicise the potential of VFC in the red meat industry, and to obtain feedback about specific meat product applications for VFC and very fast freezing (VFF).
- A prototype development activity to validate the capacity of different air and immersion based systems to achieve the temperature conditions required for VFC and VFF. Also to test under commercial conditions the various technical and financial assumptions used in economic and process simulation modeling.
- An experimental activity run in conjunction with the prototype development activity to further refine the description of the VFC regime to facilitate the successful incorporation of VFC into commercial processing strategies. Key issues identified from the recent experiments that require further investigation are the following (listed in order of priority):

    1. Confirmation that the favorable tenderness results found in lamb can also be achieved with beef
    2. Investigation of options to minimise the range expected across a lamb carcase when air chilled due to temperature and or muscle type differences
    3. Definition of the temperature conditions during the tempering period post VFC that minimise the time to rigor and the time required before deboning and or freezing is feasible.
    4. Quantification of various product outcomes including yield, colour stability and water holding capacity
    5. Characterisation of potential tenderness factors other than prevention of sarcomere shortening

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# 2 Background

The overall objective of the 07/08 Very Fast Chilling project was to investigate the potential of very fast chilling for processing of red meat in an Australasian context. The project outcomes were to include a proof of concept and process specifications for very fast chilling. The concept was to improve profitability by reducing processing time and at the same time produce meat of consistent quality; as good as or better than that from conventional chilling systems. For the experimental work the focus of the study was on lamb but beef was considered in the cost benefit analyses as well.

The project plan included an experiment to study the effect of chilling rate on tenderness development under VFC conditions, with the purpose of understanding and reducing variability of tenderness. The experiment also included a mechanistic component to characterise the change in energy metabolism during the *pre rigor* period and proteolysis associated with VFC.

Following the first experiment, the effect of deboning time on product quality and validation of carcass and yield effects with VFC was to be studied. It was envisioned that the latter experiments would be done using a commercial prototype system, i.e. the Pandura Tunnel Chiller (Pandura and FPE). However, the project plan was changed for the following reasons: 1) the commercial prototype system was not ready for use and 2) results from the first experiment suggested that an understanding of the process specifications (minimum temperature and the rate at which this minimum temperature was reached) and their interaction with electrical stimulation was essential for successful commercial implementation of VFC.

Hence, a second experiment testing the potential interaction with electrical stimulation and determining the upper and lower boundaries of the best temperature regime, identified in the first experiment, was conducted. The results of the two experiments are presented in the experimental results section.

The project also included a modelling component which was to validate chilling systems to achieve VFC across a lamb carcass. This information was used in the design of the two experiments. Further, the modelling component was to quantify economic benefits of VFC for a range of supply configurations and characterise the potential customer types amendable to a VFC process. This analysis is presented in the business case section.

It should be noted that the modelling results of the economic benefits are preliminary until information about deboning time, carcass yield and other process attributes can be tested with commercial prototypes. The energy costs of the VFC chilling system is a large component of the overall success of VFC. Accurate assumptions for energy use are also pending specifications from testing of commercial prototypes, although modelling at this stage suggests that VFC has similar energy requirements to conventional chilling.

# 3 Experimental results

Two experiments were conducted in the project using lamb loins cooled in immersion baths. Both experiments were conducted at MIRINZ AgResearch Hamilton NZ. For both experiments the loins were removed from the carcase immediately post dressing and wrapped in poly vinyl chloride (PVC) overwrap material. The first experiment – the effect of chilling rate on tenderness development - was carried out to define the temperature/time regime, within the VFC range of 0°C in 5 h, which would consistently produce tender lamb meat. Experiment 2 – the effect of electrical stimulation and determination of lower and upper limits for tenderness - was carried out to 1) confirm the successful chilling regime (-2°C in 1 h) identified in experiment 1, 2) determine the upper and lower boundaries of the chilling rate specifications and 3) test for an interaction between electrical stimulation and chilling rate. The results are summarised below but a detailed account of the methods used has not been included in this report. Please refer to the milestone reports for description of the methods (Jacob *et al.* 2008a; Jacob *et al.* 2008b)

## 3.1 Experiment 1 The effect of chilling rate on tenderness development

The five treatments in experiment 1 were: 0°C in 22 h (A, control), 0°C in 1 h (B), 0°C in 5 h (C), -5°C in 1 h (D) and -5°C in 5 h (E). Computer modelling of a lamb loin was used to design the cooling systems for the various treatments. The systems used were a range of refrigerated immersions baths operated at different temperature settings. Post-chilling storage took place in an air chiller with an air temperature of -1.5°C.

### 3.1.1 Temperature

The temperature in the loins was affected by the operator wrapping the loins prior to chilling. The temperature was higher in loins wrapped by operator 1 than in the loins wrapped by operator 2 (**Figure 1**). Operator 1 applied a very tight wrap with more layers of PVC film that reduced the chilling rate. Hence the desired chilling rates were only obtained when the loins were wrapped by operator 2. Although these differences didn't appear to be large they did impact on shear force and sarcomere length.

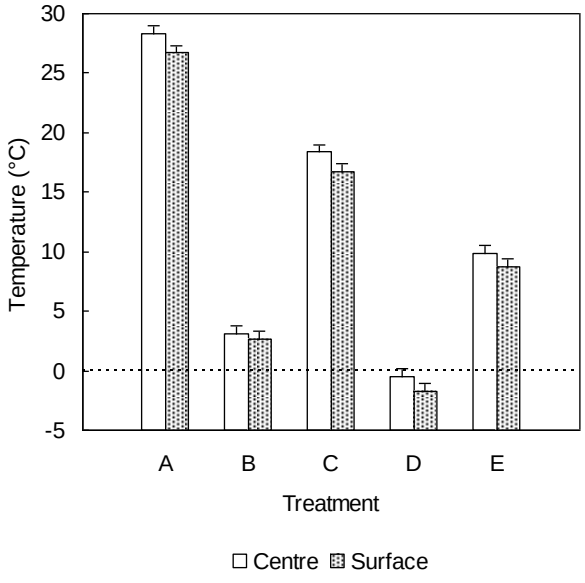

Figure 1 Loin temperature (mean of centre and surface) 1 h after commencement of chilling for treatments A, B, C, D and E (values are means and bars indicate standard errors of the mean).

