Bulletin 947 March 1960

BEEF TENDERNESS by New Methods

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An Examination of some THEORIES

TEXAS AGRICULTURAL EXPERIMENT STATION R. D. Lewis, Director, College Station, Texas

Summary

Studies were conducted by the Department of Home Economics in which tenderness data on two muscles cooked under four conditions were obtained on 91 steers. These steers were produced and fed under controlled conditions. All cattle were graded to one-third grade by the area supervisor of the USDA Meat Grading Branch for the Texas-Oklahoma area. Percent ether extract, a chemical measure of marbling, was obtained on the trimmed ribeye from the 9-10-11 rib cut.

Two types of methods were used for tenderness testing: shear force values as the objective method and panel scores for three components of tenderness as the subjective method. The three components were connective tissue, crumbliness of muscle fibers and softness. The theories relating tenderness to carcass grade and fatness, to connective tissue and muscle fibers, and to the conditions of cooking have been examined in the light of the findings from this study.

Carcass grade and marbling were not consistently nor closely related to measures for tenderness of connective tissue or of muscle fibers. Carcass grade and marbling were not as good bases for deciding between moist and dry heat methods of cooking as was formerly supposed.

Connective tissue was much more tender in loin than in bottom round steaks. In bottom round steaks it was quite tough in rare (142°F.) became somewhat more tender when cooked either well-done (176°F.) by dry heat or medium-rare (185°F.) by moist heat; and became still more tender when cooked very well-done (212°F. for 25 minutes) by moist heat. Results of these tests show that the moisture in the moist-heat method appeared to have been needed to obtain high meat temperatures and not to furnish water for the chemical change of collagen into gelatin, as had been thought previously.

Scores for crumbliness of muscle fibers recorded the amount of tiny, hard, dry particles which made the meat crumble on pressure by the teeth. This characteristic was not prominent in loin steaks but was especially outstanding in bottom round steaks cooked very well-done (212°F. + 25 minutes) by moist heat. Thus the bottom round steaks braised very well-done tended to have tender muscle fibers and tender connective tissue.

Scores for softness were highest in steaks cooked rare (142°F.) by dry heat. Apparently their high moisture content was at least partly responsible for the impression of softness.

Shear force values indicated that loin steaks became tougher as they were cooked thoroughly. Moreover, cooking by moist heat did not seem to tender them. Apparently by the time a steak temperature of 176°F. was reached, toughening had already taken place and no tendering of loin steaks occurred at higher temperatures. Shear force values of bottom round steaks braised very well-done indicated that they were much more tender than loin steaks cooked in the same way. Shear force values were rather similar for loin and bottom round steaks cooked rare (142°F.) and gave little or no indication of the presence of the tough connective tissue found by the judges. From the data presented, shear force values appeared to be less than perfect as a measure of total tenderness of meat from all cuts.

These findings indicate that these two cuts—loin and bottom round—do not respond alike to the same conditions of cooking. Much additional research is needed to explain how tender meat may be detected before cooking, what happens to the tenderness of meat as it cooks and what causes these differences in tenderness.

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COVER: Loin steak from USDA Prime Carcass has more fat and more abundant marbling than loin steak from USDA Standard Carcass.

An examination of some

Theories about Beef Tenderness

By using new methods

SYLVIA COVER and ROBERT L. HOSTETLER*

TENDERNESS IS ONE OF THE MOST IMPORTANT characteristics of beef from a consumer's viewpoint. Yet the causes of tenderness or toughness are poorly understood, and no visible characteristic is known which is thoroughly reliable as an indicator of tenderness in beef.

There are many theories about selection of meat for tenderness and the best methods of cooking to retain or to develop tenderness. While these theories have seemed logical to many people, they were seldom based on adequate knowledge. A thoroughly reliable indicator of tenderness in the feedlot or in the meat market is not known, but research is in progress to improve this situation.

Some Theories about Tenderness

Connective tissue was thought to be the principal cause of natural toughness in meat. This has resulted in the division of the meaty cuts of the carcass into the so-called "tender cuts" with little connective tissue (such as rib and loin) and the "less tender cuts" with much connective tissue (such as bottom round).

"Marbling" is the term used to indicate the presence of flecks or streaks of fat within muscles. Marbling has been regarded as an important indicator of tenderness for the following reasons: fat deposited in the cells was supposed to distend them and make them more tender; fat was supposed to spread apart the strands of connective tissue between the muscle fibers and between the muscle bundles, making the meat more tender. Marbling is an important factor in determining USDA carcass grade; Figure 1 gives illustrations of marbling.

USDA carcass grades were supposed to be good indicators of natural tenderness in beef (Bureau of Human Nutrition and Home Economics, 1952; United States Department of Agriculture, 1951; National Livestock and Meat Board, Meat Manual). However, grading is designed, primarily, to group carcasses according to certain characteristics as a means of facilitating their transfer through commercial channels. Three factors are used to determine USDA carcass grade: conformation, quality and finish (United States Department of Agriculture, 1956; National Livestock and Meat Board, *Meat Judging Handbook*). "Conformation" refers to the form or shape of the carcass and may be expected to have little relationship to tenderness. "Quality" includes maturity or age of the animal, marbling, texture, color and firmness. "Finish" refers to the amount, distribution, firmness and texture of exterior and interior fat. The *Meat Judging Handbook* discusses the way in which these factors are used in assessing USDA grades.

> Since marbling and maturity are the two most important factors considered in evaluating quality, variations in these two factors together with variations in conformation can be combined in chart form to indicate, by grades, the manner in which a superiority in development of quality is permitted to compensate for an inferior development of conformation and vice versa.

This chart is used in carcass grading and in the teaching of carcass grading, Figure 2.

Marbling and maturity are the two factors which have been considered most closely related to eating quality of meat (tenderness, flavor and juiciness). Flavor and juiciness will not be considered in this report. The importance of marbling and maturity in the above system of grading is responsible for the assumption that USDA carcass grades should be related to tenderness. Recommendations for cooking beef cuts have taken into consideration not only the cut of meat but the grade of carcass from which it came.

Dry heat methods of cooking (broiling and roasting) were considered suitable only for naturally tender meat—that with no tough connective tissue. Such cuts were thought to include rib and loin, if they came from Prime, Choice and Good grade carcasses, and a few other cuts (top round, rump and blade chuck) but only if they came from Prime and Choice grade car-

*Sylvia Cover, professor, and Robert L. Hostetler, instructor, Department of Home Econmics, Texas Agricultural Experiment Station.

casses. Such cuts from the higher grade carcasses were considered to be naturally tender because of the absence of tough connective tissue.

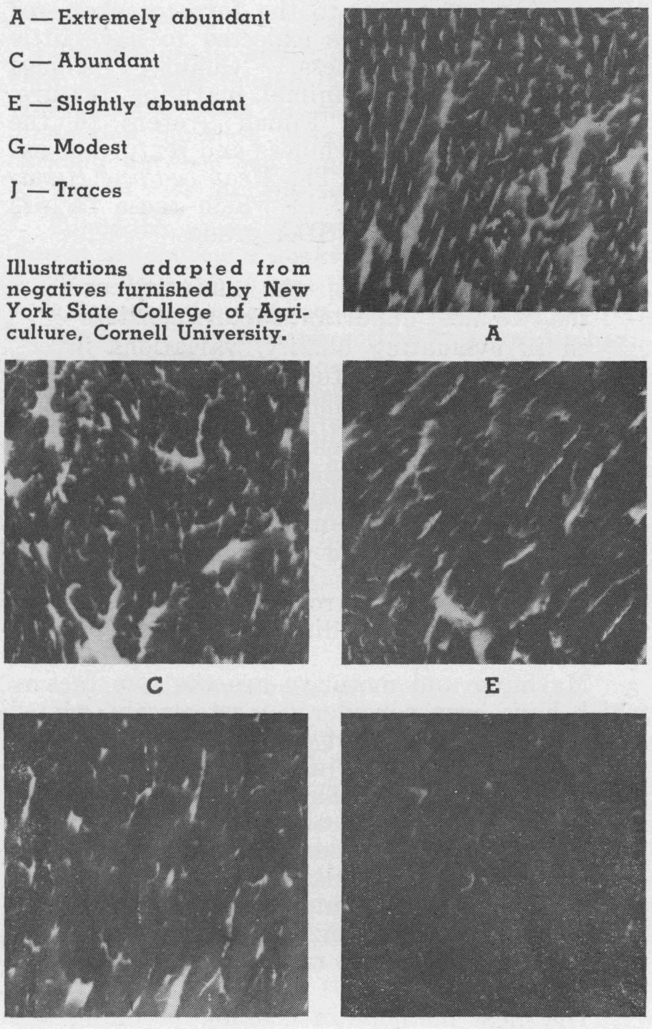
Moist heat methods of cooking, such as braising, were recommended for the "less tender" cuts —rib and loin from carcasses below the Good grade; top round, rump and blade chuck from carcasses below the Choice grade; and other cuts, such as bottom round, from carcasses of all grades. The less tender cuts were thought to contain so much or such tough connective tissue that they could be made tender only by "cooking for a long time by moist heat." Connective tissue in the meaty cuts was thought to be made up largely of collagen, a protein which was supposed to be changed into gelatin only when subjected to moist heat for a long time. The theory was that the moisture in the moist heat was needed to hydrolyze collagen into gelatin. This theory has been applied to meat cookery for many years. However, raw meat contains about 70 percent water and some drips out as it cooks. The need, therefore, for an additional source of moisture during cooking seemed questionable.

Temperature is another factor which was thought to influence tenderness of cooked meat. A so-called "principle" of meat cookery states that high heat toughens protein. This was supposed to be applicable only to the proteins of the muscle fibers. It was used as a basis for recommending that meat be cooked at low cooking temperatures and to low final meat temperatures as well. According to this theory internal meat temperatures of around 142° F. (rare) should give more tender muscle fibers than those around 176° F. (well-done), yet beef muscle reaches temperatures much higher than 176° F. when it is braised by the usual household methods. For instance, water simmers at 194° F. and boils at 212° F. The steam above water boiling in a pot covered with a heavy well-fitted lid may be slightly above 212° F. During braising, meat is exposed to these temperatures for times long enough to reach them. Cover *et al.* (1957) gave heat penetration curves which indicated that heat penetration into 1-inch steaks was relatively fast during braising so that steaks of 0.5 pounds average weight reached 212° F. in only 15 to 20 minutes cooking time and those of 0.6 pounds average weight in only 20 to 38 minutes cooking time. Cooking times longer than these would mean that the meat was held for the rest of the time at 212° F. If a steak weighing about one-half pound were braised for 45 minutes, it might be held at 212° F. for 25 to 30 minutes. A pertinent question is: "Are beef muscle fibers toughened during braising?"

Although low cooking temperatures were advised for all meat cookery, a wide variety of temperatures were classified as "low." Temperatures around 400° F. were considered "low" for broiling but "high" for roasting. Temperatures around 250° F. were considered "low" for roasting but a temperature of even 212° F. (boiling) was considered "high" for braising.

Thus, for moist heat methods the recommended *cooking* temperatures will be lower but the *meat* temperatures will be higher than for dry heat methods. As a result, the theories used for recommending cooking procedures could be confusing when actual temperatures are considered. A clear understanding of the chemical and physical factors involved in meat cookery is long overdue.

One of the difficulties in cooking meat so that it will be tender is that muscle fibers and connective tissue are so mixed in beef muscle that both must be subjected to whatever cooking conditions are selected. Thus, for steaks which presumably have tough connective tissue, the cooking method recommended is one which insures a



A — Extremely abundant

C — Abundant

E — Slightly abundant

G — Modest

J — Traces

Illustrations adapted from negatives furnished by New York State College of Agriculture, Cornell University.

Figure 1. Illustrations of typical marbling referred to in the official U. S. Standards for grades of carcass beef. (Selected from the pictures published in the chapter on Beef Grading in the Meat Judging Handbook, National Livestock and Meat Board, 1958, which was prepared by J. G. Pierce and associates, Standardization and Grading Division, Agricultural Marketing Service, U. S. Department of Agriculture.

relatively high internal steak temperature for a relatively long time. The purpose is to tenderize the connective tissue but this cooking condition would, supposedly, also toughen the proteins inside each muscle cell of the steak. As a result, theoretically, the muscle fibers of a braised steak should be toughened at the same time that the connective tissue is tendered. Lehmann (1907) recognized this problem more than 50 years ago.

Satisfactory tenderness must include tender muscle fibers as well as tender connective tissue. Because the usual recommendations mentioned have not always produced tender meat, these older theories of tenderness seemed to need further investigation.

A refinement in thinking and working with tenderness of beef has become necessary. It has been known for more than 50 years that tenderness is influenced by two structures in meat—connective tissue and muscle fibers; that these two structures are not uniformly distributed in muscles; and that some cooking methods may tenderize connective tissue while toughening muscle fibers. It became apparent that one score for tenderness was not adequate for following tenderness changes precisely and this method of testing was abandoned. Instead, a panel rated the meat for tenderness of connective tissue, for softness and for crumbliness of muscle fibers (Cover 1959), Figure 3. A mechanical cutting device was used to obtain shear force values. In this manner, four ways were provided for characterizing the tenderness of the beef used in this study. The relationship of carcass grade and fatness to each of these ways of testing tenderness was studied but was reported only for tenderness of connective tissue and shear force values.

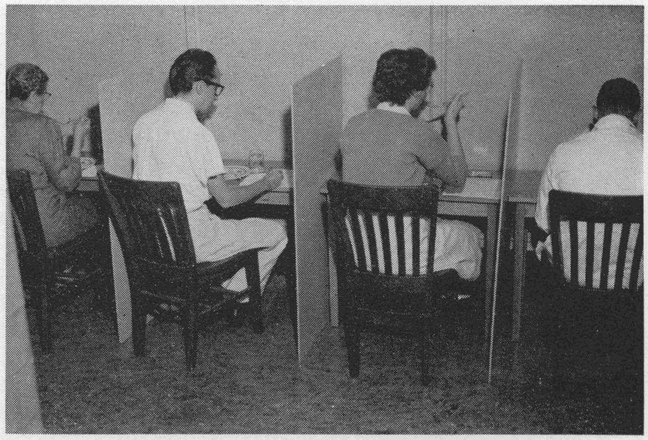


Figure 3. Panel members testing tenderness subjectively in booths made from small tables and plywood panels. Entire room is kept quiet.

