Final report

# Fat Depth Measurement

## Optimising Carcase Fat Depth Measurement


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Prepared by
Reece Williams

Murdoch University Researchers:
Kate Louden
Jayaseelan Marimuthu
Venkata Pamarla
Renji Karayakallile Abraham
Graham Gardner



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# Contents

# 1.0 Executive summary

This project investigated the ability of two devices, the Hennessy Grading Probe (HGP) and the Murdoch University-developed Microwave Scanner (MiS), to measure fat depth in beef at the P8 site and in sheep at the GR site. While the HGP is already accredited by AUS-MEAT, the MiS had not yet undergone any accreditation trials. Following two initial data collection trials, DBC would decide whether to pursue AUS-MEAT accreditation for the MiS, depending on its performance compared to the AUS-MEAT Accreditation Error Tolerances (Section 3).

The first data collection revealed that the HGP could not accurately predict fat depth, leading DBC to not continue its consideration for commercial installation and trials. On the other hand, the MiS showed positive results in accurately reading fat depths in both beef P8 and sheep GR. However, a complete dataset for beef P8 fat depth measurements could not be collected during the second trials due to inconsistencies and inaccuracies caused by hot carcass washing. As a result, DBC decided to proceed with accreditation of the MiS solely for lamb GR fat depth measurement.

Accreditation trials for the MiS measurement of GR fat depth were successfully completed, meeting all AUS-MEAT Accreditation Standards. The device has been fully integrated into the DBC plant, used daily with MiS measurements directly linked to DBC's production system. Although the MiS GR fat depth measurement is not yet printed on each carcass ticket, this feature is in progress. DBC may continue to pursue accreditation for beef pending further trial results.

The MiS device is an excellent option for processors seeking an accredited, easy-to-implement, cost-effective, mobile fat depth measurement device with a small footprint.

# 2.0 Introduction

### State of the Industry

Beef and sheep carcase trading within Australia is largely based on carcase weight (kg) and a single site measurement of subcutaneous fat depth. Consumer preference when purchasing red meat is for a lean product without excessive subcutaneous fat (Hopkins, Wotton, Gamble, Atkinson, Slack-Smith, & Hall, 1995b; Hopkins & Fowler, 2018; Thatcher & Couchman, 1983). Overfat carcasses reduce the amount of saleable lean meat yield, thus fat depth is negatively correlated to carcase value (Polkinghorne, Philpott, Gee, Doljanin, & Innes, 2008). In addition to reduced yield, excessive fatness must be trimmed to retail specifications for consumer satisfaction thus increasing labour inputs in the boning room. As such, Australian processors set price grids for carcase weight and fat depth, and pay producers on a per carcase basis as to how it fits the grid. Thus accurately determining carcase fatness in beef and sheep is essential to enhance productivity and profitability of the red meat supply chain.

The current AUS-MEAT industry standards for determining carcase single site fatness in lamb is via subjective palpation or invasive objective techniques (Anonymous, 2005). Fat scoring in lambs is performed at the GR site (110 mm from spine midline over the 12th rib) and is based on a simple 1 to 5 scale, where Grade 1 is equivalent to 0-5 mm, and subsequent grades increase in 5 mm increments (Grade 2 >5 to 10 mm, Grade 3 > 10 to 15mm, Grade 4 > 15 mm to 20mm, Grade 5 > 20 mm) (Anonymous, 2005). Current AUS-MEAT approved instruments for determining GR tissue are the GR Knife and the AUS-MEAT sheep probe. The GR Knife is a cut knife and ruler, which can measure in 1 mm increments (AUSMEAT, 2020). The GR knife can be prone to operator error, particularly when used on the hot carcase prior to the fat setting (Pearce, 2016). The average abattoir chain speed for lamb is typically too fast for the operation of the GR knife on the hot carcase (Fowler, Morris, & Hopkins, 2020) thus when used in processing plants multiple GR knife operators are required, increasing labour units. The AUS-MEAT sheep probe is an objective displacement invasive probe, with tissue depth measured in 1 mm increments. The AUS-MEAT sheep probe demonstrated good precision of prediction when operated on a moderate abattoir chain speed of 8-9 carcases (Hopkins, Anderson, Morgan, & Hall, 1995a). However the operator accuracy was variable, where Hopkins et al. (1995a) demonstrated only 30% of carcasses were probed in the correct site in one of two experiments. Perceived inaccuracies erodes confidence in the measurement, and while still on the accredited list of instruments, the AUS-MEAT sheep probe is no longer manufactured or part replacement supported (Toohey, van de Ven, & Hopkins, 2018). Due to operator difficulties keeping up with abattoir chain speeds, instrument measurements are typically replaced with subjective manual fingertip palpation of the GR site to give an estimation of fat score (Anonymous, 2005). Operators performing subjective palpation are audited under the AUS-MEAT accreditation system, however as a subjective measurement it can be biased by human error, which erodes producer confidence in carcase feedback.

Single site subcutaneous fat determination in beef is performed at the P8 site, defined as ""the point of intersection of a line from the dorsal tuberosity of the tripartite tuber ischia parallel with the chine, and a line at 90o to the sawn chine centred on the crest of the spinous process of the third sacral vertebrae" (AUSMEAT, 2016). AUS-MEAT accredited instruments are the cut and measure knife, and the Hennessy Grading Probe (HGP) (Hennessy Technology Ltd, Auckland, New Zealand) (AUSMEAT, 2020). The cut knife is inserted vertically through the P8 site, with measurement taken where the ruler emerges from the fat against the lateral side of the cut (AUSMEAT, 2020). The HGP is an optical probe with scalpel blade tip for insertion at the P8 site and the system can be connected online to the abattoir data base. The prediction of P8 fatness by HGP has demonstrated excellent precision (Hopkins, 1989; Phillips, Herrod, & Schafer, 1987) and has been an AUS-MEAT accredited objective instrument for decades. Despite this, commercial uptake of HGP has been low, with only 32% of Australian processors surveyed adopting this technology (Toohey et al., 2018).

The challenge for small processors, and in particular small mixed species processors, is implementing precise and accurate measurement technologies for subcutaneous fatness that have high precision and accuracy whilst being cost-effective and ideally be functional across species. A HGP for lamb exists, however it is not currently AUS-MEAT accredited for GR tissue depth. Early research demonstrated that HGP could successfully determine tissue depth at the GR site (Kirton, Mercer, Duganzich, & Uljee, 1995). Hennessy Technology Ltd. operation manual for HGP in lamb states the probe must be inserted 30-35 mm from spine midline through the m. longissimus thoracis (loin) between ribs 11 and 12, with the probe scalpel tip angled at 30 degrees away from the vertebrae. As such this technique results in the probe inserting directly through the centre of the loin. Recent studies assessing HGP probed through the loin as an additional lean meat yield prediction, demonstrated variability in probe accuracy at this location and concluded there was no benefit of including an HGP loin measurement into the Australian sheep processing industry (Hopkins, Toohey, Boyce, & van de Ven, 2013; Siddell, McLeod, Toohey, van de Ven, & Hopkins, 2012). Under AUS-MEAT carcase grading language, fat scoring in lamb must provide GR site tissue measurement (Anonymous, 2005), so integration of HGP as an objective measurement technology for lamb must probe directly at the GR site, or probed through the loin to develop a prediction equation for GR tissue depth.

There is a recent push in the Australian and New Zealand red meat industries to develop new objective livestock measurement technologies (Gardner, Apps, McColl, & Craigie, 2021). Ideally new technologies for predicting single site subcutaneous fatness will be non-invasive, thus cause no destruction of tissues. Technologies must be precise and accurate, while being robust enough to operate under commercial processing conditions at industry speeds, and preferably be flexible in their ability to measure in the pre- or post- chill environments (Gardner et al., 2021; Scholz, Bünger, Kongsro, Baulain, & Mitchell, 2015). A new technology for objectively measuring single site subcutaneous fatness in beef and lamb, ultra-wide band microwave system (MiS) scanning, has been developed at Murdoch University, Western Australia. MiS transmits low power, non-ionising electromagnetic waves into tissues via an antenna placed on the site to be measured, and the signal is reflected and captured by the same antenna. The permittivity and conductivity (dielectric properties) of biological tissues (bone, muscle, fat) vary distinctively, in turn altering the reflected signal, and as such MiS can distinguish the distinct boundaries between tissue layers (Marimuthu, 2016; Marimuthu, Bialkowski, & Abbosh, 2016). The low power properties of MiS cause no destruction to biological tissues thus is completely safe to use without shielding. The MiS has been designed to be portable, hand-held (weight < 1kg), and low cost (<$60,000). MiS measurement is captured instantaneously via the click of a button after placement of the antenna on the tissue site to be measured. The same prototype MiS device has been demonstrated to have good precision and accuracy of prediction of subcutaneous fat determination in both beef (Marimuthu, Loudon, & Gardner, 2021) and lamb (Marimuthu, Loudon, & Gardner, 2020).

