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On correlating penetrometry with photometry in beef roasts
(short communication)

Abstract
A fibre-optic probe mounted on the strain gauge of a compression tester was pushed into beef roasts. Reflectance decreased through the subcutaneous adipose tissue and was inversely correlated with resistance to penetration ($r = -0.82$ at 450 nm and $r = -0.84$ at 700 nm, $P < 0.01$). Resistance peaked in the connective tissue of *spinales dorsi*. Despite illuminating several cubic centimetres of meat, the fibre-optic probe responded mainly to tissues in the near field. The length of the light-path through the meat was minimal (≤ 1 mm).

Key Words: beef toughness, penetrometry, fibre-optic photometry

Zusammenfassung
Titel der Arbeit: **Über Korrelation zwischen Penetrometrie und Photometrie im Rindfleisch** (Kurzmitteilung)
Eine fiberoptische Sonde wurde mit einer Nadel eines Kompressionstesters in Rindfleisch eingeführt. Die Reflektion sinkt beim Durchstechen des subkutanen Fettgewebes und ist invers korreliert mit dem gemessenen Widerstand bei der Penetration ($r = -0.82$ bei 450 nm und $r = -0.84$ bei 700 nm, $P < 0.01$). Für den Widerstand wurde ein Peak im Bindegewebe des M. spinales dorsi gemessen. Obwohl mehrere Kubikzentimeter Fleisch durch die fiberoptische Sonde durchleuchtete werden, liefert sie nur Messwerte aus den Gewebe des nahen Umfeldes. Die Länge des Lichtweges durch das Fleisch war minimal (≤ 1 mm).

Schlüsselwörter: Rindfleisch, Zartheit, Penetrometrie, fiberoptische Photometrie

Introduction
Penetrometry of meat gives information on toughness similar to that normally obtained by shearing, because both methods respond to the tensile strength of fibres in meat (VOISEY, 1976). Penetrometry is of interest because it may be applied to bulk meat and does not require removal of a test sample (STEPHENS et al., 2004). But, when used on bulk meat such as roasts or whole sides, a probe must penetrate through tissues outside muscles before reaching the target muscle. Thus, the result is more complex than a test made on an isolated muscle.
Fibre-optic probes may be used for a variety of meat quality measurements (SWATLAND, 1995; 2003a). Unlike the situation in classical spectrophotometry, where the absorbance of chromophores is measured through a known path length with a collimated beam of light (BASHFORD and HARRIS, 1987), a fibre-optic probe detects sterance from an unknown volume of meat. Deviations from the photometric laws also occur if there is scattering or an irregular distribution of chromophores (SWIFT and RASCH, 1956).
Thus, the limitation of penetrometry is we do not know the type of tissue generating resistance to penetration, and the limitation of fibre-optic probing is we do not know the

length of the light path through the meat. Both methods were used simultaneously to investigate their modes of operation.

Materials and methods

Apparatus

The probe was formed from three large-diameter hypodermic needles (13-gauge, 90-mm length, 30°-angle sharp tip). The needles were glued with their tips together using epoxy resin and then bound tightly with a heat-shrink tube. Each needle contained a 1-mm diameter plastic optical fibre (Hewlett-Packard HFBR-EUS, Palo Alto, California) giving an elliptical window at the needle tip. The windows were flat and polished. Although the sharp tips of the three needles were at the centre of the probe, the actual tip of the probe was blunt, being formed by the epoxy-filled core between the needles. The probe was mounted on a load cell (Dillon BFG-500N, Weigh-Tronix, Fairmont, Minnesota) of a compression tester (Dillon SnapShot, capacity 1 kN, range 29 cm). Probe velocity (≈ 4 mm sec^{-1}) gave approximately 100 data points on each of four analogue inputs (depth, force and reflectance at 450 and 700 nm) for each way-in probe transect.

One of the three optical fibres was connected to a 100 W halogen illuminator through a solenoid shutter used to find the dark field output of photometers. The two other optical fibres were connected through monochromators (Zeiss 474311 and 474345) to identical photomultipliers (Hamamatsu R92HA, Hamamatsu City, Japan).

To one side of the probe, a plate on the meat surface was connected by a rack and pinion to a precision multiturn potentiometer read from a multimeter in a VXI mainframe (HP E1411B in E1421B). This gave the location of the probe tip in the meat. Thus, the reference point for spatial measurements was the level of the meat surface. As will be seen later, many of the complexities in the relationship of photometry with penetrometry were caused by deformation of the meat as it was probed. This is why the meat surface and not the position of the compression tester was used as the abscissa.

