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MEAT & LIVESTOCK AUSTRALIA

Final report

Automated assessment of intramuscular fat in lamb

Project code: P.PSH.1244

Prepared by: Prof. Robert McLaughlin
The University of Adelaide

Date published: 6 April 2021

PUBLISHED BY
Meat & Livestock Australia Limited
PO Box 1961
NORTH SYDNEY NSW 2059

This is an MLA Donor Company funded project.

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

Abstract

Intramuscular fat (IMF) is a key factor for achieving premium eating quality in lamb. A device capable of rapidly measuring the IMF% in a hot carcase would enable meat processors to identify premium quality meat prior to chilling. This project is developing a new optical device to measure IMF in hot carcases.

The device is called an IMF needle. It consists of a fibre-optic probe encased within a small needle that scans the muscle as it is inserted into the carcase. This needle technology does not require any cuts to the carcase. Our device uses a standard medical imaging technology, optical coherence tomography, to acquire a high magnification image of the fat cells in the muscle. This is different to the approach adopted by the Australian company MEQ, which measures the colour (spectrum) of the meat to estimate fat content. We believe that our approach to quantify IMF will be robust in the presence of regional and breed variations in the colour of the muscle.

In this project, we have developed a prototype system and demonstrated feasibility of performing measurements in the intact hot carcase. We have also significantly advanced our analysis techniques over our previous work (V.TEC.1718), showing a 100x speed improvement in analysis whilst still achieving similar accuracy to our earlier results, with an absolute average error < 0.9% and R^2 value of 0.6.

Executive summary

Background

Intramuscular fat (IMF) is the primary driver of eating quality in lamb. The percentage of intramuscular fat provides an objective measurement that can be used to identify premium quality meat. This project is exploring a new optical technology to rapidly assess the percentage of intramuscular fat in a hot lamb carcase. The device is being developed for use in a meat processing plant.

Objectives

The objectives of this project were to develop a prototype device and demonstrate its use in a meat processing plant. The project provides an assessment of time required to acquire and analyse a scan and validates results from these scans against gold-standard IMF% measurements. All objectives were successfully achieved.

Methodology

A prototype device was developed, consisting of four fibre-optic probes each encased within a needle. These were mounted on a handpiece and integrated with a portable optical scanner. Measurements were acquired on hot lamb carcases at a meat processing plant and correlated against gold-stand measurements of IMF%.

Results/key findings

The device was able acquire a measure in approximately 5 seconds per carcase and analyse the data in less than 1 minute. The estimated values of IMF% correlated against gold-standard values with a R^2 of 0.6, a RMSE of 1.0% and a mean absolute error of <0.9% IMF.

Benefits to industry

Each year, approximately 21.6 million lambs and 9.3 million sheep are processed for meat in Australia. With a value-add of $7 per lamb carcase and $3.5 per mutton carcase, our technology could generate an additional $183mil per year for the Australian sheepmeat industry.

Future research and recommendations

MLA has partnered with Adelaide-based start-up company, Miniprobes Pty Ltd, to translate this technology towards a commercial product. MLA have also partnered with The University of Adelaide to further develop and improve the underlying technology.

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1. Background

1.1 Meat Quality

The dominant factor to achieve premium eating quality in lamb is the percentage of intramuscular fat (IMF) (Pannier et al., 2014). The fat consists of tiny deposits of oil (lipid) between muscle fibres and significantly increases consumer perceptions of juiciness and flavour. The task of assessing meat quality can be addressed by accurately measuring the percentage of IMF in the sheep carcase.

Some scanning solutions to measure marble score (which is correlated to IMF) are available for beef but are not suitable for sheep due to speed and their requirement to chill carcases prior to scanning. These typically require a cut surface on the carcase (e.g. E+V camera). Non-invasive X-ray scanning has also been explored to estimate total body fat in sheep carcases, including dual energy X-ray (DEXA) (Connaughton et al., 2020) and CT scans. While useful for measuring total fat, they are unable to provide accurate IMF% estimates (Anderson et al., 2015).

