# final report

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# P.PSH.0888 LAMB AND BEEF X-RAY DATA EXTENDED OCM BENEFITS AND TRANSPORTABILITY FOR CUTTING BEEF

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# Abstract

Dual Energy X-ray Absorptiometry (DEXA) is an objective measurement scanning system designed to provide timely, accurate information on the lean meat, bone and fat composition of each carcase before processing. The current installations of X-Ray technology, integrated for automated primal cutting, rely on scanning being conducted adjacent to the processing location with a direct automated transfer of carcases. The work presented investigates extending the capabilities of the DEXA system by examining the transportability of data captured. Scanning could then be conducted remotely. Successful outcomes would offer greater flexibility, reduce capital outlay and supply real time data for alternative carcase grading models.

# Executive summary

The objective of this project is to determine if there is reliable correlation, for DEXA X-ray scanning data, between isolated locations within the processing chain. This could potentially provide processors an option to conduct X-ray scanning in the most appropriate location, for the process, while not compromising the cutting determination function. A positive outcome offers a reduced outlay of capital for the DEXA technology and therefore opens the door for a greater uptake of DEXA technology.
In the case of Lamb processing, trials were conducted by scanning a carcase before it enters the chiller. These hot carcasses are therefore in a pre-rigour state, the carcases then undergo shrinkage as they become chilled. This shrinkage introduces a dimensional variable which needs to be accounted for when the cut determination is derived. Another significant difficulty, with pre-rigour carcases, is to keep the carcases stable while being scanned by the DEXA X-ray. Where stable scans were produced, with the assistance of stabilisation and restricted chain speed, a recognisable pattern of the carcase relaxing followed by contraction was observed. This indicated that a small adjustment could be made to the cutting calculations if hot DEXA data is to be transferred to drive the downstream cutting systems.
Beef DEXA was also trialled to investigate the transportability of scanning, in this case an image of a beef carcase was taken before scribing and grading cuts were performed. The carcase is deformed as a result of these cuts made. Using vision systems and the scanned image we then attempted to re-fix an identifiable point on this carcase. This refixing will allow an automated processing system to calculate adjustments and prove the transportability of DEXA derived coordinates.

The practical aspects of DEXA scanning, to provide an objective carcase composition, was also explored as a part of this project. This full carcase scanning is understood to provide a more accurate carcase composition estimate, than a tissue depth measurement taken at the GR site. The existing algorithm, installed in DEXA production units, calculates a whole carcase Lean Meat Yield (LMY) value. Subsequently an updated general model has now been written with segmented LMY values, based on studies completed by Murdoch University. Scott Technology has been provided these newer calculations, these have been added to the DEXA software to predict and display apportioned LMY values for the forequarter, saddle and hindquarter. These new outputs are displayed in real-time at the point of scanning. The availability of this real-time data does open an opportunity for processors to optimise carcase returns.

Another advantage, of using the DEXA output to provide objective carcase values, is to directly calculate saleable meat yields. For this study we have used the industry standard Lamb Value calculator and input the DEXA generated LMY value and hot carcase weight, to predict a carcase value in real time.

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# 1 Background

## 1.1 Transportability of DEXA Data

### 1.1.1 Hot Lamb DEXA

A hot carcase will undergo changes during the chilling process. The aim of this work is to evaluate these changes and understand technology which could complement DEXA scanning of a hot dressed carcase. This was done by scanning a hot dressed carcase to identify the cut locations and then compare this to a scan of this carcase after chilling, by deriving and comparing the cut data. This will determine if cut hot side DEXA images can be translated to drive the lamb primal cutting machine. The ability to scan hot will open possibility for a single DEXA scanning room, to provide multiple functions. Currently X-ray systems provide automated cutting information, but in a pre-chiller location will also provide objective carcase measurement capabilities, such as carcase composition. This information in real time will allow processors to optimise carcase sorting and matching with customer specifications.

### 1.1.2 Re-fixturing of Cold Side Beef DEXA

A number of different scribing and grading cuts are performed as a part of beef processing. These cuts change the shape of the carcase and will impact on the capacity of an automated cutting module, where this cutting module is located remotely from the X-ray scanning. By undertaking beef scanning and then performing grading cuts we can use vision systems to evaluate deformation of the carcase and understand the transportability of DEXA cut data to remote cutting cells.
The outcomes of this trial will drive understanding of the challenges and provide direction for on how to progress with the automation of beef processing.

Key to the transportability of this data is the ability to re-locate or re-fix to a known point on the carcase after the grading cuts are made. We aimed to identify how accurately points of interest on the carcase can be re-fixtured using 3D scanning technology. It was planned to determine how accurately scribing cuts can be placed, if the robot system is separated from the x-ray room.

## 1.2 Extended OCM benefits

Gardener *el at* (2017) has shown that the DEXA derived LMY values offers superior accuracy when predicting the carcase composition than a single point measurement such as measuring GR tissue depth. Gardener points out that single point measurement is likely to introduce significant bias in genetically diverse populations.
The use of existing Dual-Energy X-Ray Absorptiometry (DEXA) scanning within processing plants provides an opportunity to develop objective measurements of lamb carcases. An updated DEXA based algorithm has been developed to calculate the LMY for the forequarter, saddle and hindquarter primal components in real time. Processors will have access to a more accurate valuation of each carcase before processing.
Previous work has been completed in association with the AMPC to build a spreadsheet to calculate the value of a lamb carcase based on the GR Tissue Depth. This industry led tool enables processors to evaluate the carcase boned out value, based on the measurement of the carcase weight (HSCW) and estimated fat content. This calculator has recently been extended to include the objective carcase measurement values as an alternative input. By integrating the Lamb Value Calculator outputs directly to the DEXA outputs this lamb calculator spreadsheet can be updated automatically.

# 2 Project objectives

## 2.1 Objective 1

The aim of this milestone was to evaluate X-Ray (and DEXA) scan cut data taken of a hot dressed lamb carcase compared to a chilled carcase cut data to determine if cut data can be translated from a “hot side DEXA” (or SEXA) to drive the lamb primal cutting machine.

## 2.2 Objective 2

An algorithm will be developed (and implemented into a live DEXA room) to provide real-time LMY values for the forequarter, saddle and hindquarter primal components (based on the previously developed Scott DEXA LMY algorithm) of each scanned lamb carcase.

## 2.3 Objective 3

Software will be developed (and implemented into a live lamb DEXA room) to implement the industry developed and owned lamb cuts calculation algorithm that relates key carcase traits to sub primal yield values (known as the lamb value calculator) based on measured DEXA values and available carcase traits.

## 2.4 Objective 4

An evaluation by way of trials and manual analysis will determine the ability to translate Beef DEXA scan and cut data derived from a cold Beef side DEXA scanning machine to a separately located cutting and scribing locations to provide an indication that a single Beef DEXA scanner can be used to drive remotely located scribe and rib cutting modules. Namely Vertical rib scribes Ex Dinmore, back bone scribes for the 5/6$^{th}$ junction, 11/12$^{th}$ junction, butt and where possible rack/loin/FQ brisket and plate cuts)

# 3 Methodology

## 3.1 Objective 1

### 3.1.1 Understanding Lamb Carcase Cooling

A list of potential vision systems and measurements was drawn up and evaluated into a shortlist of trials to be conducted. The best alternatives were chosen to understand how to translate this hot image into accurate data to calculate the cut line profiles.

As the carcase cools there may be consistent shrinkage rates which can be identified in relation to the period of exposure to the chilled environment. A measure was made of any deflection observed between cut lines derived from hot scans and as the carcase chills.

Carcases were scanned hot and then chilled across a 50-hour period. By re-scanning these carcases at different intervals, across this period, the Scott vision engineers were able to measure the change in target cut lines as the carcase cooled.

Trials were conducted at Finegand, in NZ and JBS in Bordertown, South Australia. The initial trial at Finegand was conducted using 100 carcases, these were scanned hot & returned to the chiller for 12hrs before rescanning. Each carcase was rescanned & returned to the chiller. This exercise was repeated every 12hrs. The chain was slowed to a speed of 5mtr/min to minimise the swing or twist of these carcases. A trial at Bordertown repeated this exercise with smaller group of carcases but scanning cycle time was reduced, scan were conducted every 2 hours.

We also wished to ascertain if the outside of the carcase, at the cut locations, does change in step with the internal bone cut locations. By marking the outside of the carcase and measuring these external markers we may understand any measurable defection between the external markers, when aligned to the cut line between ribs. Radiopaque markers were chosen, to allow a visual observation of the surface of the carcase inside the DEXA image. These scans were captured as the carcase chilled.

In this case metal staples were used, these were formed into a linear strips, as single staples were deemed to be a food safety risk. Location for marking strips were chose as shown below.

Any deflection between the external datum, indicated by the markers, versus the ribs were able to be measured in the DEXA images.

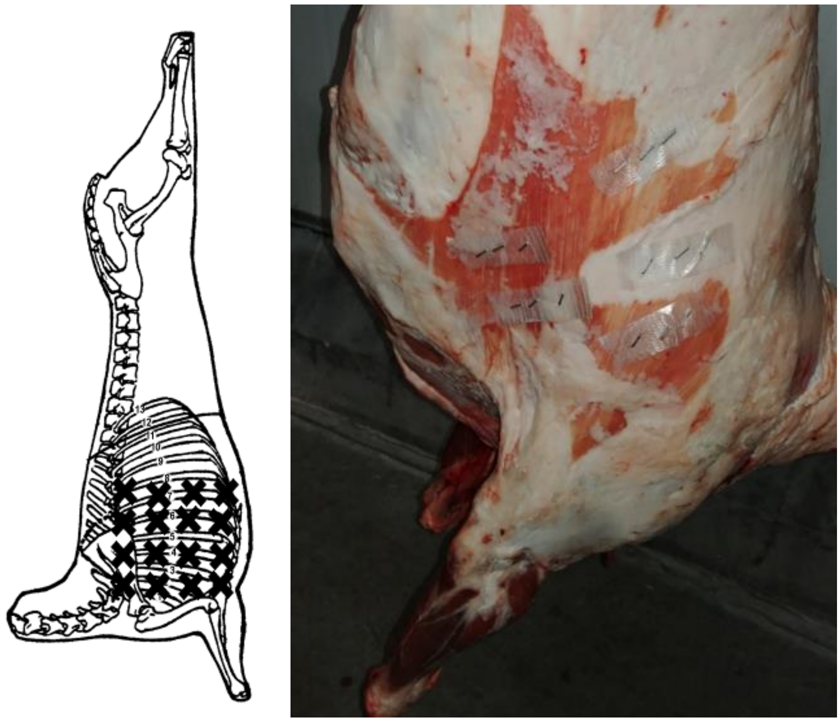

**Fig. 1 Markers locations & markers on outside of carcase**

Supplementary to understanding the external movements of the carcase, a single carcase was captured in chilled conditions, this static carcase was held inside a chilled room across a 50-hour period. Images were captured using three high definition cameras. Options were also considered for any new technology which may allow camera imaging the inside of the carcase on the cold side, then align this with the original hot x-ray image.

### 3.1.2 Stabilising Carcases

Subsequent to these observations trials were conducted using an existing stabilisation system and an evaluation was made of possible alternatives for stabilisation. Evaluate possible options for stabilisation for the hot carcase.  With the presented options presented to be evaluated with a trials to be conducted in parallel with the build of the first room.

## 3.2 Objective 2

Previous development work has proven a quantifiable relationship between the R-values from the DEXA at Bordertown abattoir and the chemical fat % within tissue mixtures of muscle and fat (Gardener et al, 2016).
An algorithm has been previously developed to predict the CT composition data (percent lean, bone and fat) from an averaged R-value over a whole Carcase (DEXA value).  This has been applied in DEXA carcase scanning installations to provide a LMY value for a complete carcase.

