Final report

On-line measurement of intramuscular fat in hot lamb carcases

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Abstract

The market for lamb meat is not currently segmented based on eating quality. However, consumers will pay a premium for high quality meat. A device to identify premium quality meat could enable the Red Meat Industry to capture additional value. Intramuscular fat is the single most important factor in meat eating quality. This project has developed a prototype device to measure intramuscular fat in a hot lamb carcase.

The device adapts a standard optical imaging technology to use in the Red Meat Industry. It comprises of a fibre-optic probe encased in a small metal needle that is able to identify traces of fat as the needle is inserted into the muscle.

This project has developed core aspects of the technology. It established an automated process to reliably fabricate the miniaturised fibre-optic probes that could allow production to be increased to a commercial scale. It has also developed artificial intelligence software to perform rapid quantification of a scan within 3 seconds. The prototype device was validated as part of a trial with the MLA Resource Flock and was able to estimate the percentage of intramuscular fat with a mean average error of 0.64% against a chemical gold-standard. Within this trial, 80% of our intramuscular fat estimates were within 1% of the gold-standard value, and 98% were within 2% of the gold-standard. This exceeds the AUS-MEAT accreditation standards in sheep, giving confidence that the device will successfully achieve accreditation in a future trial.

Executive summary

Background

The market for lamb meat is not currently segmented based on eating quality. However, consumers will pay a premium for high quality meat. This project is developing a new device to assess eating quality in lamb meat by measuring intramuscular fat. This device is intended for use in a meat processing plant, to enable assessment of meat early in the processing workflow, with the potential to allow processors to capture additional market value.

Objectives

The objectives of this project were to develop the core technologies required for this device. In particular, to develop the hardware and software for a prototype device; and undertake validation trials in a commercial meat processing plant. In addition, this project undertook research to establish whether it was feasible to automate the most complicated stages in the fabrication of the device, specifically fabrication of the miniaturised fibre-optic probes that are a critical component of this device.

Each of these objectives were successfully achieved.

Methodology

We developed a prototype device consisting of a handpiece with 4 small needles containing fibre-optic probes that could identify intramuscular fat as they were inserted into the muscle; and a scanner console that could be wall-mounted within a meat processing plan. An artificial intelligence algorithm analysed the scans to automatically quantify intramuscular fat within 3 seconds.

Results/key findings

We performed a validation trial on 205 lamb carcases at TFI Tamworth, NSW, taken from the MLA Resource flock. The device produced estimates with a mean absolute error of 0.64 IMF%, a root mean squared error (RMSE) of 0.85 IMF% and an R^2 of 0.50. 80% of estimates were within 1% of the gold standard IMF% measurement. 98% of the estimates were within 2% of the gold standard IMF% measurement. This satisfies the accuracy required for accreditation within the meat industry by AUS-MEAT.

Benefits to industry

This project has established the feasibility of using a fibre-optic needle probe to rapidly measure intramuscular fat in a hot lamb carcase. Our internal modelling suggests this could generate an average additional $7 of value per carcase, and increase the value of the Australian sheepmeat industry by $173mil per year.

Future research and recommendations

Further work will be required to complete translation and commercialisation of this device. MLA support will be critical to attract the necessary funding and support industry adoption.

Acknowledgments

We wish to acknowledge the support of Meat & Livestock Australia and The Australian Meat Processor Corporation (AMPC), for their assistance in making this work possible.

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1. Background

This project is developing a new device to measure eating quality in lamb meat. Consumers will pay a premium for quality meat. Compared with MSA Grade 3 meat, consumers will pay an extra 50% and 100% for Grade 4 and 5 (highest quality) meat (Swan et al., 2015). However, meat processors currently lack tools to allow them to exploit this opportunity.

Meat quality varies between individual sheep, so every lamb carcase needs to be tested. This is most efficiently done early in the processing workflow with the hot carcase (i.e. immediately after slaughter and prior to chilling). This testing would allow meat processors to customise carcass handling, fabrication and individual cut marketing. It would also provide valuable feedback to sheep producers to optimise breeding and husbandry choices to produce premium meat animals.

The major factor in eating quality is intramuscular fat – tiny traces of oil in the muscle that make it juicy and tender (Hopkins et al., 2006, Pannier et al., 2014). The task of assessing meat eating quality can be addressed by accurately measuring the percentage of intramuscular fat in the sheep carcase.

