Of all of the factors which constitute quality of meat, tenderness is without doubt the one which is outstanding in determining whether the meat is satisfactory or unsatisfactory when eaten. Tenderness also appears to be the quality factor which is most difficult to determine objectively.

In this paper an attempt will be made to summarize all, or nearly all, of the methods which have been reported in the literature with the hope that it will represent the present status in solving the problem of measuring tenderness. All of the methods which have been used have as their primary purpose the reflection of the experiences of a person chewing a piece of meat. Chewing a piece of meat involves the principles of cutting, shearing, tearing, grinding, and squeezing. Therefore, it may be recognized immediately that it is no simple matter to design an instrument which brings all of these principles to bear simultaneously, or in relation to one another as in chewing. Consequently, most of the instruments proposed are based upon only one of the principles.

There will be no attempt in this paper to evaluate the subjective or sensory methods or the histological and chemical methods used to measure or predict tenderness even though in some instances the results obtained with instruments have been related to the results with panels or other means by the various authors.

Since meat is not a homogeneous material, it should be noted that it is extremely difficult to evaluate or calibrate an instrument using samples of meat. In instances where a homogeneous material other than meat has been used to study the instrument itself, it is reasonable to expect that the results will not be as uniform when meat is tested. This immediately leads one to conclude that selection and number of the meat samples in experiments involving tenderness is extremely important.

Lehman's Mechanical Devices

Perhaps the earliest report of the use of mechanical means for determining the tenderness of meat is that of Lehman in 1907 (1). He used two devices, one of which determined the breaking strength of meat; the other was a determination of the force required to shear meat between two cutting edges.
In 1928, Warner (2) reported briefly to the American Society of Animal Production that a shearing device showing promise as a means of measuring tenderness of meat was under development. In 1932, Black, Warner, and Jilson (3) gave a more complete report of the use of the instrument in some extensive studies of beef from different classes and grades of animals. The authors described this instrument as consisting "of a steel blade 1/32 of an inch thick, drilled with a hole slightly larger than the sample to be tested. The hole was made square instead of round to eliminate the sliding of the edges across the sample that would occur if a round hole was used. The cutting edge was milled square and then smoothed slightly to effect a standard, reproducible dullness."

"A sample of meat was cored out with a keen, steel tool 1 1/8 inches inside diameter, similar to a cork borer. The sample was placed in the perforation of the steel blade and the blade led through a narrow slit in a wooden miter box. A hand-driven screw pull was used to pull the blade through the meat, the force required being recorded by a spring-type, self-recording dynamometer. When the instrument is in operation, the load on the meat builds up to a maximum and the fracture of the sample is sudden and complete."

In cooperation with the U. S. Department of Agriculture, Bratzler (4) completed a Master of Science thesis at Kansas State College in 1932, in which he demonstrated the value of what has now become known as the Warner-Bratzler Shear as a means of measuring tenderness of meat.

The Warner-Bratzler Shear has been a popular instrument for measuring the shearing of meat. It has been modified by motorizing to insure a constant rate of pull on the blade and the blade now commonly used is triangular in shape. The dial dynamometer for measuring force in pounds and the use of the shearing principle have remained unchanged.

The Cutting Gage of Tressler, Birdseye, and Murray

In 1932, Tressler, Birdseye, and Murray (5) described an instrument which they had constructed to determine the pressure needed to cut or puncture pieces of meat. The instrument consisted simply of a Schrader tire-pressure gage having a blunt penetrating instrument inserted in it. The puncturing or cutting end of the instrument was described as being made of metal rod 2 1/2 inches long and 5/16 inch in diameter. The end was symmetrically tapered to a cone about 3/8 inch in height and with an angle of 13 degrees. The point was rounded to have a radius of about 0.08 inches.

In using the cutting gage, as it was called, a sample of meat 3 inches square and 1 inch thick was clamped at its periphery. As the cutting instrument was pressed through the meat, it was free to perforate completely without obstruction. Eight readings were taken on each sample. The pressure gage was calibrated so that the readings could be converted to pounds.
In the second paper by Tressler and Murray (6), this cutting gage had been modified to be motor driven. Also, it was concluded that this instrument was not as satisfactory as the penetrometer described below.

The Penetrometer of Tressler, Birdseye, and Murray

In the same paper (5) in which the cutting gage (see above) was described, a penetrometer was also described. The latter was an instrument then in use in the New York Testing Laboratory for testing bituminous materials. When first used to test meat, a penetrating needle 1 3/8 inches long and 0.15 inches in diameter was used. The needle had a rounded point with a radius 0.07 inches.