### 3.2.1 Calculating the Carcase DEXA value

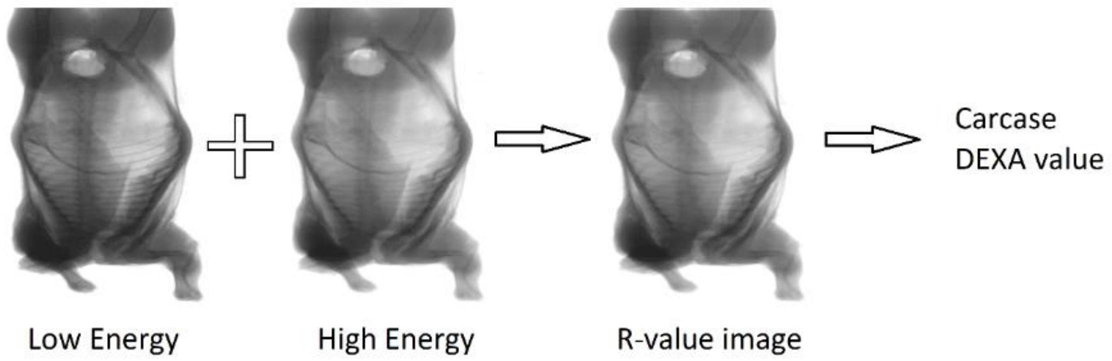


Fig. 2 - Calculating a Carcase DEXA value

### 3.2.2 Data Flow for DEXA information

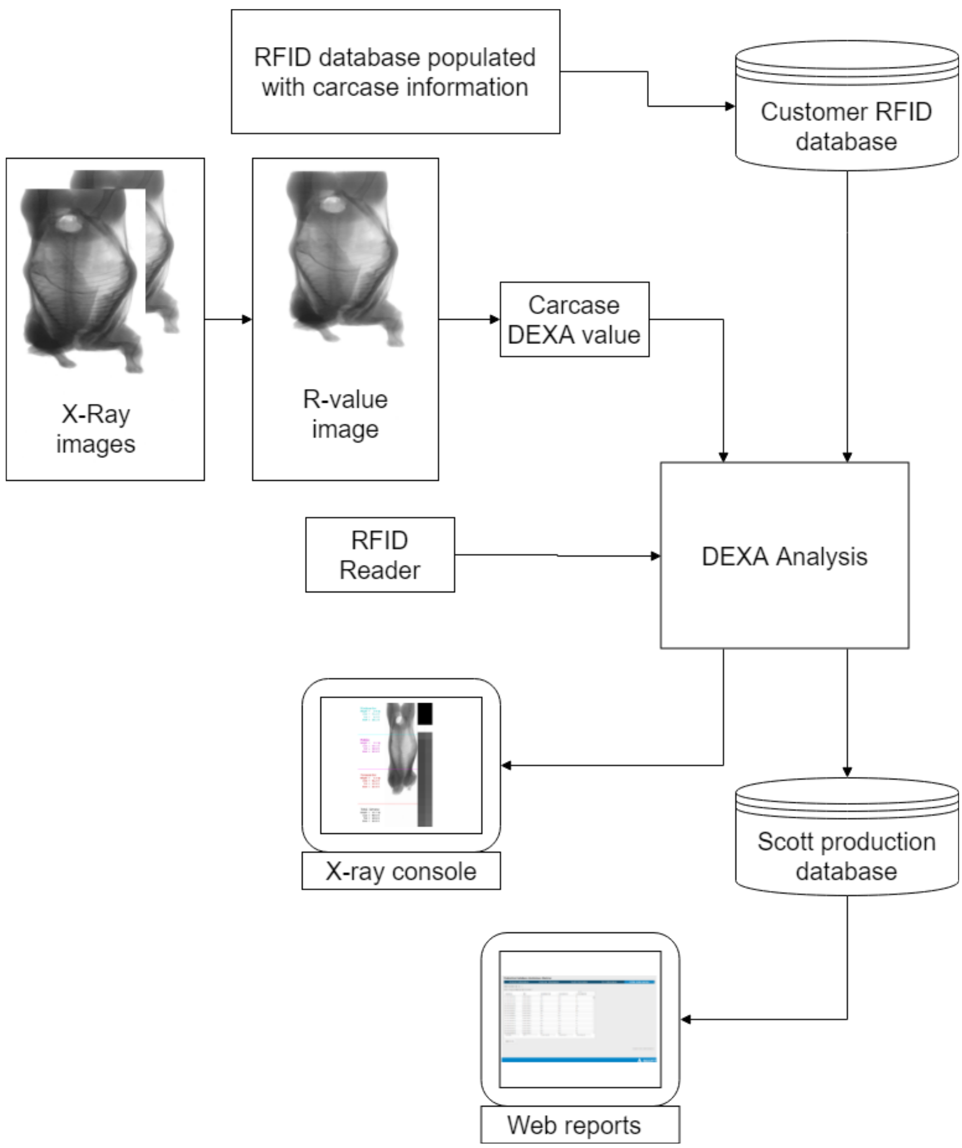


Fig. 3 – Data flow for DEXA information

## 3.3 Objective 3

The Lamb Value Calculator is proprietary software developed by MLA, Sheep CRC and Murdoch University. Scott Technology have been given permission to integrate an automated calculation.
It is important to recognise that this integrated code is proprietary information, and hence the DEXA computer will act as a data provider and collator only.
Code has been written to poll a DEXA database at regular intervals. As new DEXA lean % values are updated to the database, calculations are performed using the Lamb Value Calculator. It will also capture the radio frequency identification (RFID) code that is associated with the particular carcase scanned. For the processor chosen we have been supplied with a Carcase Re-Grading list, this data file, which contains HSCW for each Carcase matched to the RFID#.
For this demonstration this carcase list has been manually loaded onto a laptop running the Lamb Value Calculator spreadsheet.
The process involved in achieving this milestone is shown in the flowchart below.

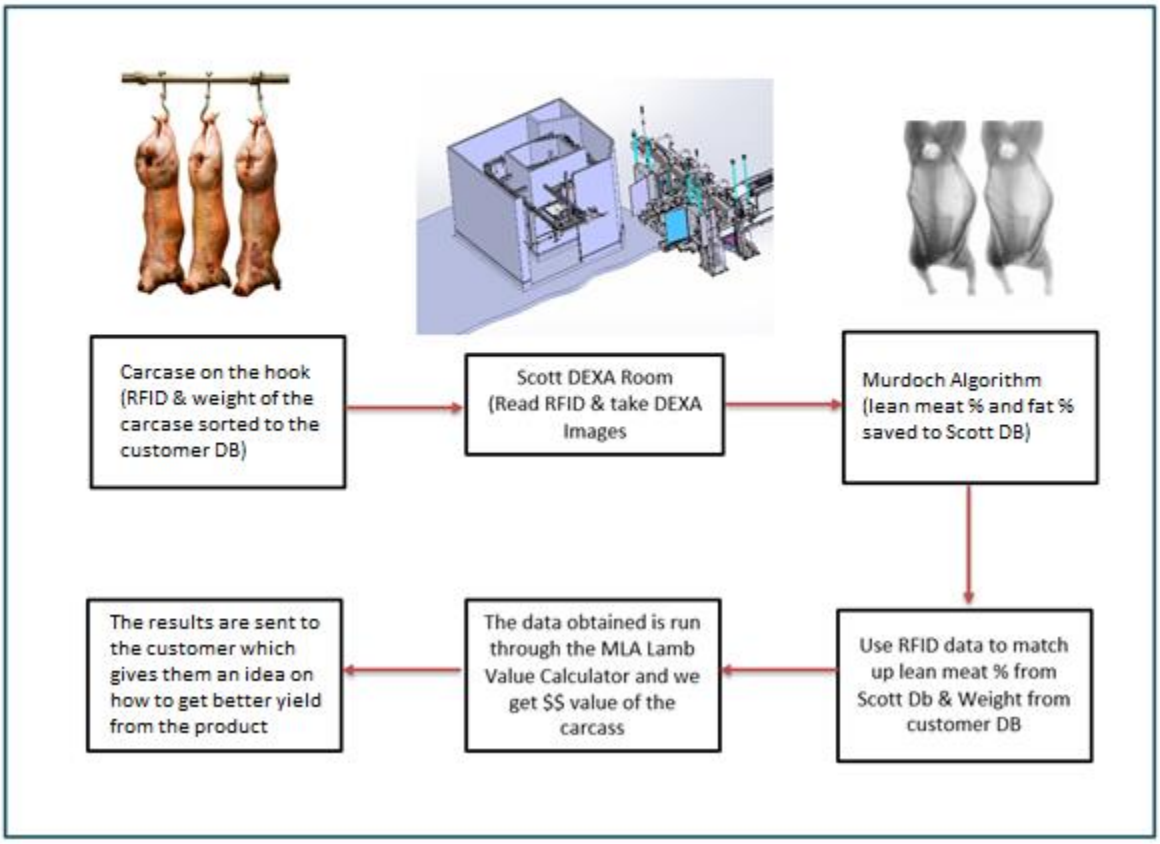


Fig. 4 – Integrating the Lamb Value Calculator with DEXA outputs

## 3.4 Objective 4

### 3.4.1 Re-fixturing requirements

A DEXA scanning system has been implemented and commissioned in the Teys processing facility in Rockhampton. In the future, Teys (as well as other processors looking to adopt beef DEXA grading technology) would like to implement cutting automation using this x-ray data. Any automated cutting system would ideally be located in a different area of the plant, to the DEXA scanning cell. The automation cell would also ideally not require further x-ray sensing to avoid the restrictions placed by requiring radiation shielding and the cost of extra x-ray hardware. Since the carcase will move and change shape when travelling between the DEXA and automation cells, a method must be found to correctly map any points of interest identified in the original x-ray image, to how the carcase is positioned when it is presented for cutting. This cutting accuracy which is achievable by such a setup would be limited by the accuracy with which this re-fixturing process can be performed.

The following methodology has been proposed to achieve this process of re-fixturing:

1. Carcase side is brought into the DEXA cell and onto a stabilisation conveyor
2. Carcase side is x-ray scanned and simultaneously 3D scanned
3. Points of interest for cutting are identified in the x-ray image
4. These points are then converted into 3D coordinates in the 3D data via a calibration
5. Carcase side comes off stabilisation conveyor, exits DEXA cell, and travels through plant to the automation cell
6. Carcase side is brought into automation cell and onto a stabilisation conveyor
7. A 3D scan is performed of the carcase side
8. The 3D scan is compared to the original 3D scan (from step 2) and a model is calculated to map the deformation and movement of the carcase
9. The original points of interest (step 3) are mapped through this model to re-fixture them onto the carcase side as it currently sits
10. Cut coordinates are generated and sent to robots to perform cuts

### 3.4.2 Pre-Trial learning process – Point of interest

This project looks specifically into how accurately steps 8 and 9 can be performed, as these will form the accuracy limits for a cutting system which is separated from the DEXA scanning.

First, existing data was analysed from a system which currently employs DEXA imaging and 3D scanning of beef carcase sides. This data consisted of 3D and x-ray scans performed on the same carcase side after it had been recirculated through the cell multiple times. The following process was then followed with this data:

1. Points of interest manually pointed on x-ray image of scan 1 (P1-Xray)

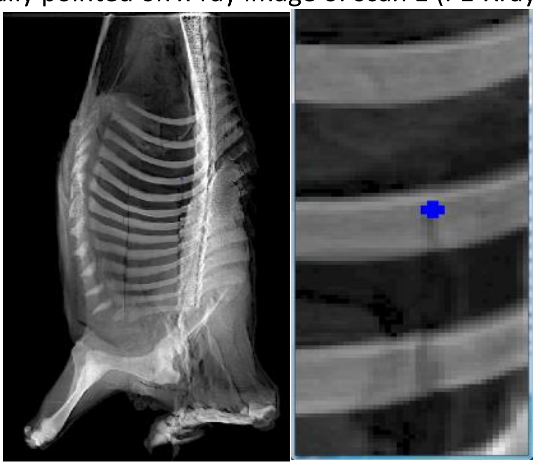

Fig. 5 – DEXA scan of beef side with point of interest identified

2. Points mapped onto 3D data for scan 1 using existing calibration (P1-3D)

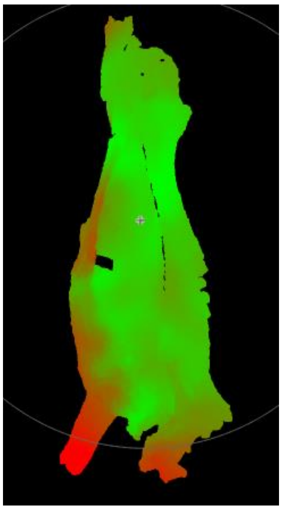

**Fig. 6 – 3D Map of carcase**

3. Model calculated to map the deformation of the carcase between 3D scan 1 and 3D scan 2

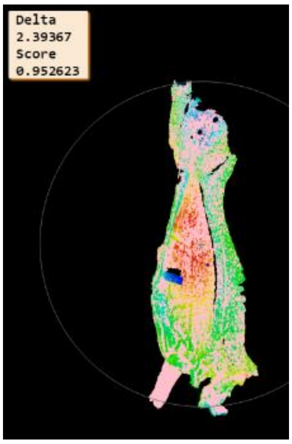


**Fig. 7 – Model map of carcase**

4. Model applied to points in step 2 (P1-3D) to calculate re-fixtured point locations (P2T-3D)
5. Re-fixtured points (P2T-3D) transformed to x-ray image coordinates using existing calibration (P2T-Xray)
6. Points of interest manually pointed on x-ray image of scan 2 (P2-Xray)

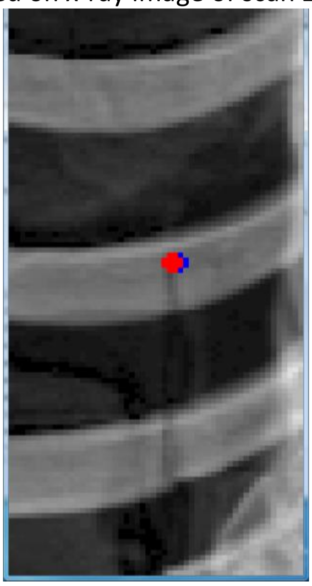

**Fig. 8 – Point of interest re mapped onto the image**

The accuracy achieved is defined as the error between the re-fixtured points of interest (P2T-Xray) and where those points actually lay on the second x-ray image (P2-Xray).