### Dardanup Butchering Company

Dardanup Butchering Company (DBC) has existing, but old-fashioned measures for determining fatness, measuring rib and P8 fat in beef, and GR tissue depth in lamb. GR tissue depth is done via manual palpation which can be imprecise. This is what sparked DBC's interested in investigating opportunities for integration of objective measurement technology to capture these fat depth measures.

Working with Murdoch University and the ALMTech team DBC established their interest in investigating the new Microwave Scanner (MiS) and the Hennessy Grading Probe (HGP) as fat depth measurement devices. DBC wanted to find an objective measurement solution that could be applied across both species, beef and sheep.

This project was established to compare the use of the HGP and MiS as objective measurement technologies and assess their precision and accuracy for predicting GR tissue depth in lamb and P8 fat depth in beef to provide a small, multi-species processing plant with a cost-effective, portable, objective livestock measurement technology.

If the technologies succeed in being a precise measurement, an extension of this project is to explore AUSMEAT accreditation for these devices and implement an accredited objective measurement technology for use in both beef and lamb at DBC.

From a broader industry perspective this is an opportunity to establish a multi-species solution for a small operator, distinct from other objective measurement projects which are typically focused on single species in large scale enterprises. Additionally, this aligns with ALMtech activities to facilitate the commercial road-testing of a handheld microwave scanner in comparison to existing industry measures or existing accredited measures such as the Hennessy probe. These measurements will displace the existing fat depth feedback already provided to farmers within the supply chain, enhancing confidence and trust in feedback.

# 3.0 Project objectives

This project aims to integrate new technologies to measure carcase rib and P8 fat depth in beef, and GR tissue depth in lamb, for Dardanup Butchering company (DBC) and assess the accuracy and precision of two different devices.

A series of experiments will compare the use of Hennessy Grading Probe (HGP) and a prototype microwave scanner (MiS) developed at Murdoch University as objective technologies to measure single site fatness in beef and lamb.

- Comparison of HGP and MiS with existing cut knife ruler measurements of P8 fat depth in beef
- Comparison of MiS with GR Knife cut knife ruler measurement of GR tissue depth in lamb
- Potential AUSMEAT accreditation of MiS for measuring P8 and GR tissue depth as a single device
- Explore the potential for lamb accreditation for HGP

# 4.0 Methodology

## Overarching Project Methodology

- Use historical slaughter data from DBC to establish weight and fat population ranges in beef and lamb. This will provide knowledge of animal types across which these measurements must predict robustly.
- Collection of slaughter and chiller data of rib, P8 and GR tissue depth using a HGP and MiS across a population range (weight and fat) defined in objective 1. above.
- Comparison of new technologies with existing measurements of rib, P8 and GR tissue depth.
- Road testing by DBC staff of MiS to enable commercial testing of MiS accuracy and precision.
- Investigate AUSMEAT accreditation requirements for new technologies.
- Facilitate AUSMEAT accreditation of the HGP in lamb, and the MiS in lamb and beef pending their successful in-plant application.

## Milestone 1-3

Data was collected on beef and lamb carcases using HGP and MiS at DBC across 3 slaughter days (July 2021):

- Beef P8 HGP (n=262)
- Beef P8 MiS (n=215)
- Lamb GR site HGP (n=126)
- Lamb GR site MiS (n=520)

For beef carcase P8 fat depth, an accredited AUS-MEAT operator measured fat depth using a cut-and-measure knife, immediately after using the MiS with a Vivaldi Patch Antenna (VPA) at the same location. HGP measurement then taken according to AUS-MEAT accreditation standards (AUSMEAT, 2020) and fat depth recorded manually.

For lamb carcasses, hot GR tissue depth was measured post-wash and electrical stimulation by a Murdoch University technician using a GR Knife and recorded manually. The Lamb HGP SP7 probe was then inserted for measurement and recorded. MiS scanning with VPA antenna was used for lamb measurements at the GR site.

## Milestone 4

Data collected in milestone 1-3 was analysed during this period.

## Milestone 5

A second round of data was collected (beef & lamb) using MiS only, across 3 slaughter days (Dec 2021):

- Beef P8 MiS (n=187) *Only two days collected due to MiS device malfunction*
- Lamb GR site MiS (n=466)

Beef carcase P8 fat depth was measured by an accredited AUS-MEAT operator with a cut-and-measure knife at the grading station. In contrast to MS 1-3 carcases were hot washed and MiS scanning performed immediately after (distance of approximately 1-2m post hot wash on the chain).

For lamb carcasses, hot GR tissue depth was measured post-wash and electrical stimulation by a Murdoch University technician using a GR Knife and recorded manually. The Lamb HGP SP7 probe was then inserted for measurement and recorded. MiS scanning with VPA antenna was used for lamb measurements at the GR site.

## Milestone 6

DBC decided post MS 5 that they would only proceed with an accreditation trial for MiS measurement of lamb GR fat depth.

The proposed guidelines for accreditation require that carcases are selected across the accreditation range for the fat scores of 1 - 5. The microwave measurements for the accreditation of fat score 1 – 5 was captured at three separate dates at the same Western Australian lamb processing facility. The first accreditation data was captured in December 2022, and has the fat scores of 1, 2, 3, and 4. On this date, there were insufficient fat score 1 carcases, and no fat score 5 carcases available, hence follow-up data collection dates were required. The second accreditation data was captured in March 2023 targeting fat score 1. The final, accreditation data was captured in April 2023 targeting fat score 5 carcases. The captured data from the above three dates have successfully met the required accreditation range of fat scores 1 – 5.

To meet the proposed guidelines for accreditation, 3 scans were taken using one MiS device to demonstrate within device repeatability and 1 scan was taken from a second and third MiS device to demonstrate across device repeatability. Each device measured the same site and within 30minutes post-mortem. All MiS predicted GR tissue depths were downloaded and sent to an AUS-MEAT representative on the same day as measurement.

## Milestone 7 – Final

Post MiS accreditation installation and implementation of the MiS at DBC permanently.

Training of DBC staff to use the MiS system independently.

Integration of MiS fat depths with DBC production system and fat depth printing onto carcase tickets.

## Microwave Scanner Details

The MiS was designed and manufactured by the Microwave Engineering team at Murdoch University under the ALMTech program. The microwave signal analysis for lamb and beef within this project was the same, with full methodology described in Marimuthu et al. (2021a, 2021b). In brief, the MiS consisted of a vector analyser coupled to a single broadband Vivaldi patch antenna (VPA), designed and fabricated at Murdoch University (Perth, Western Australia). The vector analyser was constructed using a Copper Mountain Technologies® R54 vector reflectometer (copper Mountain Technologies, Indianapolis, USA) which had an automated, inbuilt operating system, with python-based programs for data acquisition and signal processing. The MiS was calibrated individually for beef and lamb measurements. The calibration was performed just prior to measurements commencing using the “Short, Open and Load” techniques described by Marimuthu (2016)  Calibration using free-space (open), Teflon (load), and Aluminium (short). These are contained within 3D-printed cases (Figure 1).