The meat sample was held in a 1-inch deep container which was 1.5 inches in diameter and was covered with a plate having a 3/8 inch hole in the center. In the second paper (6) regarding this instrument, a modified sample container was described. It was a metal rectangular box with a telescoping top portion equipped with wing nuts on the side to tighten it firmly over the meat sample. The top had eight 3/8 inch holes through which the needle of the penetrometer was inserted.

In operating this penetrometer, the needle point was brought to rest in the vertical position on the top of the meat. A 255 gram weight was then placed over the needle and held for exactly fifteen seconds at which time a reading of the distance of penetration in millimeters was recorded. The distance of penetration was recorded on a dial geared to the movement of the needle.

The Child-Satorius Shear

In 1938, Satorius and Child (7) reported some tenderness measurements using an instrument which recorded the number of pounds force on a gage as shearing bars were pulled across a dull blade with a triangular opening through which the sample of meat was placed.

The Volodkevich Tenderness Instrument

Also in 1938, Volodkevich (8), working at the Institute of Refrigeration, University of Karlsruhe, Germany, described an instrument in which two metal wedges or artificial teeth were used. The meat sample was placed between the two wedges, one of which was stationary, the other being moveable by mechanical means. The movement of the wedge was recorded on a revolving drum, thereby giving a continuous recording of the exertion of pressure on the meat sample. The slope or character of the curve and the area under the curve on the graph were used to interpret the tenderness characteristics of the sample.

Improvements in this instrument were reported by Krumholtz and Volodkevich in 1943 (9).

The Winkler Instrument

This instrument, reported by Winkler in 1939 (10), was similar in many respects to the Volodkevich instrument and measured the force as
work expressed in unit thickness of sample. It also recorded curves which permitted analysis of the character of the sample by their shape or slope. The area under the curve was used in determining the work involved.

**Motorized Christel Texturemeter**

In 1955, Miyada and Tappel (11) described the use of a Christel Texturemeter modified by attachment of an electric motor and reduction gears. The total work and maximum shear force required to press shearing prongs through cylindrical samples of meat were recorded at two-second intervals and work diagrams were obtained by plotting the recorded data in pounds of force as a function of distance measurements. Maximum shear readings were obtained by knowing the crest of the force-distance diagram. The area under the curve represented the total work involved. Studies with beeswax as a homogeneous sample indicated that this method has considerable promise.

**The Food Grinder as a Tenderometer**

In the same paper that the Motorized Christel Texturemeter was reported, Miyada and Tappel (11) gave results of studies in which a food grinder was used to measure tenderness. By wiring the motor of the grinder in series with an A. C. ammeter and recording the ampere readings at five-second intervals, it was possible to plot power consumption in watts as a function of time to represent the total energy expended in grinding the sample. Theoretically, it was stated, increased toughness of meat would produce a corresponding increase in current consumption by the grinder.

This method was also tested with wax and with meat samples of various sizes and shapes. Pieces of freeze-dried biceps femoris of beef were cut into samples approximately 1 x 1 x 3/8 inches, rehydrated, and pressure cooked in the studies reported. Work diagrams were obtained by grinding 150 to 170 grams of cooked beef.

**Recording Strain-Gage Denture Tenderometer**

Since all mechanical means for measuring tenderness of food are designed to simulate at least some of the components of chewing in the human mouth, it is not surprising that an attempt should be made to utilize complete artificial human dentures in an apparatus. Although Volodkevich (8) had used partial dentures in his instrument, it was not until 1955 that Proctor, Davison, Malecki, and Welch (12) reported construction of an apparatus which simulated the frequency of chewing cycles and the coordination of grinding and crushing motions of chewing and included means for measuring and recording these motions.

Briefly, the instrument consists of plastic dentures fastened to an articulator with simulated cheeks, lips, and tongue made from resilient plastic material to keep the food between the teeth. The upper movable dentures are actuated by a motorized special transmission device to give both vertical and lateral movements toward the firmly fixed lower denture. Strain gages of an electrical resistance type wired to a preamplifier and oscilloscope were used to record the strains
resulting from the chewing action. The mechanism is so constructed that the frequency of chewing was 45 cycles per minute.

Tenderness of the food being measured was represented by the maximum deflection in millimeters from a zero line which can then be converted to force (pounds). In testing the instrument with a tension spring and also with a piece of firm sponge rubber, the range of error at 99.7% probability level was about 2% with the spring and 2.3% with the rubber. Tests with certain fruits, vegetables, and bread indicated the adaptability of the instrument. Relationships of readings obtained with the Christel Texturemeter and with the Strain-Gage Denture Tenderometer showed that when first bite measurements were made with the latter, the relationship between the two instruments is non-linear. Apparently there is a fundamental difference in the qualitative interpretation by the two instruments.