### 3.4.3 Trial method

Once this concept was demonstrated as being viable, a trial was planned for Teys Rockhampton. For this trial, 3D scanners (Sick Rulers) were mounted and calibrated to the x-ray scanners. A number of carcase sides were then scanned by the x-ray and 3D scanners. These carcase sides were scanned multiple times without any cuts. Cuts were then progressively be placed on the carcase sides and then rescanned after each one placed. This determined what carcase dressing activities between DEXA scanning and beef scribing would affect the accuracy of re-fixturing. It would also demonstrate whether carcases need to be re-fixtured between placing successive cuts on a beef carcase side using automation. The variation of cuts performed included:

- Spencer grading cut
- Rib 10-11 and rib 12-13 grading cut through spine with slight ribbing
- Full flank drop
- Partial flank drop
- Ventral and dorsal rib scribing cuts

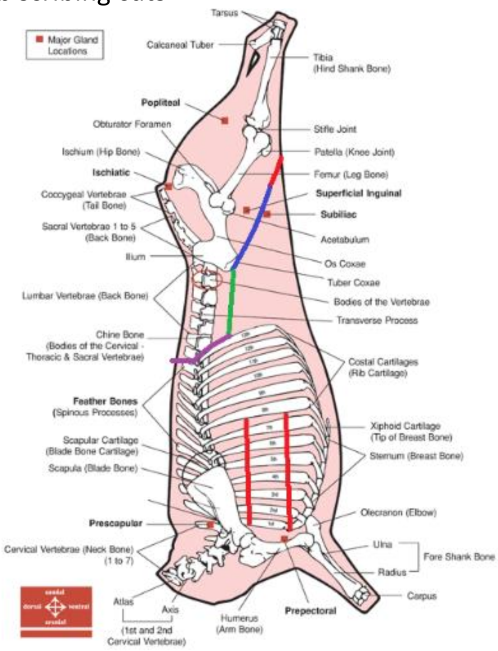


**Fig. 9 – Location of grading cuts on the carcase**

With the data collected, it was then analysed in a similar manner to the initial proof of concept analyses to determine the accuracy to which beef carcases can be re-fixtured for the purposes of DEXA-separated automation.

### 3.4.4 Test setup

During the trials, stainless steel marking pins were placed in the sides to provide accurate points of interest to use in the analysis. A strict procedure was developed and adhered to in order to ensure all markers were accounted for after the trials and there was no risk of these being left in the product. This process included using individually assigned bags for each carcase, each with exactly 10 markers. The placement of these markers was video recorded and the markers were removed and placed back into its bag and stored. Control of these marker pins was verified by a SCOTT employee and a Teys employee.

# 4 Results

## 4.1 Chilled Lamb Carcase Cut Lines

### 4.1.1 Forequarter Cut – DEXA scan trial 1

100 carcases were scanned hot (0.5 to 1 hour after kill), then again at 12, 24, 48, 36, 48, and 60 hours. The cut positions and DEXA results were compared.

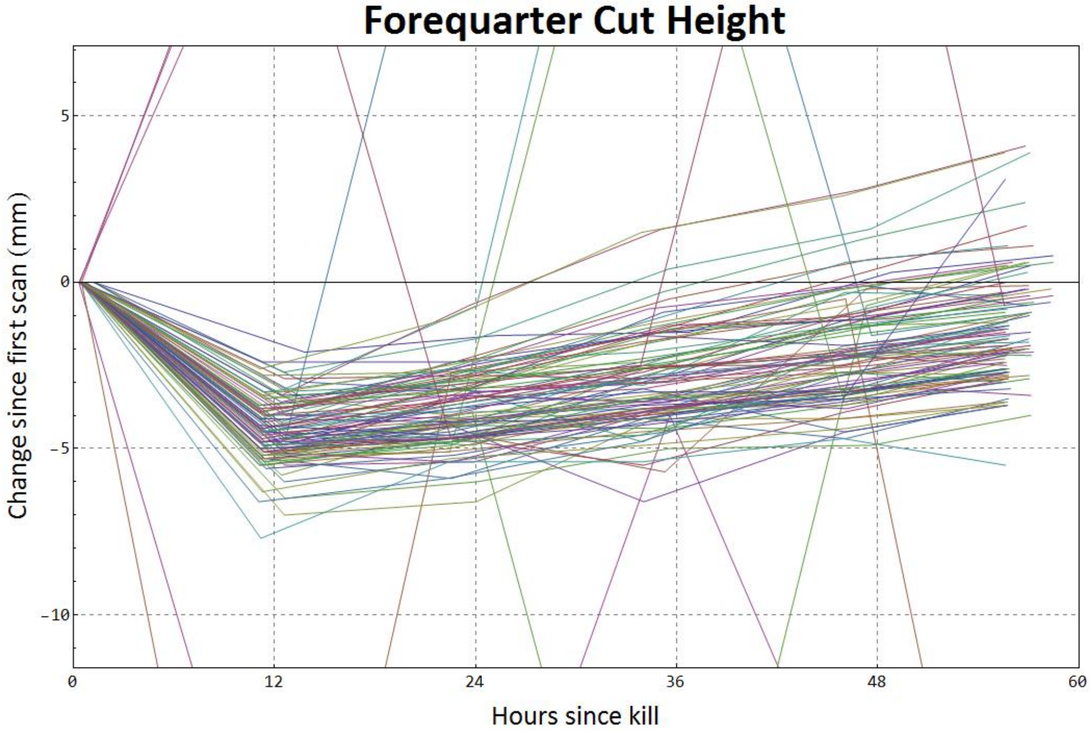


Fig. 10 Forequarter cut height - Finegand 9/9/17

After 12 hours the cut height shrunk back 4.5 mm towards the rail, then slowly relaxed again over time. (There are a few analyses which picked the wrong ribs which gives the lines going off the graph).

Previous experimentation has shown that the cut position follows a normal distribution, the typical cut position is within ±5 mm of the ideal position. Standard processing requires the carcase under chilling condition 12-16hrs, Figure 10 indicates this would represent an offset of 4-4.5mm to realign the cut position.

### 4.1.2 Forequarter Cut – DEXA scan trial 2

Subsequent trials at JBS Bordertown have also indicated unstable movement of the carcase forequarter.

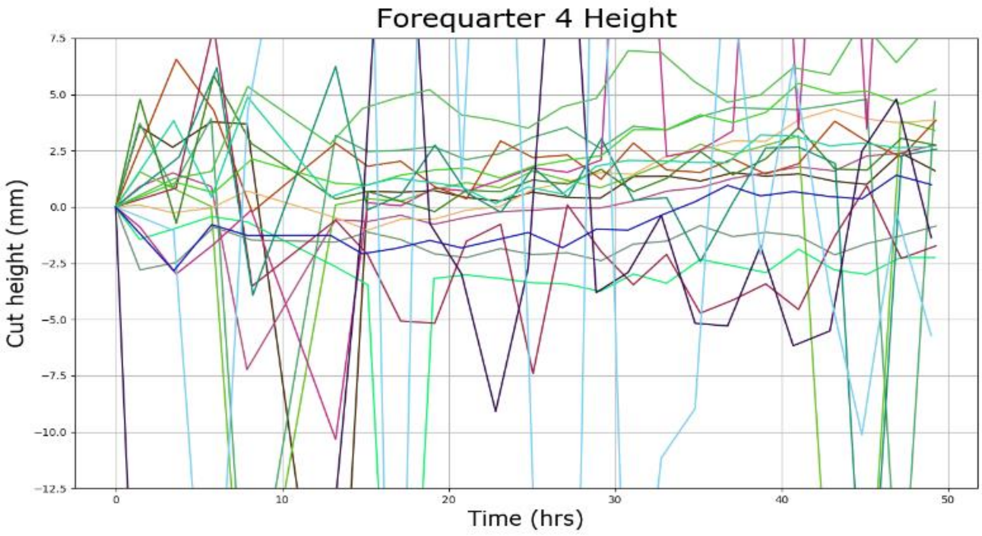


**Fig. 11 Forequarter cut height Bordertown 17/11 (extra ribs not filtered)**

This data was filtered to remove the extra rib data; a general trend can be seen on some of the carcases. However, the removal of the carcases from the chiller every 1 ¾ hr for scanning may have reduce the chilling, and resulting contraction rate.

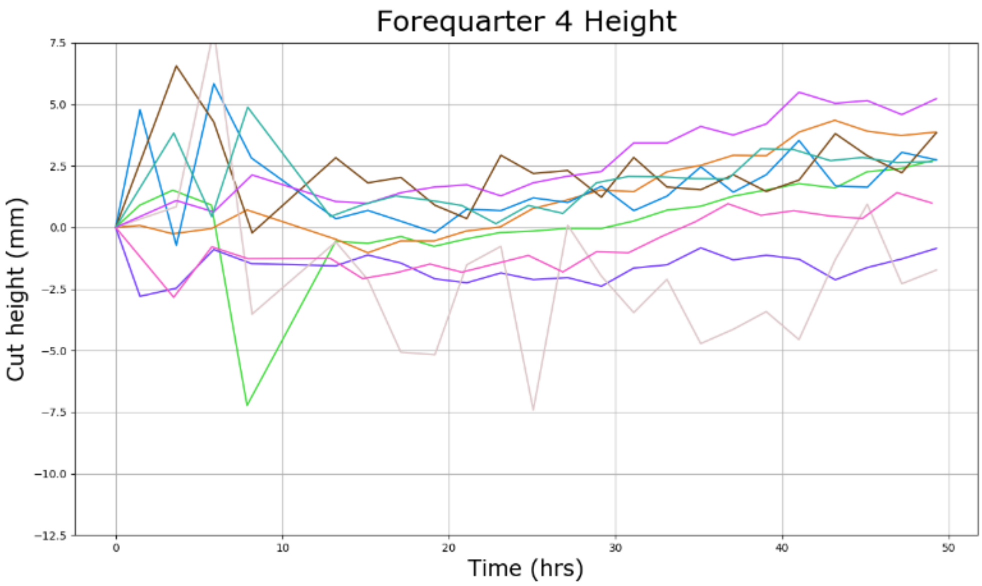


**Fig. 12 Forequarter cut height Bordertown 17/11 Filtered**

The 0-10hr data does have a lot of variability which can be associated with the lack of stabilisation system in Bordertown and also faster scan rate. Pre –rigor these carcases are moving around significantly, this can be seen in the images taken. This lack of stability is exaggerated by the multiple handing employed in repeating 2hourly scans, unhooking the carcases and returning the carcases to the chiller.
A site wide power outage also created some data loss after 9hrs of chilling, this did result in the loss of images between 9 and 13 hrs mark.

### 4.1.3 Hindquarter cut line – DEXA scan trial 1

The Hindquarter cut line has not presented a discernible pattern across this chilling period, it appears any displacement pre-rigor, or during chilling, is restricted to the middle section of the carcase.
The hindquarter (chump off saddle) cut is much more unstable.