### 3.1.2 pH

The VFC treatments had a significant effect ($p < 0.01$) on ultimate pH ($pH_u$; pH @ 48 h *post mortem*) as Treatment B resulted in a higher $pH_u$ than treatments A and E (Table 1). The VFC treatments also induced differences in the rates of pH change *post mortem*. While treatment A resulted in a decrease in pH from commencement of chilling until 24 h *post mortem*, treatments B, C, D and E resulted in an increase in pH between 0 h and 1 h followed by a decrease thereafter. Between 1 h and 10 h the rate of the pH change was faster for treatments B, D and E compared to the control but slower for treatment C (Figure 2). These differences in pH rates between treatments were reflected in the time taken for pH to reach 6 (Table 1). For all treatments including the control the temperature of the samples at the time that pH reached 6 was close to 0°C.

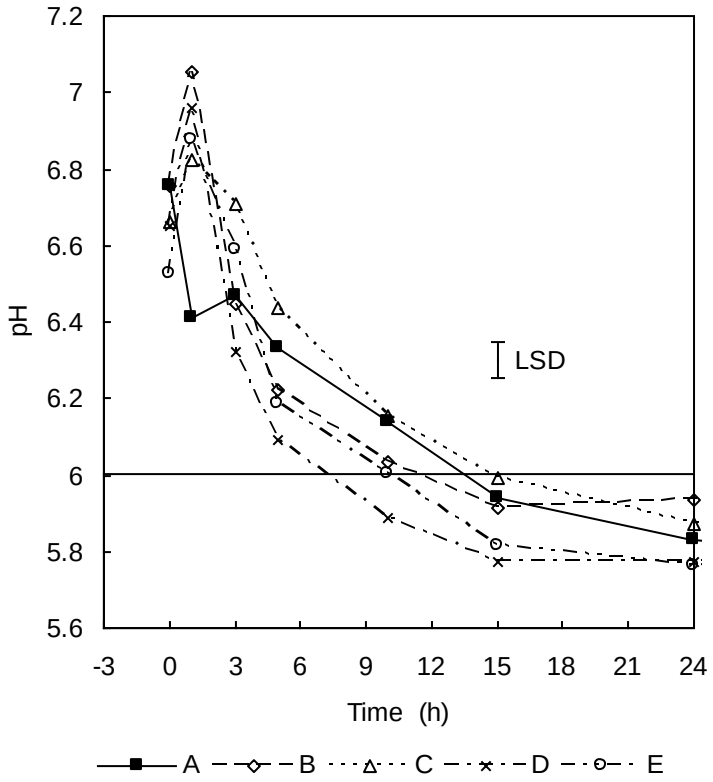


Figure 2 Rate of pH change from commencement of chilling (30 min *post mortem*) until 24 h *post mortem* for treatments A, B, C, D and E.

**Table 1** Ultimate pH (pH at 48 h) , time taken for pH to reach 6, and temperature at pH 6 for treatments A, B, C, D & E (values are means.).

| | Treatment | | | | |
|---|---|---|---|---|---|
| | A | B | C | D | E |
| $pH_u$ | $5.72^{b}$ | $5.89^{a}$ | $5.80^{ab}$ | $5.76^{ab}$ | $5.70^{b}$ |
| Time *post mortem* (h) when pH = 6 | 13.5 | 11 | 15 | 7 | 10 |
| Temperature ($^{o}$C) when pH = 6 | 1.6 | 1.6 | 0.5 | 0.5 | -0.5 |

### 3.1.3 Shear force

The difference in temperature decline introduced by the two operators resulted in a significant interaction between operator and treatment for shear force ($P < 0.01$). For operator 1 treatment A had a significantly lower shear force ($P < 0.05$) than for all other treatments and there was no difference between treatments B, C, D and E. For operator 2, treatment D had a lower shear force ($P < 0.05$) than for all other treatments (Figure 3). Hence with operator 1, all of the VFC resulted in higher shear force values compared with the control (treatment A), whereas with operator 2, one of the VFC treatments (D) resulted in significantly lower shear force values than the control, hence a potential chilling regime for successful application of VFC.

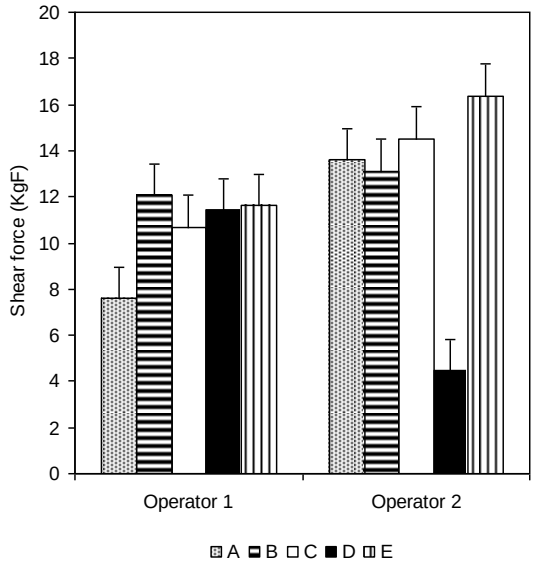


Figure 3 The shear force of loins wrapped by either operator 1 or 2 and chilling using either treatment A, B, C, D or E (values are the means and SEM of 3 ageing periods; day 2, 5 and 10).

**For all treatments the shear force decreased with ageing time ($P_{ageing} < 0.001$). Shear force was significantly lower in treatment D than in any of the other treatments (**

Figure 4) and resulted in very low shear force values as early as 2 days *post mortem* (5.3 KgF). This could not be explained by the temperature at pH 6.

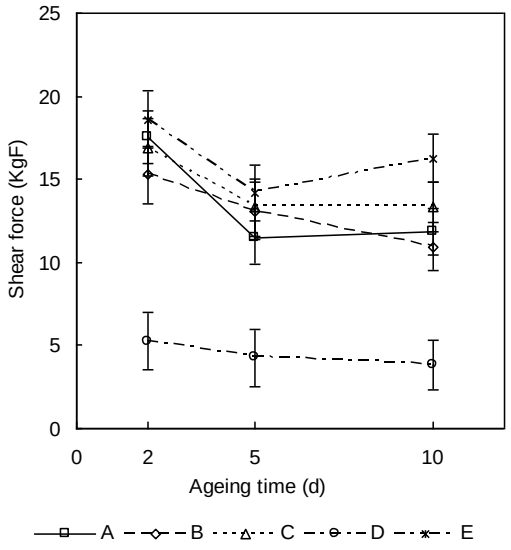


**Figure 4** Shear force measured days 2, day 5 and day 10 *post mortem* in loins wrapped by operator 2 and chilled with treatments A, B, C, D or E (values are means ± SEM).

### 3.1.4 Sarcomere length

Sarcomere length was significantly affected by treatments ($P < 0.01$) and there was an interaction with operator ($P = 0.017$). Sarcomeres were longer in loins from treatment D than treatment A, and loins in treatment A had sarcomeres that were longer than those in treatments B, C, and E (Figure 5). For treatment D sarcomeres were longer and for treatments A, B, C, and E sarcomeres were shorter for operator 2 compared to operator 1. It should be noted that, the shear force of treatment A and treatments B, C and E were lower when wrapped by operator 1. This might have been due to slower rate of temperature decline induced by the wrapping technique of operator 1 reducing the extent of cold shortening in these treatments.

