The Hydrodyne: A New Process to Improve Beef Tenderness

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ABSTRACT: The organoleptic trait most affecting consumer acceptance of beef is tenderness. The Hydrodyne process uses a small amount of explosive to generate a shock wave in water. The shock wave passes through (in fractions of a millisecond) objects in the water that are an acoustic match with water. Four beef muscles (longissimus, semimembranosus, biceps femoris, and semitendinosus) exposed to either 50, 75, or 100 g of explosives were significantly tenderized compared with controls. As much as a 72% reduction in shear force was observed for the longissimus muscle using 100 g of explosives. Reductions in shear force with magnitudes of 30 to 59% improvements were observed for the other three muscle types. Results suggest that tenderizing beef with the Hydrodyne process presents a potentially novel opportunity in the way the meat industry can tenderize meat.

Key Words: Tenderizing, Tenderness, Beef

Introduction

Tenderness is one of the most important sensory characteristics of meat. Research during the past 50 yr has been devoted to improving tenderness of meats. A variety of techniques have been introduced for tenderizing meat. Techniques, applied individually or in combination, include mechanical, chemical, conditioning, aging, electrical stimulation, pressure-heat treatment, and alternative carcass positioning. A number of these techniques require additional holding periods, space, and labor.

The Hydrodyne process (patent numbers 5,273,766 and 5,328,403), which is different from any currently used or described method(s) for meat/carcass tenderization, uses a small amount of explosive to generate a hydrodynamic shock wave in liquid medium (water). The shock wave, which occurs in fractions of a millisecond, passes through objects in the water that are an acoustical match with the water (Kolsky, 1980). Meat (muscle), which compositionally is approximately 75% water, depending on the amount of intramuscular fat and connective tissue present (Price and Schweigert, 1978), is a close acoustical match.

Experimental Procedures

In the Hydrodyne process for experimental purposes, the meat was encapsulated twice, first in a polyolefin resin (Cryovac®) bag followed by encapsulation in a polymer of isoprene (rubber) bag. Both bags were evacuated. Meat samples were supported against the floor of plastic containers (208-L capacity and 51-cm diameter), each fitted with a steel plate (2-cm thick) so the ensuing wave reflected back through the meat to intersect the incoming wave. The containers were situated below ground level and filled to the top with water. The explosive used was composed of a liquid (nitromethane) and a solid (ammonium nitrate), which were not explosive until combined. The explosive was submerged in the water to a distance of 30.5 cm away from the front surface of the meat and was wired to a detonating device. The detonating device triggered the detonation of the explosive.

In the first set of three experiments, 12 longissimus (LM) steaks (3.2 cm in thickness) were removed
from the loins (both sides) of five 2-yr-old Holstein cows at 24 h postmortem. Two steaks served as controls from each loin. Six steaks per loin (two for each treatment) were exposed to the Hydrodyne process using either 50, 75, or 100 g of explosive in a single load. An additional two steaks per loin were exposed to the Hydrodyne process using two individual loads of 50 g of explosive each, the first detonation followed by a second. The remaining two steaks per loin were frozen and treated frozen using a single 75-g load of explosive. The two steaks per treatment were vacuumed-packaged in Cryovac bags, and all steaks designated for a specific quantity of explosive were encapsulated in the same rubber bag.

In the second set of experiments, three fresh, whole (USDA Select grade) biceps femoris (BF) were purchased from a local grocery store. Eight steaks per biceps femoris were removed (3.2 cm in thickness). Two steaks per individual muscle served as controls. Six steaks per muscle (two/treatment) were exposed to the Hydrodyne process using either 50, 75, or 100 g of explosive in a single load. The two steaks per treatment were vacuumed-packaged in Cryovac bags, and all steaks designated for a specific quantity of explosive were encapsulated in the same rubber bag.

In the last set of experiments, portions of (n = 8) boneless LM, BF, semimembranosus (SM), and semitendinosus (ST) from four 2-yr-old Holstein cows were hot-boned within 1.5 h postmortem, vacuum-packaged, and stored for 1 d at 2 to 4°C, after which they were frozen at −34°C. All muscles were thawed prior to sampling and treating with the Hydrodyne process. Each muscle was divided into two equal portions (20 cm in length), one portion (random) from each muscle was exposed to the Hydrodyne process (100 g explosive), and the remaining portion from the same muscle served as the control. Individual muscle sections representing the different muscles were individually vacuumed-packaged in Cryovac bags and these individual muscle samples were individually encapsulated in a rubber bag. Steaks (3.2 cm in thickness) were cut from the muscle sections after being treated.

