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Development and use of the G2 Tenderometer

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Devices to measure meat tenderness

Background

There have been many attempts to develop meat tenderness measurement devices over the last 30 years. However, despite the 20 or so devices that are reported in the literature, the most commonly used devices are still the Tenderometer and the Warner Bratzler. The Warner Bratzler was developed in the 60's and the basic design measures the maximum force required to cut through a core of meat. Typically, a Warner Bratzler device consists of a stainless steel blade with a hole in the middle. A pre-prepared cooked meat core is placed through this hole and a triangular shaped blade slices through the meat perpendicular to the fibres using a guillotine-like action. A force gauge measures the maximum force required to perform this cutting action. The meat cores are prepared from samples that have been cooked in a standardised manner and cut to a core size of 1.27 cm diameter. Despite the widespread use of this system, it is well recognised that the preparation of the meat cores is highly operator dependent and can readily result in a high degree of variation between samples. The slicing action itself is also time-consuming, and depending upon the recording devices attached to the basic shearing apparatus, some variation can also result. Although the Warner-Bratzler system describes the cutting apparatus, the main mechanical displacement system that operates the blade are typically linear displacement motors which are very expensive.

In the early 1970's MIRINZ (Meat Industry Research Institute of New Zealand) developed the first 'Tenderometer' This device was developed in an effort to provide a quicker, cheaper and more reliable tool to measure cooked meat tenderness - one that could be used in both a research and a commercial environment. The device

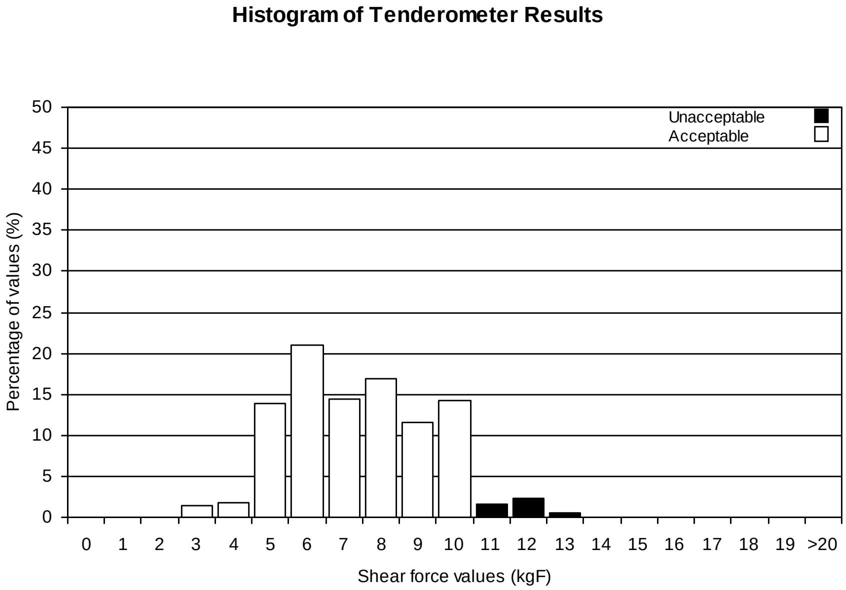
Figure 1. The G1 tenderometer

was based upon measuring the force required to shear through a 1 cm x 1 cm slice of meat. The shearing device was a triangular blade and was designed to simulate a human tooth which sliced downwards through a meat sample that was contained in a 1 cm wide tray (see

Figure 1 below). The device was based on pneumatics which required connection to a supply of compressed air, but overcame the significant cost associated with the linear displacement motors of the Warner Bratzler devices.

Figure 2. The shearing tooth mounted onto a Tenderometer.

