No Effect of Hydrodynamic Shock Wave on Protein Functionality of Beef Muscle

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ABSTRACT: The protein functionality of meat proteins after treatment with hydrodynamic shock wave was determined. Frankfurters (cooked to 71 °C) were evaluated for cooking yield, CIE L*a*b*, nitrosylhemochrome, Texture Profile Analysis (hardness, cohesiveness), and stress and strain (torsion testing). Compared to the control samples, the hydrodynamic shock waves (HSW) did not affect ($P > 0.05$) myofibrillar or sarcoplasmic protein solubility, cooking yield, or color. Textural properties and gel strength of the frankfurters were not affected ($P > 0.05$) by HSW. These results suggested that beef trim obtained from HSW-processed meat could be used interchangeably with normal meat trim in the production of further processed meats since the functionality of meat protein was not affected significantly by the HSW process.

Key Words: hydrodynamic shock wave, protein functionality

Introduction

THE MEAT INDUSTRY HAS BEEN CHALLENGED TO ATTAIN ACceptable beef tenderness with decreased aging time. Aging time increases storage, refrigeration, and labor costs (Meek 1998). The hydrodynamic shock wave (HSW) treatment (Hydrodyne Process redesigned by Long 1993, 1994) has been developed to instantaneously tenderize meat. The benefit of this process is that it can give top-quality tenderness to lower-grade cuts when treated in a plastic garbage can (Solomon, quoted in Raloff 1998). This process utilizes an explosion to create a shock wave in either a plastic garbage can or a specially designed enclosed tank filled with water. The shock wave travels through the water and objects that are a mechanical impedance match to the water (Kolsky 1963). Since meat is made up of approximately 75% water, the shock wave also travels through muscle and ruptures selected cellular components. Sarcomeres are ruptured at the Z-line and A-band/I-band juncture (Zuckerman and Solomon 1998).

Research on this tenderization process has demonstrated an increase in tenderness and a decrease in required aging time (Zuckerman and Solomon 1998; Solomon and others 1997a). However, no research has been reported concerning the effects of HSW on the functionality of meat protein destined for sausage manufacture, restructured meats, and ground beef.

Hydrostatic pressure (HP) effects on protein functionality have been well documented. HP is similar to the HSW treatment in that pressure is utilized for tenderization (Kennick and others 1980) but is dissimilar to HSW in the amount of time subjected to pressure and the method of pressure application. Hydrostatics is the study of characteristics of liquids at rest or the force that a liquid imposes on a submerged object (Zobell and Kim 1972). Mandava and others (1994) found that hydrostatic pressure increased cooking yield and improved texture of low-salt and low-phosphate frankfurters. High hydrostatic pressure over an extended period of time (5 to 30 min) increased tenderness as well as improved protein functionality characteristics and myofibrillar solubilization (MacFarlane and McKenzie 1976). Also, hydrostatic pressure improves the binding of comminuted meat and increases tensile strength (MacFarlane and others 1984). One major limitation of hydrostatic pressure is that the process has not yet been designed so that it can function in a time-efficient manner.

The 1st objective of this research was to determine the effects of the HSW process on cooking loss, cured color, cooked color, and texture of frankfurters manufactured from HSW-processed beef. The 2nd objective was to determine if this shock wave process affected protein solubility, individual proteins responsible for binding ability, and cleavage of peptide bonds.

Materials and Methods

Bovine raw materials

Bovine *Biceps femoris* (BF) muscles (n = 6, from 3 animals) were purchased from a meat-packing plant (Excel Corp., Dodge City, Kan., U.S.A.). The cuts were shipped via Federal Express and arrived the next day (4 °C). The muscle specifications were such that the muscle came from A maturity, USDA Select, Yield Grade 3 beef carcasses, aged 2 to 3 d, with a specified weight range of 4.5 to 6.0 kg for each muscle.