MINIMUM MARBLING REQUIREMENTS (WITH NORMAL COLOR, TEXTURE AND FIRMNESS OF LEAN FOR APPLICABLE GRADE AND MATURITY) FOR THE PRIME, CHOICE, GOOD, STANDARD, AND COMMERCIAL GRADES OF BEEF, BY SPECIFIED DEGREES OF CONFORMATION AND MATURITY

CARCASS GRADE	CONFORMATION EQUIVALENT	MATURITY GROUPS a	b	c	d	e	f
Prime	Minimum Prime or better	Slightly abundant	Moderately abundant	Abundant			
	Mid-point Choice*	Moderately abundant	Abundant	Very abundant			
	Minimum Choice*	Abundant	Very abundant	Extremely abundant			
Choice	Minimum Choice or better	Small	Modest	Moderate			
	Mid-point Good*	Moderate	Slightly abundant	Moderately abundant			
	Mid-point Standard*	Moderately abundant	Abundant	Very abundant			
Good	Mid-point Good or better	Traces	Slight	Small			
	High Standard*	Slight	Small	Modest			
	Minimum Standard*	Modest	Moderate	Slightly abundant			
Standard	Mid-point Standard or better*	Devoid	Practically devoid	Traces			
	High Utility*	Practically devoid	Traces	Slight			
	Minimum Utility*	Slight	Small	Modest			
Commercial	Minimum Commercial or better				Small	Modest	Moderate
	Mid-point Utility*				Modest	Moderate	Slightly abundant
	Minimum Utility*				Moderate	Slightly abundant	Moderately abundant

DEGREES OF MARBLING

1. Extremely abundant
2. Very abundant
3. Abundant
4. Moderately abundant
5. Slightly abundant
6. Moderate
7. Modest
8. Small amount
9. Slight amount
10. Traces
11. Practically devoid
12. Devoid

MATURITY GROUPS

a. Red, porous, chine bones; soft, pearly-white cartilages.
b. Intermediate maturity for Prime, Choice, Good or Standard grades.
c. Approaching maximum maturity for Prime, Choice, Good or Standard grades.
d. Cartilages slightly more than moderately ossified.
e. Cartilages nearly completely ossified.
f. Hard, white, chine bones; cartilages entirely ossified, outline of cartilages barely visible.

* *Example only.* Illustrates the extent to which more than minimum quality must be present to compensate for less than minimum conformation.

June, 1956

Figure 2. Minimum marbling requirements for grades of beef, by specified degrees of conformation and maturity. (Courtesy of Standardization and Grading Division, U. S. Department of Agriculture.)

Experimental Conditions

Meat was available from 57 steers in 1956. Shear force values for all were reported by Cover, King and Butler (1958). However, judges' scores were complete for only 55 and only these 55 steers are included in this report. Records were complete for 36 steers in 1958. All of these steers were produced at Substation No. 23, McGregor, Texas. This substation was formerly known as the Bluebonnet Farm, and the steers known as the "Bluebonnet Steers"; they will be referred to in this way throughout this bulletin. After weaning, they were full fed on a ration containing 66 percent concentrates, with weights recorded at monthly intervals until slaughter. All were in gaining condition at slaughter. Although feed was before them at all times, the rate of gain varied considerably among the animals. This is caused primarily by differences in the inherent ability to gain and usually prevails in any group of steers. A record of such differences in rate of gain was one of the purposes of the production phase of these tests.

Each year all of the steers were slaughtered within a period of 1 week and the carcasses processed in the meats laboratory of the Department of Animal Husbandry.

The ages at slaughter ranged from 13 to 16 months. Weights of the chilled carcasses used in 1956 averaged 492 pounds with a range of 301-637. Those used in 1958 averaged 469 pounds with a range of 370-561.

All carcasses were graded and placed in the upper, middle or lower third of the grade by the supervisor of the Texas-Oklahoma area of the Meat Grading Branch, Agricultural Marketing Service, USDA. Specifications for USDA beef carcass grades were revised in June 1956, separating the Commercial grade into Standard, for young animals, and Commercial, for older ones. Steer carcasses grading Commercial in the 1956 tests would have graded Standard under present specifications and are so classified here. In 1956 the carcasses graded as follows: 4 Choice, 24 Good, 26 Standard and 1 Utility; in 1958, 17 Good and 19 Standard. Production procedures were standarized and no attempt was made to obtain an equal number of animals in each grade.

A measure of marbling was obtained on all carcasses—percent ether extract of the trimmed ribeye from the 9-10-11 rib cut. This rib cut was made along the bony structure according to precise directions to provide uniformity of cutting among many animals. Ether removes the fatty substances in meat and the percentage of the ether extracted material from trimmed muscle samples is regarded as a chemical measure of marbling. Since the percent ether extract was obtained on the trimmed "eye" muscle from the 9-10-11 rib cut, percent ether extract was thought to be closely related to the marbling of ribeye

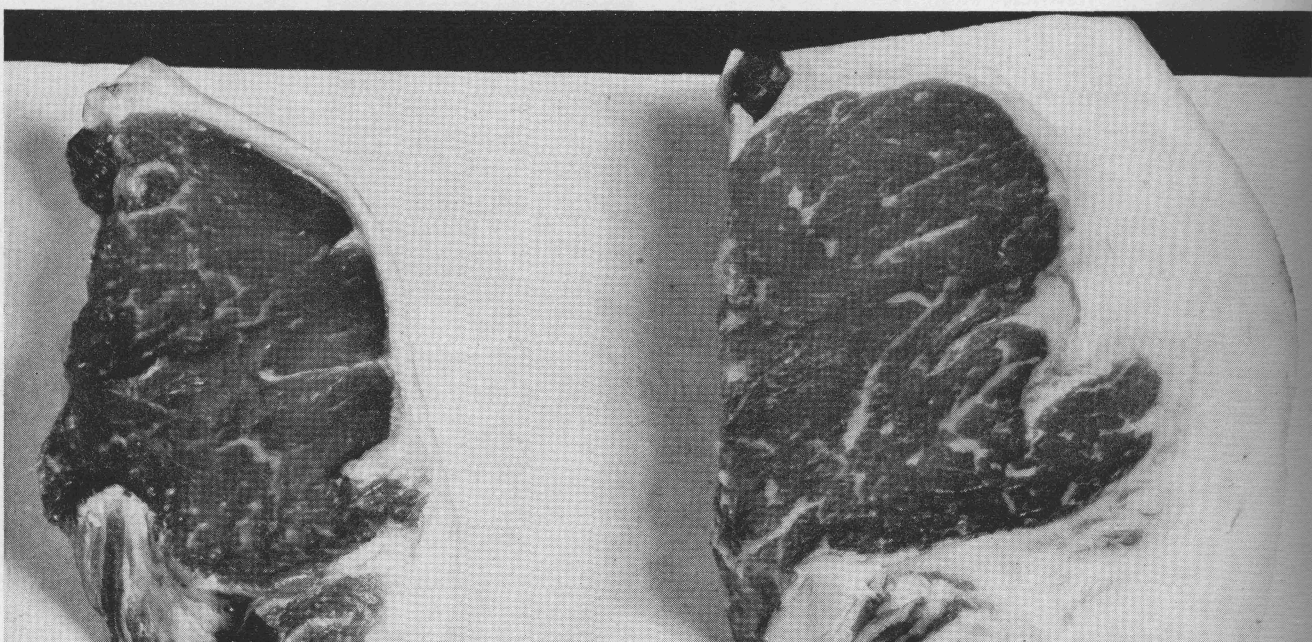


Figure 4. Longissimus dorsi muscle in loin steaks used for tenderness testing, taken from steaks shown on cover. Left, USDA Standard Carcass; Right, USDA Prime Carcass.

which is a major criterion of grade determination and thought to be a good indicator of the tenderness of the meat. These data do not include an equal number of animals with each percentage of ether extract. The percentages obtained were one of the results of research on the production of these animals.

The carcasses were aged at about 36° F. On the seventh day after slaughter, steaks containing only one large muscle were cut from loin and bottom round. The steaks were cut 1-inch thick, trimmed free of bone, wrapped individually, frozen at -20° F. and stored at 0° F. until the tests could be made, Figures 4 and 5. The steaks were cooked under standardized conditions by using both moist and dry heat methods. Thermometers were used to obtain steak temperatures and the oven or pot temperatures. Standardized methods for cooking steaks were needed so that specific variables could be studied.

A dry heat method was needed for cooking in air which would be similar to home broiling yet have the advantage of easy standardization. Because oven temperatures are more easily standardized than broiler temperatures, cooking in the oven compartment of a well-ventilated gas oven unit was considered. These oven units have glass doors through which oven and steak thermometers could be read. In them, an oven temperature could be maintained within less than 4° F. variation (±1° C.) while in the broiler the actual temperature often fluctuated 50° F. or more from the desired temperature. Preliminary work indicated considerable spattering of fat when steaks were cooked in these ovens at 400° F., the "low" temperature recommended for broiling. There was much less spattering when the oven temperature was lowered to 350° F. Even this lower temperature is higher than that recommended for roasting beef (300° F.) Adequate venting of the ovens prevented the accumulation of moisture and the steaks browned nicely. Because the broiler pans were lined with bright foil and open wire racks were used, the steaks browned on the underside without turning. The heat transfer appeared to be by radiation from the hot oven walls and the bright hot foil, by convection from the hot foil as well as from the hot gases from the combustion chamber (although these gases were deflected considerably by the large size of the broiler pan), and by conduction from the hot broiler rack.

In the tests reported here, the oven with the broiler pan, foil and wire broiler rack in place within it was regulated at 350° F. before cooking was begun. Cooking was done with the oven doors closed—one steak per oven. Steak temperatures were read through the glass oven door. The rare steaks were removed at a steak temperature of 142° F. and well-done ones at 176° F. This method of cooking steaks is practical for home use. It has been called "oven broiling" by the author in other publications, but for this bulletin it will be called "oven-cooking." This is a dry heat method of cooking. It also may be called "air cookery" as distinguished from steam, water or fat cookery.

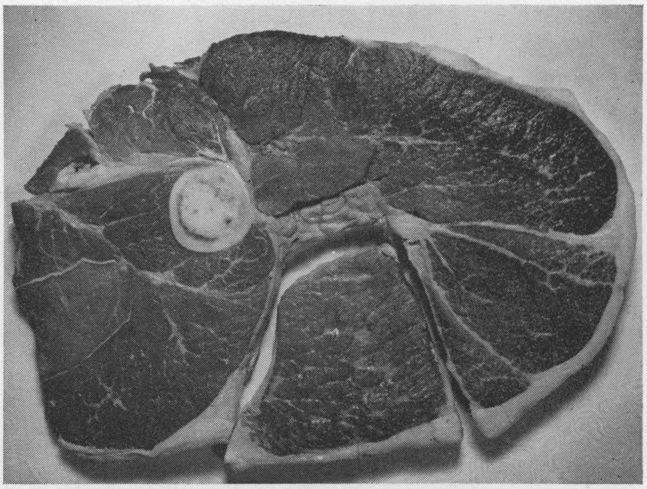


Figure 5. Round steak with Biceps femoris muscle used for testing separated from rest of steak.

A moist heat method was needed which would approximate home conditions and yet have the steak surrounded by only one cooking medium for good control of experimental conditions. Since rate of heat penetration into meat differs with the cooking medium and rate of heat penetration seems to affect tenderness, steaks cooked half in water and half in steam might present a problem in sampling for technical studies.

The braised steaks for 1956 were browned and then cooked in steam on a rack over boiling water. Browning before braising was done in this laboratory in the following way: a heavy pot was preheated to 475° F. in a standardized manner over a gas flame. One tablespoon of cooking oil was added and the steak was browned 1 minute on each side. However, preliminary work in 1957 on steaks from 30 steers indicated that browning before steaming had little or no effect on weight loss, cooking time, juiciness or tenderness (Table 1). A smoother cooking routine is possible when browning is omitted, For these reasons the 1958 braised steaks were not browned. Only one steak was cooked in each pot. Thermometers of special design were used to follow the steak temperatures. Half of the braised steaks were removed at an internal temperature of 185° F. For the others the cooking was continued to an internal temperature of 212° F. and for 25 minutes thereafter. The steaks which were removed at 185° F. were underdone. The meat and the juice were slightly pink. The steaks, which were cooked to an internal temperature of 212° F. and held there for 25 minutes, were very well-done. They were used to simulate the conditions in many homes where braising time may be from 45 to 60 minutes. This is a moist heat method of cooking. It may be called "steam cookery" as distinguished from water, fat or air cookery.

Weights, cooking time and weight losses are given in Table 2. Steaks oven-cooked to only 176° F. were well-done but those braised to a slightly higher internal temperature of 185° F. were medium-rare. Similar meat temperatures did not produce the same degree of doneness in air as in steam. The red color of meat is caused by pigments, principally myoglobin. Change in these pigments is thought to begin around 149° F. and to be complete at around 176° F. with the gray color of cooked meat. Roasts cooked very slowly in air at an extremely low oven temperature of 176° F. will become gray in color at 158° F; roasts cooked in air at a normal oven temperature of 300° F. will be gray in color at 176° F. (Cover, 1943). The full explanation of this is not known exactly although there has been some work on this problem (Tappel, 1957; Bernofsky, Fox and Schweigert, 1959). It is thought that the amount of red color left in the meat depends on the meat temperature and on the time the meat is held at that temperature. The steaks braised in steam required only 10 to 15 minutes to reach 185° F. while the oven-cooked ones required 55 to 70 minutes to reach 176° F.

Similar readings on the thermometer were reached much more quickly in steam than in air. Evaporation of moisture from the meat surface takes place freely in air, but evaporation from the surface of the meat probably does not take place at all in steam. The heat, which is needed to evaporate meat juice from the surface, slows the cooking of the meat in air, but this heat (latent heat of evaporation) is not lost when meat is cooked in steam. Therefore, the internal temperature tends to rise more rapidly in steam than in air.

In a previous study, Cover and Shrode (1955) cooked thin steaks (three-fourths inch) well-done in a broiler which had been preheated to 200° C. (392° F.). Thermometers were inserted into the steaks but internal meat temperatures were not used as the end point of cooking. The steak was browned well on one side (25 minutes), turned and browned on the other side (10 minutes). The meat temperature reached 75-78° C. (167-172° F.) in the first 25 minutes. It dropped about 5° C. (9° F.) when the steak was turned and did not recover by the end of the cooking period. The drop in temperature is believed to have been caused by rapid evaporation from the freshly turned moist surface.