Early work with the Tenderometer showed that it had a strong relationship with the Warner Bratzler and the two devices could provide equivalent results with almost 80% accuracy. Furthermore, these studies also showed that the Tenderometer could be used to predict consumer tenderness scores with approximately 70% accuracy although this level of accuracy was reduced if the meat was either very tough or very tender. Based on these very promising trials, the Tenderometer was adopted as the industry standard measurement tool for meat tenderness. Work with consumers and the Tenderometer demonstrated clearly that a shear force (Kgf) of 11 or above was perceived by consumers as being extremely tough. Shear force values of 8 to 11 were measured as acceptable, while values of less than 8 were scored as tender. Using these data, a tenderness specification was developed which required that 95% of all bites, or 1 cm x 1cm samples, should have a shear force value of less than 11Kgf, and overall all samples should have an average shear force of 8 Kgf. Extensive testing of this specification in both New Zealand and the UK demonstrated that this was an acceptable standard to ensure consumer confidence in the NZ product. These data are presented in the histogram format shown below.



Number of samples	490	Minimum	3.9 kgF
Mean	7.9 kgF	Maximum	13.1 kgF
Standard deviation	2.0 kgF	% less than 11 kgF	96 %

Figure 3. A typical tenderness histogram showing compliance to the industry-standard tenderness specification

Meanwhile, the highly successful accelerated conditioning and ageing specification for lamb processing had been developed and adopted by all lamb plants that were exporting lamb to the UK. This process, known as AC & A, was and is still considered the most reliable process to ensure an acceptable tenderness level for frozen lamb. The specification consisted of processing to an exacting standard using a high voltage stimulation tunnel and then a two-stage chilling process. All lamb was processed using this specification and the tenderness was tested routinely using the Tenderometer. Compliance was set at the tenderness specification described above and a tenderness histogram was produced to demonstrate this compliance. In the early days, most of the routine tenderness testing for the AC & A process was carried out at MIRINZ. However, once it was evident that the Tenderometer was a simple and robust instrument that could be used routinely in a meat processing plant environment, many of the plants throughout New Zealand purchased the device and continue to use them on a weekly basis as part of their quality auditing procedures.

While the Tenderometer has clearly stood the test of time and continues to be used in both research laboratories and meat processing plants throughout New Zealand and of late, Europe, more recently the need to have a unit that is more portable and flexible has become apparent. The original Generation 1 (G1) Tenderometer is bulky and relatively heavy (12kg); but perhaps more important are the limitations imposed by the pneumatics which operate the unit. While air compressors are widely available in meat processing plants, the pressure and mains power requirements limit the mobility of the unit and so they tend to be sited as permanent fixtures. Furthermore, the peak pressure is displayed via an LED mounted on the front of the Tenderometer and the shear force value has to be manually recorded after each sample measurement which allows for potential error due to incorrect value recording. Each machine, despite standardised manufacturing processes, generates different internal resistances due largely to the unavoidable friction forces that are inherent in pneumatic systems and, therefore, requires at least annual calibration. Furthermore, these effects result in instrument to instrument variability which can be particularly problematic for meat processors that have several instruments in use to audit against their tenderness specification. The pressure required to shear a meat sample is displayed in Kilo Pascals and these then have to be converted to Kilograms shear force (kgf). The conversion formula is generated during the calibration procedure. While this conversion is easily generated using a simple Excel based macro, the final shear force values are not given at the time of sample measurement.

Consumers have clearly become more discerning when it comes to the tenderness of the meat they have purchased. While the original tenderness specification still ensures that meat processed to this tenderness standard will be acceptable, it is not likely to result in claims of highly tender meat and therefore high levels of consumer satisfaction. Many NZ processors have recognised this and have refined their tenderness specification – an example of this is that 95% of bites should be less than 8 Kgf with an overall mean of 6 Kgf. Early work comparing the Tenderometer results with consumer responses demonstrated that the instrument had a very good relationship with consumers but this relationship became weaker if the meat was either very tough, or more importantly, very tender. Given the emphasis that is now being placed on supplying meat with even greater levels of tenderness, it has also become necessary to improve the accuracy of the Tenderometer for measuring very tender meat - hence this became another key component in the development of the Generation 2 (G2) Tenderometer.