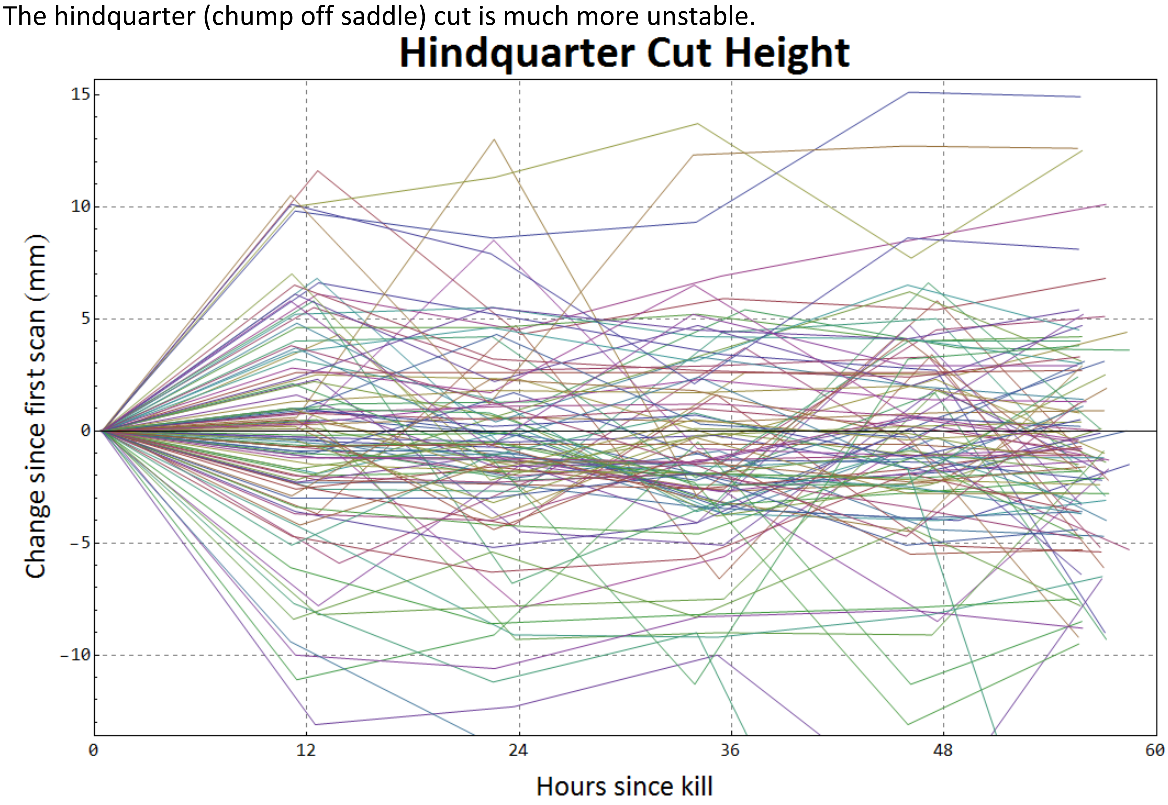


Fig. 13 Hindquarter cut height - Finegand 9/9/17

### 4.1.4 Intercostal Measurements

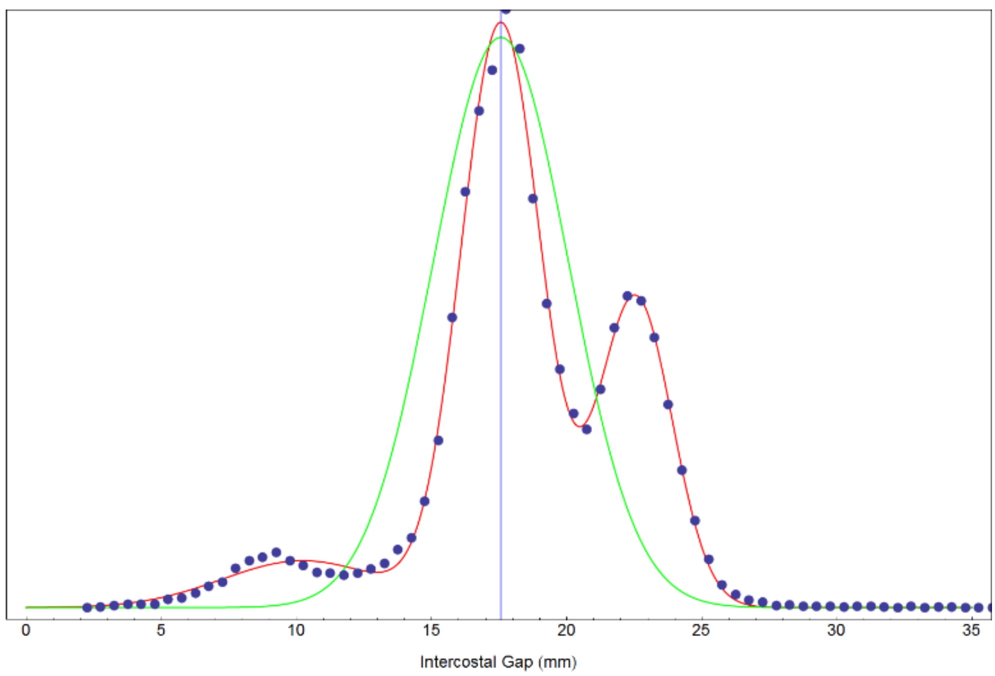


Fig. 14 Summary of intercostal gap width from all scans Bordertown

A mega analysis of the DEXA scan database has indicated an average rib gap of 17mm, this a distribution profile of this work is shown below. With our adjusted accuracy ±7 mm (refer Appendix 1) an expected error rate will be 0.629%.

## 4.2 External measurements

Some investigations were also conducted to understand if these deflections can be observed on the outer surface using external cameras or surface markers. The external markers did show extra displacement at the surface area.
It was important for these staples to be attached to the carcase exterior only, any prongs that enter too far into the muscle would not represent movement of the exterior surface. Unfortunately, as a result of these shorter prongs, a number of the marker strips fell away from the carcase during the trial. This was particularly a problem where the markers were attached to the fatty surface areas. The marker strips that fell out were then relocated away from the fatty surfaces, which meant a number of the markers were located too far from the spine & tended to merge within the scan images.

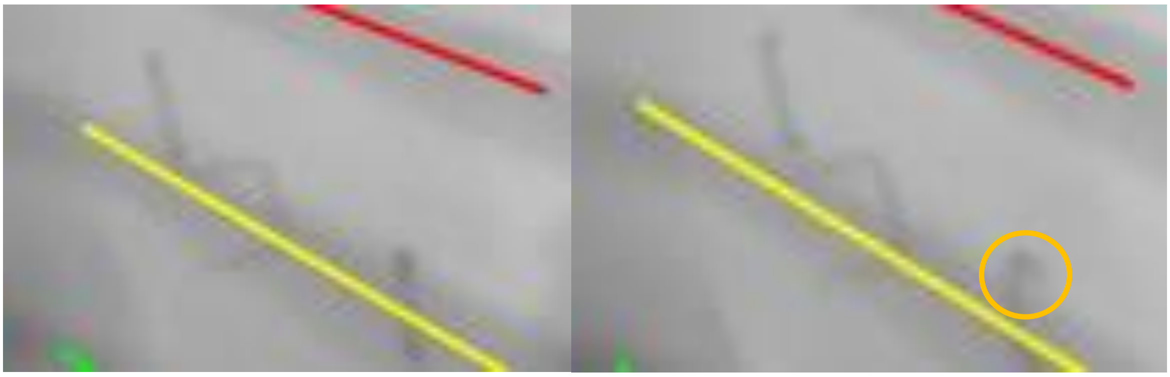

Fig. 15 Markers on carcase #15 – Deflection of surface marker to rib (18:02 17/11 vs 08:51 18/11)

A smaller number of images were therefore available for this test. Where these markers were clear, within the image, a small difference between the surface and the rib outlines was observable. This does indicate that the surface of the carcase does move, this displacement is not directly relatable.

## 4.3 Trial measurements – pre rigor

The initial trial scans were captured with the transfer chain set at a very slow speed and with assistance of a stabiliser belt. With the subsequent trial the chain was set at close to production rate and no stabilising belt, as a result there was a noticeable swing and twisting of the hot carcase. This is observed with different scans shown Figure 16.

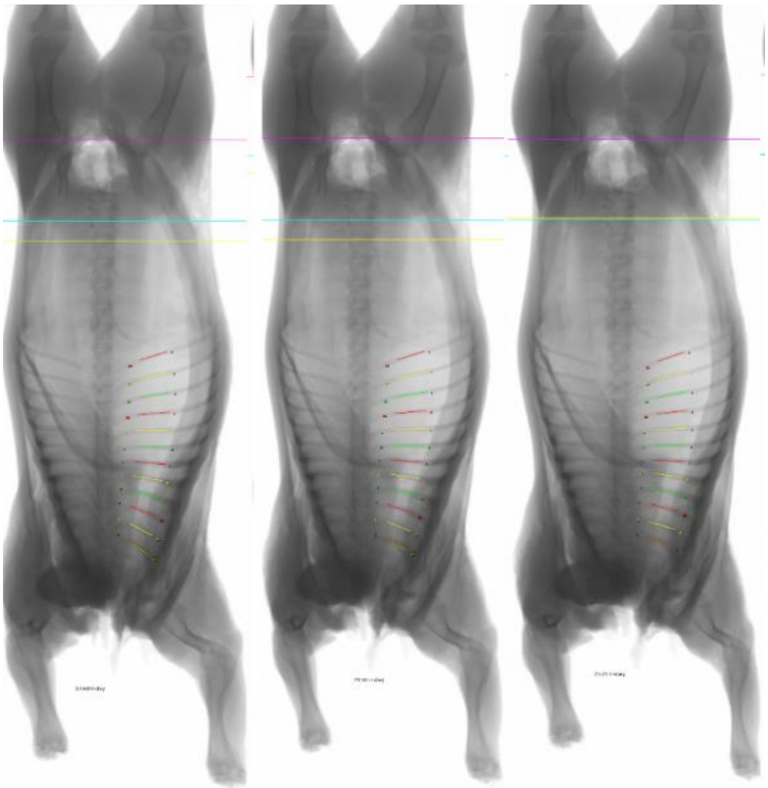

Fig. 16 DEXA scans carcase #9 – Pre-rigor.

Further testing was completed using the existing DEXA scan stabilisation belt, this belt is used currently only for chilled carcases. However, even with this simple stabilisation belt, the twist and extra swing of the pre-rigor carcases was observed at the line of the X-ray beam.

## 4.4 DEXA Calculation of LMY

Existing Scott programs have been modified so the LMY values are presented in real time within the Lamb DEXA systems installed at the JBS Bordertown abattoir. The calculations discussed have been integrated into X-ray image analysis for the primal cutting system within the DEXA reporting software. These fields update in real-time, as new scans are added to the DEXA database. These fields are directly visible via a new screen on the DEXA Production Database.

## 4.5 Real time data updating

Carcase weight values are also assigned for each component. These values are calculated based on the overall hot carcase weight (HSCW). For the DEXA demonstration we have captured a table with the HSCW and RFID from the site database. This table has been loaded onto the DEXA database. As each carcase is scanned the program will perform a look-up to a matching RFID code and the associated carcase weight. The calculations can then be performed using weight and % lean measured by the DEXA scanner.

| timestamp | rfid | total_carcass_weight | total_carcass_lean | lvc_carcass_value | lvc_gross_margin | lvc_gross_margin_percentage | lvc_ve |
|---|---|---|---|---|---|---|---|
| 26/10/2017 6:17 | 00000000 | 21 kg | 49.21% | $135.42 | -$33.36 | -24.60% | MkII |
| 26/10/2017 6:27 | 00000000 | 22 kg | 46.24% | $141.90 | -$37.39 | -26.10% | MkII |
| 26/10/2017 6:51 | 00000000 | 21 kg | 51.37% | $138.43 | -$30.72 | -22.20% | MkII |
| 26/10/2017 6:52 | 00000000 | 24 kg | 41.90% | $154.89 | -$37.01 | -23.90% | MkII |
| 26/10/2017 6:54 | 00000000 | 25 kg | 50.63% | $164.39 | -$34.50 | -21.10% | MkII |
| 26/10/2017 6:56 | 00000000 | 26 kg | 41.05% | $167.91 | -$36.57 | -21.80% | MkII |
| 26/10/2017 6:57 | 00000000 | 27 kg | 46.96% | $174.42 | -$31.15 | -17.90% | MkII |
| 26/10/2017 6:59 | 00000000 | 28 kg | 36.84% | $180.95 | -$30.72 | -17% | MkII |
| 26/10/2017 7:03 | 00000000 | 29 kg | 48.99% | $187.47 | -$30.28 | -16.20% | MkII |

Fig. 17 Lamb cuts calculator output file

## 4.6 Beef Re-fixturing

### 4.6.1 Assessing accuracy of determining marker positions after re-fixturing

The calibration between 3D scanner and X-ray data was to offer a backup option for determining marker positions if the markers were not able to be identified in the 3D data alone. Figure 18 shows the intensity and depth images from the 3D camera – the markers are not visible.