In a subsequent publication, Proctor, Davison, and Brody (13) reported alterations in the Strain-Gage Denture Tenderometer whereby force-penetration diagrams could be obtained. Characteristic diagrams for numerous foods including raw and broiled steak and sausages were reported.

It appears to the author that the Strain-Gage Denture Tenderometer offers an excellent opportunity for studying the chewing mechanism of the human and the results so far have illustrated the complexity of the mechanics of chewing and the variability of characteristics from one food to another. It probably also serves to illustrate that any instrument designed to perform only one function such as cutting, shearing, compression, or penetration does not give the complete picture of what is experienced when a food is chewed.

The Kramer Shear-Press

In 1951, Kramer, Aamlid, Guyer, and Rodgers (14) described a new instrument for measuring tenderness of fruits and vegetables. This instrument, the rugged construction of which distinguishes it from most other instruments, uses hydraulic pressure to force a series of metal plungers (plates) downward through product held in a metal box. Originally the pressure required to plunge through the material in the box was determined by measuring the pressure of the hydraulic fluid. More recently a Dillon mechanical pressure gage* has replaced the hydraulic pressure gage to give a wider range of pressure recordings. In either arrangement, the Shear-Press measures the maximum pressure required to force the plunger through the material.

In a recent refinement of this Shear-Press, called the Lee-Kramer Shear-Press, a sensitive dial mechanical pressure indicator which registers through a proving ring is placed between the hydraulically operated piston and the plunger plates, thus providing a more direct measure of force against the product being tested.

A still later modification by Decker (15) utilizes a transducer in conjunction with the Dillon mechanical pressure gage, which, when connected through an amplifier to a recording device, results in a

* W. C. Dillon, Inc., Van Nuys, California
continuous chart recording of pressure as the plunger plates traverse through the product. The recorder provides a pressure-time curve which can then be utilized to measure the total work required to penetrate the product.

A recent publication by Shannon, Marion, and Stadelman (16) presented results with poultry meat to show that there was a high correlation between Kramer Shear-Press values (maximum pounds of force per gram of sample, using one whole side of cooked breast) and panel evaluation by chewing (number of chews necessary prior to swallowing a 1 cm. cube of chicken). The samples of chicken tested in the Shear-Press were of such size that ten blades were forced through them.

To the author's knowledge, the Shear-Press has not been reported to be used to measure tenderness of meat, but in our laboratories, we have had some success in using it with both cooked chicken and cooked beef. Samples were prepared by cutting cylinders one inch in diameter with a cork borer. The cylinders were then placed in a plastic ⅜ inch thick die and sheared off with a sharp blade, thus making each sample exactly ⅜ inch thick and one inch in diameter. The samples were placed in the bottom of the test cell box and the Shear-Press operated so that plunger plates pushed through the sample. The maximum force in pounds per square inch was recorded for each sample.

Although we have made some efforts to determine the precision of the instrument, we have not been successful in obtaining adequate data to compare results with other tenderness measuring devices. One would expect, however, that the Shear-Press would have mechanical advantages over the Warner-Dratzler Shear and most other instruments.

We have made an effort to adapt the design of the cutting blade of the Warner-Dratzler Shear to the Kramer Shear-Press. However, this has not been perfected.

Discussion

Of all of the instruments for measuring tenderness reviewed here, the Warner-Dratzler Shear has been by far the most widely used in estimating tenderness of meat. It has become what might be termed standard laboratory equipment where tenderness of meat is to be measured objectively. Whether or not it can be easily replaced by another instrument would be simply conjecture.

There is little doubt that the Warner-Dratzler Shear can be improved upon mechanically to reduce experimental error. At least one study, by Hurwicz and Tischer (17), has been conducted recently to show that the variation observed in the experimental results can be ascribed primarily to the apparatus. These authors determined the maximum shear force, the total time necessary for failure in shear, and the slope of the shear force versus time curve for parawax and beeswax and various combinations of those two homogeneous materials. They came to the conclusion that the slope of the shear force versus time curve displayed the smallest coefficient of variation (4.7% vs. 7.6% for maximum shear force).

The Kramer Shear-Press, with all of its modifications shows
promise as an instrument for measuring tenderness of meat and warrants further careful study.

Conclusions

1. Of all of the several instruments which have been suggested for use in determining the tenderness of meat, the Warner-Dratzler Shear appears to have been the instrument of choice.

2. There is a great need for studies of instruments themselves to help solve the problem of objective determination of tenderness.

3. Further intensive study of the mechanics of chewing is needed.

4. It is highly desirable to have extensive rheological studies of meat.

REFRECES


8. Volodkevich, A. Apparatus for measurements of chewing resistance or tenderness of foodstuffs. Food Research 3, 221 (1938).