Introducing the G2 Tenderometer

To address all of these issues, a new Tenderometer, known as the G2, has been constructed as part of the current Meat Quality, Science and Technology programme, funded jointly by Meat & Wool New Zealand and Meat & Livestock Australia.

The key points of the design of this new unit are the miniaturisation and mobility of the unit, improved sample loading and automated sample shearing and data downloading.

The device is based on an electric motor which pushes the meat against a fixed load cell. The unit does not therefore require compressed air, just a standard power socket to plug into or batteries.

The samples are placed in a line on a tray that presents the samples to the shearing head. The new sample loading and switch sequence allows automatic cycling of the unit; in essence, this means that the 10 sample bites can be loaded into the presentation tray and the unit will then cycle automatically through the shearing procedures, testing and recording the values from each sample automatically without any further operator intervention.

Figure 4. Samples or 'bites' lined up in the presentation tray reading for shear force measurement

The unit is mains or battery powered and incorporates a digital read-out. The data can also be downloaded direct to a laptop computer. The unit can be held easily in one hand and weighs just over two kilograms. The force required to shear the sample is displayed as Kgf's on an LED sited on the face-plate of the machine and because the load-cell is in a fixed position, this means that it can be removed and replaced without the need for recalibration

The unit has been tested extensively and final modifications are complete. The next stage is to re-case the unit in a plastic moulded case which will allow it be easily cleaned and will ensure the unit is water-proof.

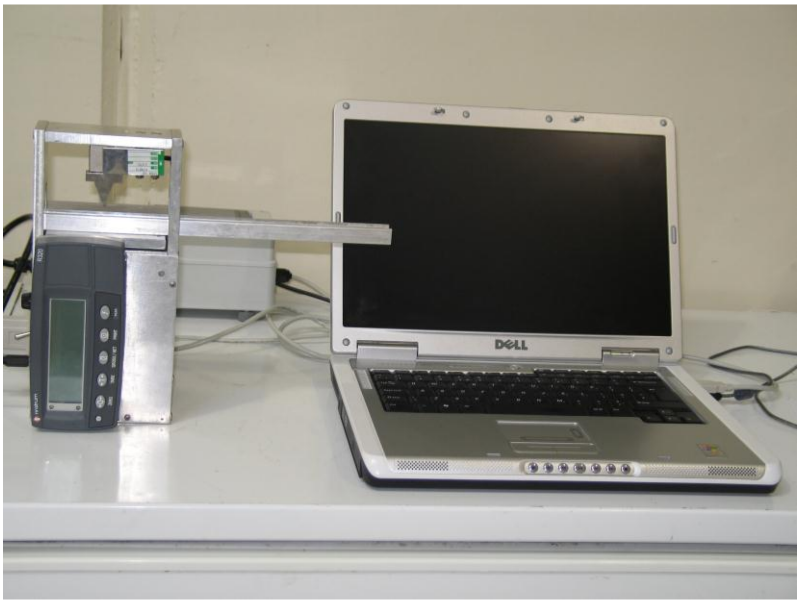


Figure 5. The G2 Tenderometer connected to a laptop PC for automatic data capture

Figure 6. View of G2 Tenderometer from above. This photograph clearly shows the raised platform with the presentation tray moving the samples up to the shearing tooth.

Comparison between G1 and G2 tenderometers.

Apart from the obvious differences in size, weight, portability and the G2 being electrically driven rather than pneumatically, there are other key differences between the G1 and G2 tenderometers:

- The G1 tenderometer relies on a moving shearing blade and a static restrained meat sample while the G2 tenderometer operates with a dynamic meat sample and a static load cell. This means that the G2 tenderometer avoids confounding the readings with the internal frictions of the machine and gives more accurate measurements of very tender samples.