Hence, while VFC induced sarcomere shortening in treatments B, C and E, treatment D appeared to prevent shortening all together – and relative to treatment D, it even appeared that some degree of shortening was induced in treatment A.

In an absolute sense, the extent of shortening was extreme for treatments B, C and E with sarcomere length below 1.3 µm. These results suggest that sarcomere shortening increased as the minimum temperature approached $0^{o}$C but shortening was limited when the minimum temperature was at or below $0^{o}$C within 1 h of commencement of chilling. This is visualised in Figure 6 for treatments B and D.

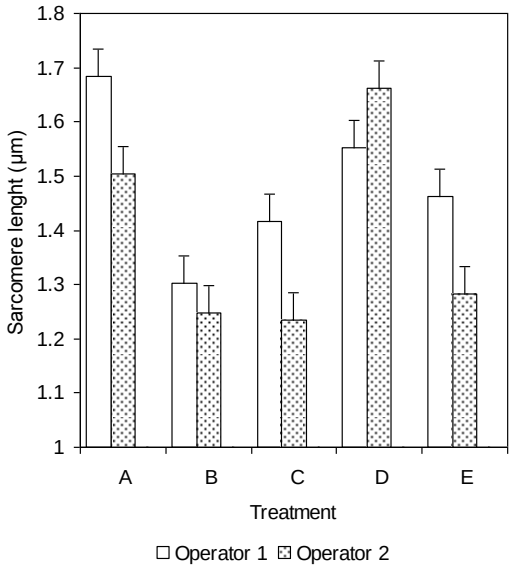


**Figure 5** Sarcomere lengths of loins wrapped by either operator 1 or 2 and chilled using either treatment A, B, C, D or E.

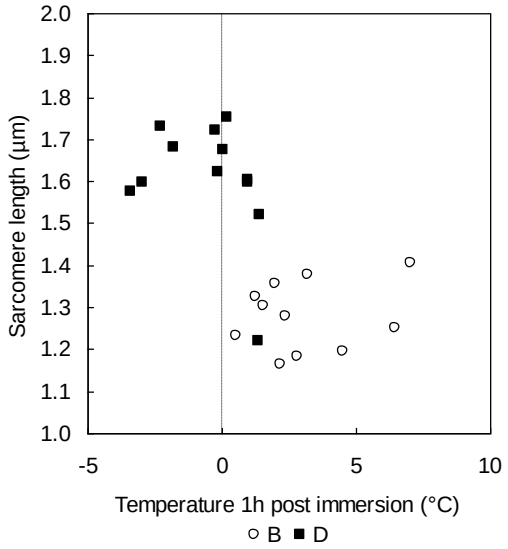


Figure 6 Sarcomere lengths as a function of temperature at 1 h after commencement of chilling for treatments B and D.

### 3.1.5 *Post mortem* proteolysis

In order to understand whether VFC accelerated *post mortem* proteolysis and thereby tenderisation, SDS-PAGE electrophoresis followed by Western blotting against desmin and troponin T was carried out on day 1, day 5 and day 10 samples from 18 loins (treatment A (operator 1 & 2), treatment D (operator 1) and treatment D (operator 2)). Please refer to the progress report by Geesink and Han (2008) for description of the methods.

The analysis showed no difference between treatments in desmin and troponin T degradation products (Table 2). The lack of difference between treatments suggests that tenderisation induced early in the *post mortem* period by VFC was not due to proteolysis. However, this result does not

rule out the possibility that proteolysis of proteins other than desmin and troponin T, such as titin, may have occurred and been responsible for the observed effect. More sophisticated analytical techniques would be required to ascertain if titin degradation was affected by VFC.
The change in the level of desmin and troponin T degradation products observed with time *post mortem* suggests that meat subjected to VFC tenderised when aged. The relatively small changes in shear force for treatments D between day 1 and day 10 despite similar changes in Desmin and Tropinin T products to treatment A may be a reflection of the shear force already being low at day1, particularly for operator 2.

Table 2 Intensity of Desmin and Troponin T degradation products from loin samples subjected to treatment A (operator 1 and 2), treatment D (operator 1) and treatment D (operator 2), 1, 5 and 10 days *post mortem*. Values are means; values with different superscripts a, b, c in the same row are different.

| Treatment | Days post mortem | | |
|---|---|---|---|
| | 1 | 5 | 10 |
| | Desmin | | |
| A | 85[a] | 26[b] | 5[c] |
| D (operator 1) | 87[a] | 31[b] | 14[c] |
| D (operator 2) | 68[a] | 26[b] | 11[c] |
| | Troponin T | | |
| A | 15[a] | 79[b] | 141[c] |
| D (operator 1) | 28[a] | 89[b] | 127[c] |
| D (operator 2) | 27[a] | 94[b] | 168[c] |

### 3.1.6 NMR Analysis

A high field Nuclear Magnetic Resonance (NMR) study was undertaken using samples collected from lamb loins in treatments A and D (operators 1 and 2). Full details of these findings are contained in the report by Warner and Rochfort (2008).
Proton spectra were obtained on a Bruker 800 MHz instrument equipped with a cryoprobe, and phosphorous spectra were obtained on a Varian 500 MHz instrument. Principal components analysis was used to analyse spectral data. Concentrations of metabolites were estimated using Chenomx software. Analysis of variance in Genstat was used to test for the effects of treatment, time and the interactions between treatment and time on metabolite concentrations.
Principal components analyses of proton spectra demonstrated significant metabolic changes during the first 24 h *post mortem* that were associated with treatment. PCA analysis for $^{1}$H NMR spectra (Figure 7) shows time related structure in the data. Vector 1 describes 0 and 1 h for treatment D but 0, 1 and 5 h for treatment A. Similarly Vector 2 describes 5, 10 and 24 h for treatment D and 10 and 24 h for treatment A. This suggests that the end state (24 h *post mortem*) was reached more rapidly for treatment D than treatment A.

