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James Steffe
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HUMAN SENSORY FIRMNESS SCALE BASED ON GELATIN GELS

By

Robyn Lynn Reynolds

A THESIS

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ABSTRACT

HUMAN SENSORY FIRMNESS SCALE BASED ON GELATIN GELS

By

Robyn Lynn Reynolds

A series of gelatin gels were produced as firmness analogues of typical meat samples for use in texture evaluation. Gels of varying concentrations of gelatin and sorbitol were made to resemble core samples of meat. The maximum force required to cut through the gel sample was determined with a Warner-Bratzler Shear, and a TA.TX2 Model Texture Analyzer equipped with a shear blade attachment. Samples were scaled with shear force values. An untrained sensory panel of 30 people and a trained panel of 12 confirmed the sensory scale using a triangle test and unstructured scales. Untrained panelists were able to distinguish between three concentration levels of gels representing three tenderness categories ($p \leq 0.001$). Significant differences were detected by trained panelists between six scaled standards. Changes in temperature significantly affected firmness; therefore, the sample temperature must be set and maintained during tests. Results suggest that scaled firmness standards based on gelatin provide a good model of meat tenderness. Gelatin gels may also be used to develop firmness scales for testing many additional food products.

DEDICATION

To my loving fiancé, Douglas Jones,

who supported me and encouraged me across the miles.

ACKNOWLEDGEMENTS

I would like to thank Dr. James Steffe for his endless encouragement and relentless support throughout my graduate career. Dr. Steffe has proven to be a role model not only through research, but in life's lessons as well.

I would also like to thank Dr. Kirk Dolan, Dr. Janice Harte and Dr. Christopher Daubert for serving on my committee. Many thanks to the Michigan State University Meat Laboratories, Ms. Carrie Wing and Mr. Richard Wolthuis for their technical support throughout the course of this study. Thanks also to all of the trained panelists who sacrificed their time for this study.

Most importantly, I would like to thank my parents, Mr. and Mrs. Keith Reynolds, who have always believed that I could accomplish anything I set out to do.

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INTRODUCTION

Perception of food texture plays a key role in human evaluation of food products. Although there are several definitions of the term "texture," the International Organization for Standardization defines texture as, "all the mechanical, geometrical and surface attributes of a product perceptible by means of mechanical, tactile and, where appropriate, visual and auditory receptors" (1995). In the early years of food evaluation, rheologists, who studied the flow and deformation of food products, measured texture properties. However, texture properties can be so complex, human sensory evaluation is necessary to explain the overall aspects of texture only experienced by humans.

Food texture is important in product development, quality control, sensory testing, and process engineering. Fortunately, there have been efforts to fully characterize the texture of many food products with methods such as Texture Profile Analysis (TPA). Knowing how to effectively characterize the texture of a food product allows one to constantly improve formulations, processing methods, product stability, and shelf life. Sensory panels along with mechanical evaluation of food products have led to an advanced understanding of textural properties. Panels are able to develop terminology necessary to describe certain textural attributes unique to a specific product. Instruments are then used to generate data that reflect levels of intensity for each textural attribute.

Sensory scales, such as those for hardness and brittleness, have been used to train panelists on intensities of textural attributes and for comparison of food products. All of these scales are composed of a variety of food products and designate the sample size, brand, and serving temperature for each scale item. In some studies, these specific food items are either difficult to obtain, due to local availability, or time-consuming to prepare and characterize due to size differences. Modifications and improvements to these standard scales can further advance the knowledge of texture evaluation and improve the accuracy of scaled food items.

Model materials, such as gelling agents, can be used to represent the texture of food products when evaluating changes in texture due to differences in formulation, processing, or temperature. Scaled standards covering a desired range of intensities and comprised of one constituent, or model material, can help decrease the variation among scaled food items. Such standards could be applied to the training of sensory panelists, meat tenderness evaluation, instrument calibration, and dental research.

Given the above considerations, the objectives of this research are:

- to develop a procedure for producing a series of gelatin gels varying in firmness;
- to characterize firmness by measuring rheological/textural behavior;
- to scale firmness standards for application to meat tenderness, and verify the scale using sensory evaluation;

- to develop practical recommendations for using gelatin gels as firmness standards.

1. Literature Review

1.1. Food Gels and Texture

Determining the texture of food is a complicated process because it involves both sensory and instrumental measurements, and their complex relationships. Measurement of food texture must take into consideration the physiology and psychology of human perception, the physical and chemical components of food structure, and food behavior when subjected to large deformation. In addition, visual, tactile and auditory stimuli influence the texture perception of a particular food before it even enters the mouth.

Sensory scientists, nutritionists, and product developers, alike are increasingly interested in relating perceived food texture to measurable physical and mechanical properties. Some foods, such as surimi and meats (Hamann and Lanier, 1987), have been studied to find correlations between subjective and objective measurements. Food gels have provided much insight into the perceived texture of fabricated foods. There are three types of gel structures that represent all levels of molecular complexity existing in food products (Morris, 1986): single component gels are in the simplest form, mixed gels are models for more complex structures, and filled gels may be used to assess the role of particulates in food systems. Gels, used as model foods, can provide good descriptions of rheological and mechanical behavior of numerous food systems.

There have been many studies where gelling agents were used to determine certain attributes of food texture. Agar has been widely used to model gelling

systems (Marrs, 1997). Agar has the ability to retain and support its shape at low concentrations, and can have a very rigid structure with good elastic properties (Matsuhashi, 1990). Carrageenan has been found to be very versatile in the area of stabilization, where texture properties such as thickening and creaminess may be enhanced. For example, carrageenan can be added to instant beverage powders so particles are suspended when milk is added (Stanley, 1990). Pectin is another alternative for modeling the texture of food systems. The number of esters present in pectin correlates with the firmness of the manufactured gel. If a soft, spreadable jam product is desired, low-ester pectin is normally used in the gelation process (Rolin and De Vries, 1990). Gelling agents have the properties necessary for providing valuable information about food texture.

Recent studies involving food gels have focused on the physical properties of gellan gum, gelatin, and mixed polymer gels. Tang et al. (1997) measured the stress-strain relationships for gellan gum in tension, compression and torsion to fully understand how gels form three-dimensional networks, and to predict their functionality within a food product. Food materials are usually subjected to large deformations during manufacturing and consumption. Lelievre et al. (1992) subjected gellan gum samples to large deformations, similar to conditions found in normal processing, to determine failure characteristics. Furthermore, gelling agents, such as gelatin and carrageenan, have been used in different concentrations to study the flavor release of aromatic compounds in model gel systems (Guinard

and Marty, 1995). It was found that the firmness of gels affects the rate of flavor release by entrapping or binding the molecules in gelling agents.

Gelatin, which is the gelling agent examined in this research, is the most commonly used gelling agent in the food industry. This material has good nutritional value, a wide range of application, and is relatively inexpensive when purchased in bulk. Gelatin gels are thermo-reversible, elastic in texture, and do not need the presence of other reagents such as sucrose or salts for gel formation (Johnston-Banks, 1990). Gelatin is able to form gels due its triple helical structure and its ability to immobilize water within complex protein chains. Because of the unique texture and sensory characteristics of gelatin, there have been some studies correlating instrumental measurements with standardized sensory data (Johnston-Banks, 1990). These studies indicate that gelatin gels may be superior to other gel systems in the areas of firmness, cohesiveness, and elasticity. Dental researchers have also used gelatin gels as elastic food models to characterize the variability of the masticatory process of chewing (Lassauzay et al., 2000). Overall, gelatin has the textural characteristics necessary for modeling sensory properties of food systems.

1.2 Sensory Scale Development

Scaling has been used in a variety of industries for many different purposes. Ratio scales for parameters such as brightness and loudness were used to study the effects of excitation at the physiological level (Stevens and Galanter, 1957).

Discrimination between scale levels appears to be based on an additive mechanism of physiological excitation. Physical properties, such as hardness and extensibility, of materials like metal and rubber may be measured and compared by using existing scaling methods. In early food texture research, Raffensperger et al. (1956) worked on developing a scale for grading toughness and tenderness in beef in relation to consumer preference. Researchers have evaluated and scaled attributes assessed during the mastication process such as cohesiveness of mass, and moisture adsorption (Munoz, 1986). However, hardness and fracturability of food materials are the most studied and applied standards in the food industry.

Texture scales for food were originally developed as a result of the "lack of an adequate bridge between theoretical rheology and practical applications" (Szczesniak, 1963). Szczesniak was the first to establish a common frame of reference for textural properties by developing a nomenclature to describe textural qualities, and defining terms such as texture and consistency. The primary purpose of developing standard scales was to start on a common ground so that all sensory panelists would understand the basic terms before applying the scales to food products. Szczesniak's six standard scales were comprised of perceptual points that were equidistant from each other and increased in the order of intensity (Szczesniak, 1963). Scales for properties, such as hardness, brittleness, and cohesiveness, provided a well-defined basis for the development and implementation of the Texture Profile Method. Table 1.1 displays the standard materials selected to represent the scale values for hardness.

Table 1.1 Szczesniak's original standard hardness scale (1963).