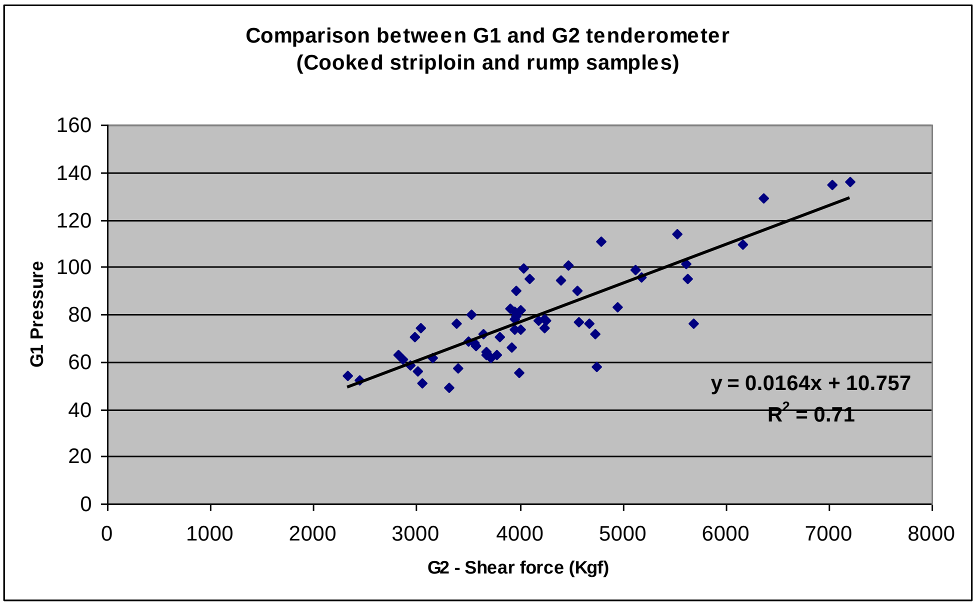
- The G1 relies on compressed air to provide a uniformly increasing pressure to move the shearing head through the sample. The resulting time required to completely shear the sample is therefore determined by the sample toughness. Essentially this means that if a set of samples or bites are particularly tough, the time required to complete the shear force testing of these is significantly longer than the time required to shear a set of tender samples. In contrast, the G2 moves at a constant rate irrespective of the toughness of the sample.

- Due to the use of increasing pressure, is not possible to see how the sample deforms during the shearing process (known as a 'force-deformation' curve). In contrast, the G2 tenderometer shears at a constant rate of travel throughout the cycle and varies the force accordingly. This permits the description of a force-deformation curve, which may provide for more versatile and useful applications (discussed later).

The two tenderometers have been used side-by-side to allow a comparison between the two units. This is important because, despite the obvious differences in the operation of the two units, it is necessary to ensure that plants or laboratories that currently use the G1 tenderometer and who may wish to change to using the G2 unit, can compare data from the old unit with data from the new one.

Over a period of two months, bites from the same sample have been measured by the G1 and G2 and the results compared. The graph below shows a selection from some of these data and the equation demonstrates that the relationship between the two is accurate to 71%. However, it is worth mentioning that much of the variation almost certainly arises from the variability in tenderness between bites from the same meat sample and thus it is unlikely that this relationship could be improved if meat is used as the testing medium.

Figure 7. Comparison in shear force between G1 and G2 tenderometers



This means that it is possible to compare the values between the two units and also to convert data from the old G1 tenderometer into G2 data using the equation above.

Using the G2 Tenderometer to measure texture

It is generally agreed that of all the eating quality attributes, tenderness is the most important. However, once tenderness is acceptable, then consumers focus on other attributes, particularly juiciness, texture and flavour. Typically, juiciness and textural attributes such as cohesiveness, fibrousness can therefore become dominant in chilled meat that has taken several weeks to get to the market. Such meat is usually very tender because it has been aged for prolonged periods. However, sometimes the texture of such well-aged meat can become less acceptable; it is described as mealy or livery having lost the fibrousness typical of meat. This can be an issue with chilled lamb that has been shipped to the UK for some 4-6 weeks by boat; such product is usually very tender but can be a little dry with poor textural qualities. Similarly, beef can also suffer from poor textural qualities if it has been through a process with high levels of electrical stimulation – such procedures result in a fast rate of pre-rigor pH fall when the meat temperature is still high. These conditions denature some of the key muscle proteins, resulting in a loss of fluid from the meat and protein disruption – evident as a modification in textural attributes once cooked and consumed.