*Figure 1 Short and load calibration blocks for the Vivaldi Patch Antenna*

## Microwave System Calibration

The standard method to calibrate the microwave system before starting to scan carcases is to perform a daily **8-step calibration technique** using the Python program loaded in the system:

1. **Open/free-space:** "Point the antenna in Open Space (air) ensuring there are no objects within 2 meters of the device (top/bottom/left/right)".
2. **Load:** The load calibration is performed by placing the load block on a table and inserting the antenna into the 'load' slot provided and two scans taken.
3. **Short:** The short calibration is performed by placing the short block on a table and inserting the antenna in the 'short' slot provided and two scans taken

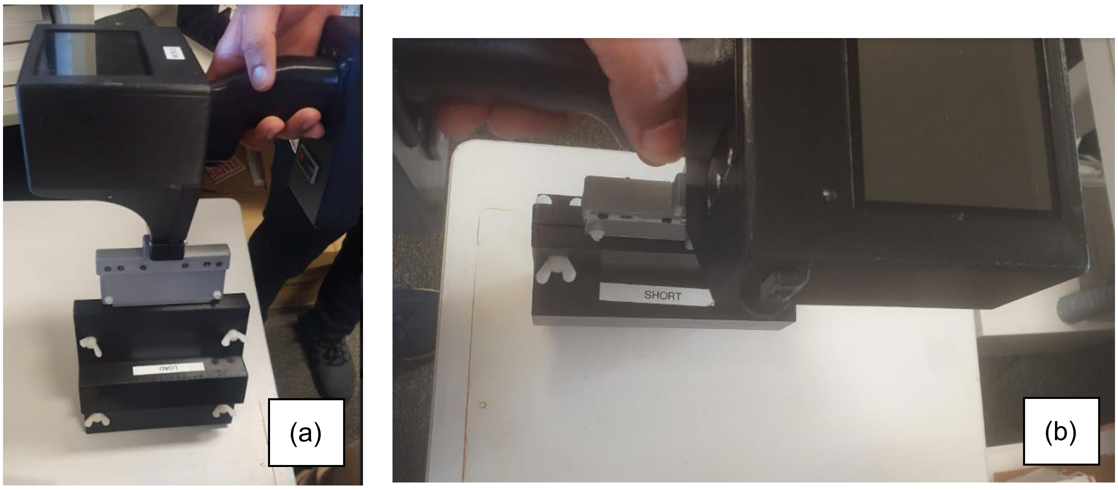



*Figure 2 Calibration of the MiS device using (a) load and (b)short calibration blocks*

4. **Tissue depth 1:** Antenna inserted into position 1 slot (Figure 4) and using the trigger switch, one measurement is captured.

5. **Tissue depth 2:** Antenna inserted into position 2 slot (Figure 4) and using the trigger switch, one measurement is captured.
6. **Tissue depth 3:** Antenna is inserted into position slot 3 (Figure 4) and using the trigger switch, one measurement is captured.
7. **Tissue depth 4: A**ntenna is inserted into position slot 4 (Figure 4) and using the trigger switch, one measurement is captured.
8. **Tissue depth 5: A**ntenna is inserted into position slot 5 (Figure 4) and using the trigger switch, one measurement is captured.

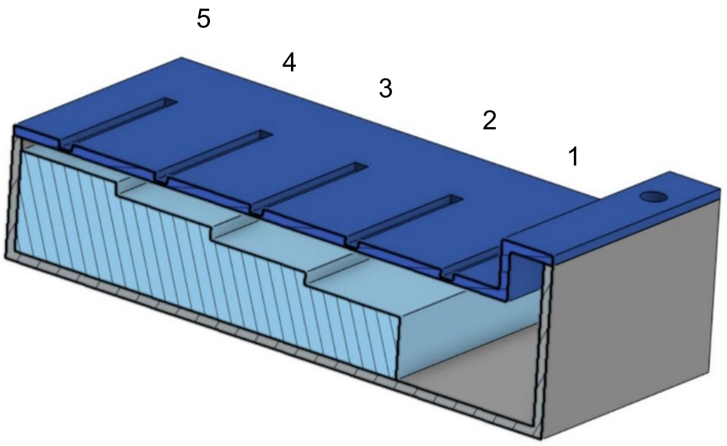



*Figure 3: Auditing block with antenna slots 1 to 5*

## GR tissue depth measurement

After successful completion of the 8-step calibration procedure, the screen of the MiS device will show 'GR tissue depth measurement and carcase number (Figure 4) when ready for scanning. To capture a measurement the antenna is positioned parallel to the spine, with the centre placed over the GR site in full contact with the carcase (Figure 5), and the trigger button on the handle depressed once.

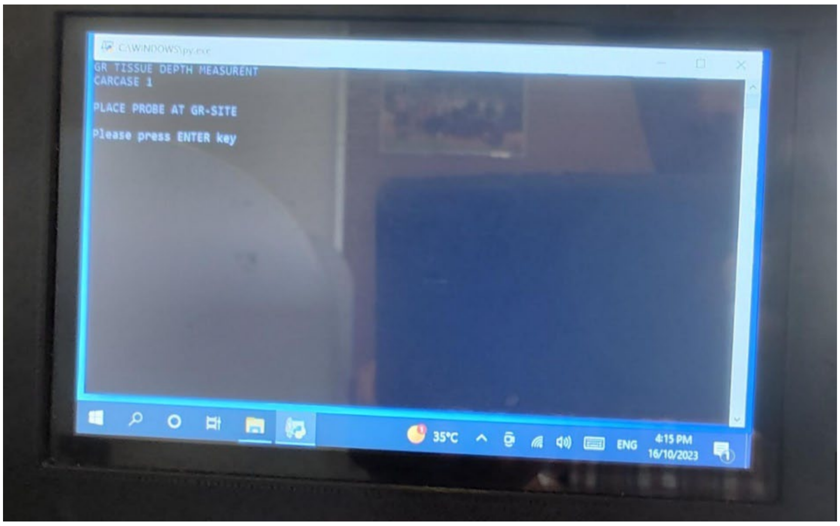



*Figure 4 Microwave system screen ready for scanning carcases*

*Figure 5 MiS coupled with VPA antenna measuring GR tissue depth with the centre of the antenna over the GR site*

## AUS-MEAT National Accreditation Standards

The MiS predictions and HGP measurements were evaluated against the AUS-MEAT national auditing and accreditation standards for lamb and beef.

For each species, AUS-MEAT specifies the minimum sample size that must be obtained and fat tolerance error limits for lamb and beef. For analytical rigor the analysis performed on the DBC data does not use the recommended minimum sample size, instead it evaluates every carcase sampled per slaughter day against the fat measure tolerances resulting in a far greater sample size than stipulated by AUS-MEAT.

### Lamb

AUS-MEAT states lamb GR measurements are recorded in fat classes, scored on a system from 1 to 5 (Table 2) (AUSMEAT, 2020).

#### Sample size:

Table 1 lists the lamb minimum sample size for AUS-MEAT auditing and accreditation, based on the daily kill numbers.

*Table 1 AUS-MEAT sample size for national lamb GR auditing and accreditation (AUSMEAT, 2020)*

| Kill Size | Sample Size |
|---|---|
| Up to 100 | 10 |
| 101 – 200 | 20 |
| 201 – 400 | 30 |
| 401 – 1000 | 40 |
| Over 1000 | 40 |

### Fat tolerances:

The correct fat class must be assigned with a tolerance of ± 2 mm of a score boundary with 90% accuracy (AUSMEAT, 2020). The fat class scores and depths are listed in Table 2.

To evaluate the precision predictors for GR tissue depth, the MiS predictions and actual GR tissue depth measurements were transformed to AUS-MEAT fat scores from 1 to 5. The error rate was calculated by determining the percentage of erroneous fat score allocations where there was a prediction difference greater than 2 mm of the actual fat score.

*Table 2 AUS-MEAT GR tissue depth fat class and corresponding depth in mm (AUSMEAT, 2020)*

| Fat Class | Fat depth (mm) |
|---|---|
| 1 | Up to 5 mm |
| 2 | Over 5 mm and up to 10 mm |
| 3 | Over 10 mm and up to 15 mm |
| 4 | Over 15 mm and up to 20 mm |
| 5 | Over 20 mm |

## Beef

AUS-MEAT states that beef the fat measurement is to be recorded in mm (AUSMEAT, 2020).

### Sample size:

Table 3 lists the beef minimum sample size for AUS-MEAT auditing and accreditation, based on the daily kill numbers (AUSMEAT, 2020).

*Table 3 AUS-MEAT sample size for national beef P8 auditing and accreditation (AUSMEAT, 2020)*

| Kill Size | Sample Size |
|---|---|
| 6 – 50 | 10 |
| 51 – 300 | 20 |
| 301 – 600 | 30 |
| Over 600 | 40 |

### Fat tolerances:

The AUS-MEAT fat tolerances for P8 are listed in Table 4. Measurements must adhere to tolerance limits with 90% accuracy (AUSMEAT, 2020).

To evaluate the precision predictors for P8 tissue depth, the error between the MiS predictions and the P8 cut knife and ruler for each carcase was determined. The error rate was calculated by determining the percentage of erroneous score allocations per slaughter day where there was a prediction difference greater than the tolerance described in Table 4. The same methodology was used to evaluate the HGP measurement against P8 cut knife and ruler.

*Table 4 AUS-MEAT fat tolerances for beef P8 auditing and accreditation (AUSMEAT, 2020)*

| Fat Depth | Tolerance |
|---|---|
| Up to and including 5 mm | + or – 1 mm |
| Over 5 mm up to and including 10 mm | + or – 2 mm |
| Over 10 mm | + or – 3 mm |

# 5.0 Project outcomes

## Milestone 1-3

First round of data collection for beef and sheep occurred in July 2021 utilising MiS and HGP.