The proximal and distal end sections of the raw material were trimmed (5.0 to 8.0 cm). The muscle was cut into 4 equal sections. Sections were stored (1 to 2 mo) frozen (−15 °C) and thawed (4 °C for 36 h) prior to treatment. Three sections were exposed to the hydrodynamic shock wave treatment with varying explosive levels at Hydrodyne Inc. (Buena Vista, Va., U.S.A.). The other section served as a control. Both the control and hydrodynamic shock wave treatments were treated in the same manner excluding the shock wave process. Location of sections was chosen in a random manner using a random numbers table so that all areas of the muscle were processed by each of the 4 treatments. The sections were vacuum-packaged in polyolefin resin bags (Product code B2650, Cryovac Division of Sealed Air Corp., Duncan, S.C., U.S.A.).

Hydrodynamic shock wave process

The bagged samples were placed on the bottom center of the hemishell tank (Model Beef hemishell-Unit 1, Hydrodyne

Inc., San Juan, P.R.) filled with water (10 °C) . Explosive (nitromethane and ammonium nitrate) amounts of 105, 200, and 305 g (H1, H2, and H3, respectively) were placed in the center of the hemishell, 26.7 cm above and from the center of the samples. The tank was covered with a vented muffler, and the explosive was detonated. Explosive amounts placed at this distance would theoretically (pressure curves, developed by Hydrodyne) create hydrodynamic shock waves with pressure fronts of 83, 104, and 124 MPa (12,000, 15,000, and 18,000 psi, respectively) that would pass through the water and beef.

Internal reference steaks

Internal reference steaks (IRS) 2.54 cm thick were obtained from U.S. Select bovine *Biceps femoris* (BF), aged 2 to 3 d, with a specified weight range of 4.5 to 6.0 kg for each muscle. IRS were packaged in the same vacuum bag along with each section of *BF* treated by the HSW used for the protein functionality determination. The steaks were included to verify that the HSW process was functioning based on reported steak tenderization effects. These steaks were obtained from 2 *BF* muscles coming from 1 animal different than those used to study protein functionality. Starting from the proximal side of the muscle, 9 consecutive pairs of IRS and control steaks were removed. The HSW-processed IRS and control steaks were cooked (AMSA 1995) to an internal temperature of 71 °C using a convection oven (Model Mark V, Blodgett Inc., Richmond, Va., U.S.A.). Six to 8 cores (1.27-cm dia) were removed parallel to the muscle fiber orientation from each steak after cooling to room temperature. Shear force was determined using a Warner-Bratzler shear device mounted on an Instron universal testing machine (Model 1011, Instron Corp., Canton, Mass., U.S.A.) with a crosshead speed of 200 mm/min. Mean values were calculated from 6 to 8 cores removed from each steak.

Frankfurter processing

BF samples were ground (Model 4532, Hobart, Troy, Ohio, U.S.A.) through a 1.25-cm plate. The ground beef (0.7 to 0.15 kg) was placed in a vacuum mixer (Model 4294, Stephan vertical-cutter/mixer, Stephan Machinery Corp., Columbus, Ohio, U.S.A.) along with sodium chloride (2% meat weight basis, MWB), sodium tripolyphosphate (0.5% MWB), sodium nitrite (156 ppm), sodium erythorbate (0.042% MWB), sucrose (2.0% finished weight basis, FWB), and water (25% FWB). The pressure was set at 20 to 25 mm Hg, and the raw materials (1.1 ± 0.2 kg) were chopped for 3 min. Amount of products used as well as feasibility of the formulation was initially developed using Least Cost Formulator software (Version IBMPC Basic 18.0, Least Cost Formulations Ltd., Inc., Virginia Beach, Va., U.S.A.). Each replication of frankfurters was processed using this initial formulation.