Panel Rating	Product	Brand or Type	Manufacturer	Sample Size	Temp.
1	Cream Cheese	Philadelphia	Kraft Foods	½"	45-55°F
2	Egg White	Hard-cooked (5 min)	N/A	½" tip	Room
3	Frankfurters	Large, uncooked, skinless	Mogen David Kosher Meat Products Corp.	½"	50-65°F
4	Cheese	Yellow, American, pasteurized process	Kraft Foods	½"	50-65°F
5	Olives	Exquisite, giant size, stuffed	Cresca Co.	1 olive	50-65°F
6	Peanuts	Cocktail type in vacuum tin	Planters Peanuts	1 nut	Room
7	Carrots	Uncooked, fresh	N/A	½"	Room
8	Peanut Brittle	Candy part	Kraft Foods	N/A	Room
9	Rock Candy	N/A	Dryden & Palmer	N/A	Room

During the development of the standard scales, several terms were introduced and defined (Munoz, 1986). A rating scale is a series of intervals used for the perceived intensity of a sensory stimulus, whereas a scale value is the number that describes the specific location of a stimulus material over the allotted range of intensities. The reference material is carefully selected to represent a specific sensory attribute and its intensity. In the early stages of scale development, groups first discussed and suggested certain food items that represented specific texture characteristics. Products were evaluated and reference materials were further considered or eliminated. When the panel felt as though a material represented a specific intensity, the product sample was accepted as part of the scale and subsequently used as a common point of reference.

Scales have proven effective for training panelists for the Texture Profile Method because there is good correlation with the instrumental measurements using scaled food items (Szczesniak et al., 1963). The standard scales have also been used for the preliminary screening of panelists, establishing definitions of sensory terms, evaluating instrumental methods, and for the selection of experimental samples. Standard scales have provided a starting point for researchers to address their specific needs and interests in sensory research.

There have been a few modifications of Szczesniak's original standard scales despite assumptions that the published examples were to be adhered to exactly. Cardello et al. (1982) established ratio scale analogues to the standard scales to show differences in scaling techniques. Cardello et al. (1982) also

substituted several references for specific standards to compensate for current and local unavailability of recommended food items. In addition, standard texture scales were modified to accommodate the conditions in Columbia (Bourne et.al., 1975). Some sensory data collected using the original scales showed a large degree of variation among trained panelists (Munoz, 1986). Munoz replaced certain standards from the existing scales with new reference materials and developed new scales to reduce the amount of variability among panelists. Table 1.2 displays the modified scale for hardness covering the entire intensity range of hardness evaluated by molar compression.

The flexibility of scales must be maintained due to the constantly changing food industry, importance of texture properties of food products and the increased interest in this area. Certain brands of food products may need to be replaced occasionally if there are formulation modifications or processing changes, both of which affect texture, thus altering the scale values. Researchers and sensory scientists need to be aware that changes are expected as the field of texture evaluation develops. Improving scales by modifying components allows for the generation of more reliable sensory data and enhanced understanding of the texture properties of food.

Table 1.2 Modified Hardness Reference Scale (Munoz, 1986).

Scale Value	Product	Brand or Type	Manufacturer	Sample Size	Temp.
1.0	Cream Cheese	Philadelphia	Kraft	½" cube	40-45°F
2.5	Egg White	Hard-cooked (5 min)	N/A	¼" cube	Room
4.5	American Cheese	Yellow, pasteurized	Land O Lakes	½" cube	40-45°F
6.0	Olive	Stuffed, Spanish type, pimento removed	Goya Foods	1 piece	Room
7.0	Frankfurter	Beef Franks, cooked 5 min. in boiling water	Hebrew National Kosher Foods	½" slice	Room
9.5	Peanut	Cocktail type in vacuum tin	Nabisco Brands	1 piece	Room
11.0	Carrot*	Uncooked, fresh, unpeeled	N/A	½" slice	Room
11.0	Almond	Planter, shelled	Nabisco Brands	1 piece	Room
14.5	Rock Candy	Life Savers	Nabisco Brands	1 piece	Room

*Area compressed with molars is parallel to cut

1.3 Textural Parameters

Food technologists involved in product development and quality assurance are interested in the mechanical properties of gels in relation to shaping, stand-up, handling, cutting, slicing or eating characteristics (Smewing, 1999). Evaluating hardness, or firmness, of model gel systems can aid in the overall characterization of these properties. According to Szczesniak (1963), hardness is a primary term in texture classification and terms such as "soft," "firm," and "hard" can be used by consumers to describe degrees of hardness. The terms "hardness" and "firmness" are sometimes not well defined in research studies and are most often used interchangeably. The most commonly used definition of hardness is the force required for a specified degree of deformation.

In a study investigating how consumers evaluate firmness using non-oral sensory methods, Szczesniak and Bourne (1969) defined firmness as the force required to compress a product to a standard distance. Sherman (1969) proposed the term "firmness" instead of "hardness" when referring to a deformation even though it was already incorporated in Szczesniak's standard scale for hardness. Munoz et al. (1986) defined firmness as "the textural property manifested by a high resistance to deformation by applied force." She evaluated the firmness of gelatin gels varying in concentration using manual shear, oral shear, and compression tests. Gels made of low concentrations of gelatin (22 to 45 g/L) along with flavoring agents showed that yield and maximum forces increased with increasing concentration of gelatin. Henry et al. (1971) evaluated the firmness of

commercial desserts, whipped toppings, and marshmallow crème as part of the Texture Profile Analysis (TPA). Overall, it is important to establish a precise definition of the parameter being assessed, in addition to the method of measurement, so that results can be clearly understood and easily compared.

1.3.1 Characterizing Gel Firmness

There are several ways to characterize the deformation of a food product. Properties should be measured differently depending on where the food product falls within the range of hardness. For example, when assessing whole meat texture, it is logical to measure the force to cut through or break the fibers of muscle (Lyon and Lyon, 1998). This type of large deformation is just one of many ways to measure the firmness of a product. In the area of food gels, there is little information on their fundamental behavior during large deformation or failure tests. Deformation parameters are usually measured by constant-speed experiments such as uniaxial compression, uniaxial tension, and three-point bending. In most food products, the stress-strain relationship is not constant during large deformation tests (Smewing, 1999). The same holds true in the case of gels where the stress usually reflects the firmness of the gel. Compression tests are most commonly used for evaluating gel properties; yet, tensile tests give a clearer picture of the stresses in a sample since shear stresses in a tensile test are negligible. Unfortunately, there are many difficulties when performing tensile tests on gels: samples may not be self-supported, samples cannot be mounted

properly in the apparatus, and cracks in the sample can lead to failure at small strains (Lelievre et al, 1992).

1.3.2 Evaluating Meat Texture

The term "tenderness" is most often used when referring to the texture of meat products. Tenderness of meat has been a major focus of research for many years, and information surrounding the cause and effects of tenderness continue to be vital to the meat industry. Consumers evaluate the texture of meat by biting through pieces with their front teeth and grinding them with their molars (Boyar and Kilcast, 1986). Boleman et al. (1997) proved that consumers are able to distinguish between degrees of tenderness and are willing to pay a premium for more tender products. Although there have been a number of instruments (Texturometer, Tenderometer, Warner-Bratzler shear) developed for direct measurement of meat tenderness, the lack of uniformity among preparing, cooking and evaluating samples has made it difficult to compare studies from different laboratories. Recently, there have been efforts to standardize the procedures for evaluating meat tenderness (Wheeler et al., 1997). With improved methods of evaluation, there will most likely be an increase in consistency among investigators for comparative evaluation.

Many instrumental methods (physical, chemical, and structural) have been used over the years to determine the tenderness of meat products (Chrystall, 1994). The most widely used methods to determine hardness, firmness, and tenderness

have been physical tests involving a shearing device such as the Warner-Bratzler Shear (Chand, 1986). Figure 1.1 illustrates the shearing principle of the Warner-Bratzler blade. The cylindrical meat sample, either ½" or 1" in diameter, is compressed by the descending anvil. During the test, the sample changes cross-sectional shape to conform to the shape of the hole in the blade, then fills in all the available area, and is sheared across the blade (Bourne, 1982). The sample experiences a complex stress pattern due to the combination of tension, compression, and shearing forces present during deformation. A force transducer measures the maximum force required to cut through the sample. Many factors may lead to variation of recorded shear force values: the width of the blades and the position of the triangle; the speed of the test; and the shape, mass, and orientation of the test samples (Lyon and Lyon, 1998).

The Warner-Bratzler Shear and subsequent adaptations of this instrument have been used in numerous studies dealing with meat tenderness. Wheeler et al. (1996) studied tenderness differences in meat that was thawed at different temperatures. Results showed that thawing steaks to a consistent temperature (3 to 6°C) yielded the best results because it prevented protein hardening during long cooking times. In addition, they found that coring the sample parallel to the longitudinal orientation of the muscle fibers increased repeatability. Lyon and Lyon (1998) evaluated three shear test devices to see if information obtained in a similar way could be interchangeable. They looked at the differences between the Warner-Bratzler Shear (BT-WB), the Warner-Bratzler blade attachment (TA-WB)

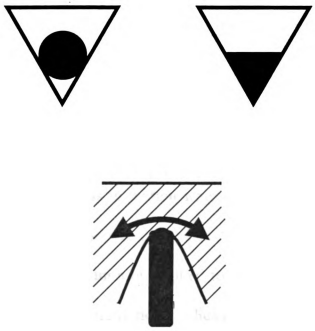

Figure 1.1. Triangular Blade of Warner-Bratzler Shear (Similar to Figure 19 shown in Bourne, 1982)

and a 45° chisel-end blade attachment (TA-WD) to the Model TA.XT2 texture analyzer. Results showed that the devices varied in their measured values; however, no significant difference ($P > 0.05$) was found between the BT-WB and TA-WB. Sensory panel results corresponding to Warner-Bratzler Shear readings have a correlation in the range of 0.6 to 0.85 (Greaser and Pearson, 1999). In addition, meat tenderness was related to firmness in sensory terminology in a study by Rajalakshmi et al. (1987). A strong relationship ($R^2 = 0.97$) was found between firmness and toughness in mutton when evaluated as part of descriptive analysis. In that study, firmness was defined as "the textural property manifested by a high resistance to deformation by applied force" and was recorded after the first few bites. Overall, results from most studies using the Warner-Bratzler Shear suggest the need for more standardization of testing procedures, and the development of calibration materials to reduce variation in shear force measurements (Wheeler et al., 1996).

