Modeled, multistage convection cooking of beef semitendinosus roasts to denature collagen and to optimize tenderness

T.H. Powell

Melvin C. Hunt

Michael E. Dikeman

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Abstract

In order to predict and establish cooking times and temperatures of beef to optimize tenderness and cooked yield, a computer model was developed utilizing heat and mass transfer theories. We cooked beef semitendinosus (eye of round) roasts in a forced-air convection oven using conventional or modeled, multistaged cooking. Conventional cooking was defined as cooking at 325EF to a core endpoint of 150EF. The model method was developed using a computer algorithm that predicted heat and moisture (mass) transfer during a three-stage cooking process that included preheating, holding, and finishing. The model was accurate in predicting actual cooking times and temperatures during cooking; temperature profile curves tracked closely between predicted and observed values. Roasts cooked by the modeled cooking regimen had lower Warner-Bratzler shear values than those cooked by conventional convection cooking. Collagen total unaltered fraction was lower (P<.05; 44 vs. 55%) and enzyme labile fraction was higher (56 vs. 45%, P<.05) in model cooked than in conventionally cooked samples. Cooking yield was not different for the modeled and conventional procedures. These results show that the modeled multi-stage cooking method was superior to the conventional cooking method.

Keywords

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MODELED, MULTISTAGE CONVECTION COOKING OF BEEF SEMITENDINOSUS ROASTS TO DENATURE COLLAGEN AND TO OPTIMIZE TENDERNESS

T. H. Powell, M. E. Dikeman, and M. C. Hunt

Summary

In order to predict and establish cooking times and temperatures of beef to optimize tenderness and cooked yield, a computer model was developed utilizing heat and mass transfer theories. We cooked beef *semitendinosus* (eye of round) roasts in a forced-air convection oven using conventional or modeled, multistaged cooking. Conventional cooking was defined as cooking at 325EF to a core endpoint of 150EF. The model method was developed using a computer algorithm that predicted heat and moisture (mass) transfer during a three-stage cooking process that included preheating, holding, and finishing. The model was accurate in predicting actual cooking times and temperatures during cooking; temperature profile curves tracked closely between predicted and observed values. Roasts cooked by the modeled cooking regimen had lower Warner-Bratzler shear values than those cooked by conventional convection cooking. Collagen total unaltered fraction was lower (P<.05; 44 vs. 55%) and enzyme labile fraction was higher (56 vs. 45%, P<.05) in model cooked than in conventionally cooked samples. Cooking yield was not different for the modeled and conventional procedures. These results show that the modeled multi-stage cooking method was superior to the conventional cooking method.

(Key Words: Tenderness, Modeling, Cooking, Semitendinosus, Collagen.)

Introduction

Mathematical models have been developed to predict cooking times and cycles of various kinds of meat products. We developed a model for cylindrical roasts from the *semitendinosus* (eye of round) muscle, known for its moderately high content of connective tissue. Conventional dry-heat cooking of high-connective tissue cuts, such as those from beef *semitendinosus* muscles, results in less tender meat in comparison to low-connective tissue cuts such as those from beef *longissiumus* muscles. The model was targeted for a forced-air-convection oven and was designed for easy adaption to software and computer equipment. We then used the model to assist in determining proper dry cooking times and temperatures to maximize tenderness of semitendinosus roasts. In previous work, we found a time-dependent denaturation of the insoluble portion of collagen that began at 131EF, with maximal denaturation occurring within 60 min at that temperature. This denaturation process resulted in tenderer meat. Above 131EF, the process occurred more quickly. On the other hand, tenderness can decrease at 158EF and above, largely due to myofibrillar hardening.

The purpose of our study was to develop and test a model to predict a dry-heat cooking regimen for beef *semitendinosus* roasts that would optimize tenderness by maximizing denaturation of the total unsolubilized fraction of collagen to the enzyme labile fraction of collagen and avoid myofibrillar toughening.

Experimental Procedures

We used six vacuum-packaged, A-maturity, USDA Choice, semitendinosus roasts to develop the mathematical prediction model. Ends were removed to make them cylindrical, and they were trimmed free of fat. The

finite-difference method, a numerical technique, was used to solve the simultaneous heat and mass transfer equations in developing the model. The model was used to predict a cooking cycle for each roast. The model accomplished the following objectives. The roasts were to be cooked in three cycles: preheating, holding, and finishing. The constraints of the preheating cycle were to heat the roasts as rapidly as possible until a point 1/4 of the distance from the end and surface of the roast reached 160EF. During the holding cycle, the oven temperature was lowered to 150EF. Heating at this temperature continued for 60 min. after the core of the roasts reached 130EF. During the finishing cycle, the core temperature was raised to the endpoint of 150EF.

Thermocouples were placed in four locations to monitor temperature during cooking in a 325EF gas oven until the endpoint temperature was reached. Cooking yields were calculated. To determine whether cooking using traditional roasting at a constant temperature in a forced-air-convection oven or the model-assisted- cooking was more effective, 12 A-maturity, USDA Choice semitendinosus roasts were prepared as described previously, and diameter and length were measured for use in the prediction model. Approximately 3.5 oz. of meat were obtained before cooking and frozen for chemical analyses. The control method of cooking consisted of placing an individual roast in a 325EF convection oven until the core temperature reached 150EF. Roasts were assigned randomly to either the modeled or conventional (control) cooking method and cooked individually. Temperature readings were obtained every 30 seconds. Cores (1/2 inch diameter) were taken from the cooked roasts to determine Warner-Bratzler shear force.