The meat batter was filled into a cookie cutter (Marcato cookie cutter, Ampia Biscuits, Italy) and then stuffed into 32-mm fibrous casings (Rapid Peel Nojax, Viskase Co., Chicago, Ill., U.S.A.) and tied into 20-cm links. Some frankfurters were inserted with thermocouples (Model 5100 datalogger, Electronic Controls Design, Inc., Milwaukie, Ore., U.S.A.) to monitor temperature during processing in the smokehouse. The frankfurters were heat-processed to an internal temperature of 71 °C. The smokehouse schedule was: 15 min for dry bulb 60 °C and wet bulb 49 °C, 10 min for dry bulb 68 °C and wet bulb 57 °C, 10 min for dry bulb 74 °C and wet bulb 63 °C, 10 min for dry bulb 79 °C and wet bulb 71 °C, and finished at dry bulb 82 °C and wet bulb 74 °C until the internal temperature was achieved (about 4 min). The frankfurters were immediately showered for 10 min and then stored in covered plastic lugs at 4 °C for 16 h prior to cooking-loss determinations.

pH, collagen analysis, and fat analysis

The pH of each *Biceps femoris* muscle was taken in triplicate to determine variation among muscles. Muscles were selected with a pH range of normal beef (5.3 to 5.8; Faustman 1994) to minimize effects on protein functionality. The pH was determined by removing 3 10-g samples from 3 similar anatomical locations on each of the *Biceps femoris* muscles and homogenizing in a stomacher (Model S10-400, Tekmar Company, Cincinnati, Ohio, U.S.A.) for 1 min in 100 mL of distilled deionized water. The pH was measured for the individual samples with a calibrated pH meter (Model AR25, Fisher Scientific, Pittsburgh, Pa., U.S.A.) and a pH electrode (Model 13-620-298, Fisher Scientific).

Insoluble and soluble collagen content was measured to determine variation among muscles. Collagen concentration was quantified by determining hydroxyproline content (Bergman and Loxley 1963) in the procedure described by Hill (1966). Determinations were performed for each Control and HSW treatment.

Percentage fat (39.1.06, AOAC 1995) was measured in triplicate for each *Biceps femoris* muscle using a Foss-Let Fat Analyzer (Model 15310 Foss-Let, A/S N. Foss Electric, Hilerod, Denmark). All muscles used in the study had less than 5% fat to minimize the effect of fat content on protein functionality. If any samples obtained had greater than 5% fat, those muscles were discarded.

Cooking loss

All of the frankfurters without thermocouples were used to determine cooking loss. Cooking loss was reported as the percentage difference between the frankfurters prior to heat processing and the frankfurters chilled after processing.

Torsion testing

A gelometer (Model 5xHBDVI+, Gel Consultants Inc., Raleigh, N.C., U.S.A.) was used to measure shear stress and shear strain of further processed products. Frankfurters were stored (4 °C) horizontally in plastic lugs for 2 d. The frankfurters were then cut perpendicular to their length into 30-mm pieces using an adjustable plexiglass-cutting device. Styrene disks were glued with cyanoacrylate to each end of the 30-mm-long sausage sample so that the grooves on each mounting disk were in line with each other. The specimen milling machine (Model KCI-24A2, Bodine Elec. Co., Raleigh, N.C., U.S.A.) was adjusted so that the sample was milled into a capstan-shaped object with an outside dia of 10 mm.

Texture profile analysis

Texture profile analysis (Bourne 1978) was performed using an Instron universal testing machine (Model 1011, Instron Corp., Canton, Mass., U.S.A.) to determine total energy, hardness, springiness, cohesiveness, and chewiness. Texture analyses were performed on chilled (4 °C) samples stored horizontally in plastic lugs for 1 d post-processing. Frankfurters were cut perpendicular to their length into 19-mm pieces and were axially compressed to a height of 4.75 mm (75% compression) to determine total energy and hardness. Pieces were compressed twice to 50% to determine springiness (b2, base width mm of 2nd compression), cohesiveness (TE2/TE1 × 100, total energy of 2nd compression over the

1st), and chewiness (50% compression peak force x springiness x cohesiveness/100). The Instron was programmed for a load range of 50 kg (100% of 50 kg compression load cell) with a crosshead speed of 100 mm/min and a chart speed of 200 mm/min.