TABLE 1. CHANGES IN CERTAIN VARIABLES WHEN BRAISED STEAKS WERE BROWNED AND NOT BROWNED

Variables		Loin	Bottom round
Averages of 30 steers			
Raw weight	Browned	206 g.	272 g.
	Not browned	188 g.	267 g.
Total cooking time	Browned	48 min.	52 min.
	Not browned	51 min.	53 min.
Weight loss	Browned	35 %	37 %
	Not browned	34 %	37 %
Shear force values	Browned	10.2 lb.	5.7 lb.
	Not browned	10.8 lb.	5.7 lb.
Tenderness of connective tissue	Browned	8.8	6.6
	Not browned	8.9	6.2
Tenderness of muscle fibers	Browned	5.7	6.8
	Not browned	5.7	6.6
Juiciness	Browned	2.1	2.7
	Not browned	2.0	2.7

TABLE 2. WEIGHT, COOKING TIME AND WEIGHT LOSS OF STEAKS

Cut	Method of cooking	Doneness[1]	Raw weight, pounds	Total cooking time, minutes	Weight loss, percent
1956 data (55 steers)					
Loin	Oven-cooked	Rare	0.4	24	13
		Well-done	0.5	56	31
	Braised	Medium-rare	0.4	11	23
		Very well-done	0.5	46	36
Bottom round	Oven-cooked	Rare	0.6	29	13
		Well-done	0.6	70	37
	Braised	Medium-rare	0.6	15	24
		Very well-done	0.6	50	39
1958 data (36 steers)					
Loin	Oven-cooked	Rare	0.4	28	14
		Well-done	0.5	61	30
	Braised	Medium-rare	0.4	14	23
		Very well-done	0.5	51	34
Bottom round	Oven-cooked	Rare	0.6	28	12
		Well-done	0.6	68	33
	Braised	Medium-rare	0.6	16	23
		Very well-done	0.6	52	37

[1]The final meat temperature of these steaks was 142°F. for oven-cooked rare; 176°F. for oven-cooked well-done; 185°F. for braised medium-rare; and 212°F. and held there for 25 minutes for braised very well-done.

Tenderness of the meat in the tests was measured subjectively with a panel and objectively with a shearing device. Tenderness scores obtained from judges have usually been recorded as a single measure. In an effort to get more precise records on tenderness differences, the tenderness of the beef used in this study was characterized in four ways: A panel, rated the meat for tenderness of connective tissue, for softness and for crumbliness of muscle fibers; shear force values were obtained with a Warner-Bratzler shearing device.

Tenderness Characterized by Scores for Connective Tissue

According to the older theories about tenderness, the more tender connective tissue was found in the so-called "tender cuts." These were cuts with little connective tissue, such as loin, which were well-marbled and from carcasses of high grade. Tougher connective tissue was thought to occur in loin cuts with little marbling and from the lower grade carcasses and to occur especially in certain muscles with a lot of connective tissue, such as bottom round. It was thought that tough connective tissue could be made tender only by long slow cooking in "moist heat."

Scores for tenderness of connective tissue in this study were based on a scale in which the highest score was the most tender. This indicated that only a tiny amount of soft connective tissue was felt. This tender connective tissue is readily masticated and is not considered objectionable. The lowest score was given to a large amount of hard connective tissue which cannot be masticated. It must be gulped or discarded. It is likely to be called "gristle" by most people. This tough connective tissue is highly objectionable. This method of scoring should be regarded as a somewhat crude attempt to record oral evidence of connective tissue. More sophisticated scoring patterns may come later.

In 1956 an 11-point scale was used (0-10). In 1958 it was reduced to a 9-point scale by omitting the zero and 10 of the 11-point scale (1-9).

CONNECTIVE TISSUE RELATED TO CARCASS GRADE

USDA carcass grade was plotted against score for tenderness of connective tissue. Graphs were made for each of the four conditions of cooking for each of the two cuts. The data for the 1956 steers are given in Figures 6 and 7 (loin and bottom round, respectively) and for the 1958 steers in Figures 8 and 9. Each of these figures has four parts: the two upper ones for oven-cooking rare (A) and well-done (B); the two lower ones for braising medium-rare (C) and very well-done (D).

Had high carcass grade been closely related to tender connective tissue, the dots in Figures 6 through 9 would have fallen along a line extending from the lower left toward the upper right. There is little or no evidence of such a trend in any of the four conditions of cooking for either of the two cuts in either year. Carcass grade, therefore, seemed to have little practical relationship to tenderness of connective tissue. Moreover, USDA carcass grades did not identify all of the tender conective tissue successfully. These findings cast doubt on the value of USDA carcass grades as a means of indicating tenderness of connective tissue.

CONNECTIVE TISSUE RELATED TO PERCENTAGE OF ETHER EXTRACT

Marbling refers to the light specks of fat in the red muscle tissue. The fatty substances were removed with ether and the amount removed in this way (extracted) was calculated as a percentage of the dry weight of the muscle. The percentage of ether extract is called a chemical measure of marbling.

The percentage of ether extract in the trimmed ribeye muscle in the 9-10-11 rib cut was plotted against score for tenderness of connective tissue. Graphs were made for each of the four conditions of cooking within each of the two muscles. The data are given in Figures 10 and 11 (loin and bottom round, respectively) for the 1956 steers; and in Figures 12 and 13 for the 1958 steers.

These graphs show no trend from the lower left to the upper right which would have occurred had tender connective tissue been associated closely with high percentage of ether extract. Moreover, the tender connective tissue was not identified successfully by percentage of ether extract of the ribeye muscle in the 9-10-11 ribs.

From these data, marbling of the ribeye in the 9-10-11 rib cut as measured by percentage of ether extract seems of doubtful practical value in choosing meat with tender connective tissue.

CONNECTIVE TISSUE RELATED TO CUT AND CONDITION OF COOKING

Tenderness of connective tissue for each cut and condition of cooking may be observed in Figures 6-9 or 10-13.

Loin steaks (Figures 6, 8 or 10, 12) scored high for tenderness of connective tissue for each of the conditions of cooking (A,B,C,D). Cooking by moist heat (C,D) did not seem to improve further the tenderness of connective tissue in these loin steaks.

Bottom round steaks contrasted sharply with loin steaks from the same carcass in that scores for tenderness of connective tissue were affected markedly by condition of cooking (Figures 7, 9 or 11, 13). The bottom round steaks cooked rare in the oven (A) contained tough connective tissue which became more tender (more easily masticated) when oven-cooked well-done (B). Braising to medium-rare (C) tendered the connective tissue about as much as did oven-cooking well-done. The greatest tendering of connective tissue occurred when bottom round steaks were braised very well-done (D).

Average scores for tenderness of connective tissue by cuts and conditions of cooking in each year are given in Table 3. Significance of the differences was determined by analyses of variance, a statistical measure of the uniformity of the difference. The actual scores vary from year to year. Changing from an 11-point scale in 1956 to a 9-point scale in 1958 could have caused some of this variation, other causes of variation were: differences in animals, in personnel on the panels and in personnel doing the cooking. Yet the similarity in trends for the 2 years is remarkable. These trends are: 1) in loin steaks, tenderness of connective tissue was not affected by condition of cooking in either year; 2) in bottom round steaks, the connective tissue was more tender oven-cooked well-done than rare and more tender braised very well-done than medium-rare in both years; and 3) connective tissue in bottom round was tougher than that in loin under all conditions of cooking except braising very well-done.

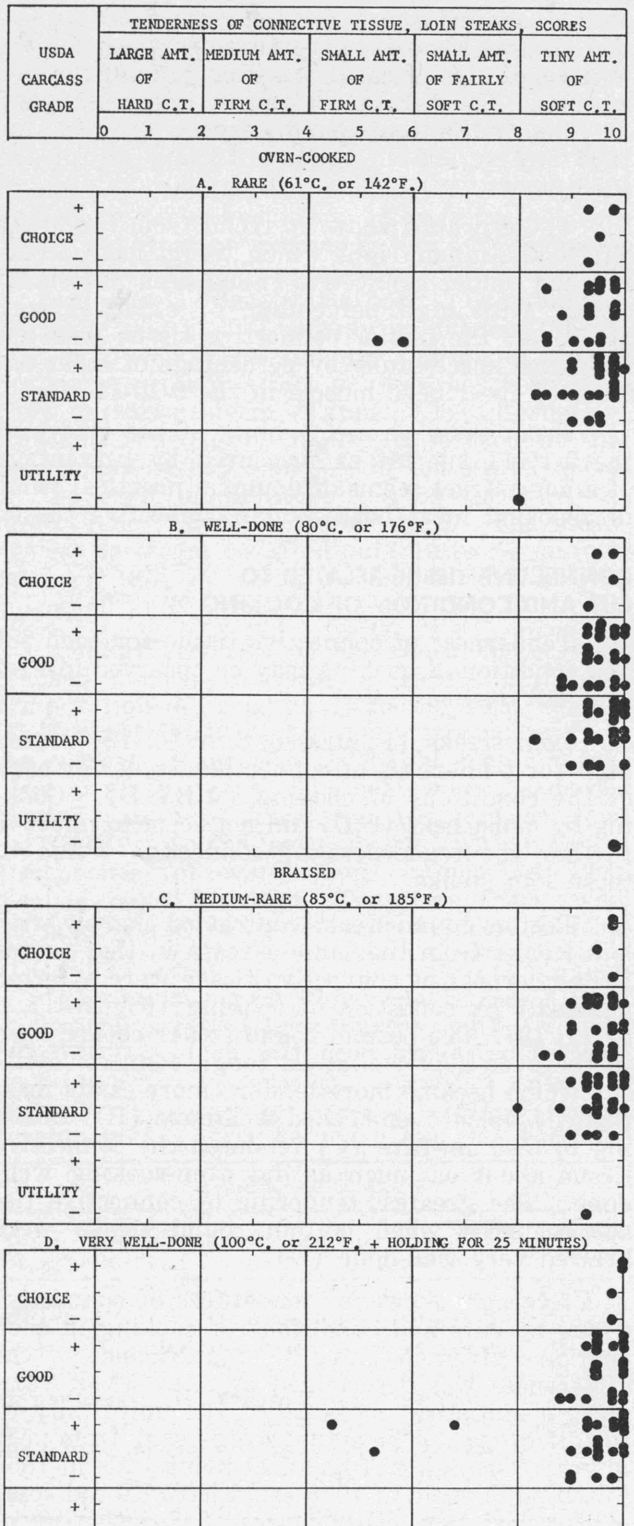


Figure 6. Carcass grade plotted against tenderness of connective tissue for four conditions of cooking. Loin steaks from 55 Bluebonnet steers, 1956.

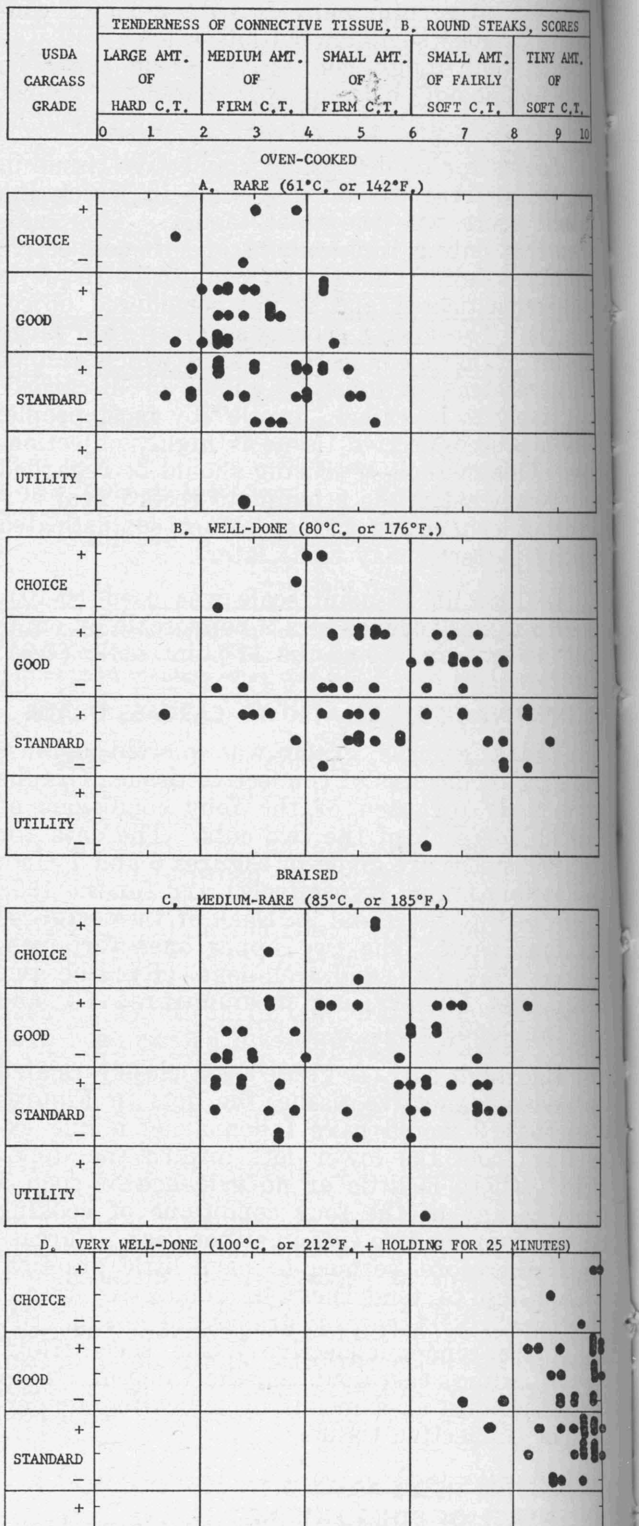


Figure 7. Carcass grade plotted against tenderness of connective tissue for four conditions of cooking. Bottom round steaks from 55 Bluebonnet steers, 1956.