In all three sets of experiments, the control and Hydrodyne samples were held or transported on ice to the testing site, and the duration of time that elapsed from the time of Hydrodyning to the time the samples were cooked was less than 2 h. All steaks were broiled to an internal temperature of 71°C (AMSA, 1995) using Farberware Open-Hearth broilers (Model 350A, Walter Kidde and Co., Bronx, NY). Internal temperature was monitored using iron-constantan thermocouples attached to a Speedomax multipoint recording potentiometer (Model 1650, Leeds and Northrup, North Wales, PA). After cooking, all steaks were allowed to cool to room temperature (25°C) before coring. A minimum of eight cores (1.27 cm diameter) were removed from each steak parallel to the muscle-fiber orientation for shear force determination using a Warner-Bratzler shear device mounted on a Food Texture Corp. Texture measurement system (Model TMS-90, FTC, Chantilly, VA).

Data were analyzed using analysis of variance and F-tests (SAS, 1994) to determine the significance of variation. Least squares means and linear contrasts were generated using SAS (1994). The Duncan’s Multiple Range test (SAS, 1994) was used to compare treatments at the α = .05 level.

### Results

In our initial set of experiments, three loads of explosives (50, 75, and 100 g) were used to evaluate their effectiveness at tenderizing LM. Results are presented in Table 1. Shear force was improved 49 to 72% in all of the fresh LM samples using the Hydrodyne process. However, the magnitude of improvement depended on the quantity of explosive used or the number of detonations performed on each meat sample. Exposing pieces of meat to two independent loads of 50 g each resulted in the greatest improvement in shear force (7.8 vs 2.2 kg) followed by the single 100 g load (7.8 vs 2.6 kg). However, successful reductions in shear force (56 and 49%) were also achieved using single loads of either 50 or 75 g of explosives, respectively. Shear force for frozen LM steaks was improved 24% (7.8 vs 5.9 kg) using the Hydrodyne process on frozen pieces of meat compared with controls (Table 1). These findings suggest that although the Hydrodyne process is effective at tenderizing frozen pieces of meat, it is much more effective for tenderizing fresh pieces of meat.

In the second set of experiments (Table 2), as much as a 19 to 30% improvement in BF shear force was observed compared to controls when BF steaks were treated with the Hydrodyne process. Initial shear force for the controls in this sample group was 4.3 kg, which was considerably less than the shear force for the controls (7.8 kg) representing the LM samples in the first set of experiments. Even though these locally

<table>
<thead>
<tr>
<th>Quantity of explosive, g</th>
<th>No. of detonations</th>
<th>Shear force, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0</td>
<td>7.8&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>50; fresh steak</td>
<td>1</td>
<td>3.4&lt;sup&gt;b,c&lt;/sup&gt;</td>
</tr>
<tr>
<td>50; fresh steak</td>
<td>2</td>
<td>2.2&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>75; fresh steak</td>
<td>1</td>
<td>4.0&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>100; fresh steak</td>
<td>1</td>
<td>2.6&lt;sup&gt;f&lt;/sup&gt;</td>
</tr>
<tr>
<td>75; frozen steak</td>
<td>1</td>
<td>5.9&lt;sup&gt;g&lt;/sup&gt;</td>
</tr>
<tr>
<td>SEM</td>
<td>.3</td>
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<sup>a,b,c,d</sup>Means within a column lacking a common superscript letter differ (P < .05).
Table 2. Effect of quantity of explosive on tenderization of beef biceps femoris muscle as measured by shear force

<table>
<thead>
<tr>
<th>Quantity of explosive, g</th>
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<th>Shear force, kg</th>
</tr>
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<tbody>
<tr>
<td>Control</td>
<td>0</td>
<td>4.3&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>50; fresh steak</td>
<td>1</td>
<td>3.3&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>75; fresh steak</td>
<td>1</td>
<td>3.5&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>100; fresh steak</td>
<td>1</td>
<td>3.0&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>SEM</td>
<td></td>
<td>.2</td>
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</tbody>
</table>

<sup>a,b</sup>Means within a column lacking a common superscript letter differ (P < .05).