Instrumental color determinations

Cooked color of the frankfurters was evaluated by determining CIE L*a*b* values with a chroma meter (Model CR-200, Minolta Camera Co., Ltd., Osaka, Japan) and reflectance values in the visible range (400 to 700 nm) using a spectrophotometer (Model 2101PC Spectrophotometer, Shimadzu Inc., Kyoto, Japan). Each device was calibrated using a white plate (Model 20933026, Minolta Camera Co.; CIE L* +97.91, a* −0.70, b* +2.44). The spectrophotometer was configured for a sampling interval of 1.0 nm, slit width of 2.0 nm, and fast scan speed. From the reflectance data, cured pigment (nitrosylhemochrome) was determined using the reflectance (R) ratio of %R at 650 nm divided by %R at 570 nm where a lower value indicated less pigment (Erdman and Watts 1957).

Protein solubility and gel electrophoresis

The solubility of the sarcoplasmic proteins was determined using triplicate 1-g samples homogenized in 10 mL of ice-cold 0.025 M potassium phosphate buffer (pH 7.2). Myofibrillar protein solubility was determined using triplicate 1-g samples in 10 mL of ice-cold 1.1 M KI/0.1 M potassium phosphate (pH 7.2). The samples were homogenized (Model no. 225318, Virtishear homogenizer, Virtis Co., Gardener, N.Y., U.S.A.) for 3 4-s bursts using a macro-fine attached to a 20-mm shaft generator (Model no. 225366, Virtis Co.). Samples were then centrifuged at 2600 g (4 °C) for 30 min, and supernatants were decanted. Protein concentration was then determined using the biuret method. Myofibrillar and sarcoplasmic protein extracts used from the protein-solubility study were subjected to SDS-PAGE (Hoeffer Mighty Small II SE 250, Pharmacia Biotech, Piscataway, N.J., U.S.A.) as described by Ashgar and others (1986). The proteins were separated using a 10% acrylamide gel and 2.6% C (bis-acryl ratio). The reference standard (M-4038, Sigma Chemical Co., St. Louis, Mo., U.S.A.) used was a wide-range marker ranging in proteins of molecular weights from 6,500 to 205,000, and 3.6 uL of each protein sample was dispensed into each well.

Statistical analysis

The experimental design was analyzed as a Randomized Complete Block Design with 6 replications of muscles and 4 treatments. Statistical analysis was performed using General Linear Model procedures (SAS Institute Inc. 1996) to determine significance ($P < 0.05$) of independent variable effects (HSW). One-sided t-tests were used to determine differences in shear value ($P < 0.05$) among internal reference steaks.

Results and Discussion

Muscle variation

To control uniformity, samples from raw bovine *Biceps femoris (BF)* muscle were specified to meet selection criteria for pH (5.3 to 5.7) and fat content (< 5%). All samples evaluated met those standards with pH (5.4 ± 0.04) and fat percentage (3.1 ± 0.9). According to Faustman (1994), 5.4 is a normal pH value for bovine *BF*. The variation in pH of the beef was controlled because pH has been reported to affect protein solubility (Hultin and others 1997). As pH decreases from 6.0 to 5.0, bovine myofibrillar protein solubility decreases (Yasui and others 1980), which can affect other functional properties of the meat proteins. Fat percentage was low for all muscles used resulting in small variation in fat among muscles. As fat percentage increases in a further processed product, protein percentage decreases, which inhibits its ability to encapsulate fat and bind water (Rust 1987).