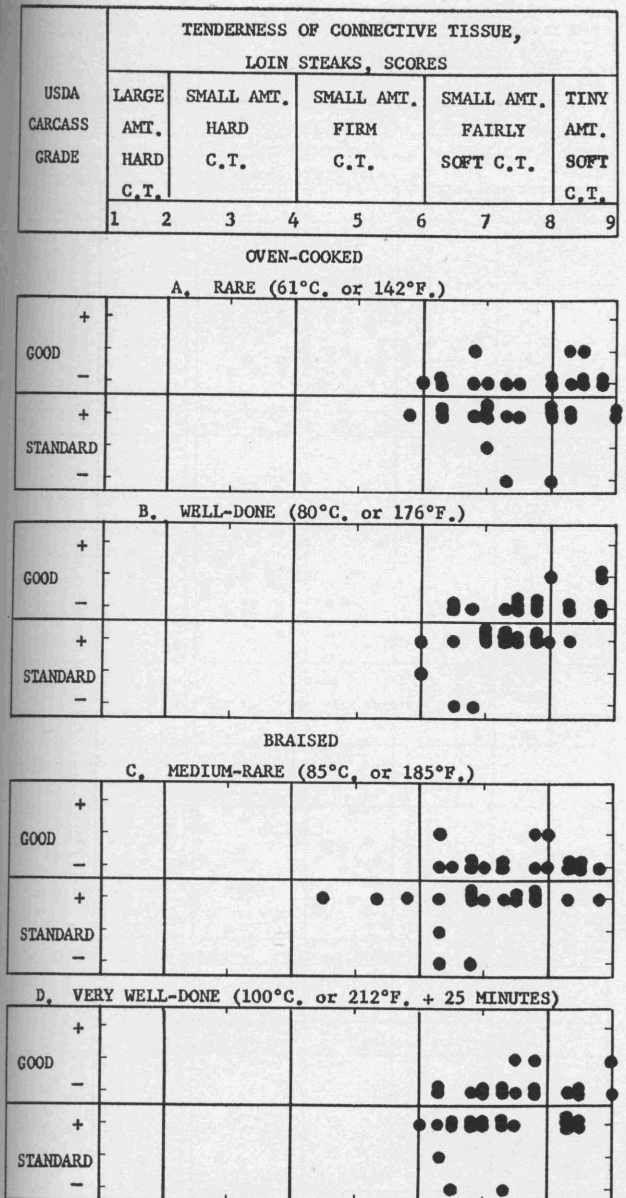


Figure 8. Carcass grade plotted against tenderness of connective tissue for four conditions of cooking. Loin steaks from 36 Bluebonnet steers, 1958.

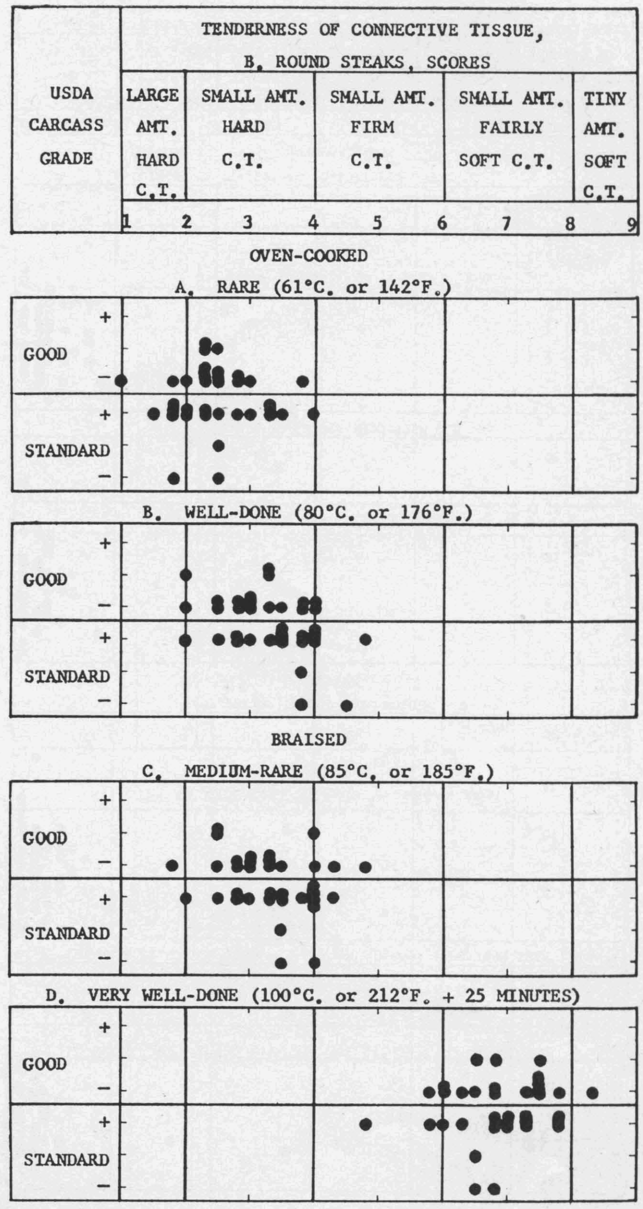


Figure 9. Carcass grade plotted against tenderness of connective tissue for four conditions of cooking. Bottom round steaks from 36 Bluebonnet steers, 1958.

RELATION OF RESULTS TO OLDER THEORIES

The theories that connective tissue is most tender (most easily masticated) in carcasses of high USDA carcass grade and in carcasses with the greater degree of marbling in ribeye were not confirmed in these tests. The data from both years were in remarkable agreement on these points. These two older theories on how to select meat with tender connective tissue seem to be of doubtful practical value for animals such as those used in this study.

The older theories and recommendations about cooking methods which are suitable for the so-called "tender" cuts seem to need revision. The connective tissue in these loin steaks did not seem to be affected by these four conditions of cooking. Thus, the old recommendations that dry heat methods of cooking be used for only those loin steaks from carcasses of Prime, Choice and Good grades and that moist heat methods be used for the lower grades to soften the connective tissue seem unwarranted for young animals such as those used in these studies.

With bottom round steaks, the results from research could be regarded as in line with the older theory that tendering of heavy connective tissue takes place only at low temperature in moist heat, but other temperature considerations should be pointed out. Although the braising temperature (212° F.) was much lower than the oven temperature (350° F.) and one of the moist heat conditions gave the greatest tendering, the

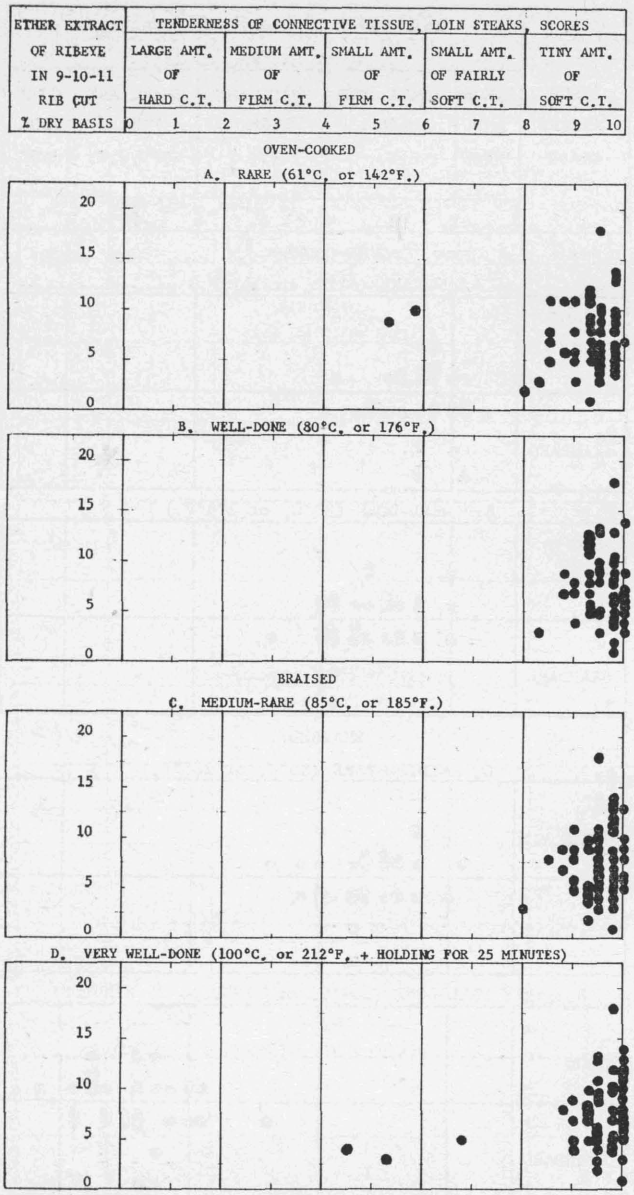


Figure 10. Ether extract plotted against tenderness of connective tissue for four conditions of cooking. Loin steaks from 55 Bluebonnet steers, 1956.

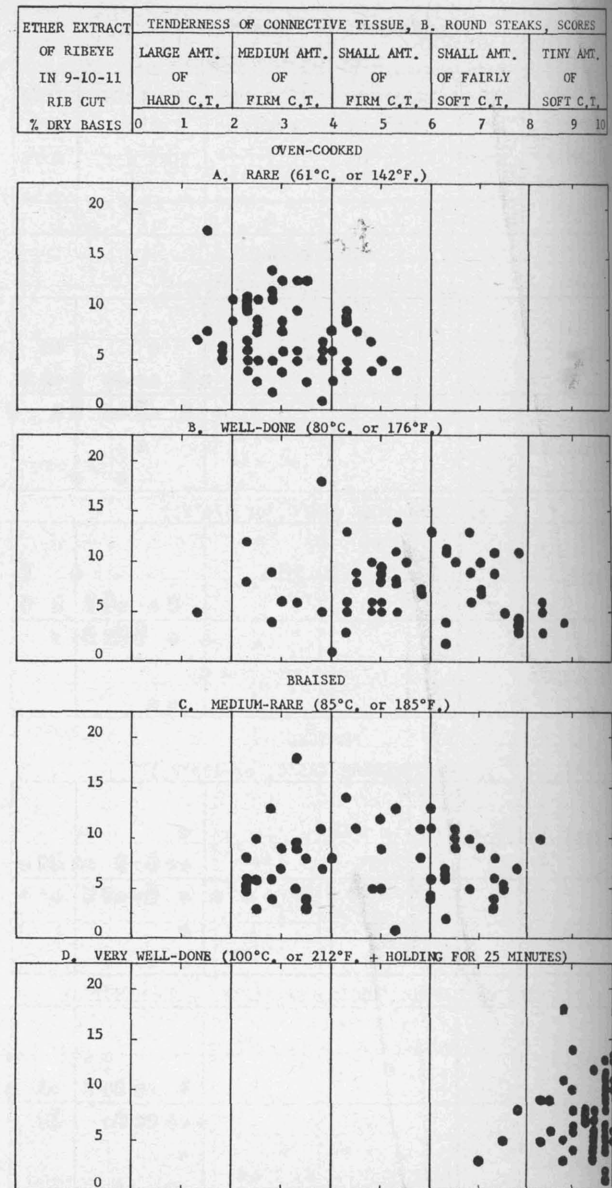


Figure 11. Ether extract plotted against tenderness of connective tissue for four conditions of cooking. Bottom round steaks from 55 Bluebonnet steers, 1956.

increase in meat temperature seemed to be the effective condition for tendering connective tissue. Steaks cooked to similar meat temperatures by dry heat in air in an oven or by moist heat in steam appeared to have similar scores for tenderness of connective tissue. Those cooked to the lowest meat temperature (142° F.) had the toughest and those cooked to the highest meat temperature (212° F.) had the tenderest connective tissue. Thus, the higher the meat temperature, the greater the tendering of the connective tissue. Meat temperatures as high as 212° F. cannot be obtained in air with the usual household equipment because of the cooling effect from evaporation of meat juices from the surface.[1] High meat temperatures could be obtained easily and quickly with moist heat methods, using either water or steam. Accordingly, if high meat temperatures were to be secured, the homemaker had to use moist heat methods. Thus, *the moisture in the moist heat methods* appears to have been needed *to obtain high meat temperature* rather than to furnish the water needed for the chemical change (hydrolysis) of collagen into gelatin. This is a simple explanation but the uncritical application of a borrowed theory delayed it for many years.

[1] In an unpublished study, Cover heated roasts for about 3 days in ovens regulated at 125° C. (257°F.). The meat temperature reached 96° C. (205° F.) during the second day. On the third day, the meat tempeature had not reached 97° C. (207° F.) and the cooking was discontinued. The roast was dry, hard and browned to the center.

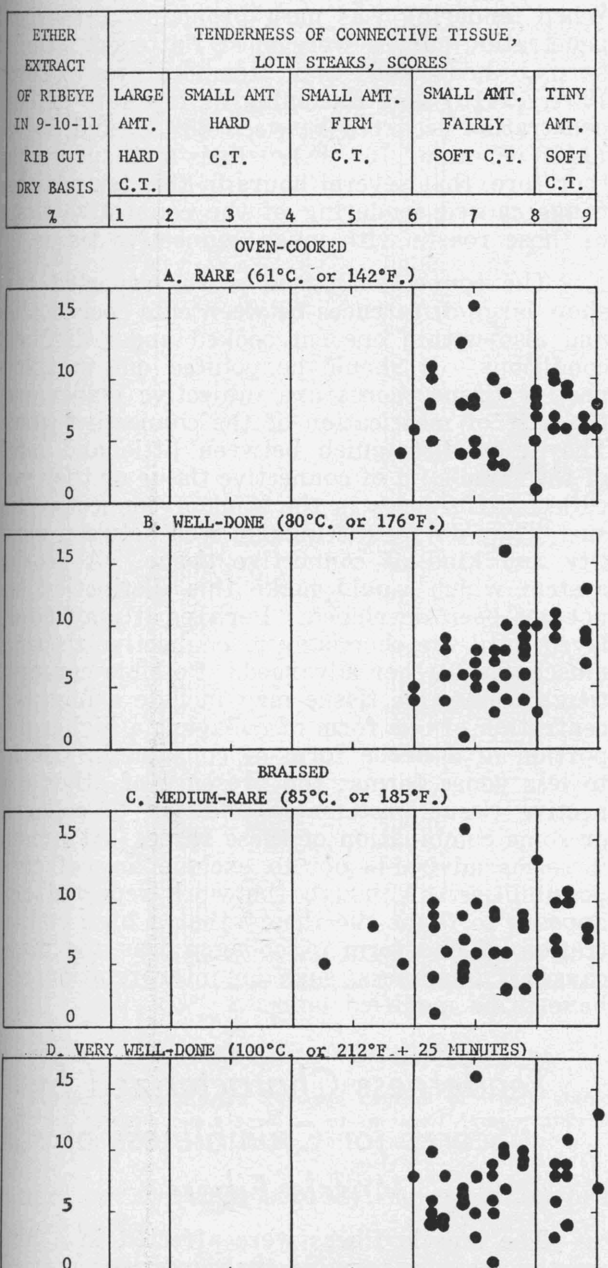


Figure 12. Ether extract plotted against tenderness of connective tissue for four conditions of cooking. Loin steaks from 36 Bluebonnet steers, 1958.