1.2 IMF needles

Our team have developed a new approach to quantifying IMF based on an optical imaging technology. Optical coherence tomography is a high-resolution, non-invasive imaging technology, commonly used in human ophthalmology and cardiology (Drexler and Fujimoto, 2015). It uses reflections of low power near infrared light to construct an image of the tissue microstructure at a scale of several microns. Work by our team has demonstrated that fat (adipose cells) appears significantly different to other tissue types (McLaughlin et al., 2012).

Optical coherence tomography is well suited to use in meat production, allowing very rapid imaging and being safe with no ionising radiation. However, it cannot image deep into tissue, and is limited to a useful imaging depth of 2mm due to optical scattering and absorption. Unfortunately, the muscle that must be assessed for meat quality can be located >1 centimetre below the surface.

Our team have developed a new technology to address this intrinsic limitation of optical imaging: an *IMF needle*. This is a highly miniaturised fibre-optic probe encased within a hypodermic needle that can acquire high quality images of tissue structure as deep in tissue as you can insert a needle.

In a previous MLA-funded project (V.TEC. 1718), we demonstrated the potential of an IMF needle to quantify IMF in cold lamb carcases. In this current project, our goal has been to develop a prototype system to assess the feasibility of this technology in a hot carcase.

2. Objectives

The objectives of this project are:

1. Develop a prototype device that allows rapid acquisition of multiple IMF needle scans.
2. Implement automated software to quantify IMF% in a hot carcase.
3. Complete data collection, demonstrating feasibility of using the device in a meat processing plant.
4. Report on speed of scanning and accuracy of IMF% estimates.

All objectives for this project were successfully completed.

3. Methodology

Our device consists of two parts: a handpiece containing four IMF needles; and a portable, battery-operated optical scanner. Within this project, we have developed prototypes for both aspects of the device and have implemented neural network software to automate analysis of the data.

3.1 Development of the handpiece

Our team have developed a handpiece that contains four IMF needles capable of acquiring simultaneous measurements in a lamb carcase. A photo of the handpiece is shown in Figure 1.

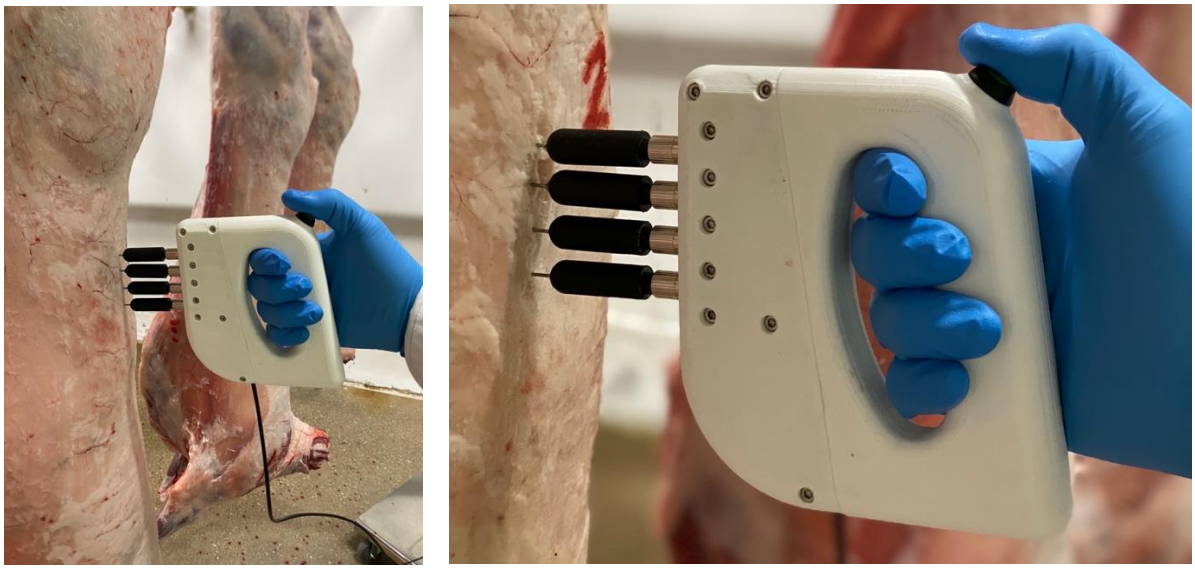

Fig. 1. The IMF scanner being tested on a lamb carcase at JBS Bordertown, November 2021.