1.4 Mechanical and Sensory Correlations

Although no mechanical test can completely replace the complexity of human sensory evaluations, there have been many useful studies comparing mechanical and sensory results. Sensory and instrumental tests may be carried out simultaneously so that correlations can be made between these different evaluation methods. Research has shown that a linear relationship often exists between sensory and instrumental tests; however, when non-linear relationships are found,

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they are not always explained (Szczesniak, 1987). Many imitative tests have been developed to mimic mastication. Each of these instruments resembled the chewing motion of food and measured stress and/or strain outputs. For instance, Proctor et al. (1955) created a strain-gauge tenderometer, which incorporated human dentures that rocked back and forth to simulate human jaw movement and corresponding strains. To obtain sound statistical correlations when performing these empirical tests, factors such as the geometry and position of the sensors and the chewing motion must be carefully considered.

The most recognized and widely used imitative test is Texture Profile Analysis (TPA) developed by General Foods during the mid 1960's (Szczesniak, 1963). The creation of the General Foods Texturometer allowed for correlations to be made between instrumental and sensory data. The Texturometer generated multiple sensory parameters that could be applied to various types of food items (Friedman et al., 1963). By combining these two methods, standardized texture parameters were established and assessed so that others could benefit from defined levels of textural attributes. Later, Bourne (1978) used the double compression form of TPA using an Instron Universal Testing Machine to evaluate the textural parameters of food. This procedure has now become a standard for texture evaluation of solid foods.

There have been many advances in food texture evaluation that have led to new techniques and equipment, and thus a more in-depth understanding of the correlation between objective and subjective measurements. When Henry et al.

(1971) evaluated the textural characteristics of semi-solid foods such as dessert puddings, pie fillings, and whipped toppings, many new physical parameters as well as sensory tests were established. Some new parameters included stringiness, maximum tensile force, and tension. Results suggested that physical values could predict essential sensory attributes. Kalviainien et al. (2000) defined and quantified the most important texture and flavor variables of high viscosity gels with different thickeners and aromas. Panelists could detect the influence of strong and weak gels on specific flavor intensities.

Other sensory studies involving gels have used the Universal Instron Machine to correlate the physical and sensory properties. "Compressive resistance" of six different gel systems was tested and correlated with sensory analysis (Daget and Collyer, 1984). In that study, the hardness of the gels was assessed by physical handling and its perception in the mouth. Both evaluations of hardness correlated closely with rupture deformation and rupture force, which were measured with an Instron. Similarly, Montejano et al. (1985) compared the sensory results from both a fundamental torsion failure test and an imitative test (TPA). The shear stress at failure and the TPA hardness were highly correlated ($R^2 = 0.94$) when evaluated by a trained panel.

MATERIALS AND METHODS

2.1. Procedure For Making Gelatin Gels

2.1.1. Formulations

Gelatin gel samples were comprised of gelatin (Great Lakes Unflavored Gelatin, Grayslake, IL) (Table 2.1), sorbitol (Roquette America, Inc., Gurnee, IL) and distilled water. Sorbitol was added to the formulation because of its ability to retain moisture and increase firmness of gels. Table 2.2 displays the actual formulations of each of the concentration levels prepared. The amount of water naturally occurring in the sorbitol (30% wet basis from manufacturer specification sheets) was accounted for in the solution formulation. Sorbitol replaced 20% of the water in each concentration level. Formulations also accounted for the amount of moisture present in the commercial gelatin. The moisture content of the gelatin on a wet basis was determined by drying four 5-gram samples in aluminum pans in an oven (Fisher Scientific, Itasca, IL) at 105°C for 17 hours (GMIA, 1986).

Table 2.1. Gelatin specifications of the three brands evaluated.*

	Great Lakes Gelatin	SKW Gelatin	Knox Brand
Type	A-Porcine	B-Bovine	A-Porcine
Bloom	225 grams	225 grams	235 grams
Color	Light tan	Light tan	White/ Off-white
pH	4.5-5.8	5.0-6.0	3.8-5.5
Moisture (%,wb)	12 max	8-12	8-13
Ash (%)	1.0 max	2.0 max	0.3-2.0

*All values obtained from specification sheets from manufacturer

Table 2.2. Formulations for gelatin concentrations.

Gelatin (bone dry), %	22.5	25.0	27.5	30.0	32.5	35.0
Sorbitol, %	15.5	15.0	14.5	14.0	13.5	13.0
Water, %	62.0	60.0	58.8	56.0	54.0	52.0
Sample Mass, g	400	400	400	400	400	400
Actual Formulations						
[1]Raw Gelatin, g	99.27	110.30	121.33	132.36	143.39	154.42
[2]Raw Sorbitol, g	88.57	85.71	82.86	80.00	77.14	74.29
Water, g	212.16	203.98	195.81	187.64	179.46	171.29

1 Average Moisture Content = 9.34% (wet basis);
2 Moisture Content = 30% (wet basis)

2.1.2. Sample Preparation

Gelatin gel samples were prepared according to a modified version of the Gelatin Manufacturers Institute of America, Inc. (GMIA) method for cold water dispersing (GMIA, 1986). This method of preparing gel samples was modified by the addition of sorbitol. Concentration levels of dry gelatin ranged from 22.5% to 35.0% and were chosen after preliminary experiments revealed limitations: gelatin gels below 22.5% were too soft to register a force response during experimentation, and gels above 35% were difficult to prepare and lacked uniformity due to the incorporation of air bubbles in the samples. The desired amount of sorbitol was added and stirred into the measured amount of water prior to the dispersion of gelatin powder. Solutions of 400 grams were prepared by pouring gelatin into an 800 ml Pyrex beaker containing the sorbitol and water at a temperature ranging from 20°C to 30°C. The solution was stirred quickly with a glass stirring rod and allowed to stand for approximately 40 minutes so that all particles were fully hydrated. The solution was gently stirred and heated to 60°C until uniform. Solutions were poured into 24 oz. plastic containers (13 x 8x 6 cm), covered with a plastic lid, placed in a 5°C refrigerator, and held overnight.

Gel samples, 1.21 cm in diameter, were cored (Figure 2.1) at 620 rpm using a ½" diameter coring cutter (G-R Manufacturing Co., Manhattan, KS) attached to a mounted 8-inch drill press (Sears, Roebuck and Co., Hoffman Estates, IL; Model No. 137.219080). Kastner and Henrickson (1969) found that a mounted core borer produced cores that were uniform in diameter. Cored samples were sliced

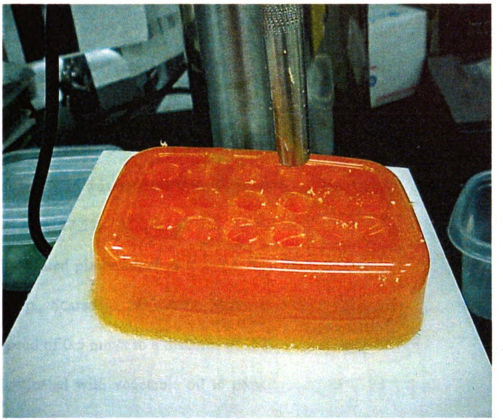

Figure 2.1. Coring gelatin samples using a mounted 8-inch drill press (Sears, Roebuck and Co., Hoffman Estates, IL; Model No. 137.219080) and a ½" diameter coring cutter (G-R Manufacturing Co., Manhattan, KS).

with a flat-edged blade to a length of 2.58 cm and stored at 5°C in airtight containers until tested.

2.2. Characterization of Firmness

2.2.1. Compression Testing and Modulus Calculation

Gel samples, 1.21 cm in diameter, were cut to 1.21 cm in length so the aspect ratio was equal to one. Eight samples of each gelatin concentration (22.5%, 25.0%, 27.5%, 30.0%, 32.5%, and 35.0%) at 5°C were compressed between lubricated plates attached to a TA.XT2 Texture Analyzer (Texture Technologies, Corp., Scarsdale, NY/Stable Micro Systems, Godalming, Surrey, UK) at a test speed of 0.5 mm/s to a distance of 25% of the original sample height. Plates were lubricated with vegetable oil to prevent samples from adhering to plates during deformation (Bagley et al., 1985). Average force values were calculated for samples at each concentration. Secant modulus values (determined at 15% strain) were calculated for each concentration.