This project extends upon research from University of Adelaide to develop a rapid-scanning technology to measure intramuscular fat. The technology uses a fibre-optic probe encased within a small, metal needle 3mm in diameter, which can be inserted into muscle. The fibre-optic probe uses an optical imaging technology called optical coherence tomography (OCT). OCT is a standard imaging modality in medical applications, including ophthalmology (2015, Schwartz et al., 2014) and cardiology (Bezerra et al., 2009). In this project, our team have re-purposed this technology to quantify the percentage of intramuscular fat in lamb.

OCT is able to acquire high-resolution images of muscle structure at a resolution of 10 - 20μm. This enables it to identify and count individual fat cells between muscle fibres. Each scan is analysed using an artificial intelligence deep learning algorithm to automatically estimate the percentage of intramuscular fat. By acquiring multiple scans of the muscle, the device is able to extract an accurate estimate of meat-eating quality.

We have developed this technology into a handheld optical scanner. The scanner has been designed for use in a meat processing plant, with measurements performed on the hot lamb carcase. This allows the meat processor to rapidly identify high quality lamb meat for sale as a premium product.

The funding for this MLA project was used to leverage additional support through the Australian Research Council Linkage grant scheme. MLA funding was leveraged at a proportion of 1.05 to 1. This project has operated in co-operation with a related project: V.TEC.1726: “Translating intramuscular fat measurement technology to the sheepmeat industry”. V.TEC.1726 was focused on commercially translating a device to the meat processing industry. In contrast, this project (V.TEC.1723) has focused on developing the core technologies required to enable translation.

2. Objectives

The broad objective of this project has been to develop the core technologies required for a fibre-optic device to measure intramuscular fat. This has included development of manufacturing processes to fabricate the fibre-optic probes, and the artificial intelligence algorithms required to automatically quantify the optical scans. This is to be demonstrated through the development and validation of a prototype device during trials at a commercial meat processing plant.

Specific objectives for the project are listed below:

1. Develop the hardware and software required for a hot carcase probe that can be deployed in a meat processing plant to measure IMF in commercial conditions.
2. Undertake trials to validate the accuracy of IMF measurement under commercial conditions, and in doing so compile a dataset to underpin an application for AUS-MEAT approval for IMF measurement.
3. Develop a prototype of the IMF needle scanner for the Australian market in collaboration with an early-adopter lamb processing partner.

Each of these objectives has been met successfully. Section 3 of this report (Methodology) details of the hardware and software developed for Objective 1, and the prototype system developed for Objective 3. Section 4 of this report (Results) details results from the trial undertaken at Thomas Foods International, Tamworth to address Objective 2.

3. Methodology

3.1 Device overview

The device consists of a handpiece with four stainless-steel needles, each needle containing two tiny fibre-optic imaging probes to analyse the meat. The handpiece is attached to a wall-mounted console that contains the necessary optical and electronic components. A photo of our prototype handpiece and the wall-mounted console is shown in Figure 1.