- HGP has high error rate of measurement at GR site, 2/3 of carcases measured had an error message. HGP was discontinued as an objective measurement for lamb GR site within this project.
- MiS lamb GR scanning was performed on a wet carcase due to abattoir chain configuration. Surface water may potentially interfere with MiS reading so a subset analysis of wet versus dry carcase MiS predictions to be performed prior to further data collection.

HGP measurement at the GR site on the lamb carcase did not work. Of the carcasses probed with HGP in slaughter group 1 and 2 (n=126), only 1/3 of the measurements (n=35) delivered a tissue thickness reading in mm. The other 2/3 of carcasses HGP probed caused an error message of ‘not through’ or ‘no reading’. The HGP SP7 operator manual states that the probe is programmed to reject a measurement when “single site fat is less than 5mm or greater 50mm, and single site meat is less than 15 mm or more than 70 mm”. While there is published literature of HGP used at the GR site (Kirton et al., 1995), Hennessy Technology Ltd. no longer supports measurement taken at this site as the technology is no longer based on a linear measurement (HennessyTechnologyLtd, 2021). The option going forward for continuing to use HGP in lamb for AUS-MEAT accreditation was to use the probe through the loin and see if equations could be developed to predict GR site fat depth. If an accurate equation could be developed, Hennessy would be approached to see if the equation could be loaded into the system prior to accreditation with AUS-MEAT. Due to the invasive nature of the HGP probe causing potential damage to the loin and the lost retail value of this high-quality cut, along with the demonstration that HGP could not determine single site fatness, DBC elected to discontinue experimental work with HGP in lamb.

The dielectric properties of substances which MiS uses to determine tissue thickness can be affected by environmental factors such as surface water (Vijay, Jain, & Sharma, 2015). Ideally, MiS scanning would be performed prior to carcase washing. However the configuration of the chain at DBC is that the weigh scale is approximately 5 – 7 metres after the washing station, immediately prior to carcases entering the chiller. Due to space restrictions, there is no availability to capture MiS measurements prior to the wash station. For slaughter group 3, two MiS measurements were recorded at the GR site, “wet” and “paper towel dried”. Prior to further data collection, an analysis of the wet and dry measurements will be performed to establish if there is any difference in precision and accuracy of prediction and if the experimental protocol needs to change.

# Milestone 4

## MiS Precision and Accuracy

### Lamb – Wet vs Dry carcase

The average precision indicators for GR tissue depth measurements on wet versus dry carcasses showed similar predictions, with slightly better accuracy on wet carcasses. The RMSEP (Root Mean Square Error of Prediction) was 0.15 – 0.20 mm lower for wet carcasses. The $R^2$ values indicated that the wet carcass measurements explained more variation than the dry, with the wet carcass frequency magnitude achieving an $R^2$ of 0.74 (4% higher) and the frequency imaginary 0.05 units higher than the dry carcass predictions.

### Lamb – Wet carcase

When combining and balancing data from all slaughter days for GR tissue depth validation, precision and slope improved. The average RMSEP was 2.32 mm, with $R^2$ explaining 75% of variation. The average bias was 0.149 mm, with a maximum of 0.458 mm, lower than individual group testing but similar to May's. The average and maximum slope deviated 0.04 and 0.10 from 1, respectively. The figure below shows the association between actual and MiS-predicted GR tissue depth.

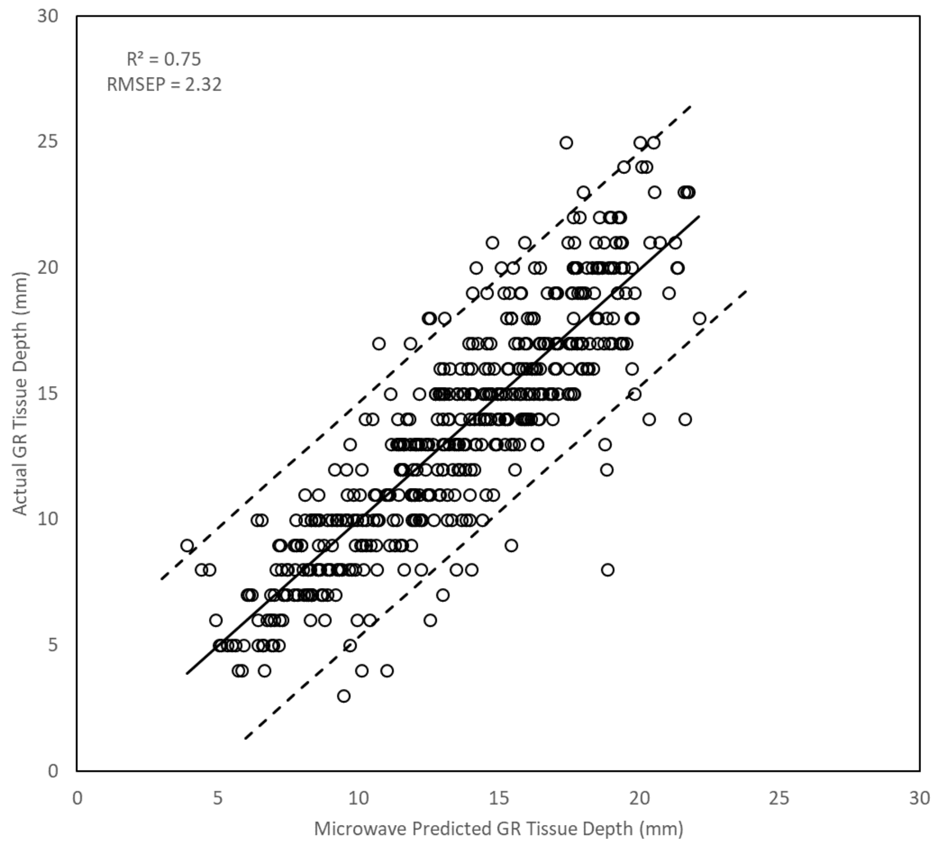



*Figure 6: The association between actual and microwave predicted hot carcase GR tissue depth (mm) using a VPA antenna. The predictions are derived from the validation tests detailed in Table 6(b) (n=478). The actual tissue depths were then regressed against the predictions. Solid line represents the relationship between predicted and actual measurements. Dashed lines represent ± RMSEP on the Y axis.*

### Beef

When validation testing was undertaken in the data from all slaughter days combined and balanced for P8 fat depth, the precision and slope improved compared to the validation testing done between slaughter-groups. The average RMSEP was 2.31 mm, with a range of 1.27 mm, while R2 on average described 83% of the variation with a range from 74% to 93%. The average bias was 0.271 mm, and the maximum bias across all 5 validation groups was 0.463. Both the average and maximum bias for the 5 balanced groups were 7 times lower than the bias reported in the within slaughter-group testing. The average slope of 0.08 was not too dissimilar to the average slope between slaughter groups of 0.12, however the maximum slope of the 5 balanced groups deviated half that reported within the actual slaughter groups. The association between the actual and MiS predicted hot carcase P8 fat depths is depicted below.