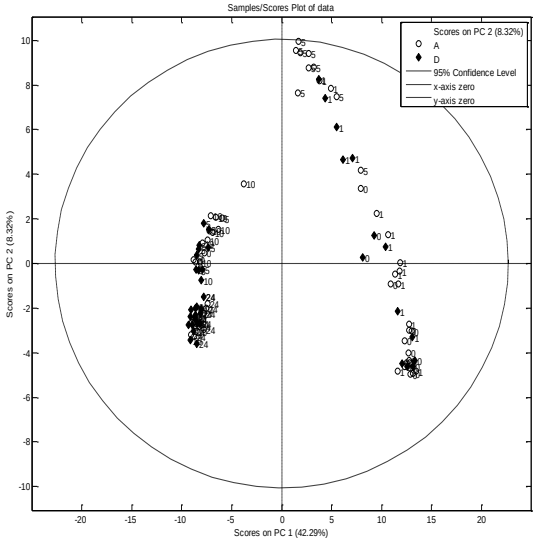


**Figure 7** PCA analysis of $^{1}$H NMR spectra (100 samples, numbers signify hours post mortem)

Thirteen metabolites were identified and concentrations quantified for; anserine, carnitine, carnosine, creatinine, inosine, lactate, $NAD^{+}$, nicotinate, succinate, valine, alanine, leucine and isoleucine. There were significant differences over time between treatments A and D for the concentrations of several metabolites particularly lactate, inosine and glucose (Figure 8). Furthermore, phosphorus spectra showed that inorganic phosphate and inositol phosphate concentrations differed significantly between the two operators for treatment D.

This effect on the rate of change of metabolite concentrations *post mortem* was consistent with the differences observed between treatments for the rate of pH decline. Together they suggest an increase in the rate of carbohydrate and energy metabolism *post mortem* due to VFC compared to conventional chill in the first 24 h *post mortem.* This effect may explain in part the mechanism for rapid tenderisation found with treatment D operator 2. Rapid metabolism may have increased the rate of *rigor* development and assisted with prevention of sarcomere shortening in response to low temperature. However further work is required to confirm this.

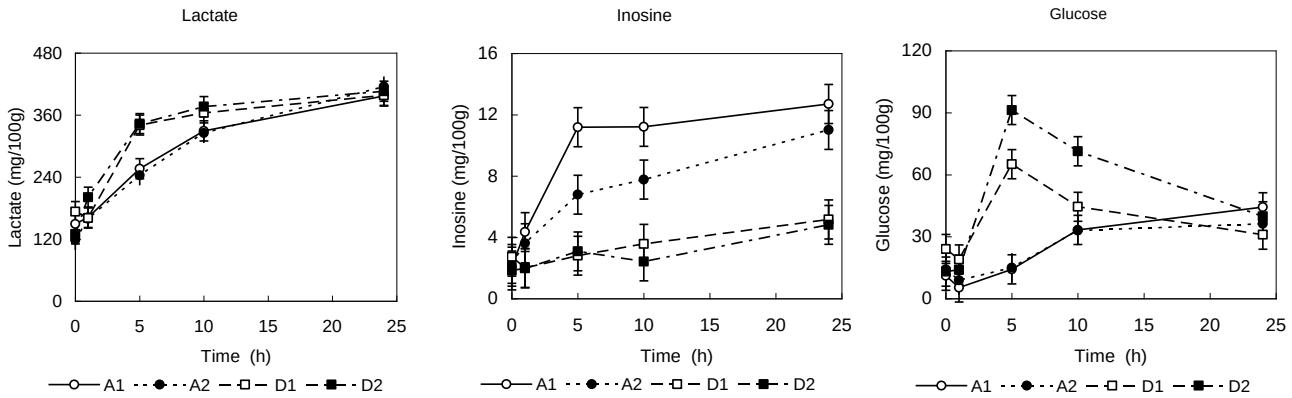


**Figure 8** Lactate, inosine and glucose concentrations at 0, 1, 5,10 and 24h post-mortem for treatments A, and D operators 1 (D1) and 2 (D2) (Values are means ± SEM)

## 3.2 Experiment 2 The effect of electrical stimulation and determination of the lower and upper temperature limits for tenderness

Hot boned lambs loins were wrapped in PVC film prior to being cooled in glycol immersion baths. The experiment was a 2 by 3 factorial design with plus and minus post dressing low voltage electrical stimulation and immersion in glycol baths at different temperatures for different time periods: -30°C for 0.5 h, -15°C for 1 h and -12°C for 2 h, making a comparison between 6 treatments in total.

### 3.2.1 Temperature

The different immersion treatments resulted in different rates of temperature change and different minimum temperatures reached (Figure 9). The mean muscle temperature for electrically stimulated and non-stimulated loins was decreased to -0.4°C, -1.5°C and -1.5°C after immersion in -30°C glycol solution for 0.5 h, immersion in -15°C glycol solution for 1 h and immersion in -12°C glycol solution for 2 h, respectively. There was an interaction between stimulation and treatments such that the temperature was lower for the non-electrically stimulated loin for the 1 h immersion treatment compared with the electrically stimulated loin (This finding warrants further investigation in future experiments, because this might impact the minimum temperature that can be achieved with VFC).
The targeted minimum temperature was not achieved for the 0.5 h immersion treatments. This may have been due to due to an insufficient rate of heat transfer between loins and the immersion liquid to achieve the desired minimum temperature or the fact that the temperature of the glycol solution wasn't sufficiently low to reduce the temperature to the target within the 0.5 h. Hence, this treatment was not tested fully due to the limitations of the conditions.

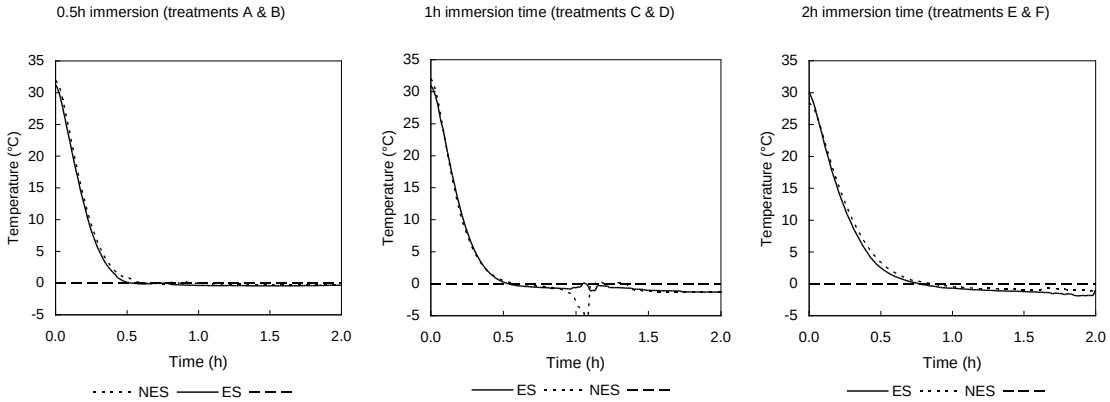


**Figure 9** The change in temperature with time for 2 h after the commencement of immersion for 0.5 h, 1 h and 2 h immersion times with (ES) and without electrical stimulation (NES).