2.2.2. Shear Force Determination

To characterize the firmness of each sample, the maximum force required to cut through the center of each gel sample was determined with a bench top Warner-Bratzler Shear instrument (G-R Elec. Mfg. Co., Manhattan, KS) (Figure 2.2), and a TA.XT2 Model Texture Analyzer equipped with a W-B blade attachment (Figure 2.3). Both blades had a ½" round bevel and were 1.016 mm

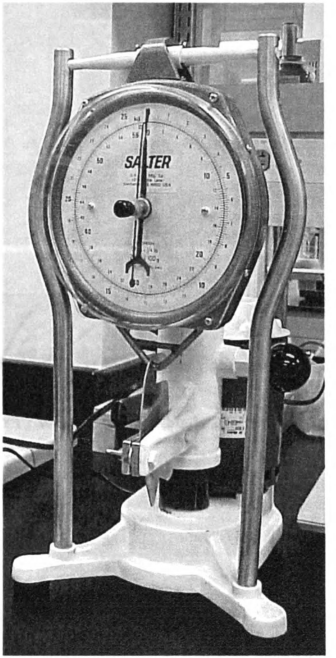

Figure 2.2. Warner-Bratzler Shear instrument with partially sheared sample.

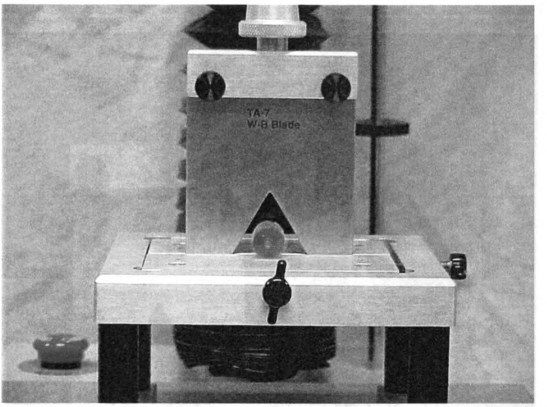

Figure 2.3. TA.XT2 Warner-Bratzler blade attachment with gelatin sample loaded for testing.

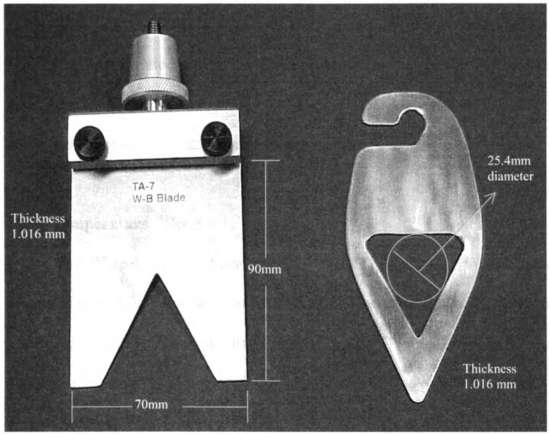

Figure 2.4. Picture and dimensions of TA.XT2 and Warner-Bratzler blades.

thick (Figure 2.4). Eight core samples at six concentrations (22.5%, 25.0%, 27.5%, 30.0%, 32.5%, and 35.0%) were tested on each instrument and the average shear values calculated for each concentration. The temperature of the gelatin samples was 5°C for the duration of the tests. The blades of both instruments sheared through samples at a speed of 3.3 mm/s.

2.2.3. Temperature Effects

The Warner-Bratzler Shear and the TA.XT2 were used to determine the effects of temperature on the shear force values of gelatin gels. Gel samples of the lowest and highest concentrations (22.5% and 35.0%) were equilibrated at three different temperatures (5°C, 15°C, and 25°C) in three Haake water baths: F3/CH, F6/C25, and D1/W19 (Haake USA, Paramus, NJ). Five gelatin samples, 1.21 cm in diameter and 2.58 cm in length, of each concentration, and at each temperature, were sheared (quickly to keep the sample temperature constant) using the Warner-Bratzler and the TA.XT2. The average shear force values were calculated and compared among the three temperatures.

2.2.4. Gelatin Brand Comparison

Two gelatin brands, in addition to the Great Lakes Gelatin used in the Shear Force Determination, were tested to compare results for different types of gelatin. The data in Table 2.1 compares the characteristics of Knox Brand Gelatin (Nabisco, Parsippany, NJ) and Rousselot ® 225 B 40 Edible Gelatin (SK Gelatin,

Waukesha, WI). Eight core samples of each concentration (22.5%, 25.0%, 27.5%, 30.0%, 32.5%, and 35.0%) made from both brands of gelatin were sheared by the Warner-Bratzler and the TA.XT2. Average shear force values were calculated for each concentration on each instrument. Shear force results of all three brands were compared.

2.3. Sensory Panel Evaluation

2.3.1. Difference Testing

An untrained sensory panel of 30 panelists was used to subjectively evaluate three concentrations (25%, 30%, and 35%) of gel samples. Volunteer panelists were comprised of graduate students, staff members, and faculty members of the Department of Food Science and Human Nutrition at Michigan State Univerisity. Sample codes, generated from a random table of numbers, were used for each of the concentrations (Meilgaard et al., 1991). Panelists signed consent forms and were given rewards for their participation.

A triangle test was chosen to determine if panelists could distinguish the difference between three levels of firmness. Individual booths with red lighting (to mask color differences) in a sensory laboratory were used for the evaluation (Figure 2.5). Panelists were served a tray that contained a ceramic plate (to maintain cool temperature) with two labeled sets of three gel samples taken directly from a refrigerator maintained at 5°C (Figure 2.6). The tray also

Figure 2.5. Sensory evaluation booth with red lighting to mask color differences.

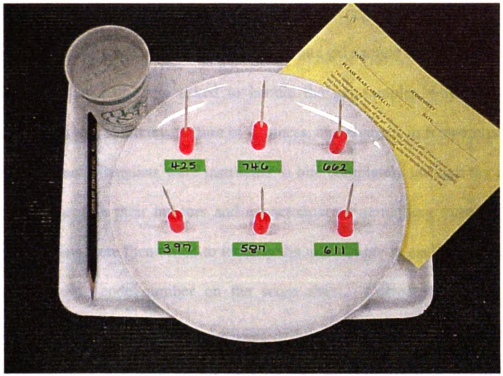

Figure 2.6. Example of tray served to panel participants.

contained a cup for expectoration, a pencil, and a score sheet. Two out of the three gel samples of each set were the same and one gel sample of each set was an odd sample. Panelists were asked to handle the gel samples with toothpicks provided to prevent tactile evaluation of firmness, and changes in temperature due to human contact. Panelists were instructed to bite completely through the center of each sample with their incisors and expectorate any remaining sample in the mouth. Panelists were then asked to identify the odd sample in each set and circle the corresponding code number on the score sheet. Correct responses were computed for each triangle test. Corresponding "P" values for the number of correct responses accounting for the total number of panelists were found using Statistical Chart 2 in Laboratory Methods for Sensory Analysis of Food (Poste et al., 1991). Statistical Chart 2 determines the probability that the different sample was correctly identified by chance alone. If the corresponding "P" values were greater than 0.05, significant differences existed between samples.

2.3.2. Trained Panelists

Twelve panelists (6 men, 6 women, age 22 to 38) participated in a trained sensory panel evaluating the firmness of the gelatin gels (Meilgaard et al., 1991). Panelists were selected based on their responses from the pre-screening difference test described above or due to their strong interest in the study.

Panel training consisted of one main session held in small groups and involved mostly explanations of the study, the purpose of training, and how

firmness of the gels was to be evaluated. Eight different concentrations of gelatin, encompassing the concentration range to be assessed, were used for training purposes. Panelists were asked to evaluate the firmness of each sample by biting through the center of the gel with their incisors and to remember where that sample rated on a firmness scale from 1 to 15.

Two evaluations were conducted in the Sensory Evaluation Laboratory at Michigan State University. Partitioned evaluation booths and red lighting were used to mask sample differences other then firmness. Every participant evaluated six samples each time on a 15 cm unstructured line scale (Poste et al., 1991). The samples were coded with 3-digit random codes and presented in a random order. Panelists were asked to record each evaluation by marking a vertical line across the horizontal line at the point that best reflected their perception of the magnitude of firmness of each sample. Cups for expectorate and toothpicks were also available on the tray presented.

The differences in firmness were studied using one-way analysis of variance, where the one source of variation was the concentration. Tukey's tests were used to determine which concentrations significantly differed from the others on the standard scale.

RESULTS AND DISCUSSION

3.1. Compression Testing

Gelatin gels do not behave like Hookean solids; therefore, secant modulus values needed to be determined to characterize nonlinear stress-strain behavior (Mohsenin, 1970). Secant modulus is the slope of the line connecting the origin and the point at which the sample was subjected to 15% strain. Equations for compressive stress (σ_c) and compressive strain ($\varepsilon_{true\text{-}axial}$) were calculated as described by Truong and Daubert (2000):

$$\sigma_c = \frac{F(H_o - \Delta H)}{\pi R^2 H_o} \qquad (1)$$

$$\varepsilon_{true-axial} = -\ln\left(1 - \frac{\Delta H}{H_o}\right) \qquad (2)$$

Where: σ_c = compressive stress (Pa)

$\varepsilon_{true\text{-}axial}$ = compressive strain (dimensionless)

F = force (N)

ΔH = deformation (mm)

H_o = initial height of sample, 12.1 mm

R = sample radius (m)

Table 3.1 displays the average values and related information calculated at 15% strain for six gelatin concentrations compressed to 25% of the original height (1.21cm). The original sample radius of each gelatin sample was 0.6 cm, which

increased slightly during the test. The values determined for stress (N/m^2) accounted for the change in sample radius as the samples were compressed. The samples had a tendency to bellow out even with the lubricated plates, therefore only a 25% deformation was used to obtain the stress and strain information. The lowest concentration (22.5%) had the lowest modulus value ($2.05x\ 10^5$ Pa); however, the 27.5% gelatin samples did not follow the increasing trend.