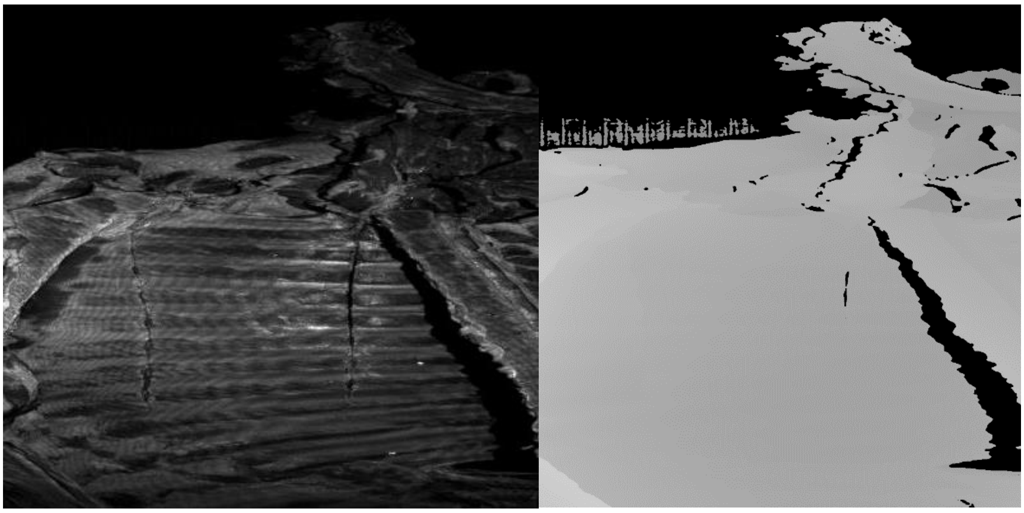

Fig. 18 Unable to determine position of markers in 3D data

Calibration of two coordinate systems to a high degree of accuracy is always difficult and in the case of this temporary setup it proved to be inadequate. The same 3D location in each coordinate system could not be resolved with sufficient accuracy to indicate if marker positions could be determined with a given tolerance.

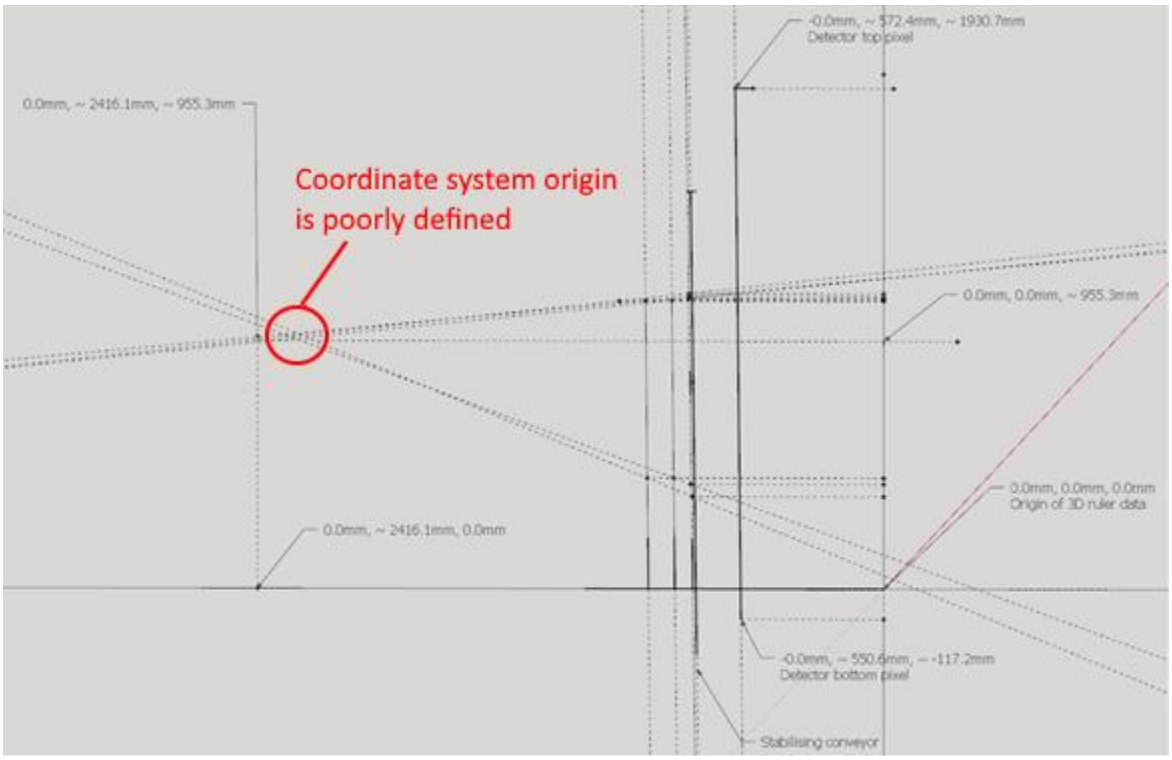


Fig. 19 Coordinate transformation could not be resolved with sufficient accuracy

Unfortunately this meant that the marker positions could not be found in each scan and the method for re-fixturing could not be satisfactorily appraised.

### 4.6.2 Assessing effectiveness of surface matching for similar surfaces

Carcase 10 was scanned in a dressed state with no cuts. It was re-scanned in an unchanged state.

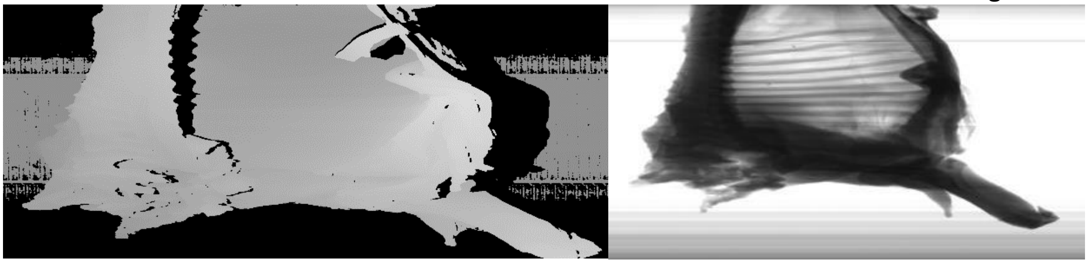

Fig. 20 Carcase 10, 3D camera & X-ray, original scan

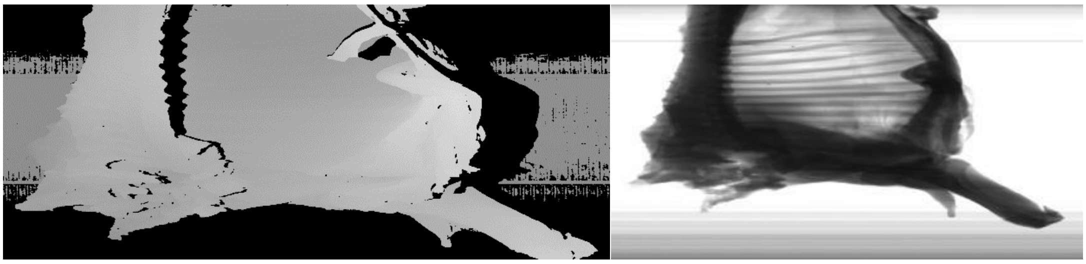

Fig. 21 Carcase 10, 3D camera & X-ray, repeat scan (no structural changes)

It proved difficult to tune the 3D camera for the environment within the short setup time-frame. As a result, the quality of the 3D data suffered and introduced artefacts (noise) in the raw data. The data could be smoothed but this removed some of the key features and reduced the potential precision of the surface matching.
Figure 22 shows an overlay of the original scan (in red) and the repeat scan (in green). The Carcase is presented in a nearly identical pose and as a result the 3D scans appear overlapped.

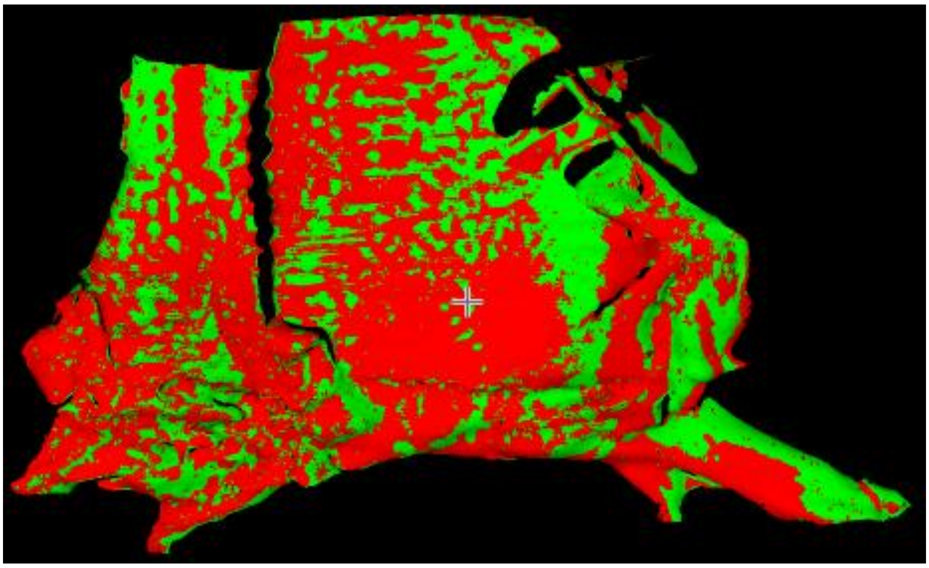

Fig. 22 Carcase 10, repeat scans present Carcase in nearly identical pose

Figure 22 shows the original scan (in green) and the deformable model created from the subsequently matched (shown in red) in the repeat scan. In some areas the model has struggled to fit the new scan despite the nearly identical presentation.

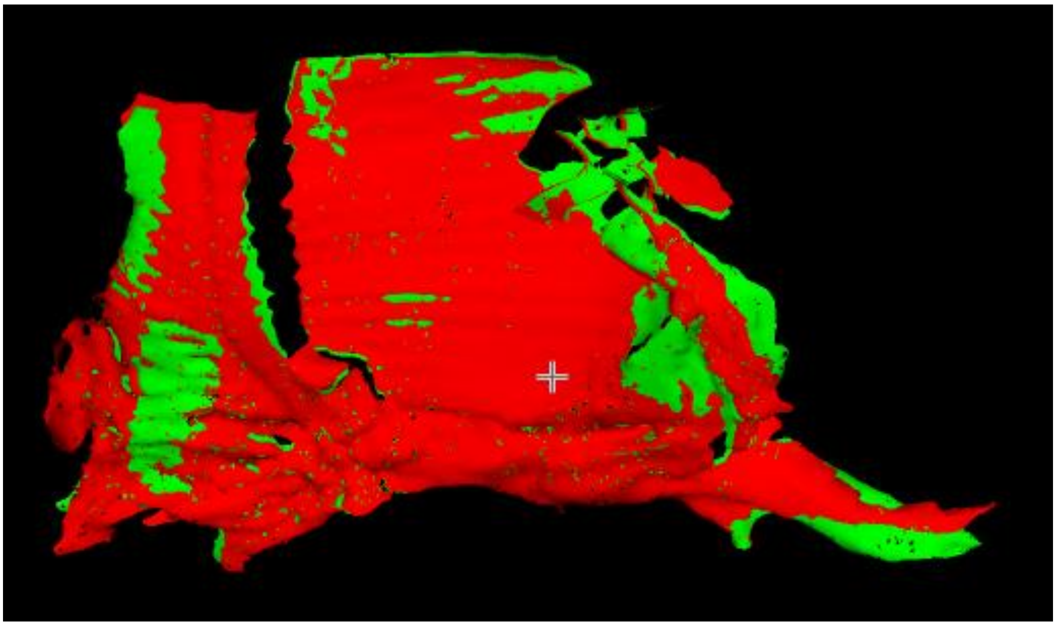

**Fig. 23 Carcase 10, deformable model struggles to cope with artefacts in 3D data**

The result of the matched surfaces is shown in Figure 23. Well matched areas are shown in green and poor areas shown in red. A "matched score" can be calculated - being the percentage of the model surface found in the new scan. Comparing with previous research the "matched score" in this case was 99.3% (previous research reported a range of 89.9% to 99.8%). Significant improvements to the matched score were made by smoothing the surfaces. A matched result of 100.0% could be achieved with significant smoothing but this appeared to remove some key features and that might affect the precision of the matching.