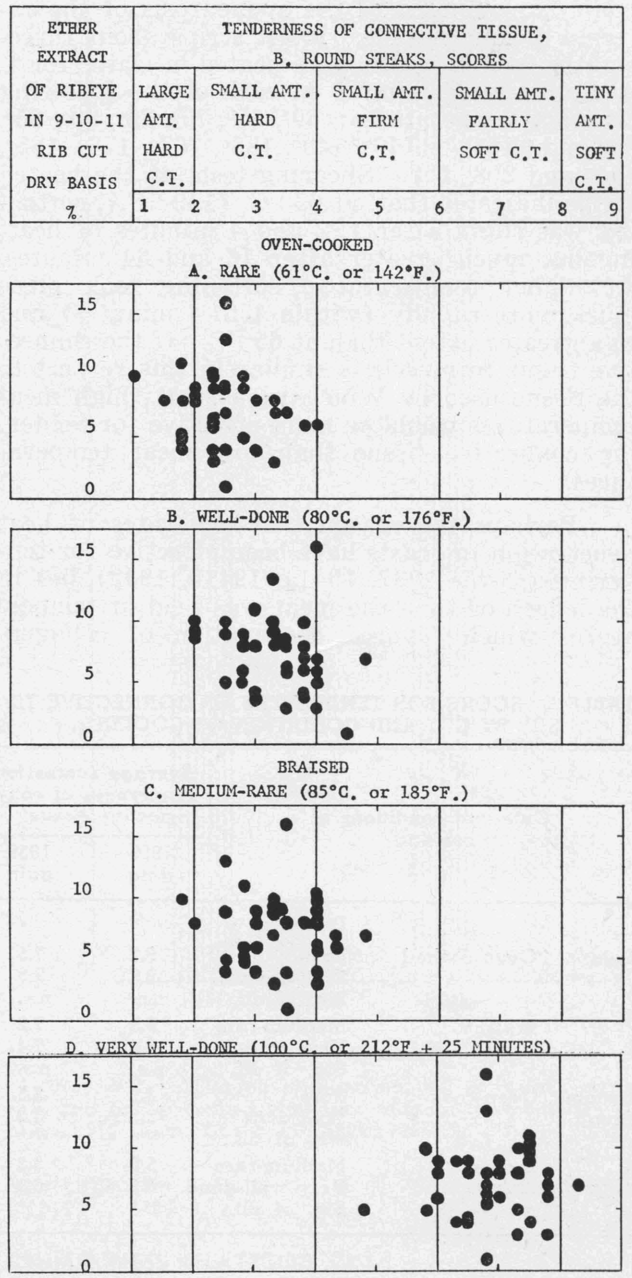


Figure 13. Ether extract plotted against tenderness of connective tissue for four conditions of cooking. Bottom round steaks from 36 Bluebonnet steers, 1958.

That degradation of *collagen in muscle tissue* does not require moist heat, in the sense of added moisture, has been indicated by chemical tests in this laboratory. Irvin and Cover (1959) found that about 25 percent of the collagen nitrogen in raw meat was lost when loin and bottom round steaks were oven-cooked rare to only 142° F. (Figure 14.) These tests were made on 26 of the 1956 steers and the oven-cooking of the test steaks was done as described here — for a short time by a dry heat method. Cover and Smith (1956) reported that about 45 percent of the collagen nitrogen in raw meat was lost when loin and bottom round steaks from 13 steers were cooked well-done by dry heat in a broiler (Figure 15) but under conditions much less well standardized than those of Irvin and Cover. Whether similar observations would be obtained with meat taken from animals older or younger than these is not known.

That higher temperatures and longer time of heating influence tendering of connective tissue has been shown by Winegarden *et al.* (1952). They used strips of connective tissue taken from the external portion of the aponeurotic sheet. This sheet is a large triangular piece of connective tissue from the flank region and the external portion is the upper and superficial part which is composed of the aponeurosis of the external oblique muscle. Moist strips about three-eighths inch in width were heated in water for 1, 2, 4, 16 and 64 minutes at each of the following constant temperatures: 60°, 65°, 70°, 75°, 80°, 85°, 90° and 95° C. (140°, 149°, 158°, 167°, 176°, 185°, 194° and 203° F.). Shearing tests on the heated strips indicated that, at 65° C. (149° F.), softening was slight after 1, 2 and 4 minutes of heating but much greater after 16 and 64 minutes. At higher temperatures, softening took place much more rapidly (within 1 to 4 minutes) and to a greater extent than at 65° C. If the connective tissue in muscle is similar in this respect to the tissue used by Winegarden *et al.*, high meat temperatures would be more effective for tendering connective tissue than low meat temperatures.

Perhaps the reason that low rates of heat penetration in roasts have been effective for tendering (Cover 1937, 1941a, 1941b, 1943) lies in the length of time the meat was held at temperatures which favored degradation of collagen.

TABLE 3. SCORE FOR TENDERNESS OF CONNECTIVE TISSUE BY CUT AND CONDITION OF COOKING

Cuts and conditions of cooking[1]			Average scores for tenderness of connective tissue[2] 1956 data	1958 data
		Doneness		
Loin	Oven-cooked	Rare	9.2	7.5
		Well-done	9.6	7.5
		Sig. of dif.	n.s.	n.s.
	Braised	Medium-rare	9.5	7.2
		Very well-done	9.4	7.4
		Sig. of dif.	n.s.	n.s.
Bottom round	Oven-cooked	Rare	3.1	2.5
		Well-done	5.5	3.3
		Sig. of dif.	***	***
	Braised	Medium-rare	5.0	3.3
		Very well-done	9.3	6.9
		Sig. of dif.	***	***
		Cuts		
Oven-cooked	Rare	Loin	9.2	7.5
		Bottom round	3.1	2.5
		Sig. of dif.	***	***
	Well-done	Loin	9.6	7.5
		Bottom round	5.5	3.3
		Sig. of dif.	***	***
Braised	Medium-rare	Loin	9.5	7.2
		Bottom round	5.0	3.3
		Sig. of dif.	***	***
	Very well-done	Loin	9.4	7.4
		Bottom round	9.3	6.9
		Sig. of dif.	n.s.	**

n.s., ** and *** indicate significance above 5 percent level, at 1 percent and 0.1 percent levels respectively.

[1]The final meat temperature was 142°F. for oven-cooked rare; 176°F. for oven-cooked well-done; 185°F. for braised medium-rare; and 212°F. and held there for 25 minutes for braised very well-done.

[2]There were 55 steers in 1956 and 36 in 1958. An 11-point scale for scoring was used in 1956 and a 9-point scale in 1958.

When tendering was most pronounced, the heat penetration curves were most flattened. Under normal household oven temperatures (Cover 1937, 1941b) this flattening or low rate of heat penetration occurred between 65° C. and 80° C. (149° F. and 176° F.). It is not surprising, therefore, that several hours in this temperature range caused tendering of the connective tissue in those roasts with much connective tissue.

The connective tissue scores reported here show large differences between cuts cooked alike and also within one cut cooked under different conditions. It should be pointed out that connective tissue scores are subjective evidence of the ease of mastication of the connective tissue. They may distinguish between little and much of the same kind of connective tissue or they may reflect differences in the kind of connective tissue. They do not distinguish well between quantity and kind of connective tissue. A scoring system which would make this distinction has not yet been developed. Perhaps it may be delayed until the chemistry of connective tissue in muscles is further advanced. Possible causes of tough connective tissue may include a high concentration of one form of collagen; a higher proportion of a dense form of collagen in relation to less dense forms; the presence of other connective tissue proteins in addition to collagen; or some combination of these three. At present it seems advisable not to exclude any of these possibilities. Although the work reported here appears to favor the theory that a high concentration of one form of collagen was the major cause of toughness, such an interpretation may have to be modified later.

Tenderness Characterized by Scores for Crumbliness of Muscle Fibers

The muscle fibers were affected in a noteworthy way by some of the conditions of cooking. It is usually thought that tender meat is cut easily by the teeth into small, soft, irregularly shaped pieces during mastication. Under certain conditions of cooking, however, the fragments were so small, hard and dry that the meat felt mealy or even powdery in the mouth. These seem unusual adjectives to apply to meat. Meat of mealy texture probably has undergone profound physical and chemical changes in the structure of the muscle fibers. Scores for crumbliness, if obtained in a systematic way, might provide a possible method of recording these gross changes. Such a systematic record might be related later to histological and chemical investigations. Because this characteristic is exceedingly complex, considerable work remains to be done on selecting adjectives which characterize it most adequately. For that reason only a brief

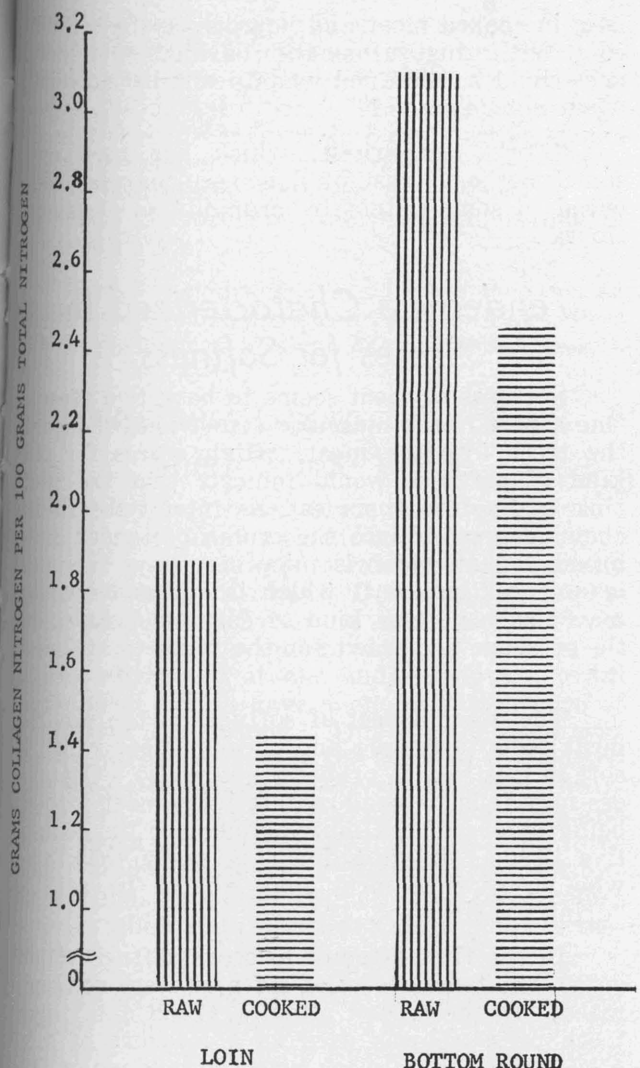


Figure 14. Collagen nitrogen content of 1-inch steaks raw and oven-cooked rare to an internal temperature of 142° F. (26 of the 1956 steers, Irvin and Cover 1960).

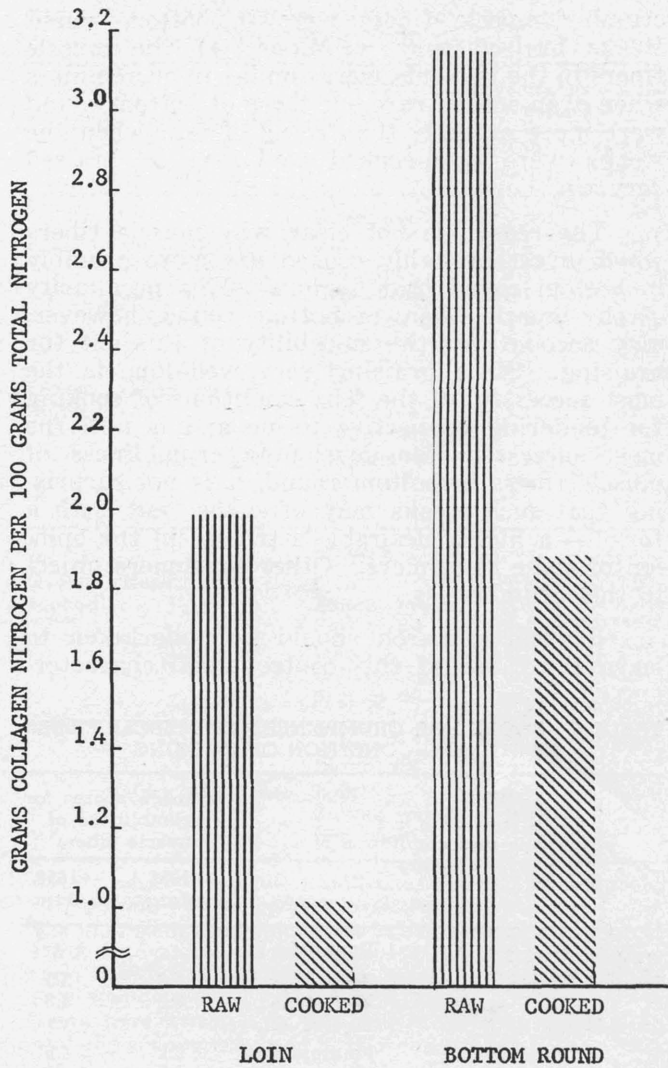


Figure 15. Collagen nitrogen content of ¾-inch steaks raw and broiler-cooked well-done without thermometers (13 of the 1954 steers, Cover and Smith 1956).

resume of the work already done will be presented here.

Low scores for crumbliness were given when the muscle fibers did not break readily across the long axis—a characteristic of tough muscle fibers. Moderate scores were given when the fibers broke fairly easily across the long axis and into rather small pieces. High scores were given when the fibers broke readily across the long axis and into very small pieces. With the highest scores the meat seemed "mealy" or even "powdery" in the mouth—an undesirable sensation to the authors. High scores for crumbliness were associated with tiny, hard, dry particles which seemed to roll out of the connective tissue network. If this network disintegrated, the entire piece of meat crumbled easily on pressure by the teeth.