Collagen content was uniform ($P > 0.05$) across the treatments within the muscles selected for this research allowing for appropriate conclusions to be drawn concerning the hydrodynamic shock wave effects on tenderness and protein functionality. Insoluble collagen ranged from 7.84 to 8.68 mg/g (S.E. = 0.38), and soluble collagen ranged from 0.92 to 1.02 mg/g (S.E. = 0.04). According to McCormick (1994), connective tissue is composed of collagen, which is highly cross-linked and not uniformly distributed in BF muscle. If the collagen had not been uniformly distributed in the samples, myofibrillar protein functionality may have been affected (Hultin and others 1997). Lack of shock wave affect on collagen agrees with reports by Solomon, quoted in Raloff (1998), stating that the HSW does not affect connective tissue amount.

Internal reference steaks

In general, the hydrodynamic shock waves decreased shear values of bovine *BF* steaks by 20% (Figure 1). These results confirmed that the process was functioning similarly to published reports on beef tenderization effects. Solomon and others (1997b) reported a 19% to 30% improvement in shear force for bovine *BF* muscles and a 53% improvement in *BF* muscles that were cold shortened when cooked on an open-hearth Farberware broiler. *BF* muscles are normally reported to have a lower reduction in shear values by HSW than *Longissimus* muscles as well as other muscles with lower amounts of connective tissue. All treatments in this study had shear values of less than 4.6 kg. Shear values lower than

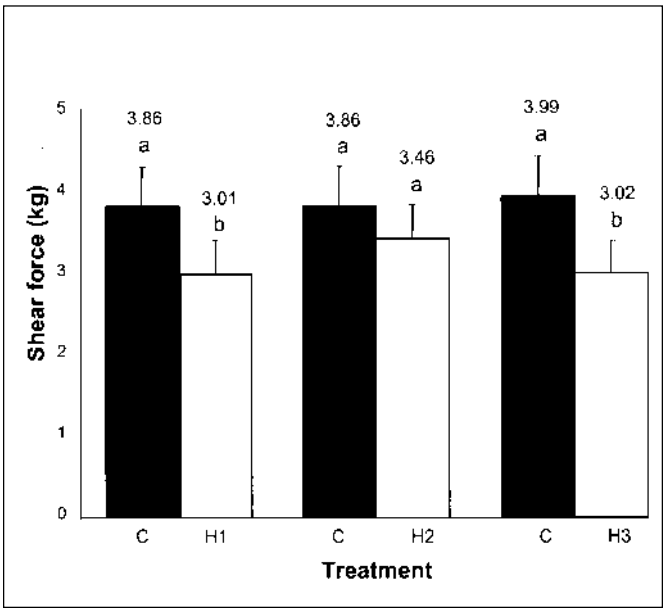

Figure 1—Effects of hydrodynamic shock waves on the shear force of 2.54-cm-thick steaks treated by detonating 105 g (H1), 200 g (H2), and 305 g (H3) of explosive in contrast to controls (C). Bar means within a pair with unlike letters are different ($P < 0.05$). Standard error lines project above bars.

4.6 kg are considered acceptable in tenderness to consumers for *Longissimus dorsi* cooked on a Farberware broiler (Shackleford and others 1991). A higher reduction in shear values may have occurred if the control samples were inherently less tender. Solomon, quoted in Raloff (1998), reported that shear force values of 6, 8, 10, and 12 kg have the potential to be reduced to 3 to 4 kg shear force with HSW. His research differed from this study because he incorporated plastic containers with steel plates placed on the bottom. This research was performed in a steel hemishell-shaped tank.

H1 and H3 reduced ($P < 0.05$) shear values of *BF* steaks compared to control steaks. H2 did not reduce ($P > 0.05$) shear values. This difference compared to those of H1 and H3 could have been due to small sample sizes (n = 6) and slight variations in connective tissue among steaks. *BF* muscles are known to be high in collagen, and the collagen is not uniformly distributed (McCormick 1994). Solomon, quoted in Raloff (1998), stated that typically 100 g explosive, placed strategically, was needed to tenderize meat in a plastic garbage can container. Nevertheless, greater reduction in shear force may not necessarily correlate with higher explosive amount since our results indicated H1 tenderized meat more effectively than H2. Solomon and others (1997a) also reported that decreasing the distance of explosive to the meat reduced shear force more than increasing explosive amount. There were no differences ($P > 0.05$) in cooking loss among internal reference steaks and control steaks.