Each needle contains a fibre-optic optical coherence tomography probe. This consists of an optical fibre encased within the needle, with a miniaturised lens fabricated at the end of the optical fibre. The design of the lens is based on earlier work by our team, where highly precise lengths of various types of fibre are fused together to shape the light beam (Scolaro et al., 2012). The lens is terminated with a tiny, angled silver mirror inside the needle, and the imaging light beam emerges from a small opening at the side of the needle. In this prototype, we have used needles with an outer diameter of 1.3mm. However, the design can be adapted to smaller or larger needles as required.

The needles are mounted on a 3D printed handpiece, which also includes a waterproof button that is used to start and stop the data acquisition. The needles may be unscrewed and removed, allowing them to be individually replaced if they malfunction.

3.2 Portable optical scanner

Within the scope of this project, we have developed a portable, battery-operated optical scanner. The scanner contains a high-resolution optical coherence tomography (OCT) scanner (Lorenser et al., 2015). We have elected to use an OEM off-the-shelf system acquired from Excelitas Technologies, a

major international supplier of OCT scanners to industry. The decision to base our system around a commercial OCT system both improves system reliability and simplifies future scaling of production.

To reduce the cost of the system, we have multiplexed a single OCT scanner between the 4 needles in the handpiece. This has required developing a high-speed mechanism to multiplex the optical signal into 4 channels. The system design is shown in Figure 2 and photos of the prototype system are shown in Figure 3.

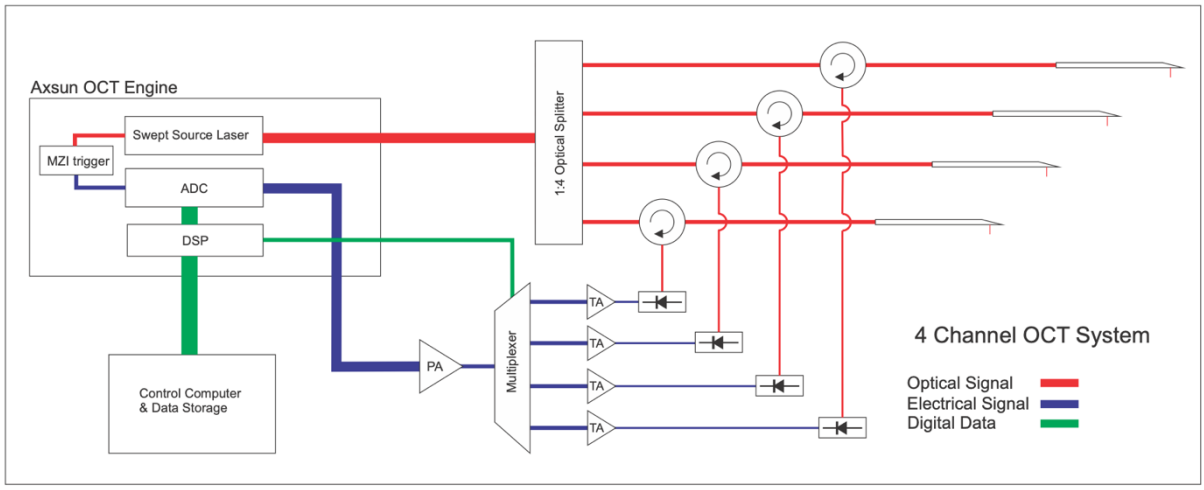

Figure 2. Design for single OCT scanner to integrate with a 4 IMF needle probes.

Figure 3. Battery-operated prototype scanner. (left) Internal components. (right) Assembled system in a waterproof carrycase (cap is shown to give an understanding of size).