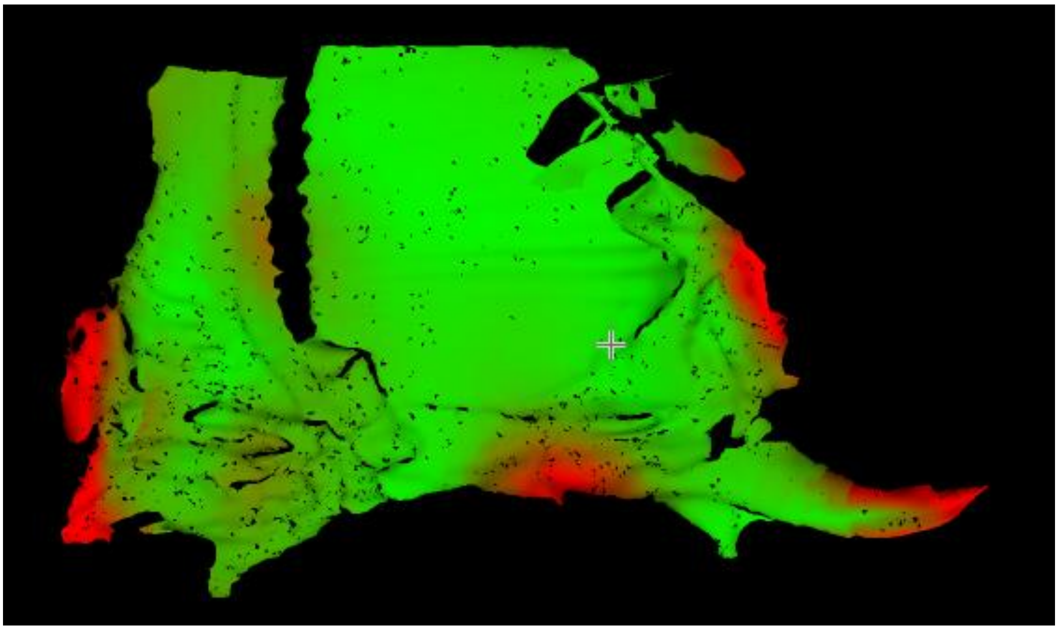

**Fig. 24 Carcase 10, very well matched scans with overall matched score of 99.3%**

### 4.6.3 Assessing effectiveness of surface matching through structural changes

Carcase 10 underwent a series of cuts after the initial re-scan. A spencer roll grading cut was made and the Carcase re-scanned. A partial flank cut was made and the Carcase re-scanned. The Carcase was then vertically scribed and re-scanned. The X-ray and 3D data is shown in the image sequence below.

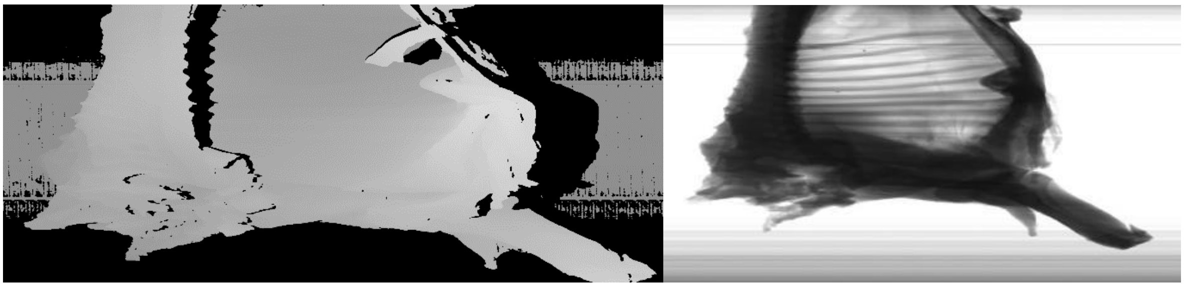

Fig. 25 Carcase 10, 3D camera & X-ray, original scan

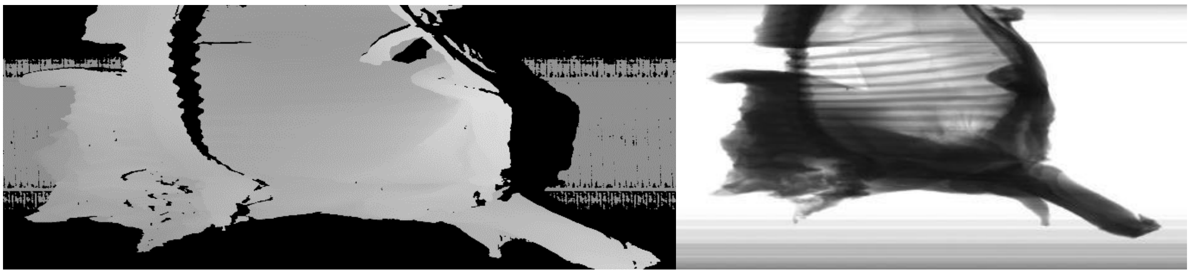

Fig. 26 Carcase 10, 3D camera, spencer roll cut

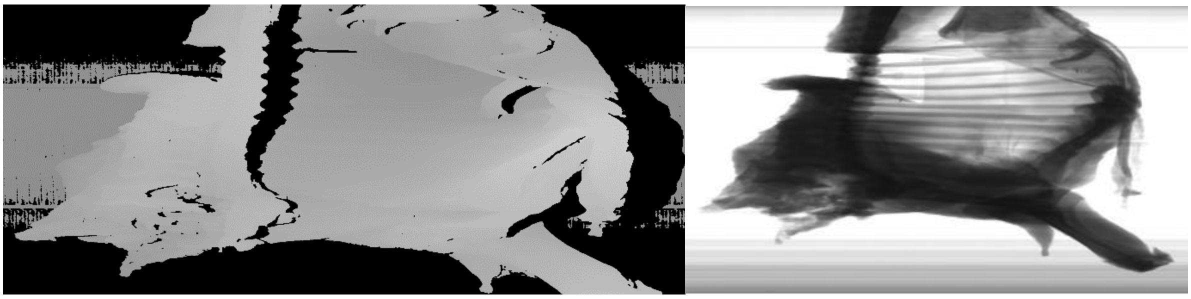

Fig. 27 Carcase 10, 3D camera, flank cut

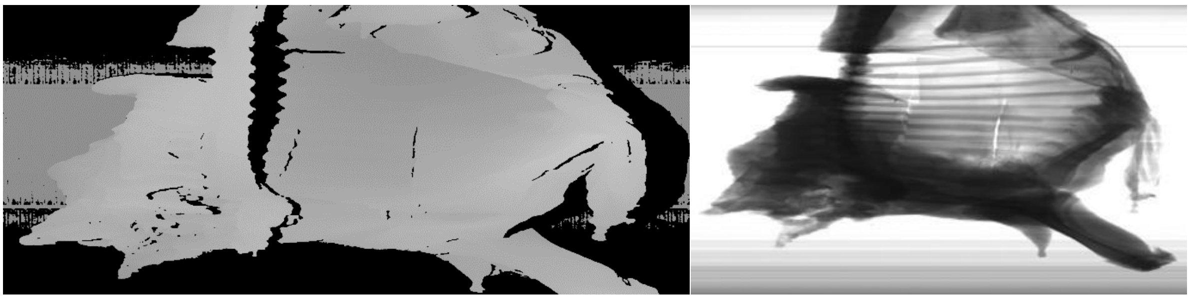

Fig. 28 Carcase 10, 3D camera, vertical scribe

The cut sequence does not drastically alter the structural integrity of the Carcase but it does add areas of occlusion after the flank has been dropped. The table below shows the matched score after each cut in the sequence:

| Scan number | Cut description | Matched score (%) |
|---|---|---|
| 1 | Original | |
| 2 | Repeat (no cuts) | 99.3 |
| 3 | Spencer roll grading cut | 96.5 |
| 4 | Partial flank cut | 91.2 |
| 5 | Vertical scribes | 88.1 |

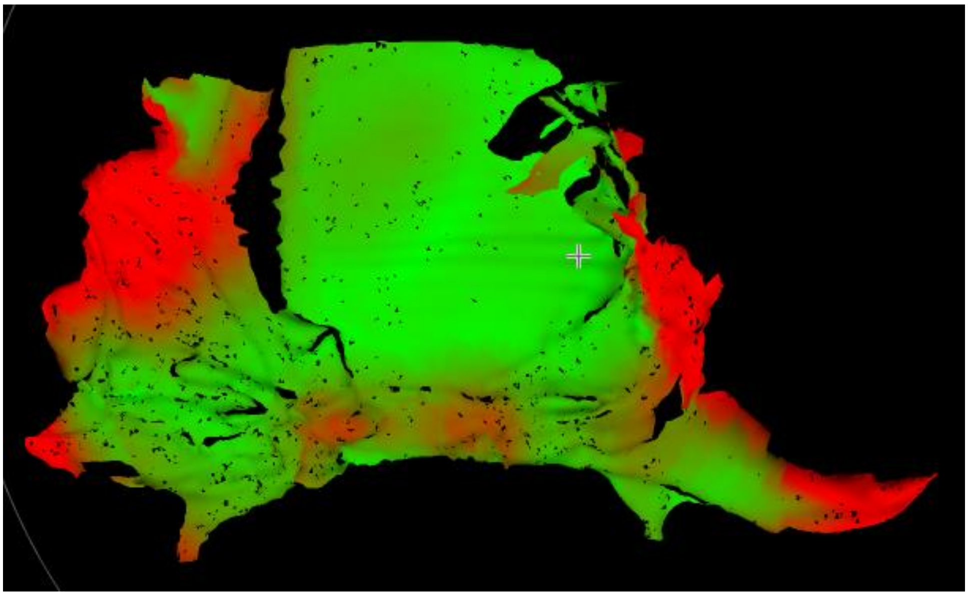

Fig. 29 Comparing original to post spencer roll cut, with overall matched score of 96.5%

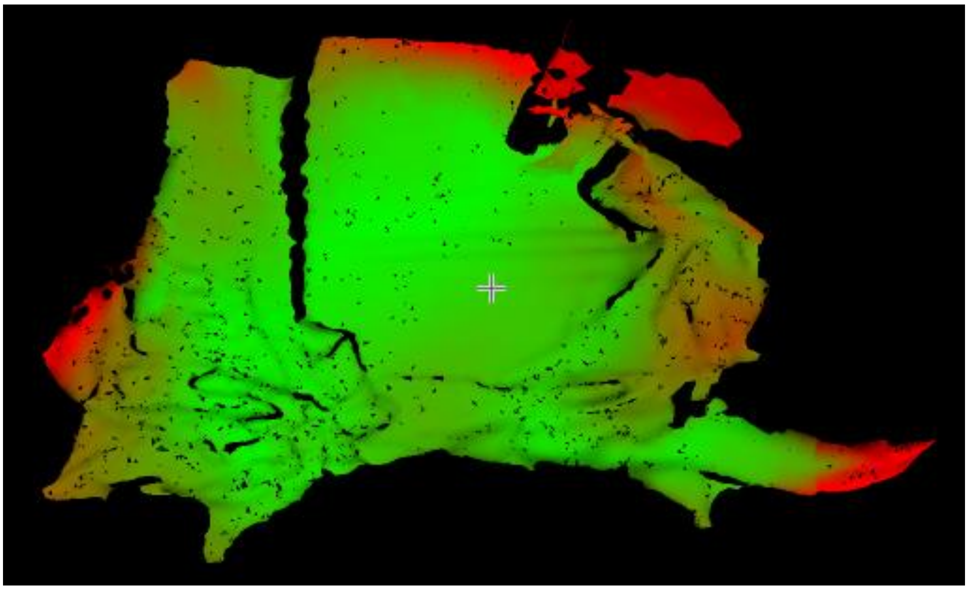

Fig. 30 Comparing original to post flank cut, with overall matched score of 91.2%

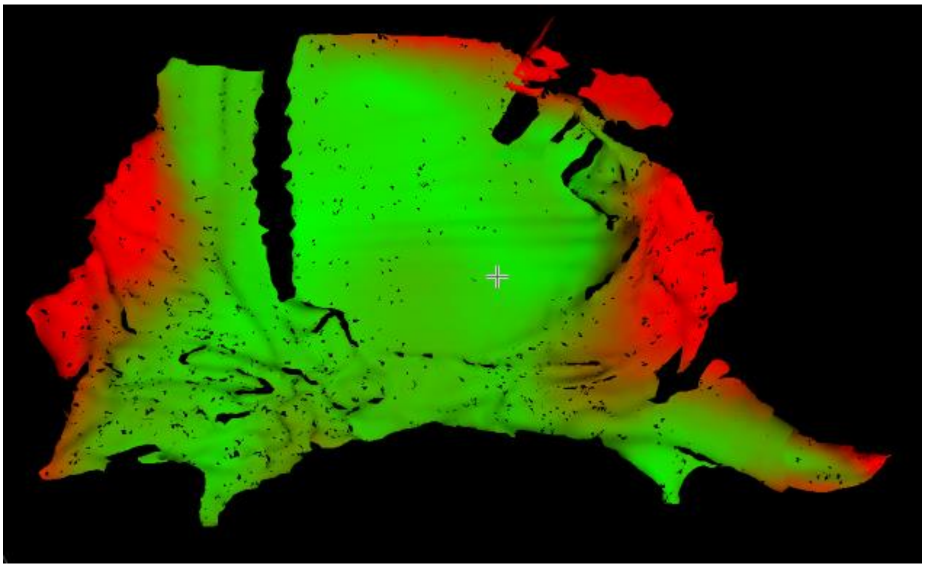

**Fig. 31 Comparing original to post vertical scribe cut, with overall matched score of 88.1%**

Carcase 14 was scanned in a dressed state with no cuts. It was re-scanned with no changes. A 10-11 rib grading cut was made, completely severing the spine, and the Carcase re-scanned. It was then re-scanned with no additional changes. The X-ray and 3D data is shown in the image sequence below.