In 1956 an 11-point scale was used (0-10). In 1958 it was reduced to a 9-point scale by omitting the zero and 10 of the 11-point scale (1-9).

CRUMBLINESS RELATED TO CUT AND CONDITION OF COOKING

Average scores for crumbliness of muscle fibers by cuts and conditions of cooking in each of the 2 years are given in Table 4. Significance of the difference was determined by analyses of variance. The actual scores vary with the year. The change from an 11-point scale in 1956 to a 9-point scale in 1958 could have caused some of this variation. Other causes could be differences in animals, in personnel on the panels and in personnel doing the cooking. Yet the similarity in trends for each of the years is remarkable. These similar trends are: 1) in loin steaks, crumbliness of muscle fibers increased with doneness during oven-cooking but not during braising; 2) in bottom round steaks, crumbliness of muscle fibers increased with doneness during both oven-cooking and braising; 3) the most crumbly muscle fibers were in bottom round steaks braised very well-done; 4) the muscle fibers in the two cuts were similar in crumbliness when oven-cooked rare but those of bottom round were more crumbly than those of loin when the steaks were oven-cooked well-done or braised very well-done.

The reason is not clear why muscle fibers which are thoroughly cooked are more crumbly in bottom round than in loin. This peculiarity of the muscle fibers of bottom round, however, may account for the suitability of this cut for braising. Since braising very well-done is the most successful of the four conditions of cooking for tendering connective tissue and is also the most successful for developing crumbliness of muscle fibers in bottom round, it is not surprising that such steaks may often be "cut with a fork" — a highly desirable attribute in the opinion of some consumers. Other consumers object to this crumbliness.

Further research should be undertaken to learn the cause of this controversial characteristic in cooked meat and how it may be controlled. With this information available, crumbliness could be obtained when desired but averted when not desired.

"Fork" tenderness, which has been used sometimes as a test of doneness, may be influenced to some extent by crumbliness of muscle fibers.

TABLE 4. SCORE FOR CRUMBLINESS OF MUSCLE FIBERS BY CUT AND CONDITION OF COOKING

Cuts and conditions of cooking[1]			Average scores for crumbliness of muscle fibers[2] 1956 data	1958 data
		Doneness		
Loin	Oven-cooked	Rare	5.3	3.3
		Well-done	6.3	4.6
		Sig. of dif.	***	***
	Braised	Medium-rare	6.2	4.5
		Very well-done	6.5	4.6
		Sig. of dif.	n.s.	n.s.
Bottom round	Oven-cooked	Rare	5.6	3.7
		Well-done	7.1	5.9
		Sig. of dif.	***	***
	Braised	Medium-rare	6.7	5.6
		Very well-done	8.0	7.1
		Sig. of dif.	***	***
		Cuts		
Oven-cooked	Rare	Loin	5.3	3.3
		Bottom round	5.6	3.7
		Sig. of dif.	n.s.	n.s.
	Well-done	Loin	6.3	4.6
		Bottom round	7.1	5.9
		Sig. of dif.	**	***
Braised	Medium-rare	Loin	6.2	4.5
		Bottom round	6.7	5.6
		Sig. of dif.	n.s.	***
	Very well-done	Loin	6.5	4.6
		Bottom round	8.0	7.1
		Sig. of dif.	***	***

n.s., **, and *** indicate significance above 5 percent level, at 1 percent and 0.1 percent levels respectively.

[1]The final meat temperature was 142°F. for oven-cooked rare; 176°F. for oven-cooked well-done; 185°F. for braised medium-rare; and 212°F. and held there for 25 minutes for braised very well-done.

[2]There were 55 steers in 1956 and 36 in 1958. An 11-point scale for scoring was used in 1956 and a 9-point one in 1958.

Tenderness Characterized by Scores for Softness

Softness of meat seems to have two aspects. One aspect is the muscular effort needed to sink the teeth into the meat. High scores for this kind of softness would indicate that the teeth sink easily into the meat, as into well-softened chewing gum or into the crumb of tender cornbread. Meat which is juicy may have this kind of softness but meat which is dry and crumbly may also have this kind of softness because little pressure is needed for the teeth to sink into it.

The other aspect of softness is the way the meat feels to tongue and cheek. Meat which is soft in this way is probably juicy also. Consumers may tend to swallow soft juicy meat without being aware of the muscle fibers or the connective tissue. It slips down so easily that those who enjoy rare meat may almost be said to "drink" their meat.

In the first attempt to score softness (1956 data), the two aspects of softness were not separated. In the second attempt (1958 data), only tooth pressure was used as a measure of softness. Much more work needs to be done on this characteristic. For this reason only a brief resume of the work already done will be presented here.

In 1956 an 11-point scale was used (0-10). In 1958 it was reduced to a 9-point scale by omitting the zero and 10 of the 11-point scale (1-9).

SOFTNESS RELATED TO CUT AND CONDITION OF COOKING

Average scores for softness by cuts and conditions of cooking in each of the 2 years are given in Table 5. Significance of the differences was determined by analyses of variance. The actual scores vary somewhat with the year. The change from an 11-point scale in 1956 to a 9-point scale in 1958 could have caused some of this variation. Changes in definition of softness could have had some effect also. Nevertheless, similar trends for these 2 years may be observed: 1) in loin steaks, softness decreased with doneness for oven-cooking and perhaps for braising also; 2) in bottom round steaks, softness decreased with doneness for oven-cooking but increased with doneness for braising; 3) bottom round steaks were softer than loin steaks only when braised very well-done. The round steaks may have been softer than the loin steaks when braised very well-done because of the more extreme crumbliness of the muscle fibers. This extreme crumbliness of the muscle fibers in bottom round steaks by this method of cooking permitted the teeth to sink in easily—the criterion of softness in the 1958 data and probably the predominate one in the 1956 data.

"Fork" tenderness, which has been used sometimes by homemakers as a test of doneness may be influenced to some extent by softness.

Tenderness Characterized by Shear Force Value

Shear force value is the most widely used objective method of measuring tenderness. The shear force values were obtained on a specially prepared sample of meat. This sample was prepared by turning back and forth under slight pressure a metal cylinder (one-half inch in diameter, sharpened at one end) along the grain of the meat. This gave a one-half inch core of meat about 1 inch long. This core of meat was cut across the grain with the knife of the electrically powered mechanical device (Warner-Bratzler Shearing Device). The knife is v-shaped and has a smoothly rounded cutting edge. The force needed to do the shearing (cutting) is registered in pounds on a dial. Higher shear force values indicate tough meat and low values indicate tender meat.

Cutting a core with the grain of the meat requires considerable care. The direction of the grain is found by pulling fibers from the outside edge of the steak. *For 1-inch loin steaks,* the corer has to be slanted from the perpendicular to follow the grain of the meat. The direction of the slant for the portion of the steak nearest the spines is different from that for the end farthest from the spines. *For 1-inch bottom round steaks,* where the grain of the meat runs more nearly parallel to the surface than it does in loin steaks, the samples have been taken in different ways. With the 1956 data the corer was inserted almost perpendicular to the top surface of the steak, even though it did not follow the grain closely. Shear force was measured by carefully adjusting the position of the core in the machine so that the shearing was done across the grain. With the data for 1958 a section from each end of the steak was cut with a knife and turned on its side. Then the corer was slanted to follow closely the grain of the meat. The cores for bottom round in 1958 followed the grain as closely as did those from the loin.

SHEAR FORCE VALUE RELATED TO CARCASS GRADE

USDA carcass grade was plotted against shear force value in Figures 16 and 17 for the 1956 steers, and Figures 18 and 19 for the 1958 steers. In the previous graphs low scores for tough steaks were placed at the left of the graphs, while high scores for tender steaks were at the right. To avoid confusion in comparing trends in shear force values with trends in panel scores, the high shears indicating tough meat were placed at the left and the low shears indicating tender meat at the right.

For the individual who likes rare steaks, the tenderness of the loin steaks from most of these animals would have been reasonably satisfactory regardless of carcass grade, when they were oven-cooked rare. This was indicated by the low shear force values (A) in Figures 16 and 18. However, some individuals will not eat rare meat. When loin steaks were cooked under the other three conditions (B, C, D) some of the carcasses would have given reasonable satisfaction for tenderness. These loin steaks of satisfactory tenderness were not limited to carcasses of high USDA grade. Yet a tendency toward high shear (tough meat) with the more thoroughly cooked meat was noticeable in some carcasses from Standard and Good grades. The wide variation in tenderness of different carcasses falling in

TABLE 5. SCORE FOR SOFTNESS BY CUT AND CONDITION OF COOKING

Cuts and conditions of cooking[1]			Average scores for softness[2] 1956 data	1958 data
		Doneness		
Loin	Oven-cooked	Rare	7.5	7.0
		Well-done	5.2	5.7
		Sig. of dif.	***	***
	Braised	Medium-rare	4.9	5.6
		Very well-done	4.7	5.1
		Sig. of dif.	n.s.	**
Bottom round	Oven-cooked	Rare	7.6	6.4
		Well-done	5.2	5.3
		Sig. of dif.	***	***
	Braised	Medium-rare	4.7	5.0
		Very well-done	5.9	5.8
		Sig. of dif.	***	***
		Cuts		
Oven-cooked	Rare	Loin	7.5	7.0
		Bottom round	7.6	6.4
		Sig. of dif.	n.s.	***
	Well-done	Loin	5.2	5.7
		Bottom round	5.2	5.3
		Sig. of dif.	n.s.	**
Braised	Medium-rare	Loin	4.9	5.6
		Bottom round	4.7	5.0
		Sig. of dif.	n.s.	***
	Very well-done	Loin	4.7	5.1
		Bottom round	5.9	5.8
		Sig. of dif.	***	***

n.s., **, and *** indicate significance above 5 percent level, at 1 percent and 0.1 percent levels respectively.

[1]The final meat temperature was 142°F. for oven-cooked rare; 176°F. for oven-cooked well-done; 185°F. for braised medium-rare; and 212°F. and held there for 25 minutes for braised very well-done.

[2]There were 55 steers in 1956 and 36 in 1958. An 11-point scale for scoring was used in 1956 and a 9-point one in 1958.

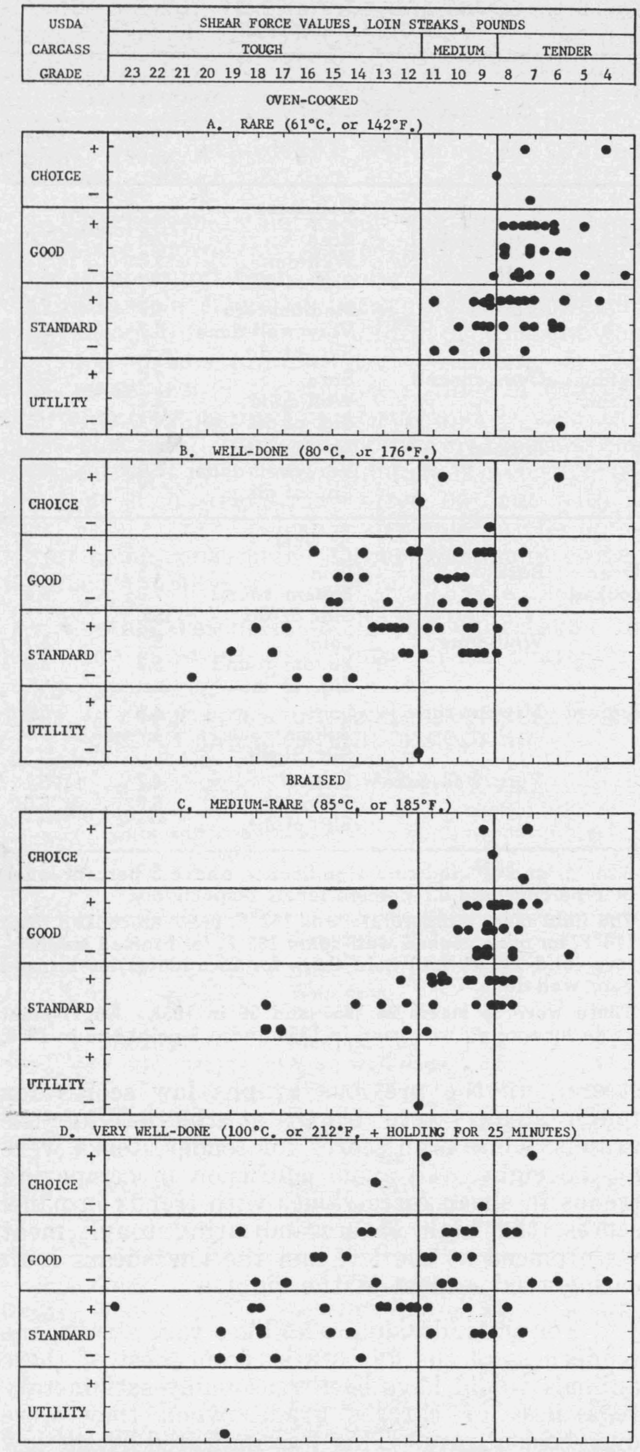


Figure 16. Carcass grade plotted against shear force value for four conditions of cooking. Loin steaks from 55 Bluebonnet steers, 1956.