The rate of temperature change during tempering in air at -1.5°C after immersion was slow such that loins remained at temperatures below 0°C for at least 24 h *post mortem* (Figure 10). The length of this tempering period may have important implications for deboning in a cold boning scenario and requires further investigation in future experiments.

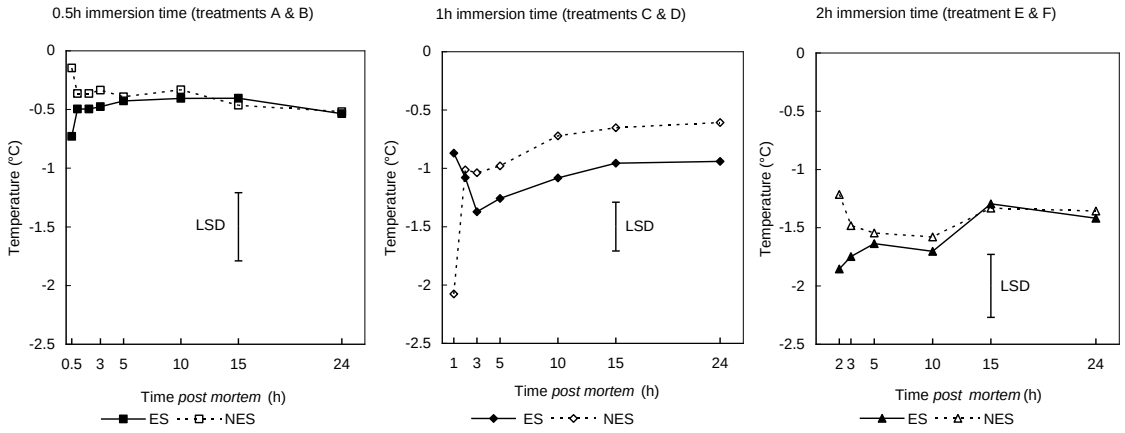


Figure 10**.** Core muscle temperatures for the period following immersion (0.5, 1 and 2 h for treatments A&B, C&D and E&F) for ES and NES (LSD values are for the interaction between treatment and time).

### 3.2.2 pH

Electrical stimulation reduced pH at the start of immersion (6.42 versus 6.68 for ES and NES respectively, LSD 5% = 0.10), but this effect had disappeared from 5 h to 48 h post commencement of chilling (**Figure 11**).

At 10 h post commencement of immersion, the mean pH of all treatments was 6.01 ± 0.03 and there was no significant difference between treatments at this time point (P > 0.05).

Compared to experiment 1, the pH data was limited because it was not possible to measure pH at 1 h post commencement of immersion as the muscle was “solid” at this time point. The consistency of the muscle returned to normal despite temperature not changing post VFC.

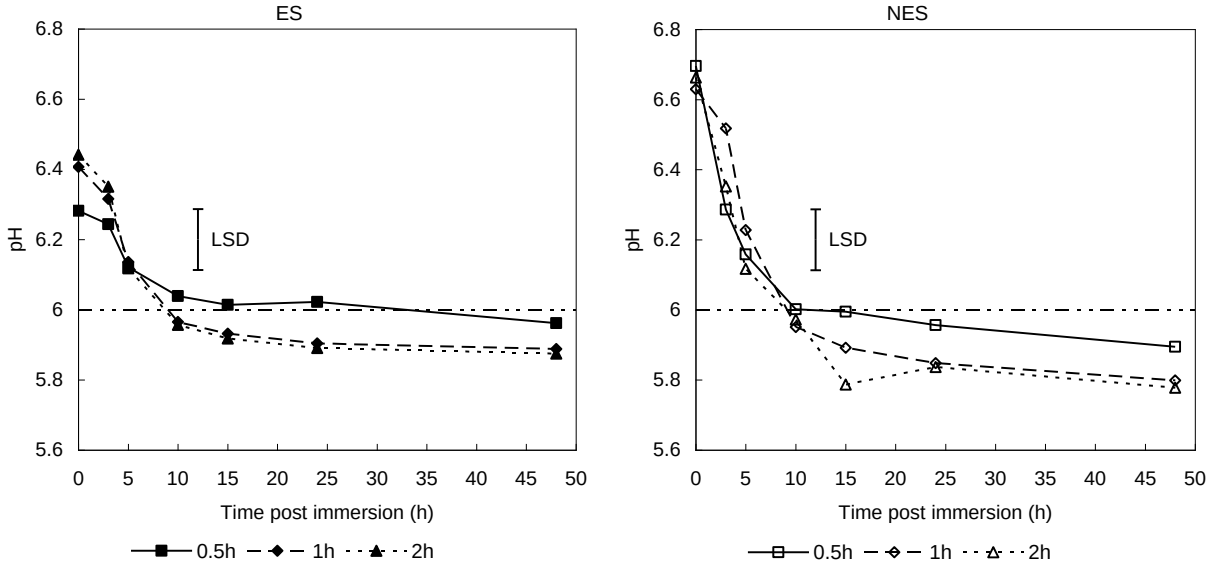


**Figure 11.** The effect of immersion time (0.5, 1, 2 h) on pH for ES and NES over the 48 h *post mortem* period (LSD is for interaction term between time and treatment P < 0.05).

### 3.2.3 Shear force

Shear force was significantly ($P < 0.001$) affected by electrical stimulation and immersion time (Figure 12). If the loins were electrically stimulated – irrespectively of immersion time, the shear force was already below 10 KgF 1 day *post mortem* and reached the benchmark of 7 KgF by 5 days *post mortem*. In contrast, when the loins were not electrically stimulated and the immersion time was 0.5 h or 2 h, the shear force were 14.9 and 11.3 KgF day 1 *post mortem* and didn't get below 10 KgF by day 5 *post mortem*. However, loins with an immersion time of 1 h (identical to treatment D in experiment 1) had an average shear force of 7.8 KgF on day 1 *post mortem* which decreased to 5.0 KgF by day 5 *post mortem*.