Protein solubility

There were no differences ($P > 0.05$) in myofibrillar and sarcoplasmic protein solubility among control and hydrodynamic shock wave treated bovine *Biceps femoris* muscle (Table 1). Myofibrillar proteins are responsible for the formation of further processed products including water-holding capacity and textural properties (Fukawaza and others 1961; Acton and others 1983; Ashgar and others 1985; Gordon and Barbut 1992). Solubility of sarcoplasmic proteins provides information about cooked and cured color because muscle pigment proteins, including myoglobin (Bandman 1987), are included in this class of proteins. Our results imply that no denaturation of myoglobin occurred. Cheftel and Culioli (1997) reported that pressures of 200 to 350 MPa for 2 to 5 min after the target pressure was reached were required to cause meat discoloration due to denaturation of myoglobin. These results substantiate data from our study. Our pressure level was less than 200 MPa, and the detonation of the explosive occurred in much less time than 2 to 5 min (Long 1993). Hydrodynamic shock waves have been shown to cause physical disruptions in the regions adjacent to the Z-lines and within the A-bands actin/myosin interaction using wave pressure of approximately 60 to 70 MPa (Zuckerman and Solomon 1998) in a plastic container. These results combined with ours suggested that the degree of structural degradation of myofibrillar proteins caused by hydrodynamic shock waves was not sufficient to affect myofibrillar protein solubility or improve it.

MacFarlane (1974) and MacFarlane and McKenzie (1976) reported that high pressure promotes the deaggregation or solubilization of myofibrillar proteins, which is important in the production of further processed products. They also reported that the solubilization of myofibrillar proteins was influenced by duration of pressurization and salt concentrations.

Gel electrophoresis

Gel-electrophoresis results support protein-solubility data since no differences were determined among control and hydrodynamic shock wave treated bovine *Biceps femoris* muscles (Figures 2 and 3). No proteolysis (breakdown of protein) of myosin or actin was visually apparent on the myofibrillar gels, and no proteolysis of myoglobin was determined visually on the sarcoplasmic gels as a result of the hydrodynamic shock wave treatments compared to the control. In contrast, O'Rourke and others (1998, 1999) reported slight proteolysis of porcine and bovine myofibrils using the hydrodynamic shock wave treatment. Differences between those results and our research could be due to different species and muscles studied. Pork loin muscle was used in their 1st study, and bovine *semitendinosus* muscle was used in their 2nd study. Also variations could be due to differences in the tanks used. Their 1st study was conducted in a plastic container (208-L capacity) with a steel plate placed on the bottom center of that container, while their 2nd experiment was conducted in a 1060-L commercial tank.

Table 1—Protein solubility[a] of finely chopped meat made from hydrodynamic shock wave treated bovine *Biceps femoris* muscles

	Protein solubility[b]		
Treatment[c]	MYO (mg/g)	SARC (mg/g)	Total (mg/g)
Control	182.3	53.7	235.9
H1	183.2	52.7	235.8
H2	180.6	52.4	233.0
H3	179.2	53.1	232.3
S.E.	2.59	0.73	2.76

[a] Means within a column are not different ($P > 0.05$).
[b] Protein solubility
MYO = soluble myofibrillar proteins
SARC = soluble sarcoplasmic proteins
Total = soluble myofibrillar and sarcoplasmic proteins
[c] Treatment: H1 = 105 g explosive, H2 = 200 g explosive, and H3= 305 g explosive placed at 26.7 cm above the meat

Cooking loss

There were no differences ($P > 0.05$) in cooking loss among frankfurters processed from control and hydrodynamic shock wave treated Bovine *Biceps femoris* muscle. Percentage cooking loss ranged from 4.7 to 5.3 (S.E. = 0.41), respectively. Lack of differences in myofibrillar protein solu-