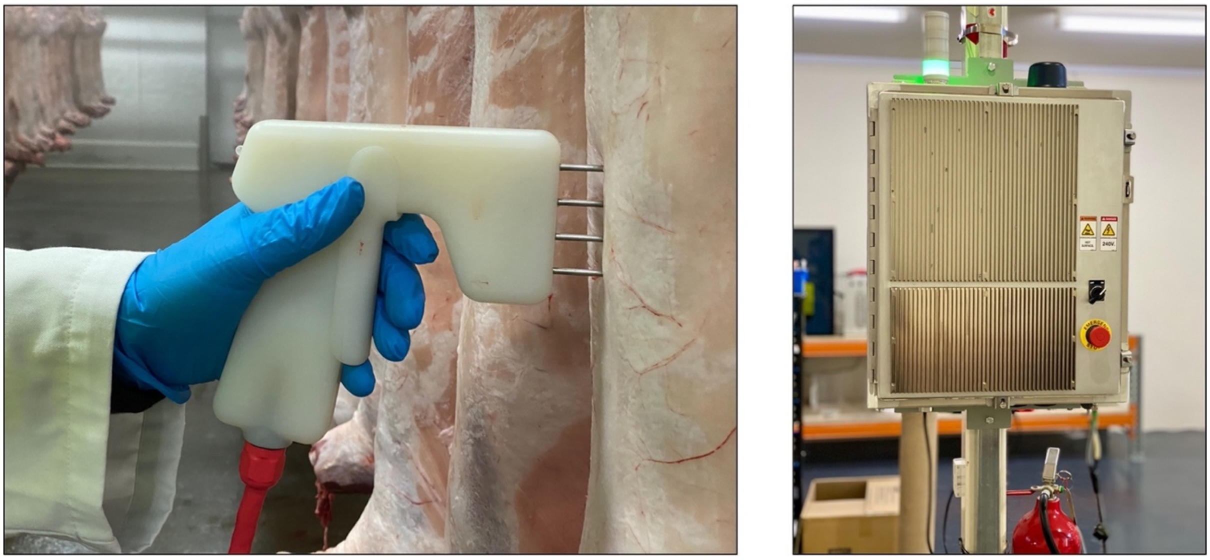

Figure 1. (left) Handpiece, comprising 4 needles to perform multiple measurements simultaneously. (right) Console that is connected to the handpiece, mounted on a stainless-steel pole.

As the needles are inserted into a hot carcase, each of the 8 fibre-optic probes (2 per needle) acquires a microscopic-scale image of the muscle structure. Figure 2 shows an example of a typical image acquired by one fibre-optic probe. This image displays a small section of the muscle up to a distance of 2mm away from the needle. Computer analysis software is able to identify the amount of fat within the muscle.

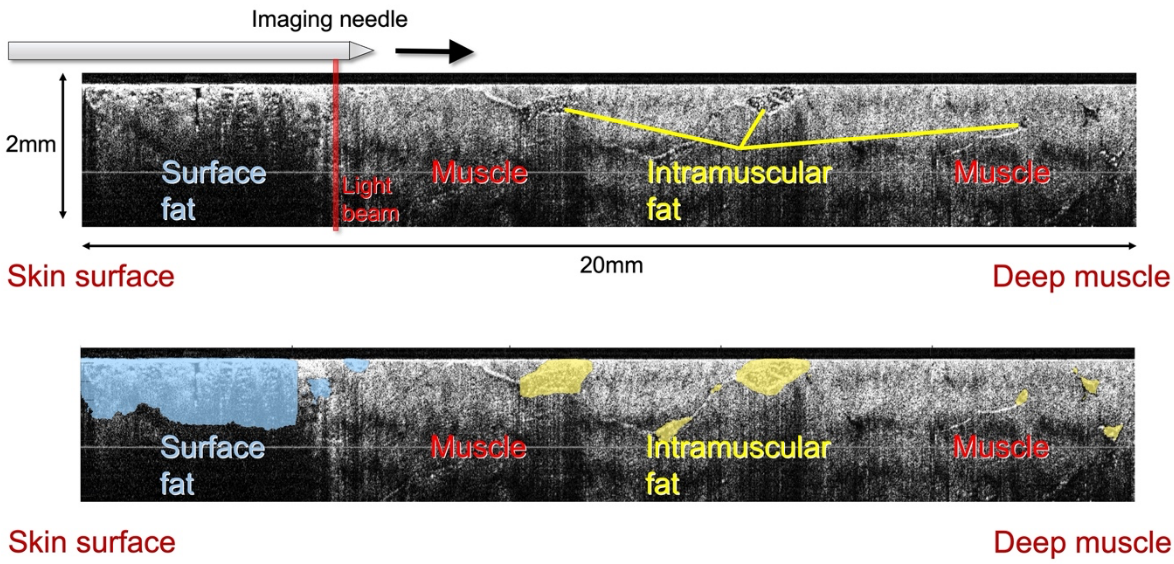

Figure 2. (top) IMF needle scan from a hot carcase. (bottom) Automatic image analysis with fat highlighted in yellow.

By automatically analysing these images with an artificial neural network algorithm, we are able to objectively quantify the percentage of intramuscular fat. The results of this analysis are also shown in Figure 2, where areas of intramuscular fat and surface fat have been coloured yellow and blue, respectively. Analysis of the scans takes approximately 3 seconds. This allows a person to scan the carcases as they are processed in the meat processing plant (15 per minute), prior to the carcase being stored in the chiller.

3.2 Handheld scanner

The handpiece comprises of 4 stainless-steel needles, shown in Figure 3. Each needle has two small holes near the pointed end, through which we acquire images of the meat. Inside each needle are two fibre-optic probes. The fibre-optic probe consists of an optical fibre, the thickness of a human hair (125 microns). We have developed a technique to place a highly miniaturised lens on the end of the fibre, using a similar optical design to that described by Walther et al. (Walther et al., 2022). There is also a tiny mirror inside the needle, which redirects the light out of one of the two holes drilled in the side of the stainless-steel needle. There is a hole for each one of the two fibre-optic probes in the needle, one on each side of the needle.