Given the importance texture can clearly play in the definition of meat quality, there are some obvious benefits in trying to quantify these changes in a meaningful and reproducible manner. To achieve this we trained a sensory panel to measure the following textural attributes during the mastication process:

- Measured during the initial bite:
    - Firmness/softness
    - Initial juiciness
    - Denseness

- Measured during the first series of chews:
    - Tenderness
    - Cohesiveness
    - Fibrousness

- Measured during subsequent chewing:
    - Cohesiveness of mass
    - Sustained juiciness
    - Chewiness/duration of chews
    - Work required to break sample prior to swallowing.

By applying a rigorous training procedure, it was possible to successfully use panelists to quantify textural changes in both beef and lamb. However, running sensory panels is expensive and time consuming and the data generated is complex and requires extensive analysis. Therefore, during the latter stages of the G2 Tenderometer development, the option to measure texture with this unit was explored. To achieve this an alternative head was designed. Past work has shown that instrumental measurements of texture have a stronger relationship with sensory panelists if the sample is compressed rather than sheared. Compressing the sample is achieved using a flat headed device (see Figure 8). While the maximum force required to completely compress the sample correlates with the tenderness value of the sensory panelists, the complete force deformation curve is required to describe some of the other textural attributes. Key points of the curve that seem to have the best correlation with the attributes of cohesiveness, fibrousness, chewiness, initial and sustained juiciness are the forces at 20, 60 and 80% of the force deformation curve, the first inflexion and the total work (total area under the curve)

Figure 8. The compression head for G2 tenderometer texture measurement

Recently, a trial was undertaken using the compression head shown in Figure 8 on the G2 tenderometer to measure meat samples that had been through different rates of post-mortem pH fall and aged for different periods of time. The meat samples were also given to the trained sensory panelists to score the attributes described above. The preliminary analysis of these data is complete and initial findings are that the compression measurement on the G2 can be used to predict initial juiciness with 62% accuracy and fibrousness with 67% accuracy. These results are encouraging but will require improvement before this set up can be used to reliably measure texture in a commercial environment: While the measurement procedure itself was found to be accurate, the manner in which the force-deformation curve is analysed for points of interest requires further development. This work will be continued over the next few months and the final procedures to enable use of the G2 Tenderometer to measure texture will be released as a bulletin update.

Appendix 1.

G2 Construction details

Linear Actuator: The actuator chosen (Hiwin LAS-1-1-50-24) provides sufficient performance for all the expected meat samples and potential testing objectives. A maximum force expected to be encountered in penetrating meat with a shearing attachment can be in excess of 40kgf (400N).

A force-deformation curve can be interpolated from the force-time data when the loading rate is constant throughout the shear cycle. Specifications provided by the manufacturers (see below) show that theoretically, the speed is constant at 12 mm/s using a 24 volt power supply as long as the force remains below 400 N. When attempting to validate these specifications it became apparent that the power provided by the two original 12 volt Ni-Cd batteries to the actuator dropped when an increased load was applied. However, the addition of a voltage regulator ensured that the batteries provided a constant (adjustable) voltage to the actuator. Following the addition of the regulator, the loading rate was shown to be constant when the motor was required to work harder. The stroke length is determined by an internal limit switch and was reduced from 50 millimetres to 40 millimetres. This provides a sufficient gap for loading and removing meat samples.

Voltage Regulator: A simple voltage regulator was produced to ensure voltage supplied to the actuator and the speed at which it operated was constant. The applied voltage was set at 15.6 Volts in order to operate at a similar speed to that of the G1 tenderometer.