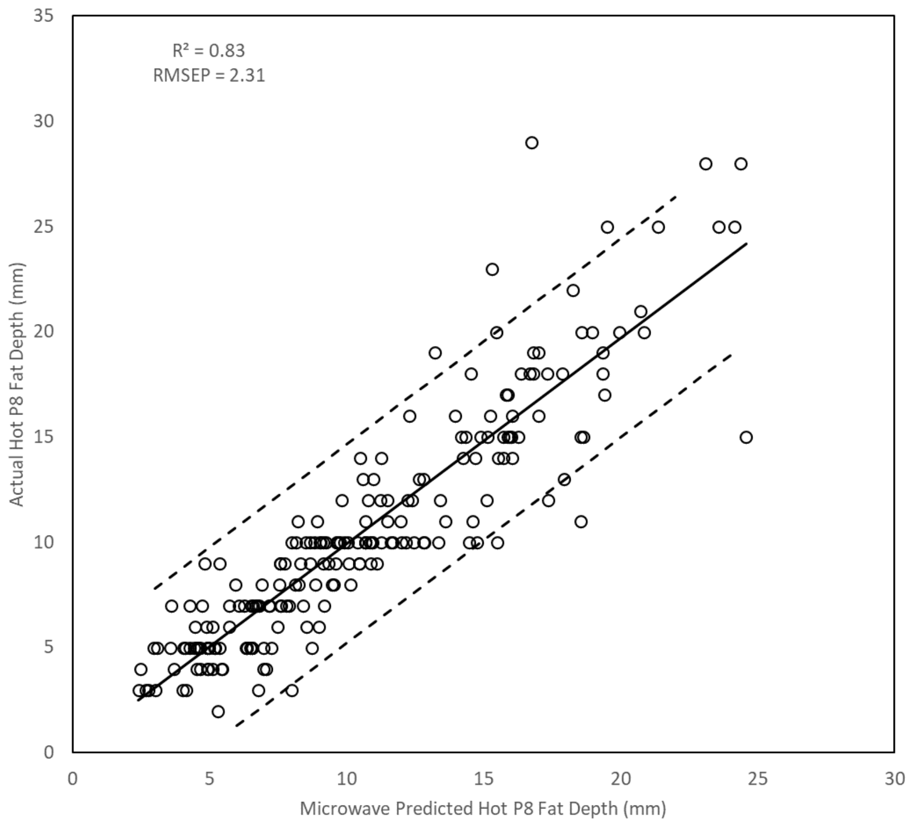



*Figure 7: The association between actual and microwave predicted hot carcase P8 fat depth (mm) using a VPA antenna. The predictions are derived from the validation tests detailed in Table 8(b) (n=205). The actual tissue depths were then regressed against the predictions. Solid line represents the relationship between predicted and actual measurements. Dashed lines represent ± RMSEP on the Y axis.*

## AUS-MEAT Accreditation

### Lamb

In the first slaughter group, MiS failed the 90% accuracy rate stipulated by AUS-MEAT, however the second and third slaughter groups adhered to the AUS-MEAT error tolerance limits.

### Beef

Neither HGP or MiS achieved the 90% accuracy rate stipulated by AUS-MEAT in the prediction of P8 fat depth, however MiS had the lowest error rates. There was a greater variation across the three slaughter days in error rate for HGP compared to MiS.

HGP is already accredited thus its use in plant only requires auditing. It was recommended that a DBC staff member perform all future HGP measurements and to receive training if required by AUS-MEAT.

### Discussion Points

#### Lamb

There was minimal difference in the MiS precision indicators between the wet and dry carcase predictions. The wet carcase predictions were very slightly improved on the dry carcase, an unexpected result, as the dielectric properties can be affected by environmental factors such as surface water (Vijay, Jain, & Sharma, 2015). The similarity between the wet and dry carcase predictions is an important finding to the industry application of the MiS device. Location of GR measurement on the chain will vary across processing plants and these results demonstrate that MiS prediction is not affected if taken on the wet versus the dry hot carcase.

Across two slaughter days, a different antenna was used. Mitigation of performance difference between antenna can be achieved by improving calibration techniques prior to measurement capture. The calibration currently used tests only the network analyser response in free space (air). It is essential that future calibrations test both the antenna performance as well as network analyser. To ensure robustness of antenna performance, future calibration will be performed not just on free space but include substrates such as metal and plastic which will represent varying extremes of impedance thus signal reflection, and be tested across materials of varying depth.

#### Beef

Neither MiS or HGP achieved the accuracy requirements for AUS-MEAT P8 fat classification. When comparing the two technologies, MiS achieved a lower overall error rate on all three slaughter days. The HGP was operated by the Murdoch staff member across all three days however they were not AUS-MEAT trained on the device. As HGP is an AUS-MEAT accredited technology it is recommended that future experiments should have an AUS-MEAT accredited DBC staff member operating the probe. This will enable any specific AUS-MEAT training if required during the routine auditing of the plant.

Similarly to lamb, across one slaughter day the MiS measurements had reduced predictive performance which again is likely due to varying antenna performance. On the first slaughter day the “S2” antenna was used to capture the first n=21 carcases prior to having battery failure, with the remaining carcases P8 depth MiS scanned using the “S1” antenna. By improving device calibration as previously discussed it is anticipated that variation between devices and days will be minimised as well as improving overall prediction of tissue depth.

### Next Steps

- Hennessy probe to be operated by AUS-MEAT trained DBC staff member
- MiS antenna performance across devices will be assessed using two MiS scanners measuring the same site on the same day
- Development of calibration blocks to ensure consistent performance across the frequency for each antenna. Calibration blocks will be designed to be small and transportable for practical ease of use within plants. Two blocks will be constructed, one composed of food-safe plastic and the other of stainless steel with the antenna slotting into the block for calibration

## Milestone 5

### MiS Precision and Accuracy

A second round of data collection across beef and sheep occurred in December 2021 utilising only MiS.

### Lamb

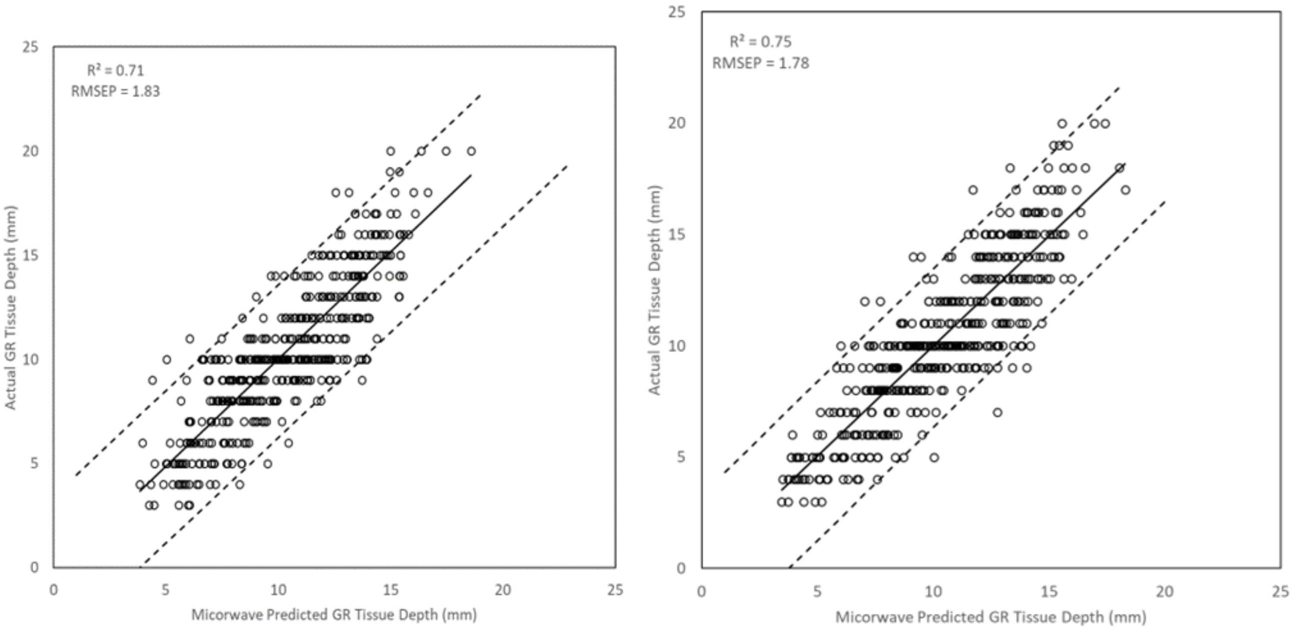



*Figure 8: The association between actual and MiS predicted hot carcase GR tissue depth (mm) using free space calibration (left) and using plastic block calibration (right) for MiS pointed at the GR site. Solid lines represent the relationship between predicted and actual measurements. Dashed lines represent ± RMSEP on the Y axis.*

### Beef

The performance of the beef MiS predictions varied substantially between days. On the first slaughter day, the precision was excellent, with an RMSEP of 2.00 mm and R2 explaining 79% of the variation. Alternatively, on the second day, the MiS had almost no predictive power, with RMSEP of 5.23 mm and R2 explaining 5% of the variation. These results were likely influenced by taking the measurements immediately after the hotwash, and therefore are not worth combining and analysing further.

## AUS-MEAT Accreditation

### Lamb

Regardless of calibration technique, when applied to the AUS-MEAT National Accreditation Standards the MiS prediction of GR tissue depth fits within the error tolerance range. MiS achieved the 90% accuracy rate stipulated by AUS-MEAT.

### Beef

These results were not compared to the AUS-MEAT error tolerances due to the variation and influence of the hot carcase wash on the MiS measurement.

## Discussion Points

Calibration blocks are required to ensure transportability of prediction between devices. Parallel experimental work is being performed to improve block calibration equation techniques to ensure transportability of prediction between devices. Recent accreditation attempts for GR tissue depth in lamb has highlighted the need for improving calibration between antenna to ensure the transportability of prediction between devices. The need for improved calibration may also be a factor describing the differences in prediction precision between days. As such, a new calibration procedure has been designed using a Teflon calibration block. This will be tested in future beef experiments to assess whether this accounts and corrects for the difference in performance between sampling days.