An exploded view of the handpiece design is shown in Figure 4.

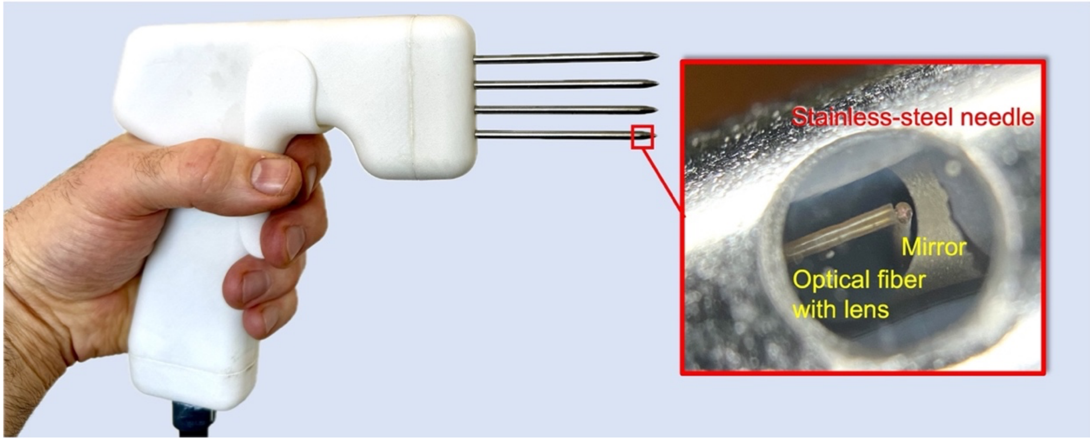

Figure 3. Handpiece with zoomed image showing the fibre-optic probe and mirror inside a needle.

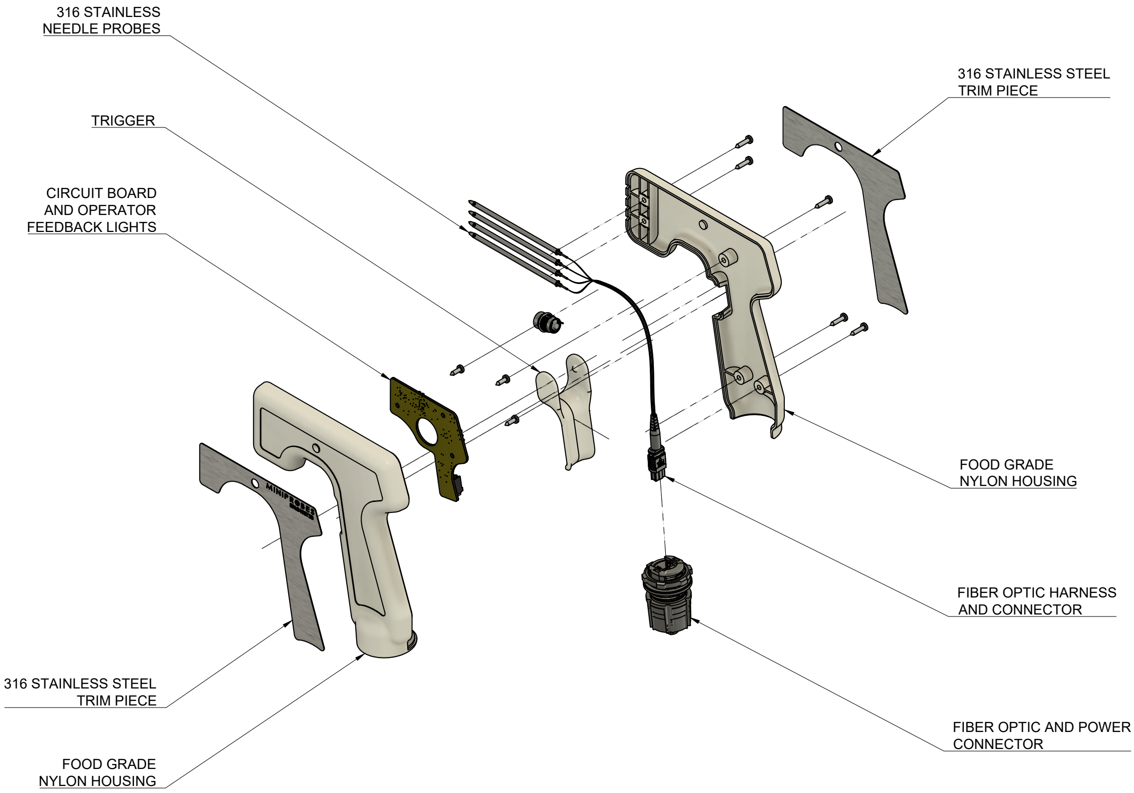

Figure 4. Design view of the handpiece.