3.3 Analysis software

In an earlier MLA-funded project (V.TEC.1718), we developed automated quantification software using a deep learning algorithm. The earlier software was based on a neural network architecture referred to as GoogLeNet (Szegedy et al., 2015). Analysis involved sequentially analysing tiny sections of the data to automatically identify fat cells in the muscle. We found this approach to be accurate, but prohibitively slow.

Within the current project, we have developed a new deep learning analysis approach which has achieved a speed increase of approximately 100x. Our new technique is based on the U-Net architecture, described in (Ronneberger et al., 2105). In this approach, a large section of the data is iteratively subsampled into smaller images, each encoding increasingly complex image features. These are then up-sampled to reconstruct the original image, where each location has been categorised as either fat or muscle. The network architecture is shown in figure 4.

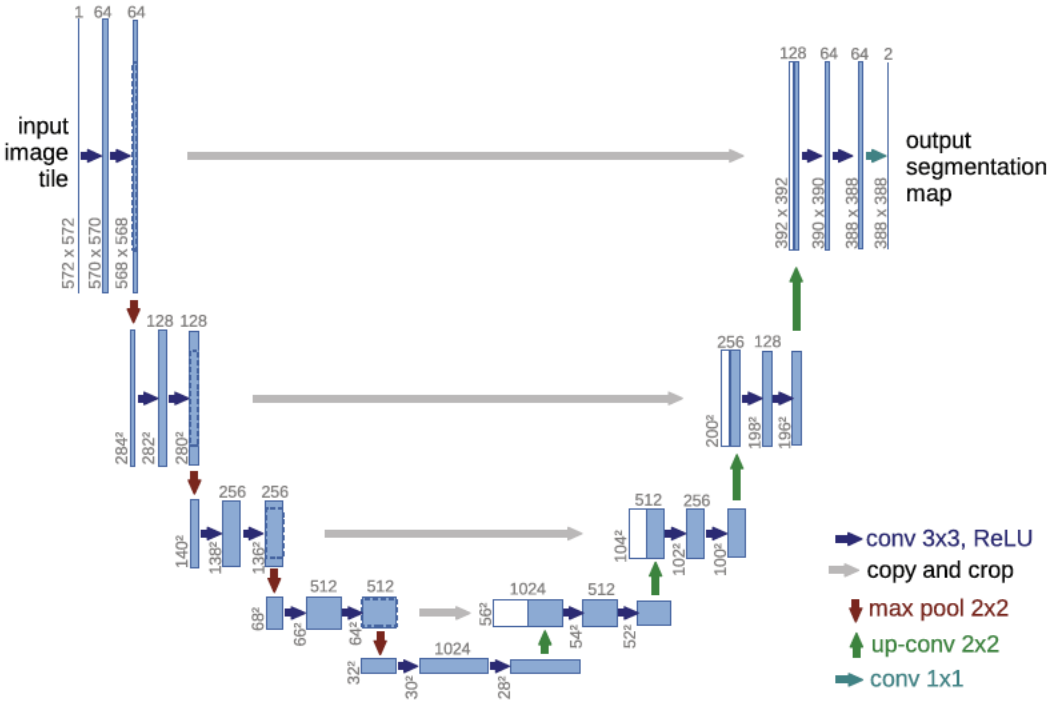

Figure 4. U-Net architecture used to quantify intramuscular fat. Image taken from (Ronneberger et al., 2105).

4. Results

4.1 Speed of scanning

In November 2021, we tested the prototype system at JBS Bordertown, South Australia. 166 lamb carcases from the MLA Resource flock were scanned hot (within 2 hours of slaughter). The following morning, the cold carcases were rescanned prior to boning.

Earlier work by our team has suggested that at least 8 scans are required for an accurate estimate of IMF. This is because each IMF needle scan only analyses muscle in the immediate 1mm vicinity of the needle insertion and IMF distribution can be heterogeneous throughout the muscle. Acquiring multiple scans provides a more robust quantification of the average IMF%. At each insertion of the 4-needle handpiece, 4 scans are acquired. We estimate that two insertions can be completed in approximately 5 seconds per carcase. This suggests that it may be feasible to acquire measurements at line-speed.