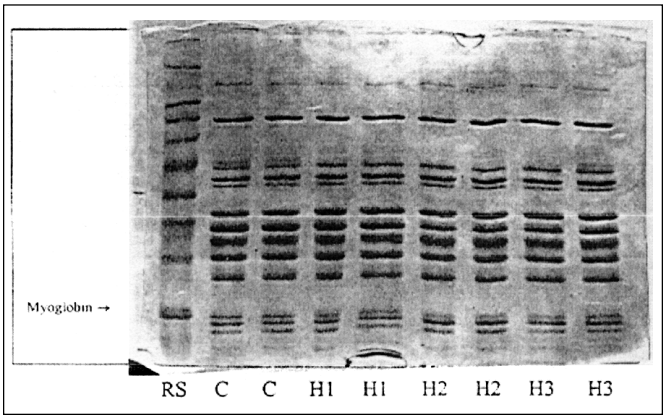

Figure 2—Electrophoretic gel of sarcoplasmic proteins from bovine *Biceps femoris* muscle treated with 0 g (C), 105 g (H1), 200 g (H2), and 305 g (H3). RS was a reference standard (M-4038, Sigma Chemical Co., St Louis, Mo., U.S.A.) to determine individual proteins.

bility and gel electrophoresis substantiate these results. These results suggested that no loss in the industry due to yield of further processed products made from the trim of muscle treated with hydrodynamic shock waves would occur compared to untreated muscle.

Cooked color

Cooked color of the frankfurters was not affected ($P > 0.05$) by treating bovine *BF* with the HSW. CIE L*a*b* values (C and H treatments) ranged from 57.3 to 58.9 (S.E. = 0.14), 20.0 to 20.6 (S.E. = 0.12), and 8.2 to 8.4 (S.E. = 0.05), respectively. CIE a* values indicating redness of products is related to myoglobin in the beef. Denaturation of myoglobin prior to production of further processed products would affect cooked color since this is a sarcoplasmic protein responsible for meat pigmentation (Bandman 1987). No difference observed in cooked color supports the sarcoplasmic protein-solubility results. Cheftel and Culioli (1997) reported that pressures greater than 250 MPa caused loss of red color in fresh meat due to myoglobin denaturation.

There were no differences ($P > 0.05$) in cured color pigment (nitrosylhemochrome) of frankfurters among control and hydrodynamic shock wave treated *Biceps femoris* muscle. Nitrosylhemochrome values ranged from 2.9 to 3.1 (S.E. = 0.015), respectively. Denaturation of myoglobin can cause differences in cured color since this protein is involved in the binding of nitric oxide to the heme ring responsible for cured color formation (Fox 1987). No proteolysis of sarcoplasmic proteins in gel electrophoresis and no differences in sarcoplasmic protein solubility further substantiate the cured color results.

Texture analysis

The hydrodynamic shock wave process did not affect ($P > 0.05$) product texture of frankfurters (Table 2). In comparison, Mandava and others (1994) demonstrated that high hydrostatic pressure applied to sausage batters improved the textural characteristics in low salt, low phosphate, and high water added frankfurters that were exposed to 150 to 200 MPa for 5 min at 10 °C. The reported key factors for texture improvements were pressure level, temperature, and time (Mandava and others 1994).

Table 2—Texture Profile Analysis values[a] for frankfurters made from hydrodynamic shock wave treated *Biceps femoris* muscles.