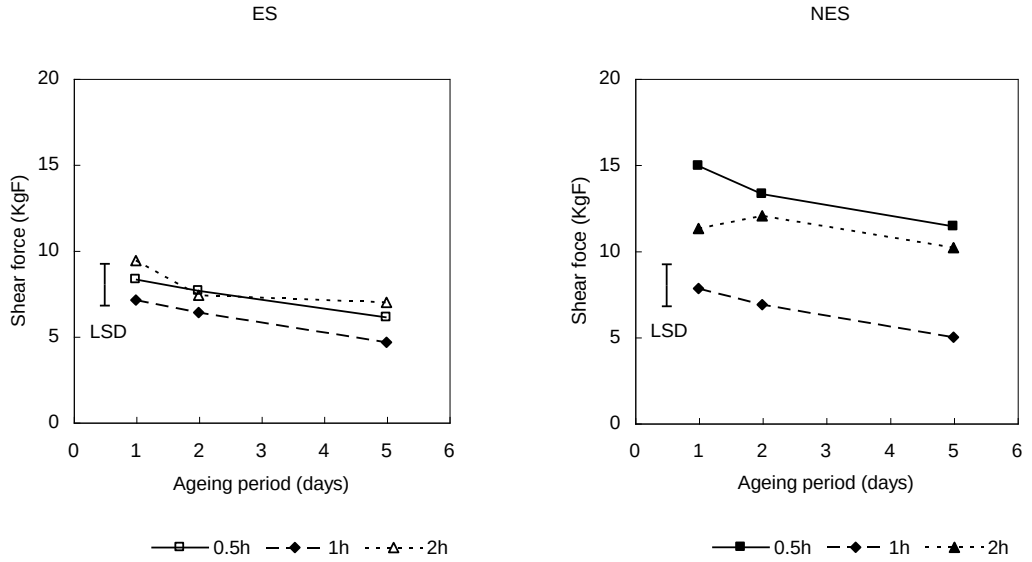


Figure 12 Shear force during ageing as affected by electrical stimulation (ES and NES) and immersion time (0.5 h, 1 h and 2 h). LSD values are for the interaction between immersion time, ES and ageing period.

### 3.2.4 Sarcomere length

Sarcomere length responded differently to the immersion chilling time depending on whether the loins had been electrically stimulated or not ($P < 0.01$). 1 h immersion resulted in the longest sarcomeres (~ 1.9 µm), irrespectively of electrical stimulation. 2 h immersion resulted in similar sarcomere length, but only when the loins were electrically stimulated. 0.5 h immersion resulted in the shortest sarcomeres (~ 1.7 µm), and again electrically stimulation resulted in longer sarcomeres (Figure 13).

The sarcomeres in this experiment were quite long (average 1.8 µm) even for non-electrically stimulated loins with 0.5 h and 2 h immersion times (> 1.6 µm) indicating limited shortening, especially relative to experiment 1 where treatments B, C and E resulted in sarcomere length shorter than 1.3 µm.

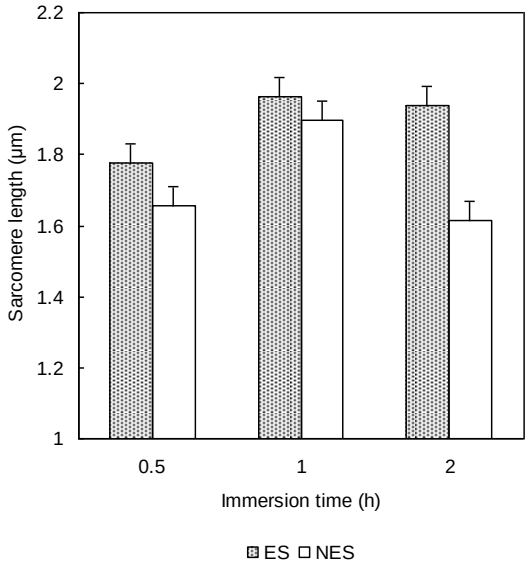


**Figure 13** Sarcomere length measured in loins subject to either electrical stimulation (ES and NES) and different immersion times (0.5 h, 1 h and 2 h).

## 3.3 Key findings

- These experiments have established that VFC can result in tender meat, confirming results published by European researchers.

- The experiments also established that VFC resulted in variable tenderness, but this could be explained at least in part by differences in minimum temperature and the rate at which this minimum temperature was reached within the VFC range. Hence, tenderness variation can be reduced by more precise specification of the temperature conditions within the VFC range. The best VFC regime was found to be a minimum temperature of approximately -2°C reached at 1.5 h *post mortem*.

- The average rate of pH change was accelerated with VFC. However the simultaneous rapid temperature decline resulted in the pH reaching 6 about 0°C. Such pH and temperature conditions would be expected to result in cold shortening (temperature < 10°C when pH > 6). The relationship between pH/temperature and tenderness is different for VFC, hence conventional pH/temperature benchmarks do not apply to VFC.

- Shortening did not occur with the best VFC regime. Prevention of shortening either by sub-zero temperature and/or low pH 1.5-2 h *post mortem* can at least partly explain the tenderness results.

- An exciting finding was that – with the best VFC regime – the meat was tender early *post mortem* (5.3 KgF). There was no evidence that this result was due to accelerated proteolysis. Furthermore, tenderness improved and proteolysis continued with time *post mortem* (ageing) in a similar way to conventional chilling.

- Electrical stimulation altered the rate of pH change under VFC conditions and broadened the minimum temperature range (although still sub-zero) and the rate at which this minimum

temperature was reached (1-2.5 h *post mortem*) at which tenderness was acceptable. This indicates that the rate of pH change may be important for optimal tenderness under VFC conditions, possibly through prevention of shortening.

- In conclusion, the best VFC regime resulted in tender meat. However without precise control of the temperature conditions the risk of producing tough meat is high. While proteolysis and prevention of shortening play key roles, the early tenderisation due to VFC cannot be explained by these factors alone.

# 4 Business case

A full cost/benefit analysis was carried out using a spreadsheet model with benefits and costs based on typical sheep and cattle processing plants in New Zealand and Australia. Full details with the spreadsheets are contained in the report by North and Kemp (2008).

## 4.1 Benefits of VFC

Eight key benefits were identified for VFC and assumptions quantified for 6 of these.

1. Reduced chiller/freezer space
2. Producing high quality chilled beef from a hot-boning process (beef only)
3. Increased display life for chilled products
4. Improved tenderness for frozen and aged-frozen products
5. Reduced weight loss (yield)
6. Accelerated ageing time for domestic product
7. Reduced microbial growth during processing and chilling
8. Continuous process allowing double shifting or 24 hr operation without expansion of chiller space

Benefits 7 and 8, reduced microbial growth and shift changes associated with continuous processing were not quantified in the models due to lack of data in these areas. However these two benefits could be significant and warrant quantification in future work.

## 4.2 Key findings

### 4.2.1 Critical factors

The modeling identified that the most valuable benefits from VFC will be process efficiency gains due to reductions in chiller space and yield improvements (Figure 14). In the case of beef, efficiencies due to hot boning represent a large additional gain compared to the benefits arrived at for sheep meat. Hot boning is essential for VFC with beef but not sheep meat although hot boning might be considered for sheep meat in start up situations.
Achieving similar or better quality outcomes compared to conventional chilling is vital for the success of VFC. Quality gains expected from VFC due to accelerated ageing, tenderness of frozen product and display life, whilst significant will have less value than the efficiency gains, should the red meat industry adopt VFC.
Verifying all assumptions used in the cost benefit analyses is a priority for future work with prototypes, but particularly so for those about chiller space and yield improvements.