4.2 Accuracy of IMF% estimation

The process required to obtain gold-standard IMF% estimates is time consuming, requiring freeze-drying of samples prior to chemical analysis or near infrared measurements in one of a small number of analysis labs in Australia. At the time of compiling of this report, analysis had not yet been completed on the data collected in November 2021. However, the data is comparable in image quality and characteristics to data acquired by our team at TFI Tamworth in 2019 using a comparable OCT scanner. In order to test the new analysis algorithm developed within the scope of this project, we performed an analysis on the hot carcase data acquired from this earlier cohort.

Example results are shown in Figures 5 – 8. In the hot carcase, fat appears as a black and white honeycomb structure showing clusters of fat cells. Muscle appears as a more uniform texture, reflecting the dense network of muscle fibres. In each of the results shown, the top image shows the data acquired from a hot carcase from a single insertion of the IMF needle. The bottom image shows the results of automated detection, with fat cells coloured in yellow.

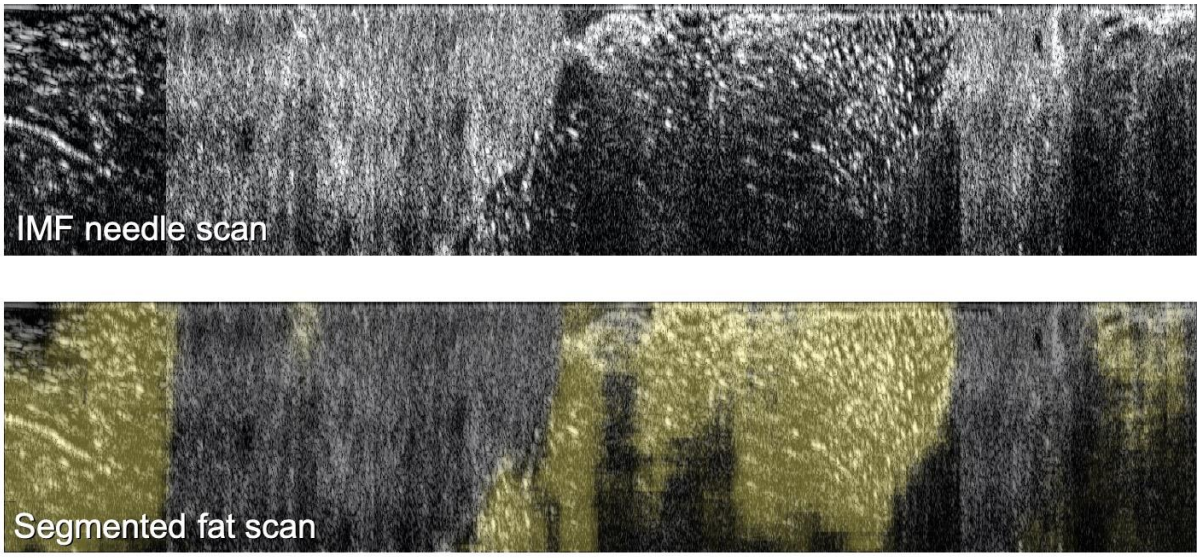

Figure 5. (top) IMF needle scan (scans are approximately 8mm x 1mm, length x depth). (bottom) Results of automated analysis. Fat is coloured yellow.