Display: The Rinstrum R320 is a precision digital indicator using Sigma-Delta A/D technology to ensure fast and accurate weight readings. The setup and calibration are digital, with a non-volatile security store for all setup parameters. This instrument is fitted with rin-LINK communications as standard. This allows a temporary isolated communications link to be established with a PC and enables software upgrades and the use of computerised setup and calibration via the rin-VIEW software.

Load Cell: The load cell is a miniature bending beam (Celtron MBB-100) type load cell that functions as a low profile platform scale for this low capacity scale application. It provides long term, high performance and is sealed for protection of the cell from water and moisture damage.

Power Supply: Two Nickel Metal Hydride batteries, each supplying 1.3 ampere hours and 12 volts, are connecting in series to provide power to the display unit, load cell and actuator. The voltage regulator will maintain a constant voltage to ensure the actuator operates at a constant speed and have sufficient current available when forced to work harder and draw more current.

Appendix 2

Protocol for sample preparation and shear force testing

Cooking procedure for shear force measurement

An end-point temperature of 75°C is used because tenderness is affected by the internal temperature of the meat and, therefore, should be standardized and consistent. Generally, there is a relationship between end-point cooking temperature and toughness with the peak of the cooking temperature – toughness curve being between 70 and 80°C. Therefore, in industrial tenderness testing it is typical to use an internal end-point cook temperature of between 75 and 80°C to ensure that the 'worse case scenario' is measured.

1. To reduce cooking time variability between samples, bone out the loin samples. Wherever possible, trim each muscle to an approximate sample size of 100g for lamb or 250g for beef.
2. Place the samples in unsealed plastic bags (200 x 250 mm, or larger), with a 100g weight to assist in submerging the meat sample in water.
3. Place the bags into the boiling waterbath so that the meat sample is completely submerged. Attach the bags to a rail across the waterbath by bulldog clips, to ensure that the open end of each bag is held above the surface of the water.
4. Monitor the temperature of the samples during cooking.
5. When the end-point temperature internal temperature of 75°C is reached at the centre of the meat sample, <u>immediately</u> transfer samples to an ice-waterbath or chiller with an air speed of at least 1m/s.
6. Once the samples have reached a temperature of 4°C, they can be prepared for Tenderometer testing.
7. Cooled samples can be stored at ≤ 2 °C for up to 48 hours before measuring shear force

Cook Loss

1. Weigh each sample before cooking and record the weight.
2. Place in suitable bag for cooking and cook using the procedure outlined above.
3. After cooking the samples should be cooled rapidly to <4ºC.

4. Before Tenderometer testing, dry the samples with a paper towel to remove the excess moisture.
5. Weigh the samples and record the weight.
6. The cook loss is presented as a percentage of the original uncooked weight

Meat Tenderness Measurement Using the G2 Tenderometer

The basic principle in assessing meat tenderness is to determine the force required to shear through a 10 x 10 mm square cross-section sample at right angles to the fibre axis. Sample preparation must be accurate as it can affect the shear force results.

1. Cut a slice off the outside of the meat to enable identification of the grain (the direction the muscle fibres are lying) in the meat.
2. Score the meat with the Tenderometer knife (double-bladed scalpel with blades set 10mm).
3. Cut ten rectangular samples (bites) from each sample using the scored marks as guides. These sample bites must be cut exactly to specification; 10mm x 10mm cross section, and a length, parallel to the fibre axis, of at least 25mm.
4. Discard the edge pieces that have been cut away.
5. The 10 meat sample bites are placed end to end in the presentation tray.
6. They are then sheared at right angles to the fibre direction, using the G2 Tenderometer.

Figure A1. Sample preparation – Five 1cm x 1cm 'bites' taken from sample. This photograph clearly shows the longituidinally fibre arrangement in each of the 'bites'

7. For each bite, record the shear force (Kgf) reading that is displayed, or download the data direct to a laptop if one is connected to the G2 Tenderometer.
8. Record up to 10 bites per sample, for smaller samples record as many bites as possible.
9. The 10 Tenderometer readings for each sample are presented as a histogram showing the mean, standard deviation and number of samples within a pre-defined 'acceptable' range.