3.3 Scanner console

The wall-mounted console, shown previously in Figure 1, comprises of a special type of optical scanner, called an optical coherence tomography scanner (Drexler and Fujimoto, 2015). These systems are commonly used in hospitals in ophthalmology (Schwartz et al., 2014) and cardiology (Bezerra et al., 2009). We have adapted this technology for use in the meat processing industry.

This optical technology shines low power, near-infrared light on the muscle. By analysing the reflections of the light, the scanner is able to generate a detailed image of the structure of the muscle and intramuscular fat. The technology is well suited to use in meat production, allowing very rapid imaging and being safe with no ionising radiation.

Internal details of the scanner design are shown in Figure 5.

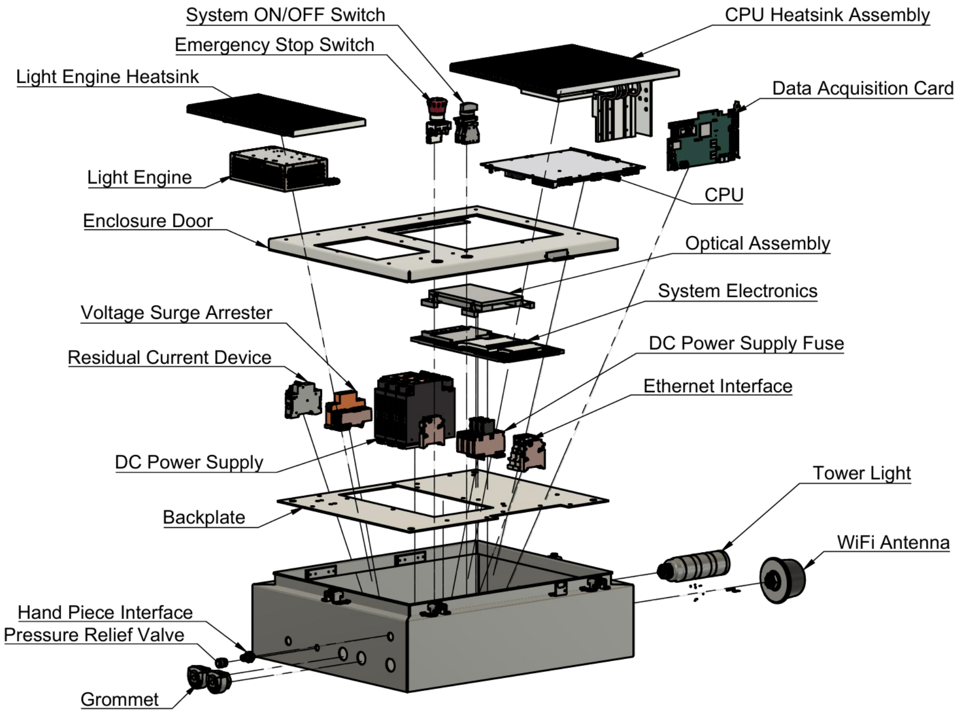

Figure 5. Exploded view of prototype scanner.

3.4 Fibre-optic probe fabrication

A key R&D deliverable of this project has been to establish reliable methods to manufacture the fibre-optic probes used within the needles. The fibre-optic probes consist of an optical fibre approximately the thickness of a human hair (125μm) with a miniaturised lens fabricated on the end of the fibre. This lens must collimate the light beam generated by the OCT system in order to acquire a high-resolution optical scan capable of identifying intramuscular fat.

Over a period of several years, our team at The University of Adelaide have developed a technique to create such a lens, detailed in several scientific publications (Walther et al., 2022, Scolaro et al., 2022). This process involved attaching sub-millimetre lengths of different types of optical fibre to the probe to generate a layered structure capable of shaping the light beam. However, the technique was slow and labour-intensive and not appropriate to scaling for commercial manufacture.