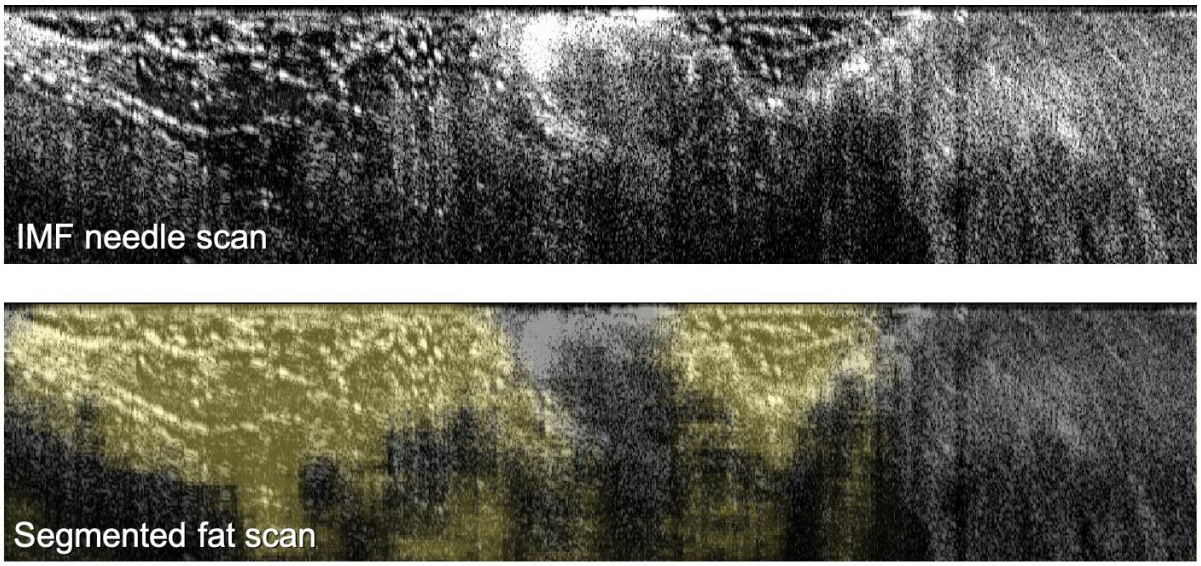

Figure 6. (top) IMF needle scan (scans are approximately 8mm x 1mm, length x depth). (bottom) Results of automated analysis. Fat is coloured yellow.

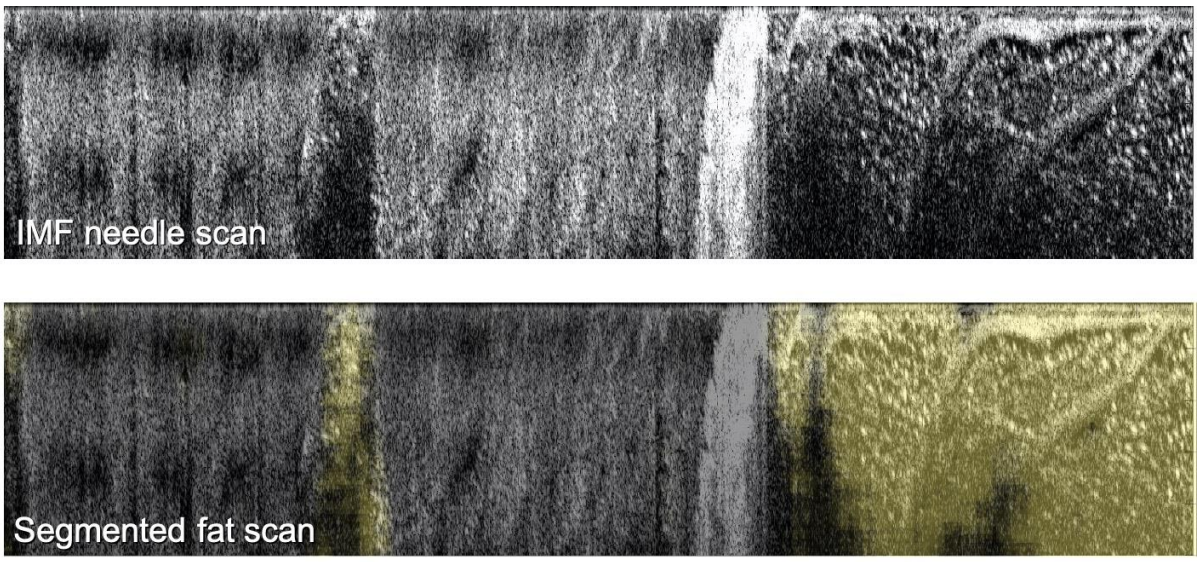

Figure 7. (top) IMF needle scan (scans are approximately 8mm x 1mm, length x depth). (bottom) Results of automated analysis. Fat is coloured yellow.