Two 1-inch-thick slices were obtained from the centers of the roasts, and five ½-inch cores parallel to muscle fiber orientation were obtained from each slice (total of 10 cores per roast). Cores were sheared using a Warner-Bratzler shear attachment on an Instron Universal Testing Instrument. Peak shear force, peak energy, and total energy were determined for each core and then averaged to create one value per roast. Approximately 3.5 oz. of meat were obtained from the remainder of the roast for chemical analysis. An effort was made to keep samples free of seam fat, connective tissue and crust. Total chemical fat and moisture were determined for both raw and cooked products. To determine the effects of modeled cooking on collagen denaturation, Ringer's- soluble fraction (RSF), enzyme-labile fraction (ELF), and total unaltered fraction (TUF) of collagen were determined.

Results and Discussion

Our model predicted cooking time within 4 min for all roasts except one. Additionally, temperature profile curves at the core and surface tracked closely between observed and predicted values (Figure 1). The model underpredicted moisture loss, because it did not account for physical water loss from myofibrillar contraction during heating. Peak shear force and total energy were lower (P<.05) in roasts cooked according to the model (Table 1). The model cooking technique takes advantage of the denaturation of collagen that occurs at 131EF and above, but keeps meat below the temperature (<149EF) where myofibrilla toughening occurs. Even with a much longer cooking time, cooking yields were the same as with conventional cooking (Table 2), apparently because of a relatively high air moisture content in the oven during the holding cycle.

Table 1. Effect of Cooking Method on Shear Force Measurements of Beef *Semitendinosus*

Variable	Model	Control	$P > F$
Peak force (kg)	3.3±.5	4.7±.2	>.001
Peak height (mm)	19.1±2.7	16.8±.7	.067
Peak energy (J)	16.4±5.0	14.5±2.5	.430
Total energy (J)	36.7±5.4	47.8±3.4	.002

The predicted cooking and holding times for the model roasts were very close to the observed values. Variance from the predicted values, particularly in the surface temperature measurements, can be attributed partially to the precision of the oven thermostat at low temperatures (below 210EF). In

some cases, short-term ventilation was required to cool the cooking environment, resulting in a loss of moisture in the oven, thereby slightly altering the actual cooking conditions from those predicted. Nevertheless, a reasonable estimate of cooking time was obtained from the computer model.

No differences were found in fat or moisture content between cooking methods (Table 2). Percentages of TUF were lower (P<.05) and those of ELF were higher (P<.05) for the model roasts than for the controls (Table 3). No differences were found in RSF between the two cooking methods. Shear force measurements, particularly peak force and total energy, were highly correlated (- .79 and - .80, respectively) with TUF.

The increased tenderness of the model roasts was due to a decrease in TUF collagen. Some of the other observed effects may have been related to the activity of collagenase.

These results suggest a mechanism for the improved tenderness of high-collagen meats with long-time, low temperature cooking. Changing the focus to the composition of the much larger insoluble collagen fraction was very informative with regards to the tenderness of the cooked product. The model multistage cooking method was superior to the control cooking method.

Table 2. Effect of Cooking Method on Cooking Yields and Proximate Composition of Beef *Semitendinosus* Roasts

Variable	Model	Control	*P>F*
Cooked yield, %	74.3 ± 3.6	73.0 ± 2.6	.46
Moisture (raw), %	72.3 ± .7	73.0 ± .7	.11
Fat (raw), %	2.6 ± .8	2.8 ± .8	.67
Moisture (cooked), %	63.4 ± 1.4	63.1 ± .8	.84
Fat (cooked), %	4.6 ± 1.4	3.4 ± .8	.28

Table 3. Effect of Cooking Method on Collagen Denaturation of Beef *Semitendinosus*

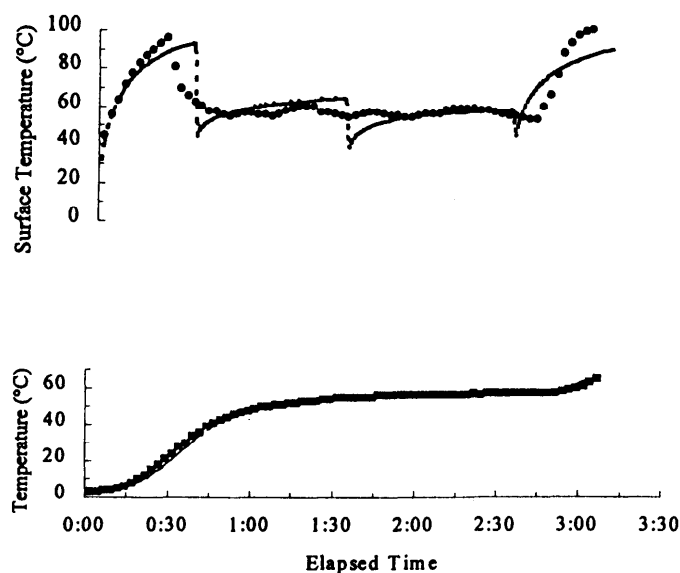| Collagen Fraction	Model	Control	*Pr>F*
RSF, %	8.0 ± .9	8.6 ± 1.1	.335
ELF, %	56.1 ± 8.9	44.7 ± 4.3	.030
TUF, %	43.9 ± 8.9	55.3 ± 4.3	.030

Figure 1. Temperature Histories (■ Core, Observed; ▬ Core, Predicted; ● Surface, Observed; - - - Surface, Predicted) for a Representative Beef *Semitendinosus* Roast Cooked in a Forced-air Convection Oven According to Model Specifications.