Bi-axial compression was chosen as an evaluation method because it simulates the act of biting between the molar teeth, and results indicate the firmness of a sample. Other studies have successfully used this method to evaluate the firmness of food products. However, in this study, there are a few reasons why results did not accurately reflect the true mechanical properties of the samples. Most of error can be attributed to the sample geometry. Core samples tended to have a tapered shape due to the process of coring, so the diameter was not always uniform. In addition, when subjecting a gel sample to a low deformation (25%), few differences can be observed among concentrations. This allows for too much variation between concentrations and no basis of comparison. Also, compression with a flat plate gave a lateral expansion with the applied load, which required a larger force before reaching the yield point. Overall, data from compression produced less consistent results. Testing in the shear mode (discussed in the next section) was superior as compared to compression testing.

Table 3.1. Determination of secant modulus values at 15% strain.

Concentration (%)	*Raw Force (N)	*Raw ΔH (mm)	*Stress (N/m^2)	*Secant Modulus (Pa)
22.5	4.13	1.69	3.08 E4	2.05 E5
25.0	6.11	1.69	4.55 E4	3.03 E5
27.5	7.71	1.69	5.74 E4	3.82 E5
30.0	6.66	1.69	4.96 E4	3.30 E5
32.5	7.25	1.69	5.40 E4	3.59 E5
35.0	7.65	1.69	5.70 E4	3.79 E5

*Values represent averages of eight gelatin samples per concentration.

3.2. Evaluation of Shear Forces

The average shear force values for each concentration of gelatin gels were calculated for both instruments (Warner-Bratzler and TA.XT2) and displayed in Table 3.2. The standard deviations for each average shear force value were also calculated. Figure 3.1 shows how the shear force values increased as the gelatin concentration increased when shearing samples on both instruments. The average shear force values ranged from 1.5 kg to 6.8 kg for the Warner-Bratzler and from 3.2 to 9.4 kg for the TA.XT2. Overall, the TA.XT2 produced higher standard deviations most likely due to the high degree of instrument sensitivity as compared with the standard Warner-Bratzler. Higher standard deviations may also reflect slight variations among samples. Correct and consistent positioning of the gel sample in the center of the shearing device is important for obtaining good results. The concentration of the gelatin may vary slightly along the length of the sample due to the entrapment of air in the setting gel and the surface foam that may have formed during upon heating. Shearing should occur as close to the center of the sample as possible. Overall, these results show that the concentration of the gelatin influences the intermolecular linkages forming the gel network, which affects the firmness of the gel. As seen in other studies, shearing was the most effective method to discriminate across gel concentrations, and compression was the least effective (Munoz, 1986).

Figure 3.2 shows the correlation between the Warner-Bratzler and the TA.XT2. A strong correlation ($R^2 = 0.95$) exists between these two instruments

Table 3.2. Average shear force values for gels with different gelatin concentrations evaluated on the Warner-Bratzler and the TA.XT2.

Concentration (%)	Avg. WB Shear Force (kg)	Avg. TA Shear Force (kg)
22.5	1.5 (0.12)	3.2 (0.18)
25.0	2.5 (0.09)	4.2 (0.30)
27.5	3.0 (0.05)	5.4 (0.22)
30.0	3.9 (0.09)	5.5 (0.27)
32.5	5.8 (0.26)	7.5 (0.32)
35.5	6.8 (0.28)	9.4 (0.40)

Standard deviations are shown in the parentheses next to the average shear force value.

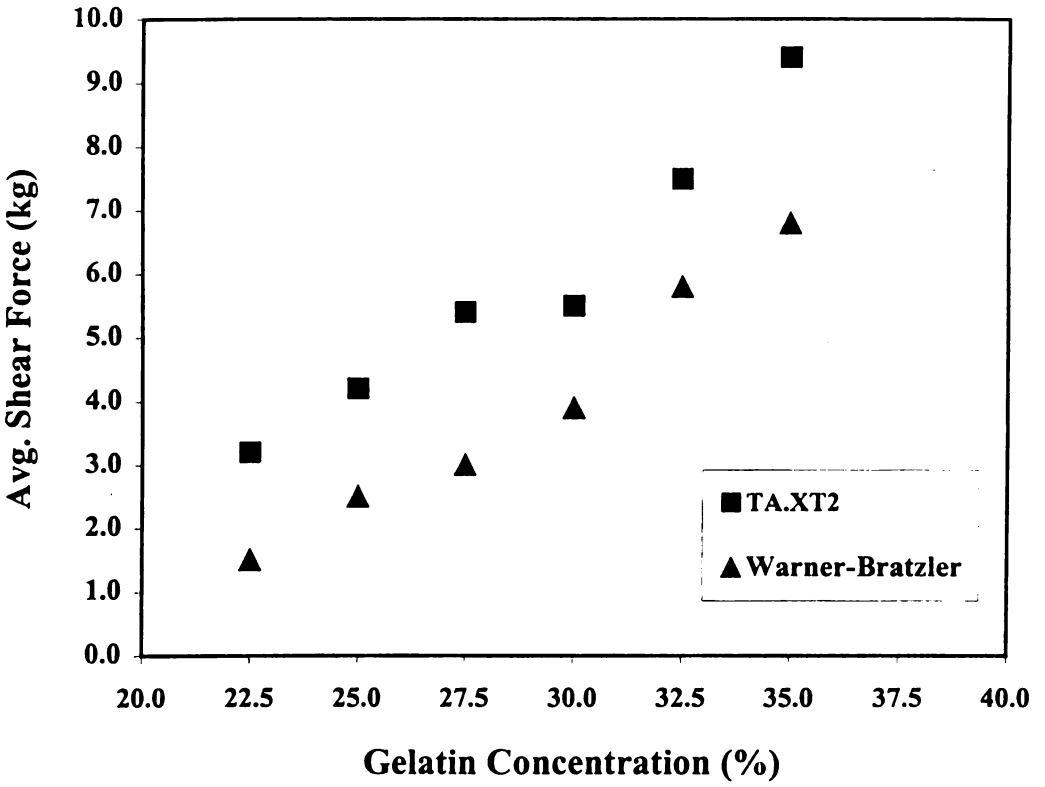

Figure 3.1. Average shear force values vs. gelatin concentration for the Warner-Bratzler shear instrument and the TA.XT2.

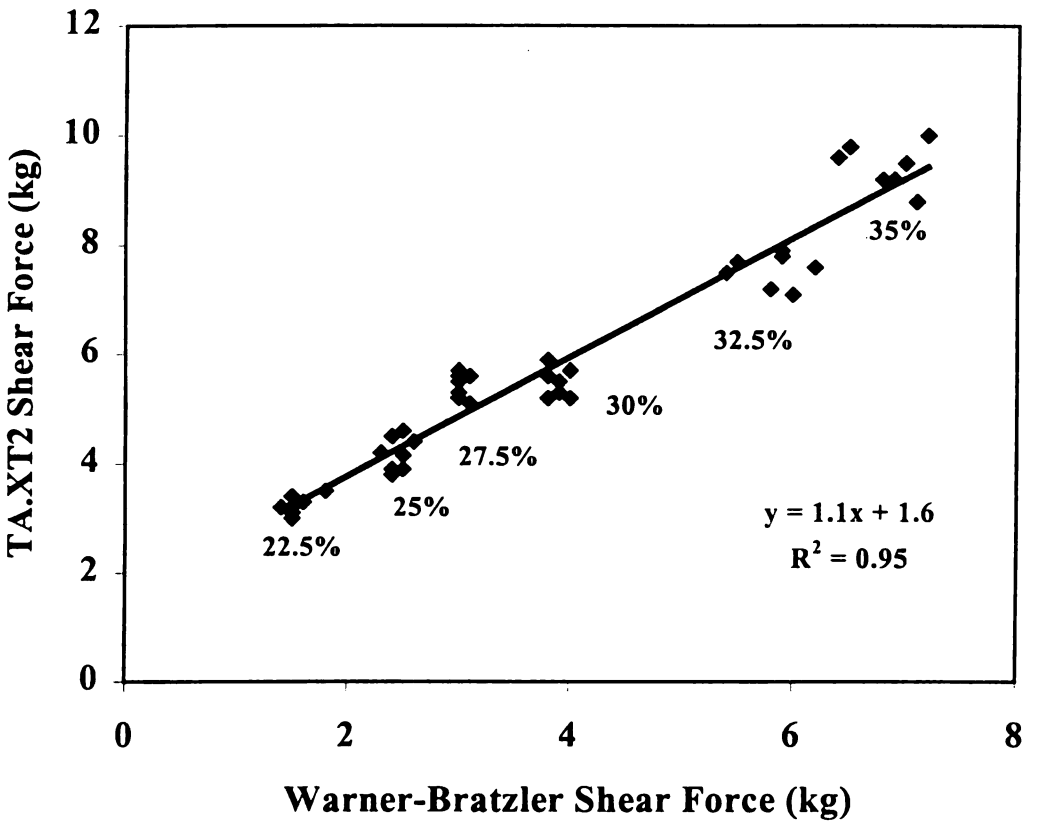

Figure 3.2. Warner-Bratzler and TA.XT2 Correlation.

when evaluating the shear force of gelatin gels at 5°C. However, given the slope of the line in Figure 3.2, there is consistently a 10% increase in TA.XT2 shear force value per kilogram increase in Warner-Bratzler shear force value. These differences have also been seen in another study where many shearing instruments were compared (Lyon and Lyon, 1998). A possible reason for this discrepancy is the actual shearing speed of the instrument. Although the manufacturer specifies the speed to be 3.3 mm/s throughout the shearing of the sample, the actual speed of the Warner-Bratzler was determined (in the MSU Meat Laboratory) to be approximately 4.3 mm/s. If the sample is very firm, it has been suggested the motor cannot maintain a constant speed while shearing through a sample (Johnson, 2001). In addition, the beveled edges of the blades may be slightly different depending on the way they were crafted, which may also account for the different average shear force values. Also, during the downward motion of the anvil on the Warner-Bratzler system, the blade will also experience some downward motion while deforming the spring in the force transducer. Overall, the Warner-Bratzler and TA.XT2 are both suitable for the evaluation of gelatin core samples because the results of each are consistent and reproducible.