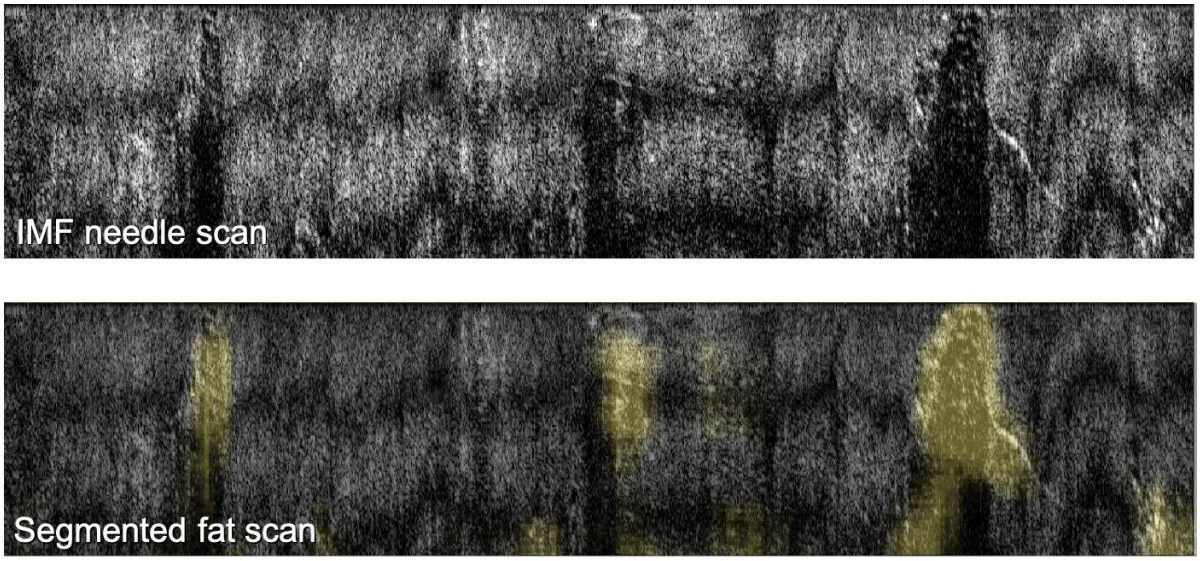

Figure 8. Example of detection of small areas of fat (scans are approximately 8mm x 1mm, length x depth). (top) IMF needle scan. (bottom) Results of automated analysis. Fat is coloured yellow

Gold-standard IMF estimates for 30 carcases were measured using chemical and NIR analysis, with an IMF range from 3.7% – 9.7%. In Figure 9, the results computed using our improved U-Net deep learning algorithm (vertical axis) are plotted against the gold standard values (horizontal axis). The algorithm provided estimates with a mean absolute error of 0.85% IMF, a RMSE of 1.0% and a R^2 of 0.6. These results are comparable to those calculated using our earlier, slower algorithm.