### 4.2.2 Operating costs

No significant change in operating costs is expected between conventional process and VFC. Calculations suggested that very similar energy, labour and packaging costs will occur for VFC compared to conventional systems.

### 4.2.3 Cash flow

With the assumptions used, cash flow was positive for the industry after 2 years and maximum benefits were reached after 15 years (Figure 15**,** Figure 16 and Figure 17)
For sheep meat, the estimated cash flow gave a net present value (NPV) of NZ$75 million (or A$65 million at exchange rate of 0.87) and an internal rate of return (IRR) of 214%.

For beef, the estimated cash flow gave a net present value (NPV) of NZ$63 million (or A$55 million at exchange rate of 0.87) and an internal rate of return (IRR) of 247%.
Greater benefits were attributed to sheep meat than for beef because of the need for greater capital investment with beef. Nonetheless these estimated returns are very high for both commodities and represent a very good investment subject to the assumptions being proven in prototype development work.

### 4.2.4 Sensitivities

Sensitivity analyses showed that the cash flow generated by VFC was influenced by throughput (Figure 15), carcass weight (Figure 16) and product value (Figure 17) for both beef and sheep meat. However cash flow was most sensitive to a change in throughput suggesting that larger plants or plants processing larger carcasses will benefit most from implementing VFC.

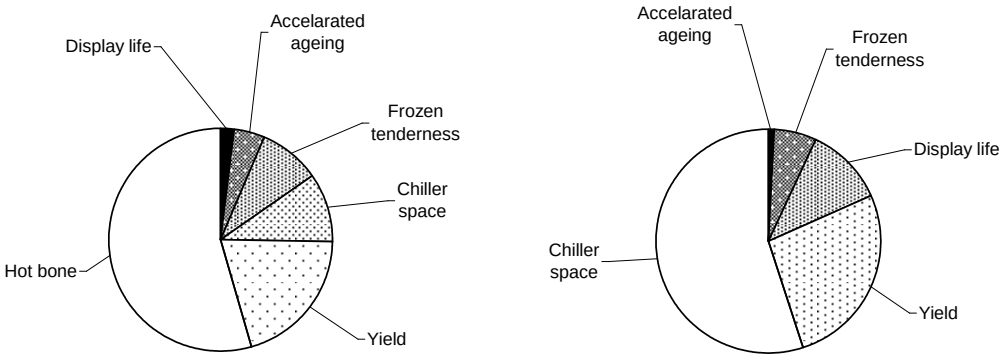


Figure 14 Relative annual benefits attributed to VFC for beef and sheep meat after 15 years (values represent a percentage of total benefits)

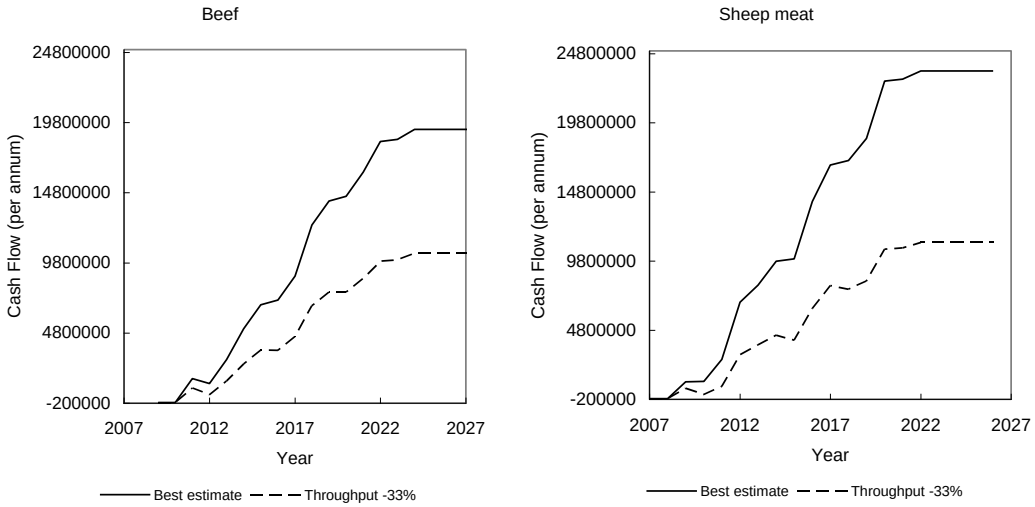

Figure 15 Sensitivity analysis of cash flow versus time for throughput of beef and sheep meat (values in NZ$)

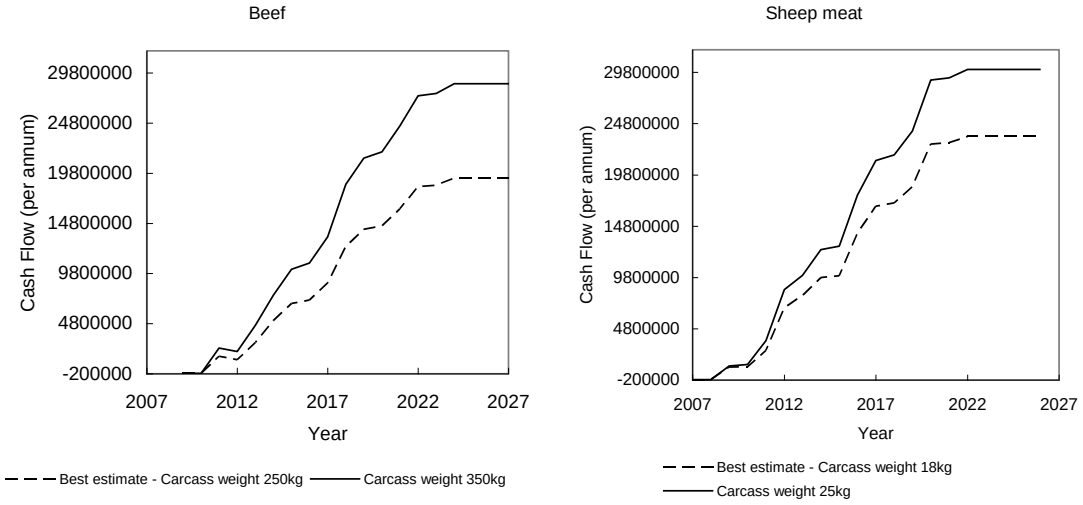


Figure 16 Sensitivity analysis of cash flow versus time for carcase weight of beef and sheep meat (values in NZ$)