Reflectance measurements were made with very low ambient light. The probe was standardized with the tip perpendicularly touching an opal glass plate. Only 20% of the dynamic range of the photomultipliers was used at standardization because reflectance of adipose tissue around the probe was higher than for opal glass perpendicular to the probe.

Software and statistics

Components were operated using a bus (IEEE 488) to controllers (Zeiss MPC 64 and HP E1421B with relay, multiplexer and multimeter cards). Software was written in HP BASIC for Windows following algorithms outlined by SWATLAND (1998). Data were evaluated statistically using simple correlation coefficients and linear regressions adapted from STEEL and TORRIE (1980) and programmed in HP BASIC. Standard deviations are indicated.

Samples

All measurements were made on Canada AAA beef rib roasts (the posterior two ribs of the forequarter). Roasts (n = 7) had 26.5 ± 5.0 d aerobic aging *post-mortem*. Ambient temperature in the laboratory was 14°C. Roasts were taken from a refrigerator at 4°C and measured over a period of several hours. Probe transects were related to the anatomy of

roasts using tracings of the posterior face of the roast, as described by SWATLAND (2003b). Thus, the location of the probe tip in subcutaneous adipose tissue, *spinales dorsi*, intermuscular adipose tissue or *longissimus thoracis* was known. On the posterior surface of rib roasts, the two largest muscles were a thin layer of *spinales dorsi* and the eye muscle formed by *longissimus thoracis*. Other muscles adjacent to the vertebral column and between the ribs were not included.

Results

Control with probe in air

Both photometers (one collecting at 450 nm and the other at 700 nm) detected similar light intensities from the illuminating fibre when the probe was in air with minimal scattering. As the probe moved through air towards a sheet of white paper supported on polystyrene foam, the light intensity in both collecting fibres increased almost equally, until the probe tip burst through the paper and into the foam. The output from the strain gauge showed an offset ≈ 10 mm between minimum reflectance and maximum resistance. In air, the optical fibres collected light from the medium in advance of the probe tip. But how far in advance of the probe would light be collected in meat with a high degree of scattering?

Reflectance in different tissues

Penetrating roasts from a dorsal to ventral direction and passing first through subcutaneous adipose tissue (Fig. 1, 1), the maximum resistance to penetration was always the thick connective tissue aponeurosis of the *spinales dorsi* (Fig. 1, 2). This pattern occurred in all samples probed. Beyond this point the pattern was more variable, but could still be matched to anatomical tracings. Resistance decreased through intermuscular adipose tissue ventral to *spinales dorsi* (Fig. 1, 3), increased at first contact with *longissimus thoracis* (Fig. 1, 4), decreased if the probe passed through intramuscular adipose tissue within a cleft of the *longissimus thoracis* (Fig. 1, 5), increased at some point within the outer part of *longissimus thoracis* (Fig. 1, 6), and decreased toward the central axis of *longissimus thoracis* (Fig. 1, 7). Variability in this pattern depended on whether or not the probe hit a cleft of intramuscular adipose tissue in *longissimus thoracis*, and on exactly where the peak connective tissue of *longissimus thoracis* occurred.

The pattern for reflectance at 700 nm (Fig. 2) matched the resistance to penetration (Fig. 1). Reflectance decreased as the probe moved through subcutaneous adipose tissue (Fig. 2, 1) and the minimum reflectance (Fig. 2, 2) matched peak resistance to penetration (Fig. 1, 2). Thus, reflectance decreased as resistance to penetration increased. Low resistance in adipose tissue (Fig. 1, 3 and Fig. 1, 5) had matching peaks of high reflectance (Fig. 2, 3 and Fig. 2,5). High resistance within *longissimus thoracis* (Fig. 1, 6) matched low reflectance within the muscle (Fig. 2, 6).

The pattern for reflectance at 450 nm was a poor match to resistance to penetration. Only the first two components were evident: passing through subcutaneous adipose tissue, and hitting maximum resistance in the *spinales dorsi*.

Despite the subjective evidence of reflectance at 700 nm being related to resistance to penetration, this was difficult to confirm statistically at all depths of penetration. Reflectance was correlated with resistance as far as the position 2 shown on Figs. 1 and 2 ($r = -0.82$ at 450 nm and $r = -0.84$ at 700 nm, $P < 0.01$), but inclusion of data at greater depths confounded the correlations ($r = 0.31$ at 450 nm and $r = -0.15$, $P > 0.05$).