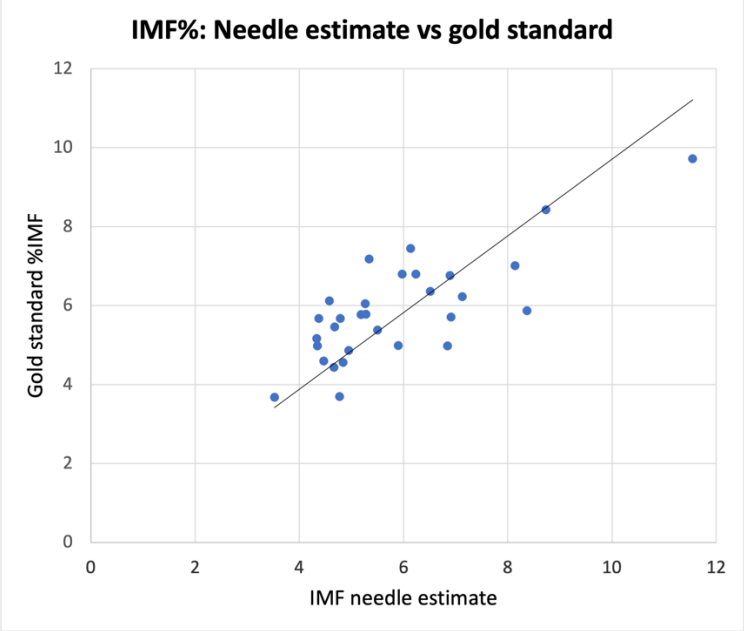

Figure 9. IMF estimates on 30 hot carcases using the IMF needle and U-Net analysis.

The software was able to analyse the IMF data at a speed of 1.8 seconds per needle scan. This suggests that it may be feasible to analyse a carcase at line speed of a meat processing plant. We note that, in a commercial system, there will be some addition time delays for pre-processing and post-processing of the data, and that we will need to analyse all 8 needle scans to provide an accurate estimate of IMF

in the carcase. However, much of this processing could be performed in parallel. We estimate that that total processing time could potentially be reduced to significantly less than 1 minute with appropriate hardware optimisations.

5. Conclusion

5.1 Key findings

This project has demonstrated the feasibility of a new device for quantifying IMF%. The device uses IMF needles to acquire high resolution scans of tissue structure which show clear differentiation between muscle and intramuscular fat. A limitation of this approach is that each needle analyses a very small section of muscle. However, this project delivered a 4-needle handpiece capable of rapidly acquiring multiple scans. Our preliminary validation studies suggest it may be feasible to scan a carcase in approx. 5 seconds, and that analysis of the data may be completed in significantly less than 1 minute. Quantification of the IMF needle scans gave R^2 of 0.6 against gold-standard values, with a mean absolute error <0.9% IMF.

5.2 Benefits to industry

A new technology to quantify IMF% would allow meat processors to quantify sheep carcase quality immediately after processing, allowing them to customise carcass handling, fabrication and individual cut marketing. It would also provide valuable new feedback throughout the livestock farming process, allowing sheep producers to optimise breeding and husbandry choices to produce a higher proportion of premium meat animals.

Meat Standards Australia defines 3 grades of meat (MSA 3, 4 or 5 star). Studies show that consumers are willing to pay 150% and 200% for grade 4 and grade 5 meat, respectively (Swan et al., 2015).

The distribution of MSA Grade 4 and 5 meat in Loin and Topside, taken across >1400 lamb carcases from the MLA Resource Flock was assessed in (Pannier et al., 2014). For Loin, 84% of carcases were MSA Grade 4 or 5, and for Topside 8% of carcases were MSA Grade 4 or 5. By identifying these carcases, processors and brand owners have the opportunity to charge a premium for the higher-grade meat.

Our internal modelling of the regression between IMF% and MSA grading suggests that knowledge of IMF% will add value of approximately $7 per lamb carcase (assuming the standard deviation of IMF% within the cohort is approximately 1.5%). For mutton, we assume a much smaller value-add of $3.50 per sheep carcase.

Each year, approximately 21.6 million lambs and 9.3 million sheep are processed for meat in Australia. With a value-add of $7 per lamb carcase and $3.5 per mutton carcase, our technology could generate an additional $183mil per year for the Australian sheepmeat industry.

6. Future research and recommendations

IMF needle technology has potential for translation to a commercial product in its current form, and also scope for future research and development. MLA has committed to supporting both of these activities.

In collaboration with MLA, Adelaide-based start-up company Miniprobes Pty Ltd has been awarded a Cooperative Research Centre Project (CRC-P) grant to translate the current IMF needle technology towards a commercial product. The CRC-P grant program is administered by the Department of Industry, Science, Energy and Resources.

In parallel, MLA has partnered with The University of Adelaide, who have been awarded an Australian Research Council Linkage grant focused on R&D for the next generation of IMF needle technology. The R&D project will explore the development of improved optics using multi-photon 3D printing technologies and improved quantification through new deep learning neural network algorithms.

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