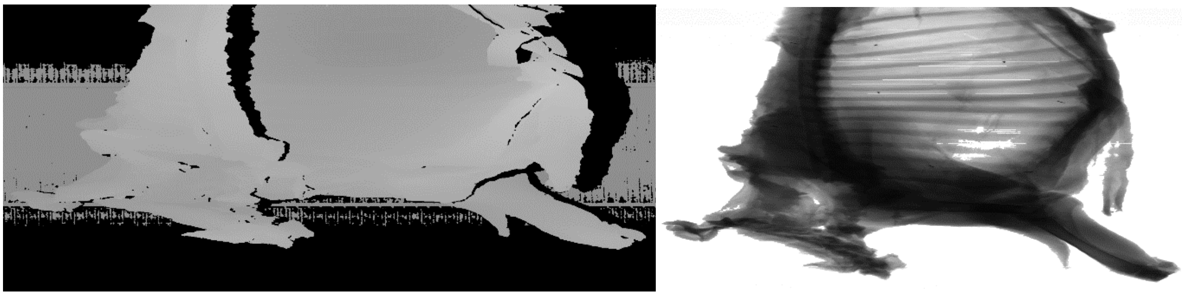

**Fig. 32 Carcase 14, 3D camera & X-ray, original scan**

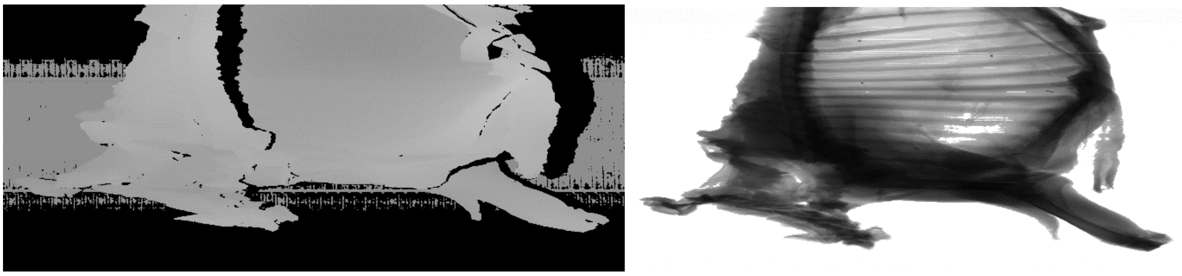

**Fig. 33 Carcase 14, 3D camera & X-ray, re-scan (no structural changes)**

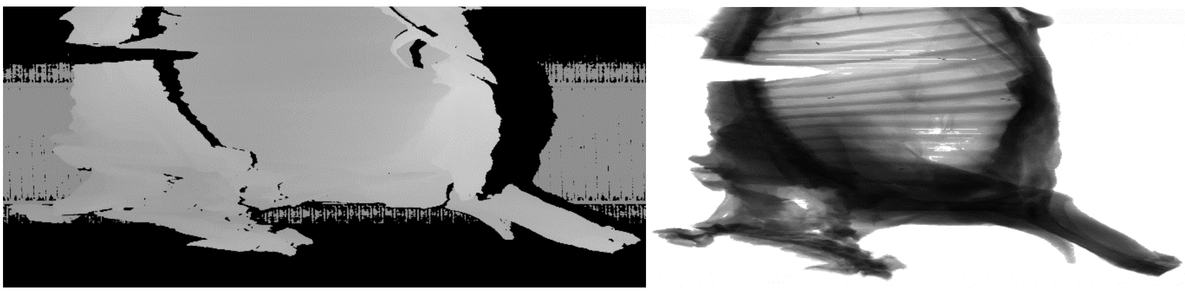

**Fig. 34 Carcase 14, 3D camera & X-ray, rib 10-11 grading cut through spine**

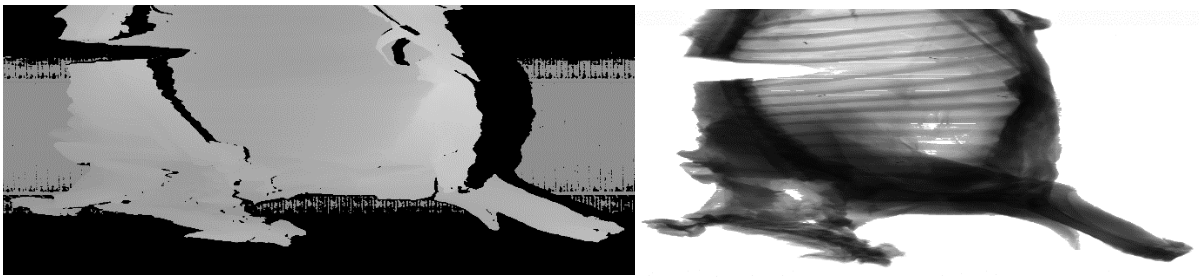

Fig. 35 Carcase 14, 3D camera, rib 10-11 grading cut re-scan

In this case the surface matching appeared to perform poorly, even for the initial repeat scan. The overall result reported a score of only 79.8% - well outside the range of the previous research. The overall structural changes to the Carcase before the cuts (in red) and after (in green) are clearly visible in the overlayed surfaces in Fig. ~~Figure 35~~. The surface matching was not robust, very small changes to the smoothing process could alter the results quite drastically. After the cut, the surface matched much better to the repeat scan than the first scan.

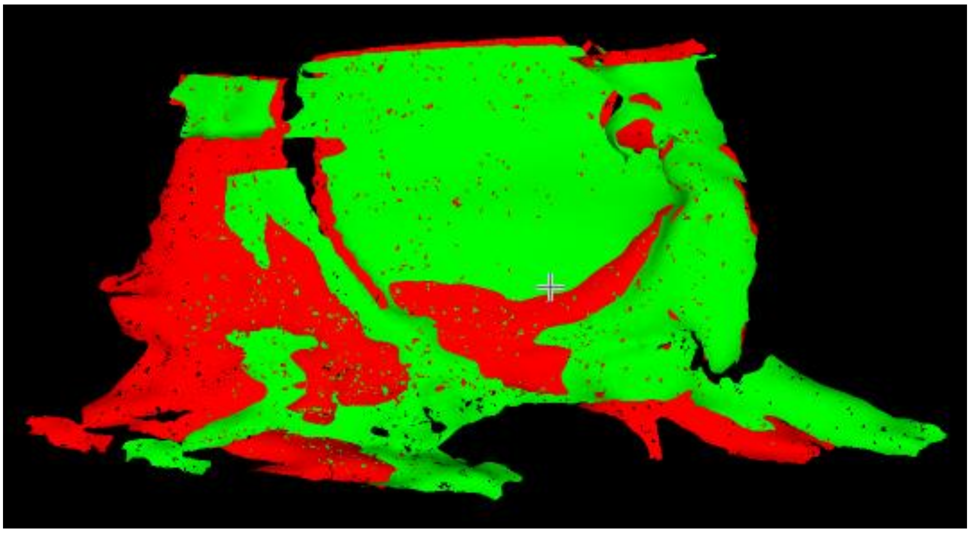

Fig. 36 Carcase 14, significant variation in 3D data due to genuine structural changes

| Scan number | Cut description | Matched score (%) |
|---|---|---|
| 1 | Original | |
| 2 | Repeat (no cuts) | 79.8 |
| 3 | 10-11 rib grading cut | 68.8 |
| 4 | Repeat (10-11 rib grading cut) | 76.8 |

# 5 Discussion

## 5.1 Hot DEXA to Chilled Carcase

### 5.1.1 Carcase Shrinkage

The most positive results were found using the DEXA scanning at reduced speed (5mtr/min) and using a simple belt stabilising system. The belt stabilisation will be a key component of any work moving forward. Measurements made using these more stable arrangement have shown that there is a small amount of expansion of the carcase. The area of interest for a processor will be around the 12-16 hour mark. In our 1st trial at 12 hours the cut height shrunk back 4.5 mm towards the rail, then slowly relaxed again the period measured (50hrs).
This small deflection was very difficult to observe with any external measurements, even when the carcase was held static, hanging inside the chiller. Also it was observed via the external markers that there was an extra displacement associated with the outside of the carcase. Although this was only a matter of a few pixels.

### 5.1.2 Stabilising a Hot carcase for DEXA scanning

The stability of the hot carcase adds a particular complexity to these measurements. Trials have been conducted using hot carcases with an existing DEXA scanner, with stabilising belt. Post rigor lamb carcases have been successfully stabilized sufficiently for DEXA analysis at chain speeds of up to 60 feet per minute. With carcases at 2 feet centres this equates to a carcase X-Ray rate of 30 carcases per minute. The stabilizing technique is to use conveyor belts travelling at chain speed to grip the hind leg hocks and to arrest swing at shoulder level.
The carcase stabilization equipment successfully used for post rigor carcases is not as successful for pre-rigor carcases.
Compared to post rigor carcases, pre rigor carcases have a very low level of torsional and bending stiffness. This is very noticeable between the aitchbone and the rib cage. If a post rigor carcase hanging from a skid and gambrel is rapidly rotated in plan through 90 degrees by moving the gambrel, the torso of the carcase follows the hind legs quite closely. If a pre rigor carcase is rotated in the same way, rotation of the torso lags well behind rotation of the hind legs. After the hind legs have been moved and made stationary, torsional oscillations of the torso will continue for up to 10 seconds. As the torso oscillates, the rib cage distorts and the rib ends either side of the sternum cut move vertically relative to each other.
While the stabilizers arrest cross chain swing of pre rigor carcases quite well, they do not satisfactorily remove twist and swing in the direction of chain travel.
Satisfactory results can be obtained by reducing chain speed to 20 – 30 feet per minute.
The degree of twist and swing in pre rigor carcases on a shoulder stabilizer travelling at 60 feet per minute is shown in the following frames from video footage. 10 video frames covered a travel distance of about 2 feet over approximately 2 seconds.