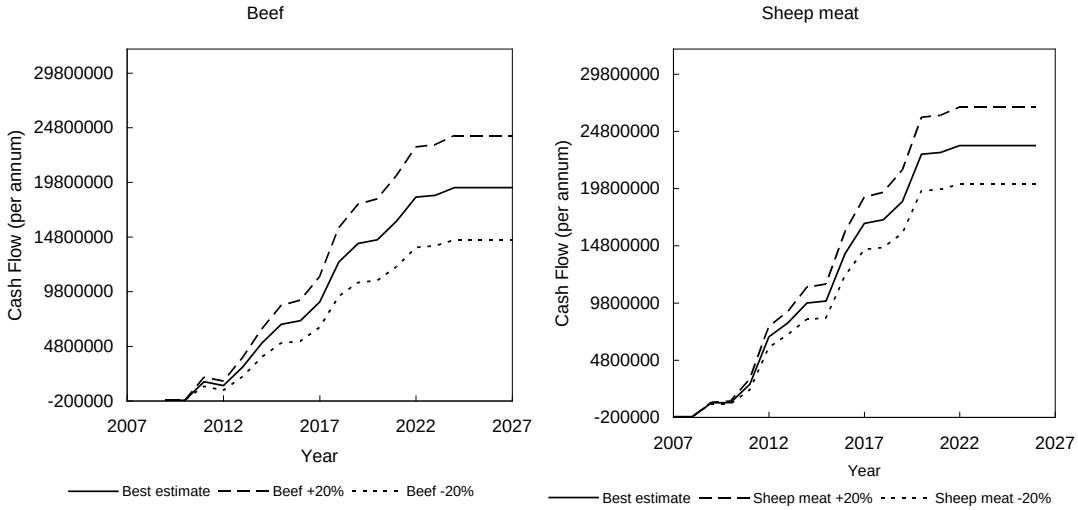


**Figure 17** Sensitivity analysis of cash flow versus time for product value of beef and sheep meat (values in NZ$)

# 5 Implications and conclusions

Proof of concept and some description of the process specifications have been achieved by the project to date. Components of the process specification which remain undefined such as boning time and associated specific quality outcomes require commercial prototypes to be available for testing.

This project has therefore reached a stage where development work with commercial prototypes would be advantageous to take the concept closer to becoming commercially viable. Furthermore closer dialogue with prospective users of VFC would be advantageous to refine development priorities. Notwithstanding this critical phase being reached there is a need to do continue with a controlled experimental program as well to support findings from the development work.

# 6 Publication plan

### 6.1.1 Industry update (Appendix A)

### 6.1.2 ICoMST 2009 poster(s)

Experiment 1
Experiment 2

Meat Science papers

1. Refining very fast chilling. 1 Understanding the tenderness variation

   Tenderness, sarcomere and proteolysis data from experiment 1

2. Refining very fast chilling. 2 Electrical stimulation effect and temperature boundaries

   Tenderness, sarcomere and proteolysis data from experiment 2
3. Refining very fast chilling. 3. Physical and biochemical changes

   NMR data – experiment 1; temperature data – experiment 2

# 7 Acknowledgements

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# 9 Appendix A

December 2008

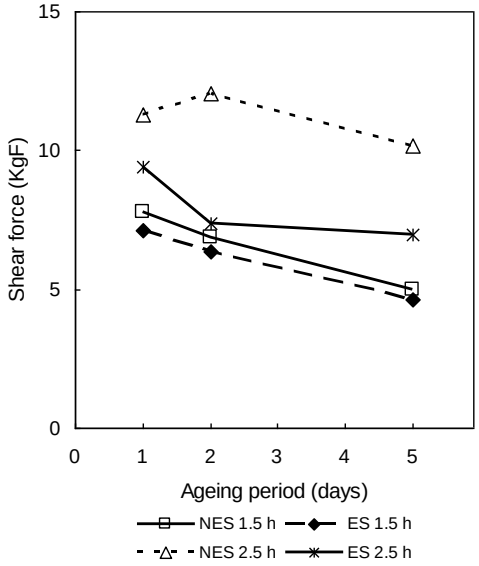
INDUSTRY UPDATE – VERY FAST CHILLING

Summary

Meat of acceptable tenderness has been demonstrated with **Very Fast Chilling,** but results have been variable. A joint Australian and New Zealand research team has studied specific chilling regimes within the **Very Fast Chilling** definition and found that the best **Very Fast Chilling** regime resulted in consistently tender meat. However without precise control of the temperature conditions the risk of producing tough meat is high. While proteolysis and prevention of shortening play key roles, the early tenderisation due to **Very Fast Chilling** cannot be explained by these factors.

Key findings

- It was established that **Very Fast Chilling** can result in tender meat, confirming results published by European researchers.
- It was also established that **Very Fast Chilling** can result in variable tenderness, and this could be explained by small differences in minimum temperature and the rate at which this minimum temperature was reached within the **Very Fast Chilling** definition. The best **Very Fast Chilling** regime was found to be a minimum temperature of approximately -2°C reached at 1.5 h *post mortem*. Hence, tenderness can be optimised by strictly controlling the temperature conditions within the VFC range.
- The rate of pH change was accelerated with **Very Fast Chilling**. However the rapid temperature decline resulted in the pH reaching 6 about 0°C. Such pH and temperature conditions would be expected to result in cold shortening (temperature < 10°C when pH > 6). Therefore the relationship between pH/temperature and tenderness is different for **Very Fast Chilling**, and conventional pH/temperature benchmarks do not apply to **Very Fast Chilling**.
- Shortening did not occur with the best **Very Fast Chilling** regime. Prevention of shortening either by sub-zero temperature and/or low pH 1.5-2 h *post mortem* can partly explain the tenderness results.
- An exciting finding was that – with the best **Very Fast Chilling** regime – the meat was tender 2 days *post mortem* (5.3 KgF). There was no evidence that this result was due to accelerated proteolysis. Furthermore, tenderness improved and proteolysis continued with time *post mortem* (ageing) in a similar way to conventional chilling.
- Electrical stimulation altered the rate of pH change under **Very Fast Chilling** conditions and broadened the minimum temperature range (although still sub-zero) and the rate at which this minimum temperature was reached (1-2.5 h *post mortem*) at which tenderness was acceptable. This indicates that the rate of pH change may be important for optimal tenderness under **Very Fast Chilling c**onditions, possibly through prevention of shortening.


15
10
5
0
Shear force (KgF)
0
1
2
3
4
5
Ageing period (days)
NES 1.5 h
ES 1.5 h
NES 2.5 h
ES 2.5 h