MiS beef P8 scanning was performed on a wet carcase due to abattoir chain configuration. The performance of MiS was markedly reduced from previous experiments at DBC where measurements were taken prior to the hot wash. Surface water appears to be interfering with MiS readings in beef. It was recommended the platform on chain be altered to allow for measurements to be taken prior to the wash. Alternatively additional experiments can be performed to directly compare dry versus wet MiS measurements in beef (as performed previously in lamb).

### Next Steps

DBC elected to proceed with MiS AUS-MEAT accreditation for lamb only.

## Milestone 6

This milestone involved undertaking AUS-MEAT accreditation for the MiS device measurement of GR tissue depth in hot lamb, previous MS reported that the device was falling within the error tolerances.

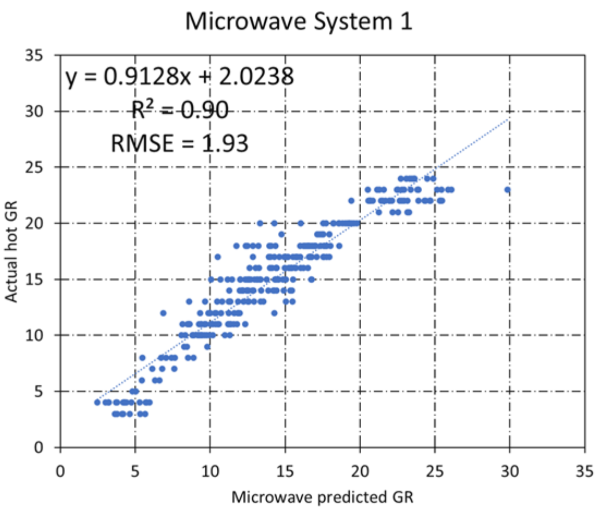



*Figure 9: Actual hot GR tissue depth vs MiS system 1 predicted tissue depth*

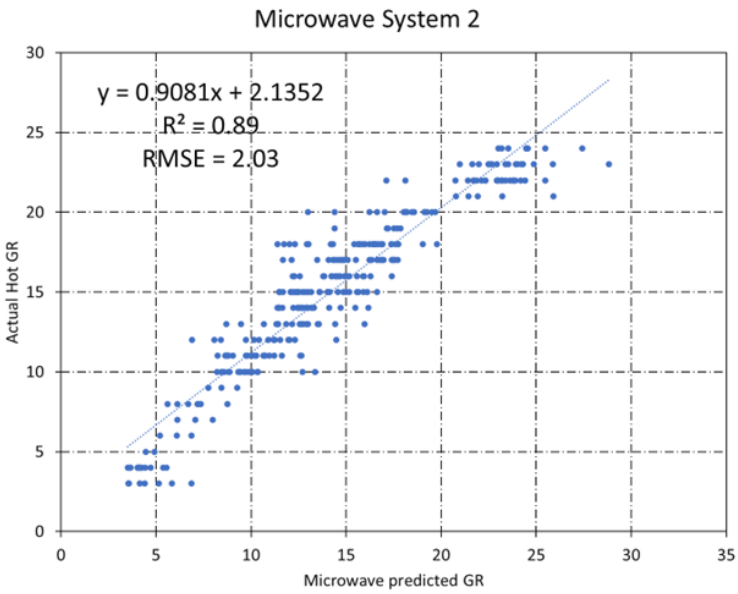



*Figure 10: Actual hot GR tissue depth vs MiS system 2 predicted tissue depth*

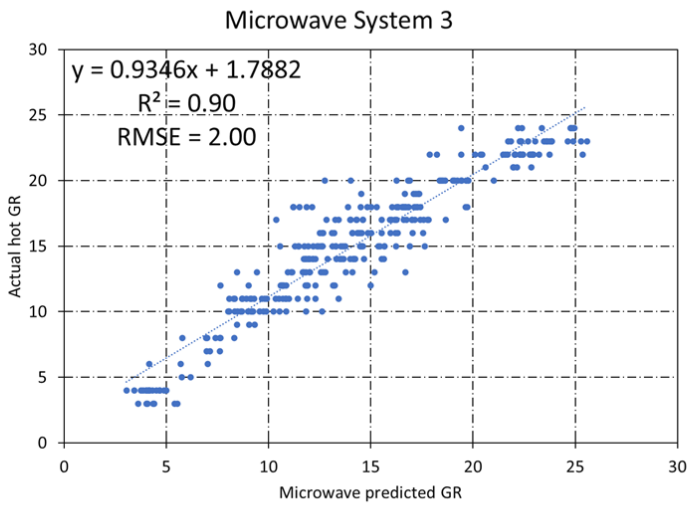



*Figure 11: Actual hot GR tissue depth vs MiS system 3 predicted tissue depth*

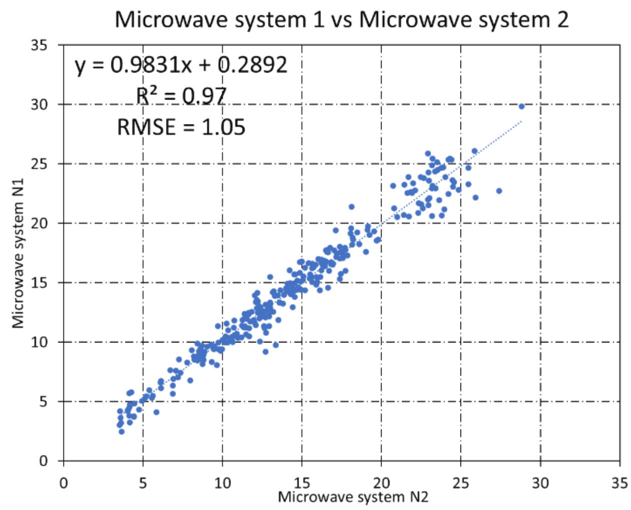



*Figure 12: MiS 1 vs MiS 2*

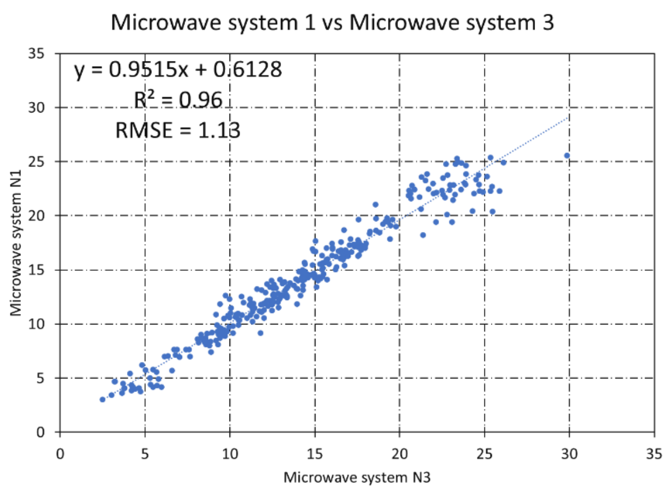



*Figure 13: MiS 1 vs MiS 3*

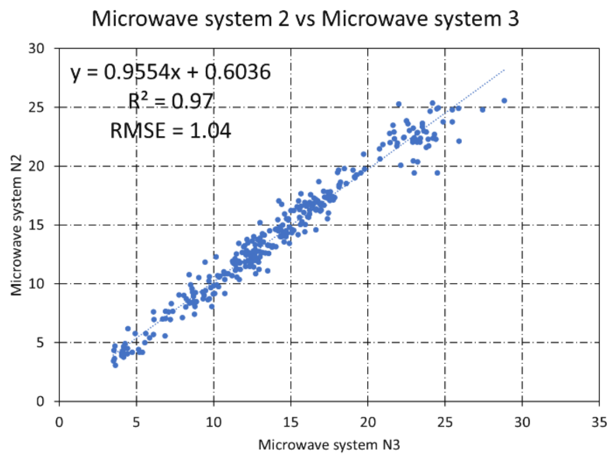



*Figure 14: MiS 2 vs MiS 3*

## Discussion Points

- MiS achieved AUS-MEAT accreditation as an objective measurement technology for GR tissue depth
- When applied to the AUS-MEAT National Accreditation Standards the MiS prediction of GR tissue depth fits within the error tolerance range
- The repeatability of three measurements within the same device meets the AUS-MEAT National Accreditation Standards within the error tolerance range
- The repeatability of measurements across three different microwave devices meets the AUS-MEAT National Accreditation Standards within the error tolerance range

## Next Steps

- Identify and design how commercial microwave device will communicate with DBC database and carcase barcode system.
- Install and integrate commercial device into DBC.
- Training of DBC staff in using microwave device.