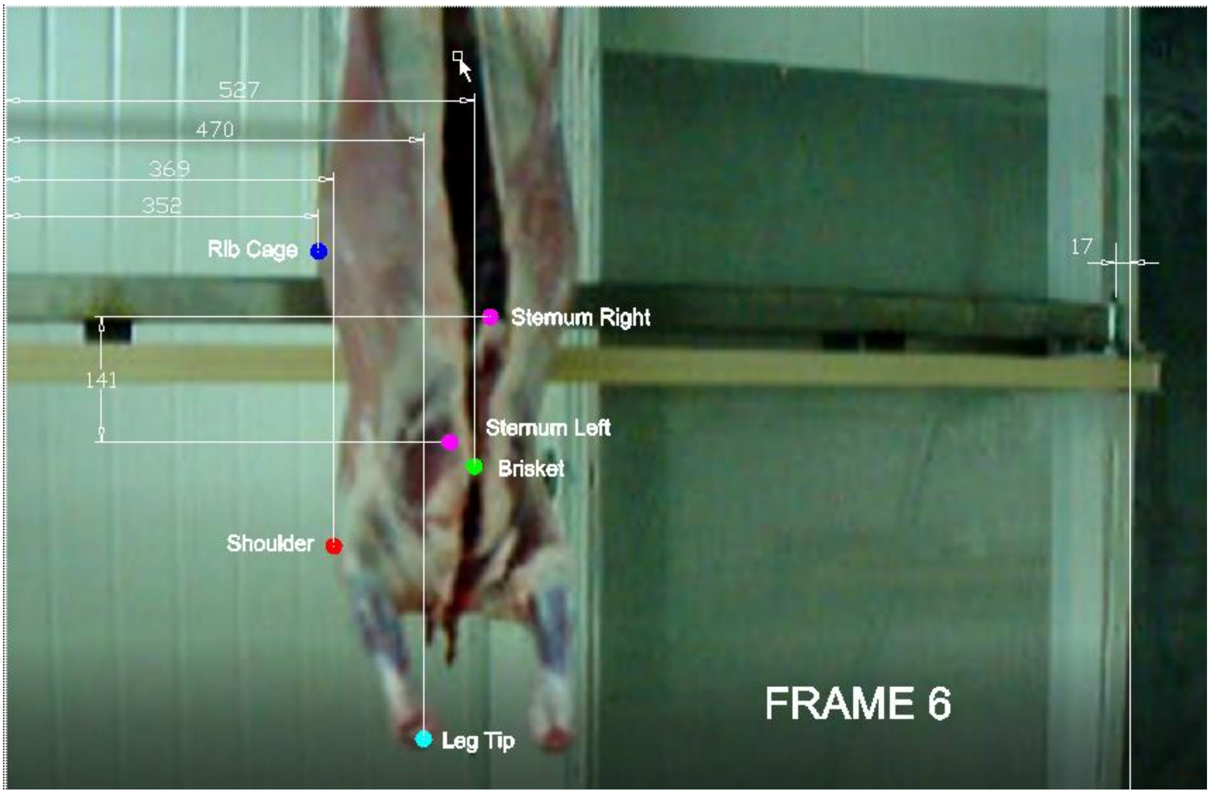


Fig. 37 Twist & swing measurement points

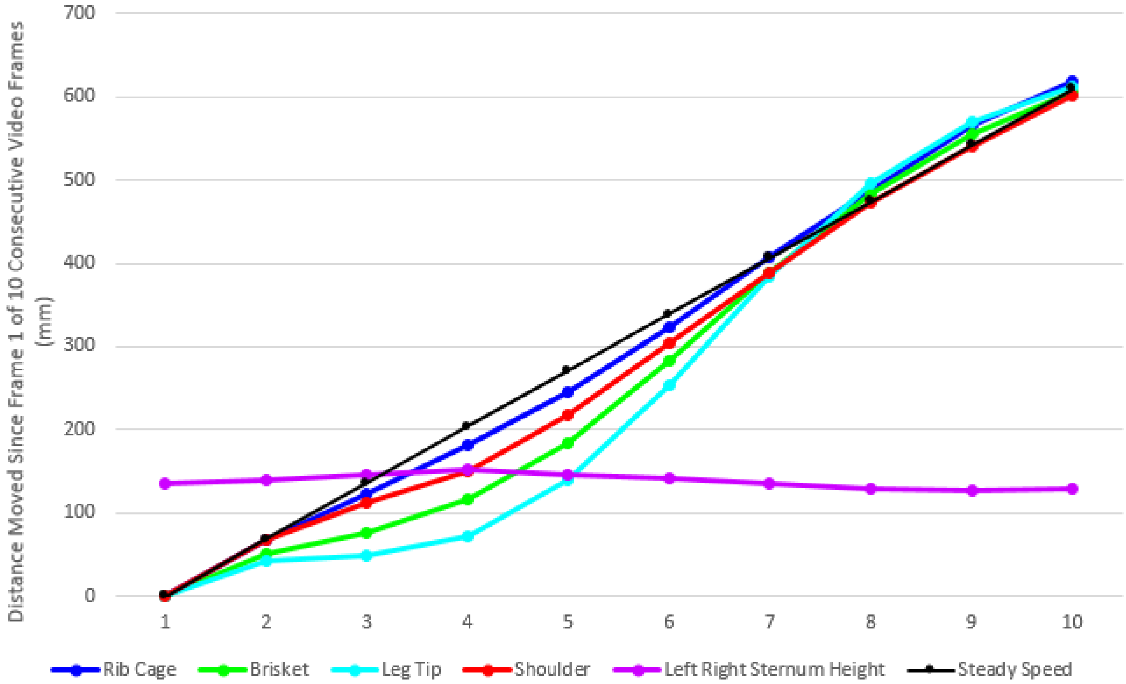


Fig. 38 Pre-rigor carcase swing measurement with Stabiliser

If there was no swing and no twist, the magenta line would be horizontal and the coloured lines would be coincident with the black line.

It takes about one second for a carcase to be X-Rayed. In about half a second between frames 1 and 4 the relative horizontal movement in the direction of chain travel of the trailing (left) leg tip and the conveyor chain was 110mm.

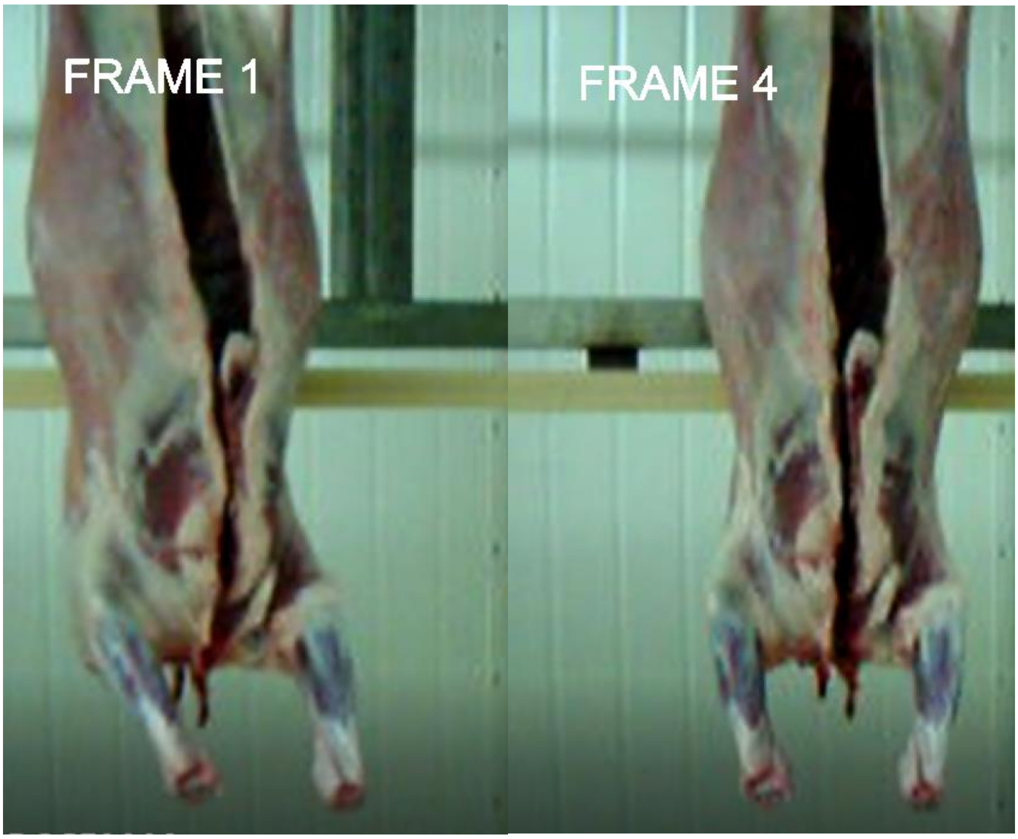


Fig. 39 Relative movement which creates burred X-Ray

Relative movement this large will result in a blurred X-Ray image with severely distorted proportions. Carcase velocity and torsional alignment relative to chain travel needs to match for good DEXA analysis. There are various possibilities for improvement on existing rub rail arrangements.

## 5.2 Re-fixturing Beef

Calibration of two coordinate systems to a high degree of accuracy is difficult and in the case of this temporary setup it proved to be inadequate. The same 3D location in each coordinate system could not be resolved with sufficient accuracy to quantify the precision of the re-fixtured data. Unsurprisingly the surface matching seems to perform much better in areas where the surface integrity has been well maintained. Fortunately the rib area seems to be one area that is well matched. Matching smaller sections of the Carcase surface scan might provide better results but this will require higher precision scans and a better signal to noise ratio than was achieved in this study.

It would seem that the amount of detail/resolution of the surface can have a significant impact on the results of the matching. The overall matching performance did seem to improve with heavy filtering/smoothing of the surface but this would likely reduce the precision of the localised matching. This could lead to reduced accuracy in the positional data. The trade-off between robustness versus precision of the surface matching is something that will require further investigation.

# 6 Conclusions/recommendations

## 6.1 Hot carcase DEXA scanning to Chilled Carcase

### 6.1.1 Offset accuracy

The variation introduced by the introduction of an offset has been calculated to reduce accuracy to 87% within ±5 mm (but 97% within ±7 mm). Note over time the accuracy slowly decreases, as the deflection curve changes. This correct offset will be related to the chilled period between hot scan and cut definition.
An analysis was conducted to confirm that theoretical cut accuracy, using the cut line derived from a hot DEXA scan plus an offset, would not result in a greater number of cuts intersecting the ribs. The average 4-5 intercostal gap was found to be 17mm, the calculated error rate would be 0.629%. It is recommended by the Scott Vision engineers that this simple offset adjustment (4.5mm) would easily be implemented.

### 6.1.2 Future work - Trialling offset and stabilisation

By capturing some further hot carcase scans, and with the implementation of the RFID tracking systems, this offset could be easily trialled. However, any distorted DEXA images created by the relative movements of the carcase while travelling along the chain these movements will need to be minimised or eliminated to provide acceptable DEXA scans.
A number of potential solutions have been investigated by the Scott development engineers, a viable option which does dampen the torsional movement of the carcase at scanning is being developed.

## 6.2 Lean Meat Yield

A predictive linear model provided by Murdoch University has been used to calculate CT LMY values for each of the carcase sections. Gardener et al (2016) have demonstrated that there are limitations to calculations for sectioning of the LMY values. The work showed that accuracy was maintained for the saddle section of the carcase, however the predictive accuracy of the algorithm is reduced for the forequarter and hindquarter sections. They have indicated that is due to the thicker tissue in these sections. There is potential for more accurate algorithms to be developed by alternative methods, such as collating the pixels in the DEXA image.

## 6.3 Re-fixturing

This research has not managed to positively or negatively confirm the suitability of this re-fixturing technique. There is still some indication that it will be possible to achieve a good outcome if clean high-resolution 3D data is available. The benefits of a successful implementation are significant and we recommend further investigation in a more controlled environment.

It is clear that a trial system will require very careful setup to ensure sufficient accuracy and this error source should be minimised in future research. We would recommend a series of workshop trials that begin with an absolute best case scenario to quantify the maximum achievable accuracy.

# 7 Key messages

## 7.1 Hot Carcase Scanning with DEXA

A simple offset of approximately 4.5mm must be considered when dealing with lamb carcases scanned hot, then chilled, before deriving cut locations. This adjustment will increase the variability of the forequarter cut to a 95% accuracy within +/- 7mm. Analysis of the intercostal gap has indicated this will not result in a greater number of cuts intersecting the ribs.
The implementation of systems to eliminate blurring of DEXA images will need to be introduced, a likely solution is being developed.

## 7.2 DEXA Lean Meat Yield Data

A DEXA scanner can provide real-time data LMY data, in particular the % lean for a whole carcase, this data can then be used to directly calculated value, such as demonstrated by the MLA's Lamb Value Calculator. A RFID system to reference individual carcases and the upstream measured weight is invaluable to providing these outputs in real-time. This adjusted Lamb Value calculator would be installed into a processors site computer to communicate with the DEXA database via Ethernet.

## 7.3 Re-Fixturing Beef

Precise calibration is difficult to achieve, even with a well-designed and static setup. The temporary calibration procedure proved inadequate in resolving accurate data positions in this project. This meant no reliable result could be determined.
The ability to re-reference or re-datum a carcass will offer huge benefits to current and future meat processing installations. We believe it is important research and based on the knowledge and experience we have gained over this project we suggest a series of "stepping stone" projects as described above to further develop the re-referencing technique.

# 8 Bibliography

G.E. Gardner, S. Starling, O. Brumby, J. Charnley, R. Glendenning, R. Coatsworth, J. Hocking-Edwards, J. Petersea, A. Williams DEXA Lamb Eating Quality and Supply Chain Grading. Meat and Livestock Australia Final Report A.MQA.0017; 2016.