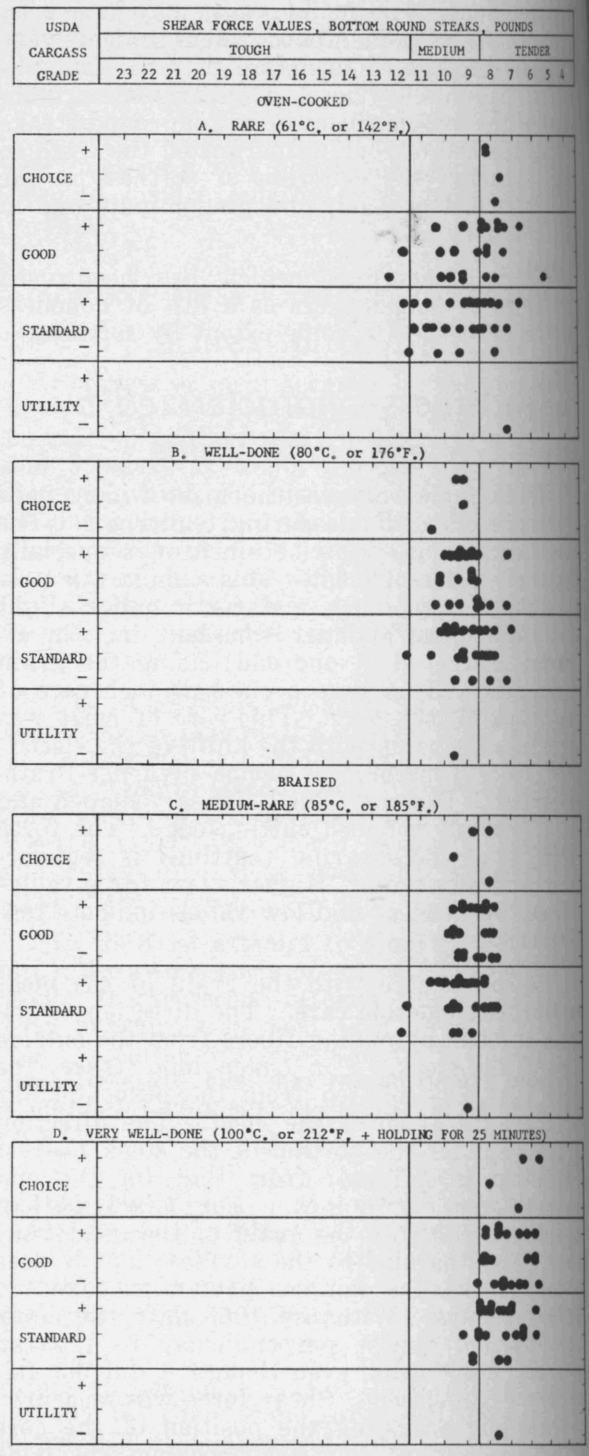


Figure 17. Carcass grade plotted against shear force value for four conditions of cooking. Bottom round steaks from 55 Bluebonnet steers, 1956.

each of these grades indicates that factors other than those which determine USDA carcass grade are involved in tenderness.

SHEAR FORCE VALUE RELATED TO ETHER EXTRACT

Percentage of ether extract in trimmed ribeye muscle was plotted against shear force value in Figures 20 and 21 for the 1956 steers, and Figures 22 and 23 for the 1958 steers. These graphs show that steaks from many carcasses with low percentage ether extract in ribeye were not only tender but as tender as those from other carcasses with higher percentage ether extract. It seemed that marbling as measured by ether extract could have had little practical effect on shearing tenderness of meat.

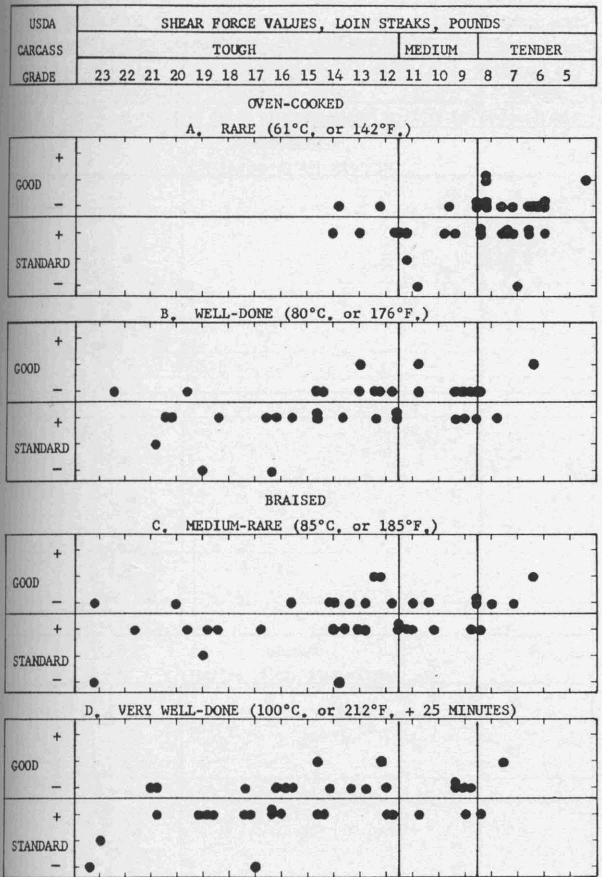


Figure 18. Carcass grade plotted against shear force value for four conditions of cooking. Loin steaks from 36 Bluebonnet steers, 1958.

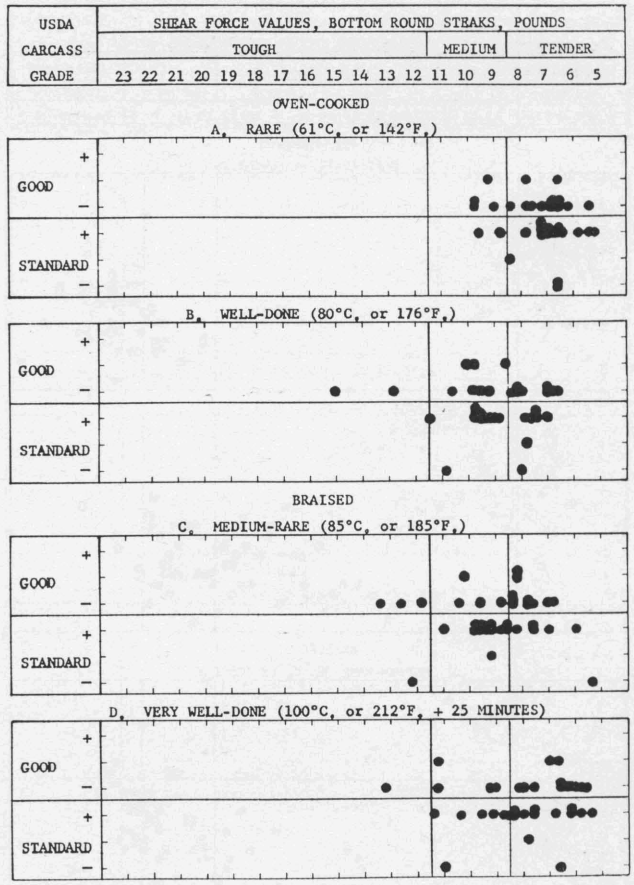


Figure 19. Carcass grade plotted against shear force value for four conditions of cooking. Bottom round steaks from 36 Bluebonnet steers, 1958.

SHEAR FORCE VALUE RELATED TO CUT AND CONDITION OF COOKING

Shear force values for each cut and condition of cooking may be observed in Figures 16 through 23. The range of shear force value was much wider for loin than for botton round steaks.

Loin steaks (Figures 16, 18 or 20, 22) had the lowest shear force values (most tender) when oven-cooked rare (A). When they were oven-cooked well-done (B) they had somewhat higher shear force values indicating that the meat was somewhat tougher. Cooking by moist heat did not seem to be effective for obtaining uniformly low shear force values (tender meat) in these loin steaks.

Ranges in shear force values for bottom round steaks (Figures 17, 19 or 21, 23) oven-cooked well-done (B) in both years were much narrower than those for loin steaks. This is true also for bottom round steaks braised to 185° F. (C) and to 212° F. (D). High internal temperature of the steak appears to have had less toughening effect in bottom round steaks than in loin steaks. Some possible implications of these observations will be discussed in a subsequent technical article.

Shear force values averaged by cuts and conditions of cooking in each of the 2 years are given in Table 6. Significance of the differences was determined by analyses of variance. The actual shear force values vary from year to year as would be expected. The trends which were similar within each of the years are: 1) loin steaks had lower shear force values (more tender) when oven-cooked rare than by any of the other three conditions of cooking; 2) bottom round steaks had lower shear force values (more tender meat) than loin steaks when both were oven-cooked well-done and when both were braised very well-done.

RELATION OF SHEAR FORCE VALUES TO PANEL SCORES

For some time there has been considerable speculation about the relationship of the objective measurement shear force value to the subjective measurement panel score. Do shear force values and panel scores measure the same thing? Do they follow the same trends when used together?

When panel ratings were based on one composite score for tenderness, some workers have reported that the agreement between the two measures of tenderness was close but others have found it to be less close. Coefficients of correlation between score for tenderness and shear

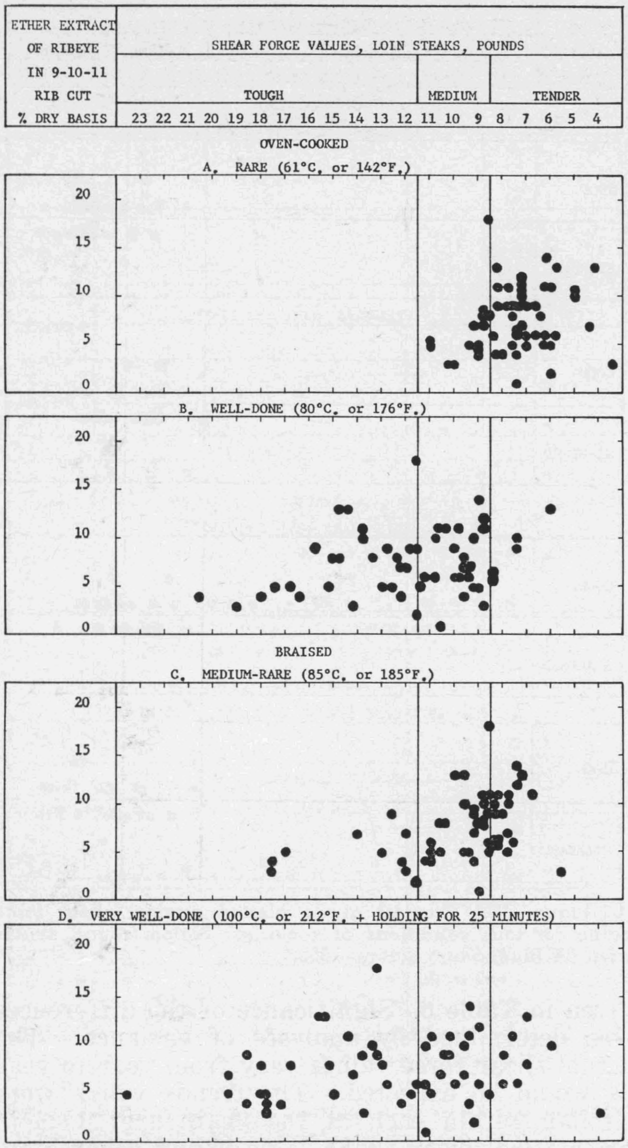


Figure 20. Ether extract plotted against shear force value for four conditions of cooking. Loin steaks from 55 Bluebonnet steers, 1956.

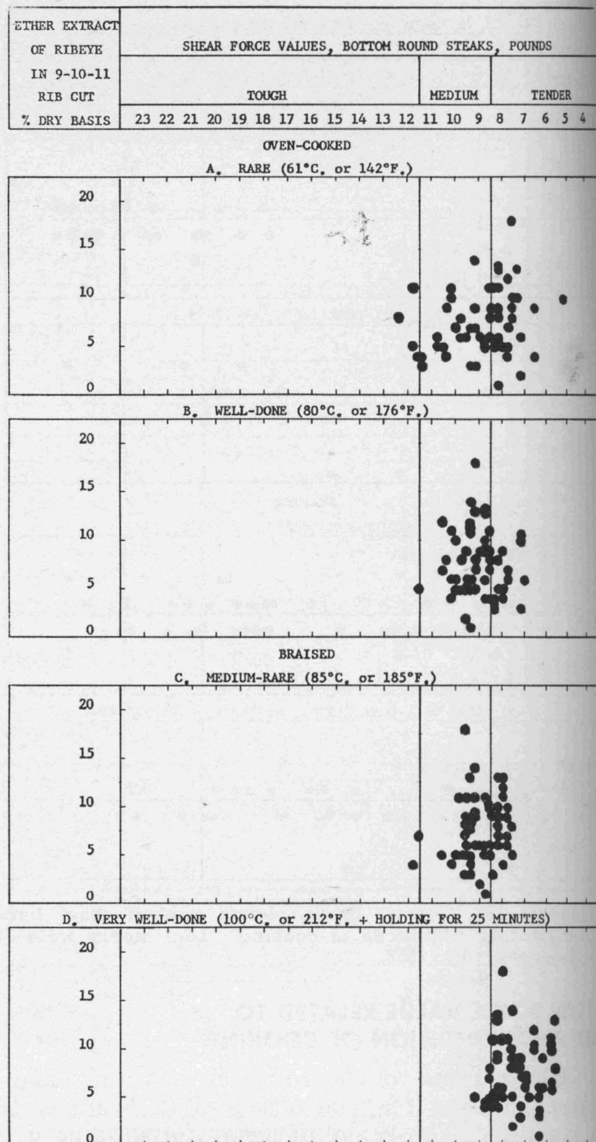


Figure 21. Ether extract plotted against shear force value for four conditions of cooking. Bottom round steaks from 55 Bluebonnet steers, 1956.

force value which have been reported for beef are: 0.9 for 50 muscles cooked in lard at 250° F. (Ramsbottom and Strandine, 1945); -.839 and -.891 for broiled and braised loin steaks and -.730 and -.863 for broiled and braised bottom round steaks (Cover and Smith, 1956); -.369 for steaks oven-cooked at 232° C (450° F.) and -.404 for braised steaks (Paul, Bean and Bratzler, 1956).

When attempts were made in this study to relate shear force value to tenderness of connective tissue and to the other components of tenderness, problems were encountered which are beyond the scope of this bulletin. They will be discussed in a subsequent technical paper. It is apparent that there is no simple answer to the question, what components of tenderness do shear force values measure?

Although, shear force value may later be shown to be less than a perfect measure of total tenderness for all cuts, it could continue to have a place as a research tool. The data obtained with this method vary in such remarkable ways with cuts and method of cooking that they may stimulate new work of a basic nature.

Discussion

Tenderness in this study has been related to carcass grade and marbling in two ways: shear force value and score for tenderness of connective tissue. Because other research workers will need statistical measures for comparison with their own data, the coefficients of correlation for carcass grade and ether extract with each of the two measures of tenderness are given in Table 7.