	Texture Profile Analysis[b]					
	50% compression				75% compression	
Treatment	Spring (mm)	Cohes	Chewi (kg*mm)	Peak force (kg)	Total energy (kg*mm)	Hardness (kg)
Control	8.67	56.4	85.6	17.1	196.1	38.4
H1	8.68	58.4	84.4	16.1	181.6	35.1
H2	8.71	52.9	85.8	18.0	183.2	36.0
H3	8.73	55.3	83.1	17.4	159.6	31.0
S.E.	0.025	0.56	1.67	0.30	3.00	0.63

[a]Means within a column are not different ($P > 0.05$).
[b]Texture Profile Analysis:
Spring = Springiness, base width (mm) of 2nd compression
Cohes = Cohesiveness = (total energy of 2nd compression divided by total energy of 1st compression) × 100
Chewi = Chewiness = (hardness at 50% compression, peak force) × (springiness × cohesiveness) divided by 100
Peak Force = The peak force during the 1st compression cycle (50 % compression)
Total Energy = The total energy of the positive force area during the 1st compression
Hardness = The peak force during the 1st compression cycle (75 % compression)
[c]Treatment: H1 = 105 g explosive, H2 = 200 g explosive, and H3= 305 g explosive placed at 26.7 cm above the meat

Though no differences ($P > 0.05$) were detected in gelometer torsion testing, potential trends suggest that the control sample tended to be slightly more brittle and tougher than hydrodynamic shock wave treated samples (Figure 4). In a comparison of the shear values of internal reference steaks (IRS) with torsion testing values, shear stress of the frankfurters was less as shear values of IRS decreased. Interestingly, shear stress of H2 tended to be higher than H1 and H3, which was similar to the WBS results of the IRS.

Conclusions

MEAT PROTEIN CHARACTERISTICS WERE NOT AFFECTED BY THE hydrodynamic shock wave treatment. Trim removed from hydrodynamic shock wave tenderized beef (Hydrodyne Process) can be used interchangeably with normal beef trim in the production of further processed products.

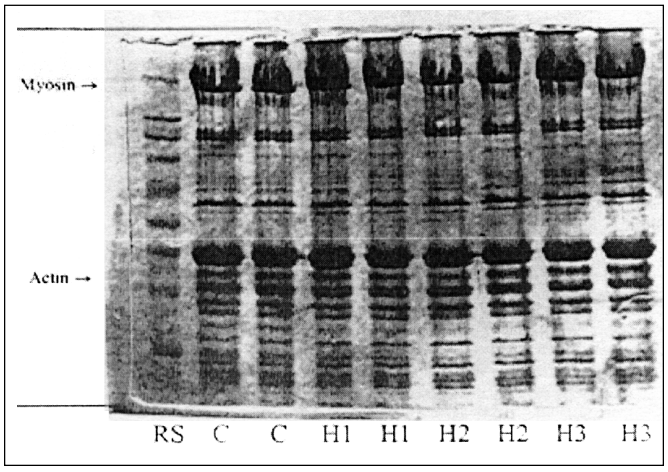

Figure 3—Electrophoretic gel of myofibrillar proteins from bovine *Biceps femoris* muscle treated with 0 g (C), 105 g (H1), 200 g (H2), and 305 g (H3). RS was a reference standard (M-4038, Sigma) to determine individual proteins.

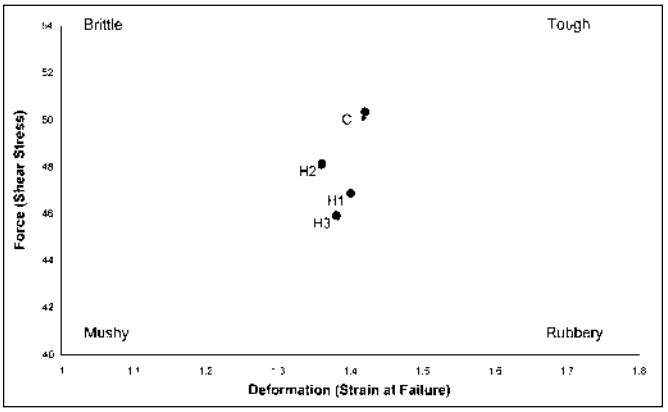

Figure 4—Texture map for torsion tester adopted from Lanier (1986) and Hamann (1987). Samples are frankfurters made from bovine *Biceps femoris* muscle treated with the HSW process at 0 g (C), 105 g (H1), 200 g (H2), and 305 g (H3) of binary explosive.

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