The values found for the shear forces in the current study are similar to the three categories (Red, White and Blue) for beef tenderness defined by Boleman et al. (1997). The ranges for the three categories of beef tenderness were based on shear force values: 1) 2.27 kg to 3.58 kg (Red); 2) 4.08 to 5.40 kg (White); and 3) 5.90 to 7.21 kg (Blue). The three concentrations of gelatin that fell within or

around each of three tenderness categories were 25%, 30% and 35%, respectively. Since consumers are able to distinguish between different degrees of tenderness and are willing to pay more for more tender meat, these three gelatin concentrations were chosen for sensory evaluation to see if panelists could detect differences using gelatin as a model material (Section 3.5). The gelatin concentrations chosen for this study (22.5% to 35%) represent a wide range of firmness, yet all fall within the range used to evaluate beef. Therefore, firmness standards made of gelatin gels at the concentrations used are potentially good model materials for tenderness evaluation. In addition, although the Warner-Bratzler and the TA.XT2 proved to be sufficient instruments for evaluating gels, the Warner-Bratzler shear force values were used in subsequent tests to be consistent with the Boleman et al. (1997) study.

3.3. Temperature Effects on Gelatin Gels

Many foods exhibit changes in rheological behavior as temperature increases or decreases. Gelatin gels also exhibit this behavior when exposed to different temperatures. Figure 3.3 shows the correlations between the Warner-Bratzler and the TA.XT2 for three different test temperatures (5°C, 15°C and 25°C) at two gelatin concentrations (22.5% and 35%). The figure displays a higher correlation (R^2 = 0.92) for the lower concentration of gelatin, and a lower correlation (R^2 = 0.82) for the higher concentration of gelatin. This variation in shear force values at the higher concentration may be due to sample uniformity. At the higher concentrations of gelatin, it was more difficult to obtain completely uniform samples due to partial air entrapment.

Each concentration showed an increase in average shear force as the testing temperature decreased on both the Warner-Bratzler and the TA.XT2 (Figure 3.4). Table 3.3 shows that the slopes of the 35% gelatin samples (-0.19 and –0.1) were steeper than the slopes of the 22.5% gelatin samples (-0.09 and –0.05). These results show that the gelatin gels are more affected by changes in temperature at higher concentrations. Overall, temperature has a strong effect on the textural properties of gelatin gels. Because of this, the temperature of the gelatin gels must be clearly established, and carefully monitored, if firmness standards are to be used for sensory panel training, instrument calibration, or for any other model material application. Based on this study, a ± 1kg variation in shear force value is

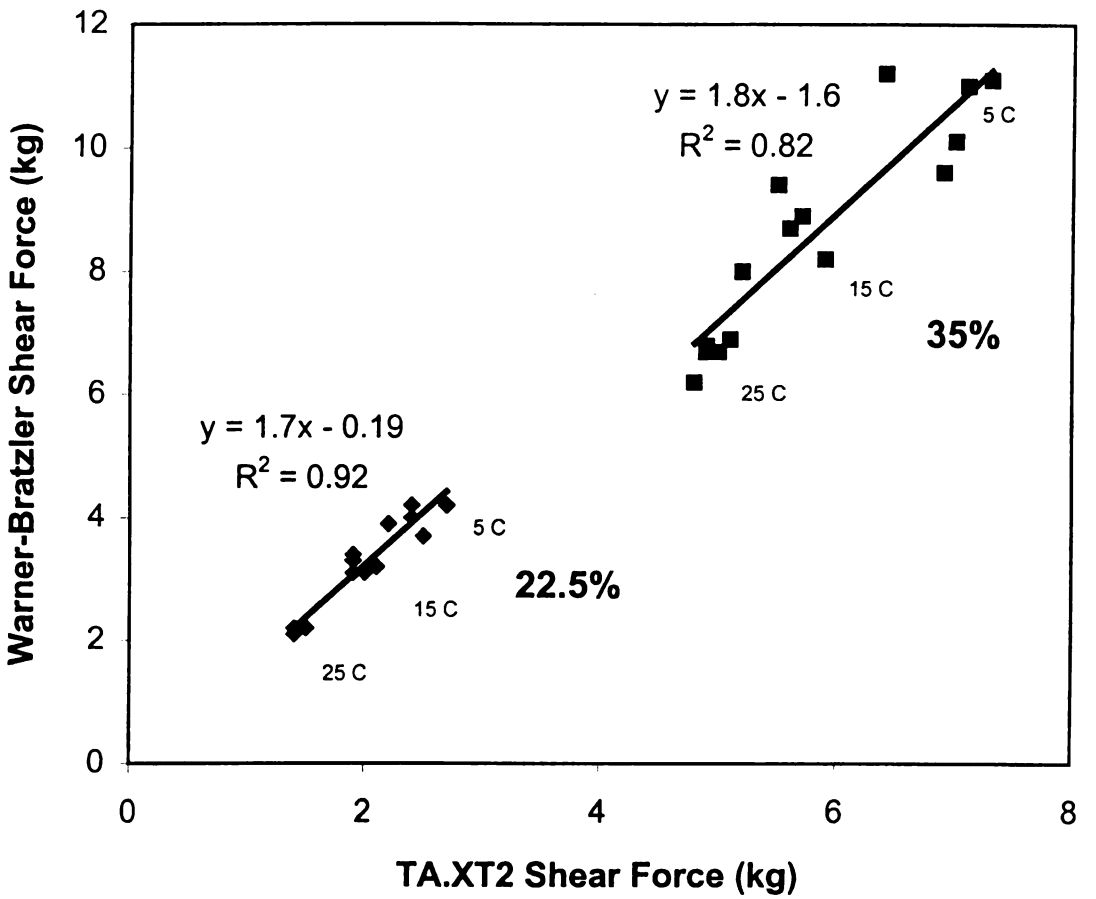

Figure 3.3. Effect of temperature on shear force measurements of 22.5% and 35.0% gelatin gels.

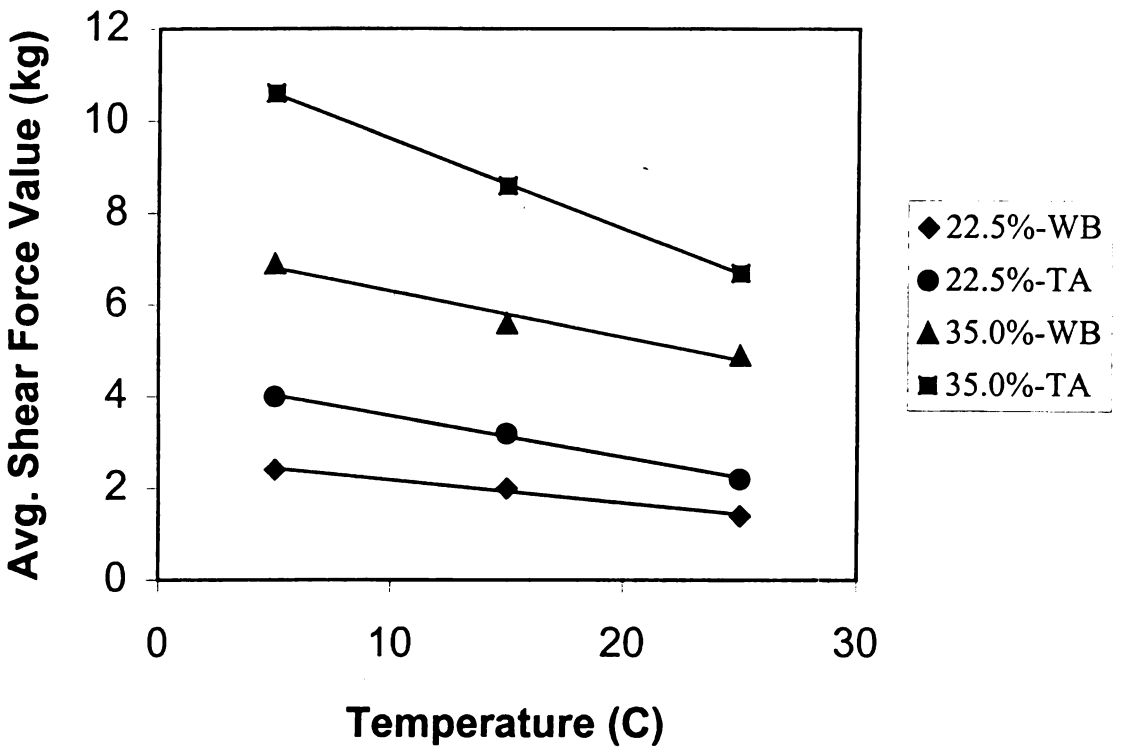

Figure 3.4. Average shear force values vs. test temperature for 22.5% and 35% gelatin concentrations. (Each point is an average of five values).