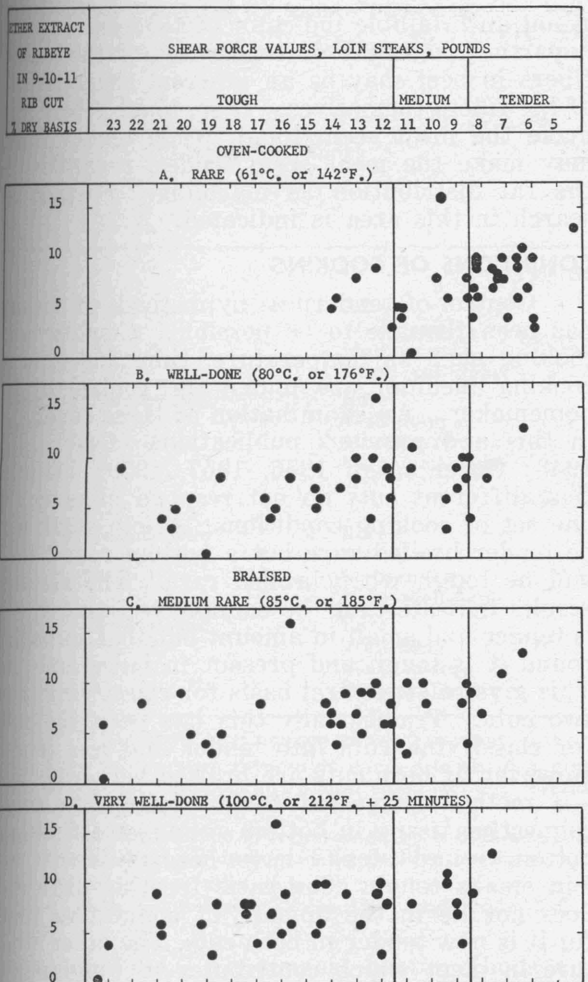


Figure 22. Ether extract plotted against shear force value for four conditions of cooking. Loin steaks from 36 Bluebonnet steers, 1958.

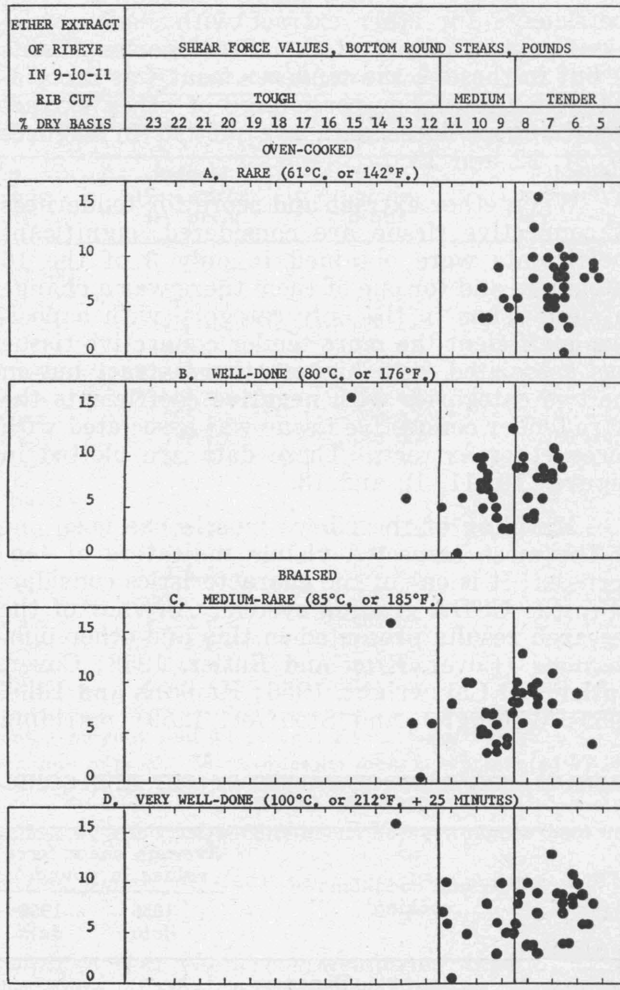


Figure 23. Ether extract plotted against shear force value for four conditions of cooking. Bottom round steaks from 36 Bluebonnet steers, 1958.

GRADES

Significant coefficients for shear force value with carcass grade were obtained in only 5 of the 16 categories but in these 5 the tenderer meat was associated with the higher carcass grade. An oddity may be noted in oven-cooked loin steaks. The coefficients were not significant for rare but were significant for well-done in both years. What importance, if any, should be attached to this observation is not clear at present because of the wide range in shears within the grades cooked well-done (Figures 16 and 18). Moreover in 1955 with 31 steers and in 1957 with 30 steers the coefficients were not significant for well-done oven-cooked loin steaks.

When the relationship of carcass grade to score for tenderness of connective tissue is considered, significant coefficients were obtained in only 3 of the 16 categories — one of which was opposite in sign. This means that in the two categories with positive coefficients, the more tender connective tissue was associated with carcasses of higher grade but in another category with a negative coefficient the meat with the tougher connective tissue was associated with carcasses of higher grade. These data are plotted in Figures 6, 7, 8 and 9.

USDA official grades have been regarded as indicators of meat "quality." Since homemakers regard tenderness as an indispensable characteristic of "quality," they expect it in meat from carcasses of high USDA grades. Much promotional and educational literature contains such statements as "If you want your steaks to be tender, buy U. S. Prime or U. S. Choice grades." In view of the research results in this and previous publications such recommendations do not identify all of the carcasses with reasonably tender meat. Work to discover causes of tenderness or toughness in meat so that this characteristic may be labeled in buying and selling can be regarded as looking toward quality control for the beef industry. It has possibilities of effecting savings to the homemaker, the retailer, the packer and the producer.

MARBLING

Marbling was measured in this study by the percentage of ether extract on the dry basis. The coefficients for ether extract with shears were significant in only 4 of the 16 categories (Table 7) but in these 4, the tenderer meat was associated with the higher percentage of ether extract (marbling). These data are plotted in Figures 20, 21, 22 and 23.

When ether extract and score for tenderness of connective tissue are considered, significant coefficients were obtained in only 3 of the 16 categories and for one of them there was a change in sign. Thus in the only category with a positive coefficient the more tender connective tissue was associated with higher ether extract but in the two categories with negative coefficients the more tender connective tissue was associated with lower ether extract. These data are plotted in Figures 10, 11, 12 and 13.

Marbling of the ribeye muscle has been one of the most respected visible indicators of tenderness. It is one of the characteristics considered in the USDA grading system. In view of the research results presented in this and other publications (Cover, King and Butler, 1958; Cover, Butler and Cartwright, 1956; Hankins and Ellis, 1959; Wellington and Stouffer, 1959) marbling

TABLE 6. SHEAR FORCE VALUES BY CUT AND CONDITION OF COOKING

Cuts and conditions of cooking[1]			Average shear force values in pounds[2] 1956 data	1958 data
		Doneness		
Loin	Oven-cooked	Rare	7.4	8.7
		Well-done	11.8	13.4
		Sig. of dif.	***	***
	Braised	Medium-rare	9.7	13.5
		Very well-done	12.5	14.9
		Sig. of dif.	***	n.s.
Bottom round	Oven-cooked	Rare	8.9	7.3
		Well-done	9.0	9.0
		Sig. of dif.	n.s.	*
	Braised	Medium-rare	9.0	8.9
		Very well-done	7.4	8.0
		Sig. of dif.	***	n.s.
		Cuts		
Oven-cooked	Rare	Loin	7.4	8.7
		Bottom round	8.9	7.3
		Sig. of dif.	***	n.s.
	Well-done	Loin	11.8	13.4
		Bottom round	9.0	9.0
		Sig. of dif.	***	***
Braised	Medium-rare	Loin	9.7	13.5
		Bottom round	9.0	8.9
		Sig. of dif.	n.s.	***
	Very well-done	Loin	12.5	14.9
		Bottom round	7.4	8.0
		Sig. of dif.	***	***

n.s., *, and *** indicate significance above 5 percent level, at 5 percent and 0.1 percent levels respectively.

[1]The final meat temperature was 142°F. for oven-cooked rare; 176°F. for oven-cooked well-done, 185°F. for braised medium-rare; and 212°F. and held there for 25 minutes for braised very well-done.

[2]There were 55 steers in 1956 and 36 in 1958.

is not an infallible indicator of tenderness. Perhaps the toughness or tenderness of the muscle fibers in beef may be an inherent characteristic of the fibers themselves. If so, tough fibers may make the meat seem tough while tender fibers may make the meat seem tender, regardless of the fat distribution as marbling. Further research in this area is indicated.

CONDITIONS OF COOKING

Control of tenderness by methods of cooking has been thought to be possible. Conditions of cooking such as temperature, time and kind of cooking medium are under the control of the homemaker. An examination of these conditions in this and previous publications (Cover 1937, 1943; Cover *et al.* 1956, 1957, 1959) indicates that different cuts do not respond alike to any one set of cooking conditions. A loin steak may be tender broiled rare but a bottom round steak will be tough when broiled rare. The research results indicate that the connective tissue in loin is tender and small in amount but that in bottom round it is tough and present in large amounts. This gives a structural basis for classifying these two cuts. Traditionally this has been the basis for classifying cuts into tender and less tender. However, if both cuts are braised very well done —a method suggested for tendering the tough connective tissue in bottom round—we find that bottom round steaks have become tender and loin steaks tough. The basis for this difference does not lie in the amount of connective tissue for it is now tender in both cuts. The other structure in meat which contributes to toughness is the muscle fiber. The muscle fibers in loin steaks appear to be toughened by heat much more than those of bottom round steaks. The muscle fibers of the two cuts differ in some inherent manner which is not clear at present. However, this inherent tenderness difference between muscle fibers of different cuts from the same animal should stimulate further research of a basic nature.

The degree of tendering of connective tissue appears to depend on the meat temperature reached and also on either the time to reach this temperature or on the time the final meat temperature is maintained. The time to reach those meat temperatures, which are effective for tendering connective tissue, depends not only on the temperature of the cooking medium but on the kind of cooking medium. For cooking media such as water or steam (moist heat), the rate of heat penetration is high even at low cooking temperatures (194-212° F.). For a cooking medium such as air, the rate of heat penetration is low even for cooking temperatures (257° F.) which are considerably higher than the moist heat temperatures. Thus moist heat methods, such as braising, have high rates of heat penetration and the meat temperatures quickly reach the temperature of the medium. For the rest of the cooking period the meat is held at the temperature of the

TABLE 7. CORRELATION OF SHEAR FORCE VALUE AND SCORE FOR CONNECTIVE TISSUE WITH U.S. CARCASS GRADE AND ETHER EXTRACT

Cuts and conditions of cooking			Coefficients of correlation			
			Shear force value versus[1]		Score for tenderness of connective tissue versus[2]	
			U.S. carcass grade[3]	Percent ether extract dry basis	U.S. carcass grade[3]	Percent ether extract dry basis
			1956 data (55 steers)			
Loin	Oven-cooked	Rare	—.257 n.s.	—.226 n.s.	+.141 n.s.	—.005 n.s.
		Well-done	—.319 *	—.257 n.s.	+.034 n.s.	—.029 n.s.
	Braised	Medium-rare	—.492 ***	—.404 **	+.195 n.s.	+.183 n.s.
		Very well-done	—.227 n.s.	—.175 n.s.	+.203 n.s.	+.274 *
Bottom round	Oven-cooked	Rare	—.180 n.s.	—.231 n.s.	—.119 n.s.	—.301 *
		Well-done	+.064 n.s.	+.065 n.s.	—.209 n.s.	+.101 n.s.
	Braised	Medium-rare	—.236 n.s.	—.139 n.s.	—.068 n.s.	—.065 n.s.
		Very well-done	+.255 n.s.	—.050 n.s.	+.045 n.s.	+.127 n.s.
			1958 data (36 steers)			
Loin	Oven-cooked	Rare	—.254 n.s.	—.304 n.s.	+.087 n.s.	—.024 n.s.
		Well-done	—.416 *	—.414 *	+.560 ***	—.466 **
	Braised	Medium-rare	—.384 *	—.375 *	+.306 n.s.	+.231 n.s.
		Very well-done	—.456 **	—.418 *	+.336 *	+.256 n.s.
Bottom round	Oven-cooked	Rare	+.218 n.s.	—.165 n.s.	—.005 n.s.	—.137 n.s.
		Well-done	+.067 n.s.	+.078 n.s.	—.416 *	—.294 n.s.
	Braised	Medium-rare	+.052 n.s.	—.040 n.s.	—.238 n.s.	—.099 n.s.
		Very well-done	—.058 n.s.	+.010 n.s.	+.121 n.s.	+.056 n.s.

n.s., *, **, *** indicate significance above 5 percent, and at 5 percent, 1 percent, and 0.1 percent levels, respectively.

[1]Shear force values were in pounds needed to shear a one-half inch core of meat. Because tender meat is represented by low shear values and tough meat by high shear values, correlations between tender meat and high carcass grade are indicated by negative coefficients.

[2]Because connective tissue is represented by a high score and toughness by a low score, correlations between tender meat and high carcass grade are indicated by positive coefficients.

[3]USDA carcass grades were coded to one-third of each grade as follows: Canner 1-3, Cutter 4-6, Utility 7-9, Commercial 10-12, Standard 13-15, Good 16-18, Choice 19-21 and Prime 22-24.

cooking medium. Thus moist heat methods are convenient for obtaining the high meat temperatures needed for tendering the connective tissue quickly, even though the moisture in the moist heat methods is not needed to furnish water for the chemical change (hydrolysis) of collagen into gelatin.

"Simmering" (194-203° F.) is often referred to as low temperature cookery and much to be preferred to "boiling" (212° F.) which is spoken of as high temperature meat cookery. Meat temperatures reach 194-203° F. during "simmering" but 212° F. during boiling. Gentle boiling and vigorous boiling take place at the same temperature (212° F.). Vigorous boiling is accompanied by severe agitation which may break the meat into small pieces or strings. It should be noted that this may be the result of the mechanical beating and not of the temperature, *per se*. "Simmering" (194-203° F.) is thought to tender connective tissue and leave muscle fibers tender, while "boiling" has been thought to tender connective tissue but to toughen muscle fibers. Toughening of muscle fibers is indicated in this study by low scores for crumbliness. This toughening appeared to have already taken place by the time a meat temperature of 176-185° F. had been reached and little if any further toughening took place between 185° F. and 212° F. *Thus it appears that the recommendation that braising be done at the low temperature of simmering rather than at the high temperature of a gentle boil is of questionable value.* Further work along this line is indicated when equipment suitable for controlling temperatures at 190° F. ± 2° F. is available.

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Acknowledgment

This study was supported in part by Southern Regional Project SM-19 "Motivating Factors in Consumer Purchases of Beef as Related to Objective Measurements Used to Predict Beef Acceptability."