During this current project, we have developed a fully automated manufacturing system that is able to fabricate the fibre-optic probes without manual effort. The manufacturing system performs the actions of preparing the optical fibre for assembly, splicing and cleaving different types of optical fibre to form the miniaturised lens, and performing a quality control check on the final product. The details of this manufacturing system are protected as trade secrets. They form a valuable deliverable of this project and enable the possibility of achieving commercial-scale manufacture of the meat quality measuring device.

3.5 Automated quantification algorithms

Our team have developed an artificial neural network to analyse the scans. The algorithm identifies traces of intramuscular fat within the scan using a 5-layer Feature Pyramid Network with approximately 4.9 million parameters. The network was trained on data from 10,000 individual probe scans, acquired on 650 lamb carcases across 5 separate site visits. This training data was manually labelled to identify individual collections of fat cells in the muscle and teach the network how to automatically recognise these in new scans. We have an ongoing program of actively expanding the training data with scans acquired during subsequent site visits.

3.6 Field trials

Meat & Livestock Australia maintain multiple flocks of genetically diverse sheep around Australia, referred to as the MLA Resource Flock. At regular intervals over the year, groups of 100 – 250 sheep are slaughtered and assessed. In particular, a sample of meat is taken from the loin and chemically analysed to accurately measure the percentage of intramuscular fat to provide a gold-standard estimate of IMF%.

For the field trial detailed in this report, a portable system was used to acquire measurements at Thomas Foods International (TFI), Tamworth, NSW in October 2024. Measurements were taken from 205 lamb carcases. The handpiece was inserted into the loin muscle once to acquire 8 individual probe scans of different parts of the loin. These scans were then analysed in real-time and used to provide an estimate of the percentage of intramuscular fat for the carcase.

4. Results

The results for all 205 carcases are plotted in Figure 6. Estimates from the IMF needles were compared against gold standard measurements from chemical and NIR analysis performed by researchers from the University of New England, Armidale, NSW. Gold standard IMF values had a range from 3.1% – 9.7%.

Figure 6 shows the automated IMF needle estimates (vertical axis) plotted against gold standard values (horizontal axis). The device produced estimates with a mean absolute error of 0.64 IMF%, a root mean squared error (RMSE) of 0.85 IMF% and an R^2 of 0.50.

80% of estimates were within 1% of the gold standard IMF% measurement. 98% of the estimates were within 2% of the gold standard IMF% measurement. This satisfies the accuracy required for accreditation within the meat industry by AUS-MEAT.

The average data analysis time was 3 seconds per carcase, enabling us to analyse data at the rate that carcases are processed in a commercial meat processing plant.