Table 3.3. Comparison of slope values to demonstrate effects of temperature.

Material	Slope	Intercept	R^2
35% - TA	-0.19	11.6	0.99
35% - WB	-0.10	7.3	0.97
22.5% - TA	-0.09	4.5	0.99
22.5% - WB	-0.05	2.7	0.99

recommended. The corresponding allowable temperature range (calculated using the equation of the line with greatest slope in Figure 3.4) is approximately ± 2.5°C. Therefore, a testing temperature of 5°C (± 2.5°C) is recommended to minimize temperature induced sample variation.

3.4. Comparison of Brands

Table 3.3 and Figure 3.5 show the comparison of the three gelatin brands used in this study. The specific characteristics of each brand can be found in Table 2.1. Figure 3.5 shows the variation between each brand of gelatin. These differences can be attributed to the nature of the gelatin source and the natural heterogeneity of this substance. For example, the SKW gelatin, which is derived from a bovine source, did not have as high a shear force as the two brands of gelatin derived from porcine. The chemical composition of the gelatin and the way in which the proteins were hydrolyzed also contribute to the firmness of the gel sample.

These results suggest that careful preliminary testing is needed before deciding on which concentration ranges to use. Gelatin gels derived from porcine were proven easier to prepare and analyze than gelatin gels derived from bovine sources. Bloom values may also be compared carefully so that the desired firmness is achieved. The Bloom values for the Great Lakes Gelatin, SKW Gelatin and Knox Brand Gelatine were 225, 225, and 235 grams, respectively. Bloom values may vary a little due to the natural variability of the gelatin batch itself; however, different brands of gelatin can be compared easily by this characteristic.

Table 3.4. Comparison of average Warner-Bratzler shear force values of three brands of gelatin.

Concentration (%)	*Great Lakes (kg)	*SKW (kg)	*Knox (kg)
22.5	1.5 (0.12)	1.5 (0.11)	1.8 (0.08)
25.0	2.5 (0.09)	1.6 (0.17)	2.5 (0.10)
27.5	3.0 (0.05)	2.7 (0.10)	3.3 (0.08)
30.0	3.9 (0.09)	3.2 (0.11)	3.7 (0.21)
32.5	5.8 (0.26)	3.2 (0.23)	4.9 (0.14)
35.0	6.8 (0.28)	4.6 (0.13)	5.2 (0.23)

*Refer to Table 2.1 for gelatin specifications of the three brands evaluated. Standard deviations are shown in the parentheses next to the average shear force value.

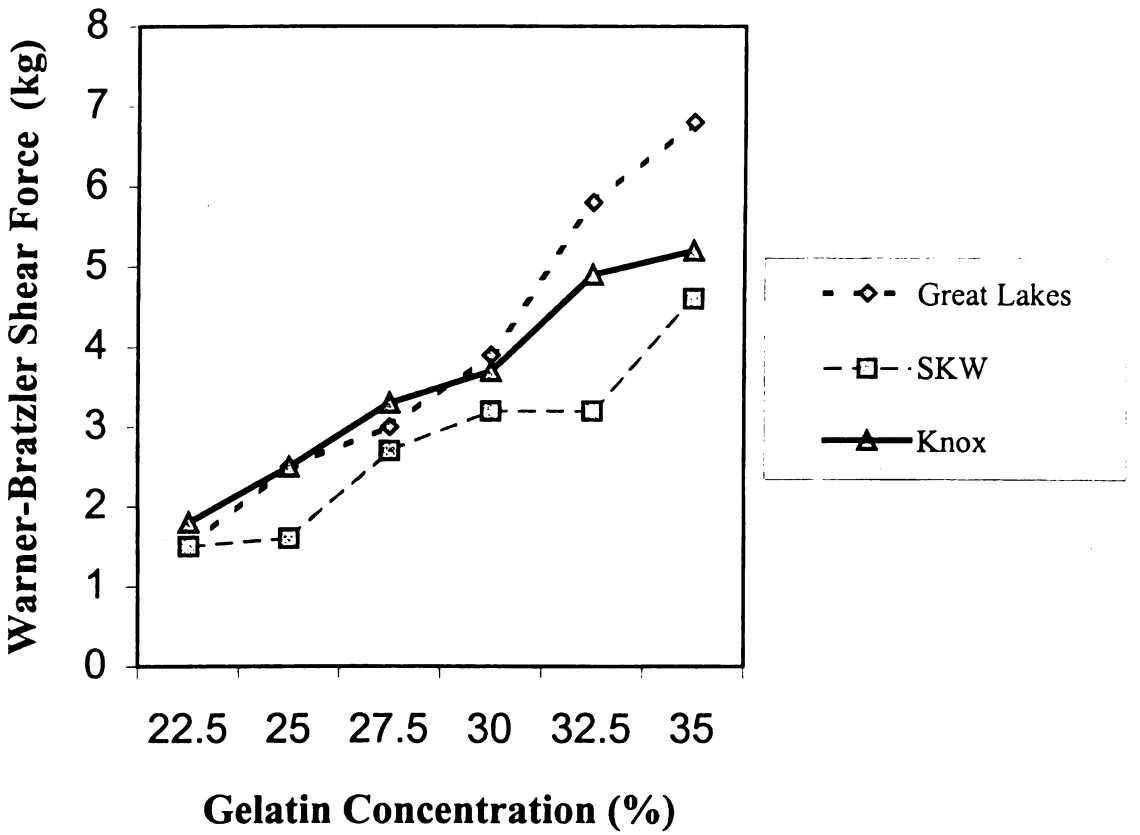

Figure 3.5. Average shear force values for three brands of gelatin at six different concentrations.

3.5. Difference Testing

Table 3.4 displays the concentrations that were chosen for sensory evaluation. The three concentrations (25%, 30%, and 35% of Great Lakes Gelatin) were selected for the triangle test because the corresponding shear forces fell within or around the three shear force categories describing beef tenderness. Table 3.5 shows the number of correct responses for panelists participating in the triangle tests. At a critical P value of 0.05, detectable differences existed between all three sample pairs. The probability that the results happened by chance was less than 0.001. More panelists (18/20) could detect the difference between the 25% and 35% gelatin samples than the other pairs of samples.

Results show there are substantial differences in firmness among gelatin samples. Panelists overwhelmingly gave correct responses when the concentration differed by only 5% gelatin. Just as consumers can distinguish between categories of beef tenderness, panelists can detect differences in firmness when three different concentrations are used to reflect specific degrees of beef tenderness.

Table 3.5. Determining sensory parameters for difference testing from shear force results.

Meat Categories	*Shear Force Range (kg, WB)*	*Gelatin Concentration*	*Avg. Shear Force (kg, WB)*
Red	2.27-3.58	22.5%	1.5
		25.0%	2.5
		27.5%	3.0
White	4.08-5.40	30.0%	3.9
		32.5%	5.8
Blue	5.90-7.21	35.0%	6.8

Table 3.6. Correct responses from triangle tests.

Gelatin Concentration	*Correct Responses*	*Total Responses*	*% Correct*
25% and 30%	*16	20	80%
30% and 35%	*14	20	70%
25% and 35%	*18	20	90%

*Panelists were able to detect a significant difference between all concentration levels ($p<0.001$)

3.6. Trained Sensory Panel

Tables 3.6 to 3.9 show the scaling results from the trained sensory panel. Panelists marked off a firmness response on a 15 cm unstructured line for each of the six gelatin concentrations. The distance from the origin of the line to each mark was measured in centimeters and recorded as ratings on Tables 3.6 and 3.8. Tables 3.6 and 3.7 display the firmness ratings from the unstructured scales and the ANOVA values for the first sensory evaluation. Tables 3.8 and 3.9 display the firmness ratings on the unstructured scales and the ANOVA values for the second sensory evaluation. The correlation between the average shear force values determined by the Warner-Bratzler and the average ratings determined by panelists from both panels was excellent (Fig. 3.6). There was a strong correlation ($R^2 = 0.98$) between the panelists' responses and the shear force values.

The Tukey's test, for each set of panel results, determined that a significant difference existed among gelatin concentrations if their average values differed by a value of 2.24 for the first panel and 2.33 for the second panel. Panelists detected significant differences between all concentration levels in the first panel except between 22.5% and 25.0%. In the second panel, panelists detected significant differences between all concentration levels except between 25.0% and 27.5%. Overall, panelists agreed on where each gel sample fell on the firmness scale. All panelists followed the training instructions and used the entire scale when evaluating the firmness of the gel samples with their incisors; therefore, overall firmness ratings fell very close together on the scale.

Table 3.7. Results of the first unstructured scale test.

	Gelatin Concentration (Code)					
Panelist	22.50% (656)	25.00% (157)	27.50% (138)	30.00% (536)	32.50% (396)	35.00% (868)
1	0.4	2.4	4.5	7.5	11	14
2	0.2	5.5	7.2	9.5	12	14.8
3	1.4	3.8	5.5	7.8	11.5	13.9
4	1	3.4	6	5	11	15
5	0.2	3.4	7.5	5.4	9.3	15
6	0.8	2.1	4.1	7.3	14.3	11.7
7	0.6	3	3.8	5.5	10.7	14.2
8	1.3	2.7	3.5	11.9	8.2	10.2
9	1	0.8	1.2	10.5	12.6	14.5
10	0.5	2.7	3.7	9.7	13.2	15
11	0.4	1.4	9.2	11.4	14.5	15
12	0.2	1.8	4.8	3.5	7.6	13.5
AVG	0.7	2.8	5.1	7.9	11.3	13.9
Std Dev.	0.4	1.2	2.1	2.7	2.2	1.5

Table 3.8. ANOVA results for first unstructured scale test.