## Final Milestone

MiS was installed at DBC in October 2023. The MiS device is located on the chain at the smallstock weigh scales and ticket machine. The device is attached to the chain via a carabiner and a retractable line. The MiS device is connected to the DBC production server (SQL database) via Wi-Fi. The figures below depict the location of the MiS device on the chain and operator measurement of hot carcase GR tissue depth.


Figure 15 (a) MiS device location on chain when not in use. (b) MiS measuring hot carcase GR tissue depth

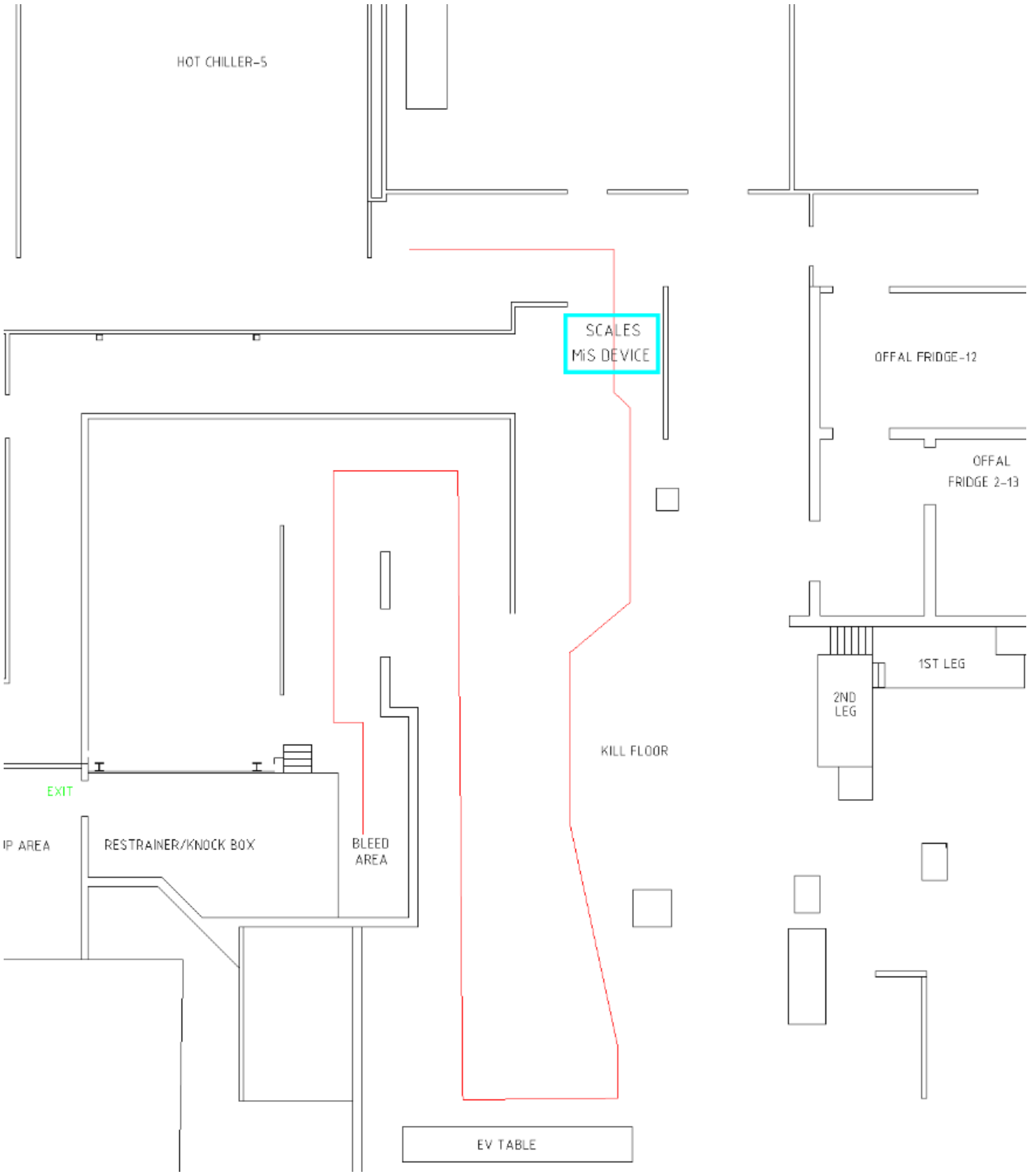



*Figure 16: DBC Plant layout with MiS location shown*

## Data management

Calibration log and measurement data is saved within the DBC SQL server.

# 6.0 Discussion

Overall this project was a success in lamb, with the HGP probe being dismissed and the MiS ultimately chosen for accreditation, which was successfully undertaken and achieved. Besides the lack of accuracy of the HGP compared to the MiS, the MiS device took measurements quicker, which contributed to the decision to dismiss the HGP from the project. Both devices are similar in terms of cleaning; the body of each device is cleaned using a damp cloth and iso-wipes. However, the MiS antenna only requires a wipe down of the carcase contact point on the antenna, whereas the HGP device, which requires insertion into the carcase for measurement, needs each measurement spike cleaned.

The MiS is currently located on the smallstock chain, but being mobile, it can be positioned anywhere along the smallstock line that is suitable for a processor. The device can be used by an operator in normal production or removed from its stand and taken where needed. No significant infrastructure changes were necessary to install the device.

The MiS device has proven its robustness, with only one occurrence of device fault and flat battery during the trial. It has been in use at DBC since the accreditation trials and has withstood daily production and cleaning. DBC has not experienced any broken antennas since the device has been on site. However, they did encounter issues with the charger port and the battery not holding a charge. This was the most significant issue faced during trials and post-installation. While utilizing a USB-C port is convenient for mobile use, it is not robust enough for the production floor. Instead, the device could use a cannon plug charging configuration similar to the HGP device, which would make it more durable.

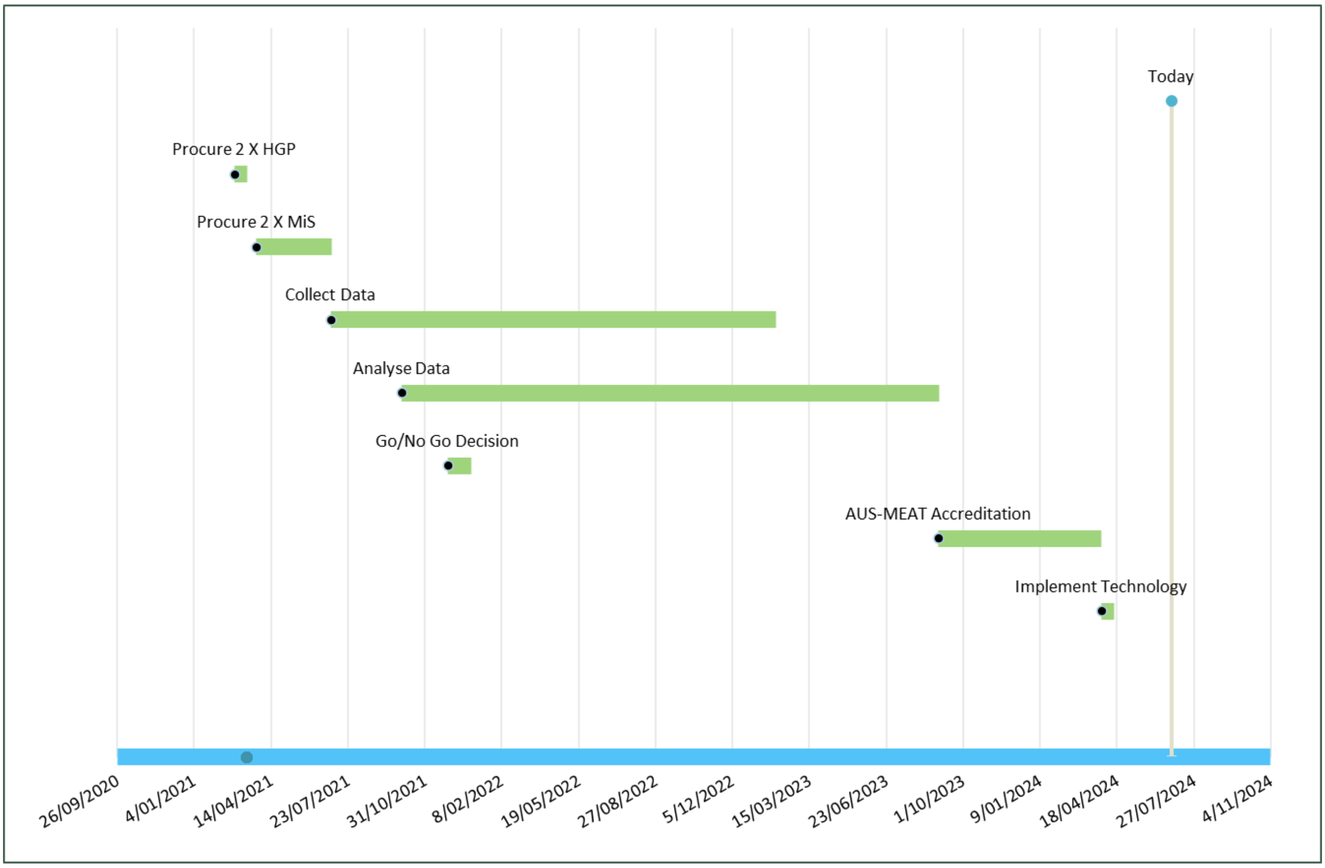
The MiS device uses WiFi to connect directly to the DBC production system database, linking the MiS data with existing production data for each carcass scanned. A report was created using DBC’s Power BI software to compare the accuracy of the device with the operator’s manual measurement of fat depth. DBC is in the process of setting up the MiS fat score to be printed on each carcass ticket. This requires a change in management to be submitted and approved internally, along with the programming of production software to implement this change.