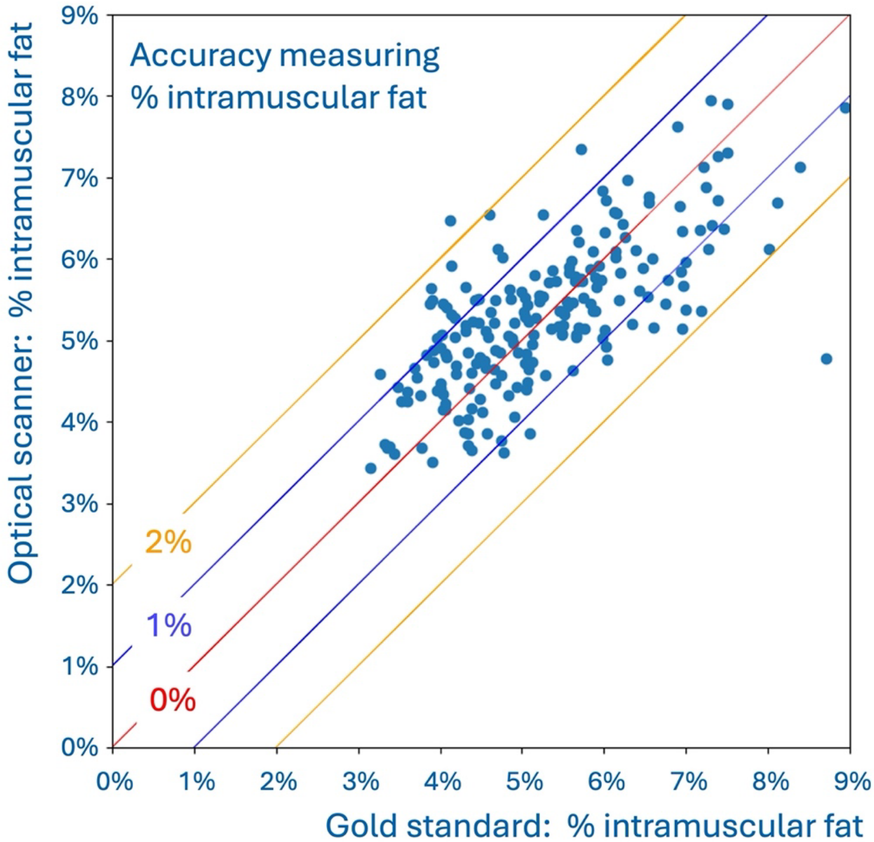

Figure 6. IMF% estimates vs gold standard values. 205 carcases. Blue lines show 1% error margin. Points within the blue lines are within 1% of the gold standard value. Orange lines show 2% error margin.

5. Business Plan

A confidential business plan for the commercialisation of this device has separately been submitted to MLA for review and approval.

6. Conclusion

6.1 Key findings

This project has completed critical research and development towards developing a new technology to quantify the percentage of intramuscular fat in lamb. Within this project, we have established the following key findings:

- Optical coherence tomography is an optical imaging technology capable of visualizing intramuscular fat in a hot lamb carcass.
- The imaging optics can be incorporated into a small fibre-optic needle for acquiring images deep within a muscle.
- Manufacture of the fibre-optic probes can be automated, with the potential to increase production to a commercial scale.
- Artificial intelligence (AI) algorithms can quantify intramuscular fat with commercially relevant levels of accuracy.
- Real-time quantification is possible at speeds matching a commercial meat processing plant's line speed (3 seconds per carcase).
- Quantification accuracy is comparable to the levels required for AUS-MEAT accreditation for measuring the percentage of intramuscular fat.

6.2 Benefits to industry

The development of a practical device to measure intramuscular fat (IMF) has the potential to significantly enhance the value of the Australian sheepmeat industry:

- **Domestic Markets**: Such a device would enable meat processors and retailers to segment meat products based on eating quality, providing consumers with a more consistent product and allowing premium pricing for high-quality meat.
- **International Markets**: It would offer Australian meat exporters a competitive edge by providing objective quality measures, distinguishing their products from those of other countries.

Our internal modelling shows a strong correlation between IMF% and MSA grading, estimating that knowledge of IMF% could add approximately $7 per lamb carcass (assuming a standard deviation of 1.5% for IMF%). For mutton, we estimate the value-add to be $3.50 per sheep carcass.

Figure 7 illustrates the distribution of MSA Grade 4 and 5 (high-quality) meat in the Loin and Topside cuts, derived from over 1,400 lamb carcasses in the MLA Resource Flock (Pannier et al., 2014; adapted from Swan et al., 2015). For Loin, 84% of carcasses achieved MSA Grade 4 or 5, while only 8% of

Topside carcasses reached this standard. The ability to identify these high-quality carcasses would allow processors to charge a premium to consumers.

Each year, about 21.4 million lambs and 6.6 million sheep are processed in Australia (Meat & Livestock Australia, 2023). With a value-add of $7 per lamb carcass and $3.50 per mutton carcass, this technology could generate an additional $173 million annually for the Australian sheepmeat industry.

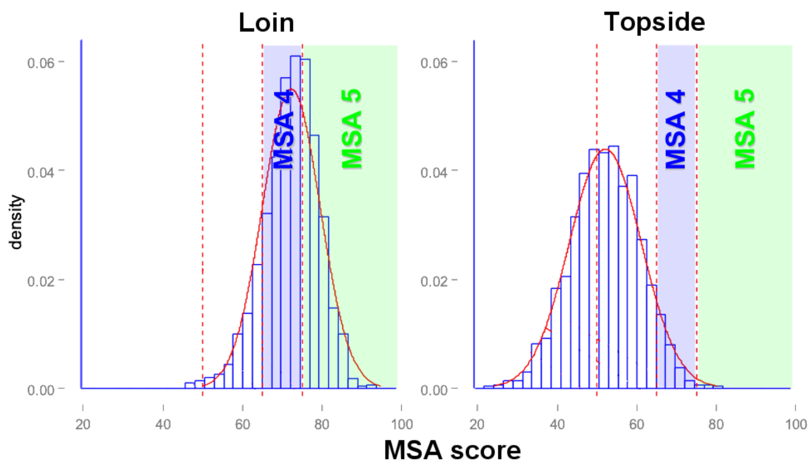

Figure 7. Distribution of MSA scores from >1400 animals from the MLA Resource Flock.