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1547.8	5	309.6	89.5	4.89E-28	2.35
Within Groups	228.3	66	3.46			
Total	1776.1	71				

Table 3.9. Results of the second unstructured scale test.

	Gelatin Concentration (Code)					
Panelist	22.50% (288)	25.00% (996)	27.50% (972)	30.00% (738)	32.50% (112)	35.00% (611)
1	0.8	6.3	3.2	9.4	12.2	14.5
2	1.5	3.4	6.9	4.8	10	12.3
3	0.2	3.1	4.8	8.1	13	14.6
4	0.1	1.7	3	6.6	10.7	14.9
5	0.1	1.6	6.7	9.5	12	13.4
6	2.2	4.3	5.6	11.5	10.5	12.4
7	0.5	5.3	7.5	8.8	10.5	14.7
8	1	2.7	5.4	6.6	12.1	8.8
9	0.9	0.8	6.7	7.8	12	14.4
10	0.1	8.5	3.6	12	14.9	14.2
11	0.9	8.4	9.2	13.8	12.5	14.8
12	0.2	1.8	4.4	9	13	14.9
AVG	0.7	4.0	5.6	9.0	12.0	13.7
Std Dev.	0.7	2.6	1.9	2.5	1.4	1.8

Table 3.10. ANOVA results for second unstructured scale test.

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1464.7	5	292.9	78.7	1.87E-26	2.35
Within Groups	245.7	66	3.72			
Total	1710.4	71				

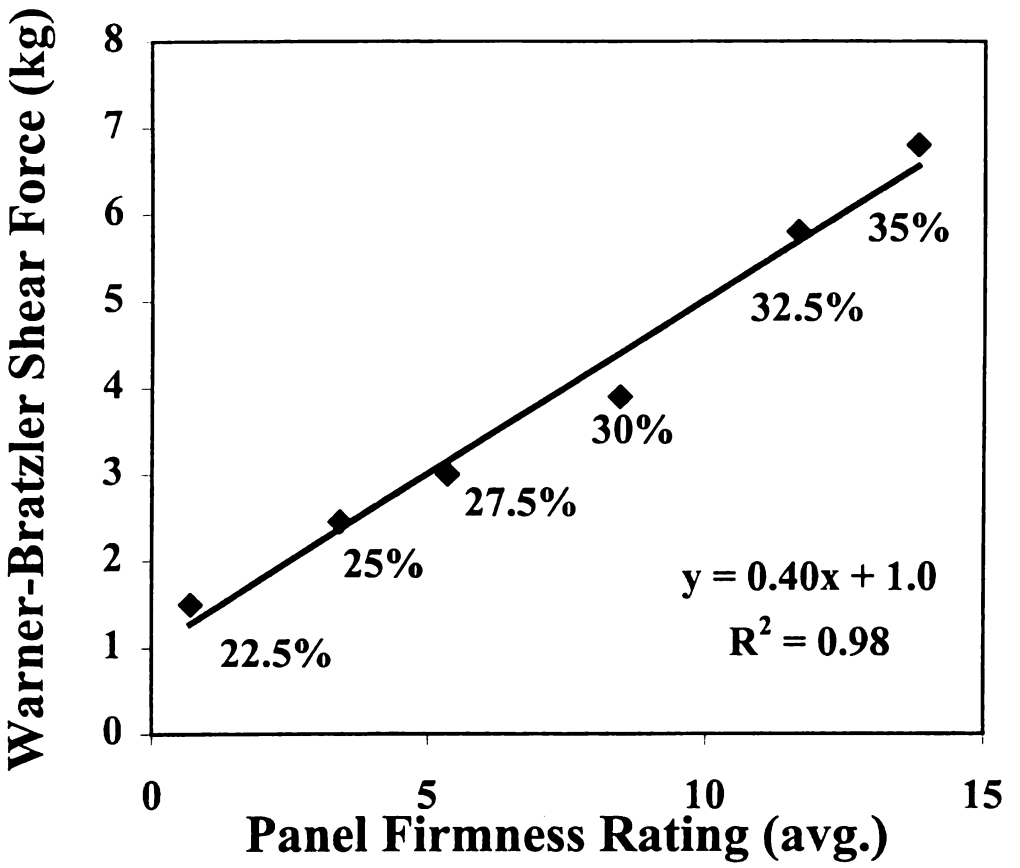

Figure 3.6. Trained panel results for scaling of gelatin gels (results include first and second unstructured scale tests).

3.7. Practical Recommendations

There are several recommendations that can be made regarding the preparation and use of firmness standards made from gelatin gels. First, the specific brand of gelatin and its source (either porcine or bovine) may influence the firmness characteristics and/or the variability of the standards. From this study, gelatin derived from a porcine source is recommended due to ease of preparation and the accuracy of results. Certain gelatin specifications, such as moisture content, are needed so that they can be factored into formulations. The Bloom value of the gelatin will also affect the firmness of the standards. A Bloom value within the range of 225-250 grams is suggested if very firm gels are desired. Method of dispersion should be taken into account if preparation time is a crucial factor. Overall, preliminary experimentation with many concentration levels and several brands is necessary to achieve the desired firmness standards.

Firmness standards must maintain a specific temperature during testing. Holding gelatin gel standards at cold temperatures show less sample variation and are easy to achieve with a water bath or a refrigerator. A temperature of 5°C (± 2.5°C) is recommended to minimize firmness variation. Samples sheared within this temperature range produce the most repeatable results. Although aging effects were not specifically evaluated in this study, a shelf life of less than four days is recommended due to potential mold growth and possible changes in texture. Experience in the current study suggests that solutions be made one day and the gels used on the following day. In addition, batch-to-batch variations may occur

due to fluctuating storage conditions and/or the natural heterogeneity of the gelatin.

Based on the gelatin gel procedure determined in this research, there are some specific practical suggestions that can be made in applications involving meat tenderness. Porcine gelatin (225 Bloom), with a pre-determined moisture content, should be used in the sample formulations. Gelatin concentrations ranging from 22.5% to 35.0% should be prepared by dispersing the gelatin in a solution of water and sorbitol (20% replacement of water) held at room temperature. Solutions should be completely melted by heating to 60°C, poured into a mold, and allowed to gel in a refrigerator. Gel samples should be cored and tested quickly or stored (in an air-tight container) at 5°C to prevent temperature fluctuation.

A standard scale of six benchmark levels can be established by preparing the following gelatin concentrations and the corresponding Warner-Bratzler shear values (kg): 22.5% (1.4-1.8), 25.0% (2.3-2.6), 27.5% (2.9-3.0), 30.0% (3.1-3.5), 32.5% (3.9-4.5), and 35.0% (5.1-5.6). Once these firmness standards are established and characterized by a Warner-Bratzler or a TA.XT2, sensory panelists can be trained on each of the gelatin concentration levels. Difference tests can be used to screen panelists prior to formal training and unstructured scales can be used to evaluate panelists during the course of training. Panelists can then evaluate meat samples (or similar materials) with corresponding shear force values when they have a good feeling for the firmness scale established with gelatin.

SUMMARY

Six scaled standards of firmness (22.5%, 25.0%, 27.5%, 30.0%, 32.5%, 35.0%) composed of gelatin gels were chosen to represent six distinct degrees of firmness and compared to tenderness of meat. The range of firmness was restricted to these concentration levels due to the limitations of the testing method at low concentrations and lack of uniformity at high concentrations. This range can be expanded if other testing methods are implemented and uniform gels can be achieved.

Compression testing and the calculation of secant modulus values for gelatin gels produced inconclusive results. The results produced by shearing samples on both the Warner-Bratzler and the TA.XT2 proved to be superior in accuracy, and a better reflection of the texture (firmness) of each standard. Untrained panelists were able to distinguish among three concentration levels of gels representing three tenderness categories ($p \leq 0.001$) in three consecutive tests. Significant differences were detected by trained panelists between all six scaled standards. Overall results suggest that significant differences exist between all six firmness standards, thus supporting the instrumental results.

It was found that variations in temperature caused changes in the firmness of samples. The temperature of the gel samples must be closely monitored during testing and should not vary any more than $\pm 2.5^{\circ}C$ to prevent any textural changes. Different brands of gelatin may also contribute to changes in firmness among

samples of the same concentration level. Hence, preliminary experiments are needed to achieve desired firmness levels to ensure proper testing conditions.

A simple procedure for producing firmness standards made from gelatin gels has many food and dental research applications. Results suggest that scaled firmness standards made from gelatin and sorbitol are good model materials of meat tenderness. Using gelatin gels as an indicator of meat tenderness may lead to a more standardized method of texture characterization, and may reduce the variability from human or instrumental assessment. In addition, firmness standards made from gelatin gels can be used in place of current scaled food items in the training of sensory panels. Because these standards are made of one naturally abundant primary constituent, problems with local unavailability of brands and numerous sample size and temperature specifications can be eliminated. Lastly, dental researchers trying to determine the effectiveness of denture designs, implants, and cutting surfaces can use gelatin gel standards as food models.

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