| Date Time | Kill Number | GR Depth | Calculated Fat Score | Operator Palp Fat Score | HSCW (kg) | Operator Code | Kill Lot ID |
|---|---|---|---|---|---|---|---|
| 2024-05-20 09:01:17.075702 | 4087135 | 10.87 | 3 | 3 | 24.40 | 515 | 114499 |
| 2024-05-20 09:01:53.060254 | 4087138 | 15.06 | 3 | 4 | 26.90 | 515 | 114499 |
| 2024-05-20 09:02:22.608388 | 4087141 | 13.99 | 3 | 3 | 26.50 | 515 | 114499 |
| 2024-05-20 09:03:12.730144 | 4087143 | 14.71 | 3 | 4 | 27.30 | 515 | 114499 |
| 2024-05-20 09:05:37.187604 | 4087150 | 13.96 | 3 | 4 | 28.40 | 515 | 114499 |
| 2024-05-20 09:06:12.118080 | 4087151 | 11.97 | 3 | 3 | 25.70 | 515 | 114499 |
| 2024-05-20 09:08:03.895130 | 4087156 | 15.34 | 3 | 3 | 26.60 | 515 | 114499 |
| 2024-05-20 09:08:47.269537 | 4087158 | 11.14 | 3 | 3 | 25.30 | 515 | 114499 |
| 2024-05-20 09:09:41.734564 | 4087161 | 14.67 | 3 | 3 | 26.90 | 515 | 114499 |
| 2024-05-20 09:10:03.271898 | 4087162 | 10.98 | 3 | 2 | 27.60 | 515 | 114499 |
| 2024-05-20 09:10:35.535698 | 4087164 | 14.93 | 3 | 4 | 27.20 | 515 | 114499 |
| 2024-05-20 09:11:16.710450 | 4087166 | 14.60 | 3 | 3 | 28.40 | 515 | 114499 |
| 2024-05-20 09:11:26.378942 | 4087167 | 12.99 | 3 | 4 | 29.30 | 515 | 114499 |
| 2024-05-20 09:12:09.771410 | 4087169 | 12.34 | 3 | 3 | 25.40 | 515 | 114499 |
| 2024-05-20 09:13:05.875533 | 4087172 | 12.07 | 3 | 2 | 26.80 | 515 | 114499 |
| 2024-05-20 09:13:16.509965 | 4087173 | 10.95 | 3 | 2 | 24.50 | 515 | 114499 |
| 2024-05-20 09:13:33.276024 | 4087174 | 14.90 | 3 | 3 | 27.20 | 515 | 114499 |
| 2024-05-20 09:14:09.222198 | 4087176 | 14.11 | 3 | 3 | 24.70 | 515 | 114499 |
| 2024-05-20 09:15:51.613426 | 4087181 | 15.09 | 3 | 3 | 25.70 | 515 | 114499 |
| 2024-05-20 09:18:45.035590 | 4087188 | 14.65 | 3 | 3 | 25.60 | 515 | 114499 |
| 2024-05-20 09:18:53.459116 | 4087189 | 11.97 | 3 | 2 | 26.70 | 515 | 114499 |
| 2024-05-20 09:19:24.867725 | 4087190 | 12.38 | 3 | 3 | 26.00 | 515 | 114499 |
| 2024-05-20 09:20:13.230452 | 4087193 | 13.03 | 3 | 2 | 25.00 | 515 | 114499 |
| 2024-05-20 09:21:31.100714 | 4087197 | 12.34 | 3 | 2 | 24.10 | 515 | 114499 |

*Figure 16: Power BI showing the report created to compare manual grader fat depth measurement and MiS prediction*

## Project Timeline

The project was slightly delayed due to accreditation trial delays and feedback from AUS-MEAT.



### Benefit for Industry

Although there has not yet been a reduction in labour and the MiS device is still slower than palpation for taking measurements, this may improve over time with full integration into the plant's processing software and optimization of the MiS installation height for rapid measurement.

The GR fat depth measurement accuracy has significantly increased, as demonstrated by the data analysis in this report. While it is currently difficult to quantify any monetary gains resulting from the improved measurement accuracy, this will be assessed over time.

The device can provide more accurate feedback to producers, enhancing compliance and quality.

### Future Work

Though accreditation of the MiS device in Beef was not achieved within this project, Murdoch and DBC will continue working towards accreditation. To pursue MiS as an objective technology in beef at DBC it is recommended that a platform is placed prior to the hot wash to allow for measurements to be taken on a dry carcase. Murdoch suggested that a comparison study is undertaken to compare pre and post hot wash readings to clearly illustrate the importance of measurement location and avoiding wet carcases. In addition it was suggested that the device is retested in beef using a new Teflon calibration block.

DBC in future are hoping to see the MiS device accredited for use in pork. Aside from the benefits of having the device taking accurate measurements, it would be an advantage to have the same device able to be used across all three species being processed at DBC. This would mean a reduction in training requirements across different technologies, consistency in measurement accuracy and consistency in integration of the devices measurements into DBC’s production system. DBC have no interest in pursuing HGP any further.

# 7.0 Conclusions / recommendations

For a processor seeking a cost-effective, easy-to-implement, small-footprint device to measure GR fat depth in sheep, the MiS is a highly suitable option. The project demonstrated that the MiS device not only meets AUS-MEAT Accreditation Standards but also provides improved accuracy in fat depth measurement compared to traditional methods. While the device is still slower than palpation at this early stage, full integration with the plant’s processing software and optimization of the installation height are expected to enhance measurement speed over time.

The MiS device has been fully integrated into DBC’s plant and is used daily, linking measurements directly into the production system. Although the MiS GR fat depth measurement is not yet printed on each carcass ticket, this feature is in progress. The device's robust performance, with only minor issues such as charger port and battery charge problems, further emphasizes its reliability.

Ensuring that operators are correctly trained in the device's proper placement is key to achieving accurate measurements. Additionally, having the appropriate connections into your production system is crucial for utilizing the MiS measurements effectively. The project’s success is also attributed to the collaboration with Murdoch University, whose researchers professionally and accurately completed accreditation trials and provided ample support to operators learning to use the device.

In conclusion, the MiS device stands out as an excellent option for processors looking to enhance fat depth measurement accuracy in sheep, offering ease of implementation, cost-effectiveness, and robust performance.

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# 9.0 Appendices

## 9.1 Glossary

| Term | Description |
|---|---|
| ALMTech | The ALMTech project is supported by funding from the Australian Government and in partnership with R&D Corporations, Commercial Companies, State Departments & Universities. The ALMTech program project rationale was to realise significant productivity and profitability improvements for the Australian red meat industry delivered via advanced measurement technologies. |
| AUSMEAT | Authority for the Uniform Specification of Meat and Livestock. |
| GR | Location of fat depth measurement in sheep, located 110mm from the carcase midline over the $12^{th}$ rib. |
| HGP | Hennessy Grading Probe. |
| MiS | Microwave Scanner developed by the Murcoh University Microwave Engineering team. |
| P8 | Location of fat depth measurement in cattle, located on the rump. |
| VPA | Vivaldi Patch Antenna. Antenna type utilised with the MiS device. |