7. Future research and recommendations

The project has demonstrated that it is practical to measure intramuscular fat in a hot lamb carcase using a fibre-optic needle probe. It has also established that these fibre-optic probes could potentially be manufactured at the scale required for a commercial product, and that artificial intelligence algorithms can provide a rapid, fully automated estimate of the percentage of intramuscular fat.

This device would also be appropriate for quantifying intramuscular fat and marbling in beef. We have performed preliminary experiments demonstrating that this device is able to acquire high quality scans in a hot beef carcase. This would allow pre-sorting of the beef carcases as they are stored in the chiller and provide valuable planning information to improve efficiency during boning. Future work will identify what modifications should be made to adapt this device for use in beef.

This project has enabled our team to make significant progress in translating the device towards commercial usage. However, significant work remains prior to being able to commercially release the device to the Australian red meat industry. Future projects will be essential to complete translation and commercialization of this device. Various State and Federal Government programs are available to support the commercialization of Australian technologies like this. Additional support from MLA will greatly enhance the chances of obtaining the required funding through these Government initiatives.

MLA support will also play a crucial role in driving market adoption, which is key to the success of this technology. While some segments of the Australian red meat industry tend to be cautious in adopting new technologies, there is increasing recognition within the sheepmeat sector of the significant growth potential offered by objective measurement of meat-eating quality. Initiatives to assist early-adopter meat processors in trialling this device will accelerate industry adoption and help ensure the commercial viability of its development.

8. References

2015. *Optical coherence tomography: Technology and applications,* Switzerland, Springer International Publishing.

BEZERRA, H. G., COSTA, M. A., GUAGLIUMI, G., ROLLINS, A. M. & SIMON, D. I. 2009. Intracoronary optical coherence tomography: a comprehensive review clinical and research applications. *JACC Cardiovascular Interventions,* 2**,** 1035-1046.

DREXLER, W. & FUJIMOTO, J. G. 2015. *Optical coherence tomography: technology and applications,* Switzerland, Springer International Publishing.

HOPKINS, D. L., HEGARTY, R. S., WALKER, P. J. & PETHICK, D. W. 2006. Relationship between animal age, intramuscular fat, cooking loss, pH, shear force and eating quality of aged meat from sheep. *Australian Journal of Experimental Agriculture,* 46**,** 879-884.

PANNIER, L., GARDNER, G. E., PEARCE, K. L., MCDONAGH, M., BALL, A. J., JACOB, R. H. & PETHICK, D. W. 2014. Associations of sire estimated breeding values and objective meat quality measurements with sensory scores in Australian lamb. *Meat Science,* 96**,** 1076-1087.

SCHWARTZ, D. M., FINGLER, J., KIM, D. Y., ZAWADZKI, R. J., MORSE, L. S., PARK, S. S., FRASER, S. E. & WERNER, J. S. 2014. Phase-variance optical coherence tomography: a technique for noninvasive angiography. *Ophthalmology,* 121**,** 180-187.

SCOLARO, L., LORENSER, D., QUIRK, B. C., KIRK, R. W., HO, L. A., THOMAS, E., LI, J., SAUNDERS, C. M., SAMPSON, D. D., FULLER, R. O. & MCLAUGHLIN, R. A. 2022. Multimodal imaging needle combining optical coherence tomography and fluorescence for imaging of live breast cancer cells labeled with a fluorescent analog of tamoxifen. *J Biomed Opt,* 27.

SWAN, A., PLEASANTS, T. & PETHICK, D. 2015. The economic value of eating quality in a terminal sire breeding objective.

WALTHER, J., GOLDE, J., ALBRECHT, M., QUIRK, B. C., SCOLARO, L., KIRK, R. W., GRUDA, Y., SCHNABEL, C., TETSCHKE, F., JOEHRENS, K., HAIM, D., BUCKOVA, M., LI, J. & MCLAUGHLIN, R. A. 2022. A Handheld Fiber-Optic Probe to Enable Optical Coherence Tomography of Oral Soft Tissue. *IEEE Transactions on Biomedical Engineering,* 69**,** 2276-2282.