In the last set of experiments (Table 3), shear force (kilograms) was improved 66% (8.3 vs 2.8) in the LM, 59% (10.5 vs 4.3) in the SM, 53% (7.8 vs 3.7) in the BF, and 56% (12.9 vs 5.7) in the ST after treating with the Hydrodyne process (100 g of explosive). Hot-boning the intact muscles and holding them for 1 d at 2 to 4°C before freezing resulted in high shear values that would suggest that “cold shortening” of the muscles occurred (Locker and Hagyard, 1963). If the high shear values were a result of the cold-shortening phenomenon, results indicate that the Hydrodyne process was effective at significantly tenderizing “cold-shortened” meat, regardless of muscle origin.

Discussion

To be an acoustic match with water, the object, in this case meat, must possess a ratio of E/D similar to water, where E is the bulk modulus of elasticity and D is the density (Kolsky, 1980). The high proportion of water in meat (75%) provides an excellent acoustic match with the liquid medium (water) in the container. The shock wave is generated and transmitted through the water. The relationship between the wave velocity and the wave period of the ensuing shock wave is such that the front surface of the wave, when reflected by the steel plate fitted at the bottom of the container, intersects the remaining portions of the incoming wave. The pressures within the meat at this time are the sum of the incoming pressure and the reflected pressures at each point in the meat. The result is an increased pressure within the meat (doubling effect) and a nearly uniform pressure exposure within the meat from the front surface to the bottom surface. Pressure fronts were measured (not in tabular form) using transducers designed to capture pressure transmissions. One problem we encountered in recording pressure fronts is that the transducers that are available are designed to measure pressure fronts with a longer time duration than the fraction of a millisecond we encounter in the Hydrodyne process. The pressure fronts were measured in the last set of experiments, which used 100 g of explosives. Shock pressures in the range of 6.05 × 10<sup>6</sup> to 7.03 × 10<sup>6</sup> kg/m<sup>2</sup> were observed at the front contact surface of the meat where the transducers were attached. Uniformity of shock pressure transmission is achieved by supporting the meat against a steel surface and reflecting the shock wave back to intersect the incoming wave.

MacFarlane (1973) was the first to report that prerigor pressurization (hydrostatic pressure) significantly tenderized beef and sheep muscle. Hydrostatic pressure alone (MacFarlane, 1973; Elgasim and Kennick, 1980; Kennick et al., 1980) or in combination with heat (Bouton et al., 1977, 1978) has been shown to have a significant tenderizing effect on beef and sheep muscle. MacFarlane (1973) reported that a hydrostatic pressure of 1.05 × 10<sup>7</sup> kg/m<sup>2</sup> at 30 to 35°C for a 2 min duration was effective at increasing meat tenderness. Kennick et al. (1980) demonstrated that high hydrostatic pressure tenderized meat and(or) accelerated meat aging. The Hydrodyne system uses a hydrodynamic shock wave to tenderize meat. Hydrodynamics, which occurs instantaneously, is the motion of fluids and the forces acting on solid bodies immersed in these fluids. Hydrostatics, which is not instantaneous, is the characteristics of liquids at rest.
and the pressure in a liquid or exerted by a liquid on an immersed object.

Shackelford et al. (1991) reported that Warner-Bratzler shear force values of top loin steaks should not exceed 3.2 kg for a 95% confidence level, 3.9 kg for a 68% confidence level or 4.6 kg for a 50% confidence level to assure overall tenderness ratings of “slightly tender” or greater from a trained sensory panel. Results for Hydrodyned loin muscle samples in the present study indicated that the resulting shear values of 2.6 and 2.8 kg after detonation of 100 g of explosive were well within the 95% confidence level described by Shackelford et al. (1991). In fact, the 50 and 75 g of explosives used to tenderize fresh LM samples were sufficient quantities to produce shear values comparable to the 68% confidence level described by Shackelford et al. (1991). Extrapolating the results for the BF, SM, and ST samples in Table 3 that were Hydrodyned using 100 g of explosive and using the shear force value thresholds reported by Shackelford et al. (1991), it can be deduced that the Hydrodyne process was, in most instances, successful at improving meat tenderness and provided meat that was considered to be tender, regardless of muscle origin or type.

**Implications**

The findings reported in this paper indicate that the Hydrodyne process was effective in reducing shear force values and improving meat tenderness in beef. Furthermore, the Hydrodyne process was an effective technique for tenderizing “cold-shortened” muscle. The Hydrodyne process presents a potentially new and alternative method for tenderizing meat. The process presently is designed as a batch system and research is currently underway at evaluating a Hydrodyne unit with a capacity of 1,060 L of water that would accommodate approximately 272 to 363 kg of meat per detonation.

**Literature Cited**