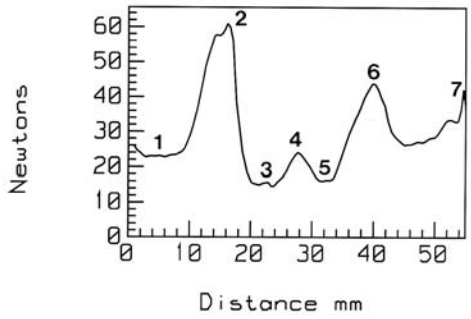

Fig. 1: Resistance to probe penetration from subcutaneous adipose tissue (1), ventral connective tissue aponeurosis of *spinales dorsi* (2), intermuscular adipose tissue (3), dorsal part of *longissimus thoracis* (4), intramuscular adipose tissue within a cleft of *longissimus thoracis* (5), intramuscular connective tissue of *longissimus thoracis* (6), and within the axis of the *longissimus thoracis* (7) (Widerstand beim Durchdringen mit der Sonde des subkutanen Fettgewebes (1), des ventralen Bindegewebes der Aponeurose des *M. spinales dorsi* (2) des intermuskulären Fettgewebes (3), des dorsalen Abschnitts des *M. longissimus thoracis* (4) des intramuskulären Fettgewebes im Spalt des *M. longissimus thoracis* (5), des intramuskulären Bindegewebes des *M. longissimus thoracis* (6) und entlang der Achse des *M. longissimus thoracis* (7))

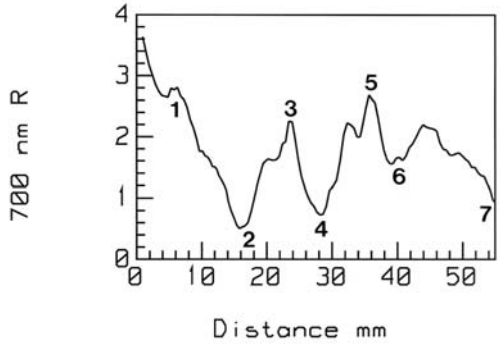

Fig. 2: Reflectance at 700 nm matching Fig. 1 (Reflexion bei 700 nm entspechend Fig. 1)

Reflectance at 450 nm was lower ($P < 0.001$) than reflectance at 700 nm in subcutaneous adipose tissue (0.251 ± 0.107 *versus* 3.676 ± 1.174), in *spinales dorsi* (0.029 ± 0.031 *versus* 1.091 ± 0.608) and in intermuscular adipose tissue (0.130 ± 0.078 *versus* 3.127 ± 1.119). The low reflectance of muscle relative to adipose tissue needs little explanation because muscle has a dense protein microstructure and a high concentration of myoglobin. Comparing differences between 450 nm and 700 nm, it is important to remember adipose tissue may retain some erythrocytes with haemoglobin trapped in capillaries while red meat has a high concentration of myoglobin. Reflectance at 450 nm is close to the Soret absorbance band of both haeme proteins (SWATLAND, 1989).

Discussion

The control test in air showed the fibre-optic probe detected structures approximately 10 mm in advance of the probe tip. But within meat, this was greatly reduced. Near-field effects dominated over far-field effects giving an effective optical path ≤ 1 mm, despite many cubic centimetres being illuminated. In other words, although a meat probe may appear to be illuminating a relatively large volume of tissue, the tissue close to the optical windows has a disproportionately large effect.

When used as a penetrometer, the primary resistance originated from the thick connective tissue aponeurosis of the *spinales dorsi* (Fig. 1, 2), and reflectance decreased towards this point (Fig. 2, 2). But why was this inverse relationship difficult to detect at depths ventral to *spinales dorsi*? The answer may involve the elastic deformation of deeper tissues. In advance of a cutting edge, meat is compressed. Its fluids are squeezed aside and only resilient fibres remain to resist the blade (SWATLAND, 1978). As the probe moved into the meat it may have dragged a layer of fibres anchored behind the probe tip. Thus, resistance would have been detected slightly behind the probe tip, while tissue reflectance was detected from the near-field in advance of the probe tip.

Attempts to correlate full-depth optical with penetrometer signals failed, not when both signals moved unidirectionally as in the initial penetration of subcutaneous adipose tissue, but when signals moved bidirectionally to create peaks. In other words, although both signal vectors (reflectance and resistance) were synchronous, they were no longer matched spatially. Image analysis methods such as rubber sheeting (RUSS, 1990) might be used to solve this problem retrospectively, but not easily or inexpensively to enhance the performance of meat penetrometry.

In summary, simultaneous application of penetrometry and fibre-optic probing was useful in showing the optical path through meat may be much shorter than previously assumed. But elastic deformation of tissues made it difficult to use optical signals to identify mixed tissues encountered in penetrometry. Although matching patterns were visible subjectively in signals, they were slightly out of alignment and simple correlation coefficients were weak.

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