# The History of INSTRUMENT ASSESSMENT OF BEEF

## A Focus on the Last Ten Years


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National Cattlemen's Beef Association

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In the eighty-year history of grading beef in the U.S., subjective human judgment has been the primary tool determining carcass yield and quality grades and consequently carcass value. Objective means of evaluating the attributes of beef, including carcass yield and quality grades as well as other beef characteristics such as cutability, tenderness and appearance, increases the functionality of a value-based marketing system. Improving the consistency and accuracy of evaluations to improve conformity and consistency of beef products with the use of instrumentation ultimately contributes to increased producer and consumer satisfaction with beef and enhances communication with all segments of the beef industry.

## Historical Overview

Instrument assessment of beef is a concept that has been evolving over a thirty-year period. In 1978, it was concluded by the U.S. General Accounting Office and reported to the U.S. Congress that the United States Department of Agriculture (USDA) needed to "increase research efforts to develop instruments to accurately measure beef carcass characteristics" [9]. As a result, in 1979, with the intent of developing more objective means to determine USDA grades of beef carcasses, the Food Safety and Quality Service (FSQS) (now Agricultural Marketing Service & Food Safety and Inspection Service) joined the National Aeronautics and Space Administration (NASA) and the Jet Propulsion Laboratory in a study to develop an instrument for objective evaluation of carcass quality and yield grade traits [11,13,14]. Ultrasound and video image analysis (VIA) were the two technologies identified by NASA that could potentially satisfy the goals of USDA for objective grading of beef [13,14].

In 1980, the USDA-Agricultural Research Service (ARS) assumed the task of developing an instrument for yield and quality grading beef carcasses [13]. ARS determined that they were seeking an instrument system that exhibited accuracy, precision, speed and durability and a "Request for Proposals" (RFP) describing the need for such an instrument was created [13]. VIA technology was determined to have the greatest potential for accomplishing the USDA's goals [11]. As a result, researchers at Kansas State University were awarded a USDA contract in 1980 to develop the first VIA instrument prototype for the objective determination of beef carcass yield and quality grades.

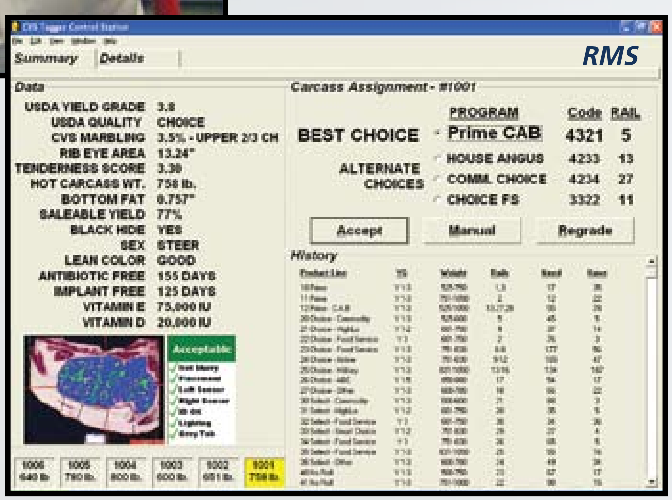
With the success of the initial VIA technology being established through published research, the objective, instrument assessment of beef gained greater attention from USDA and the livestock industry. The National Cattlemen's Association (NCA) indicated their interest by passing a resolution urging further development of instrument grading at their national convention in 1984 [13]. Also in 1984, the USDA gathered industry representatives (beef, pork and lamb) to discuss the status and future of instrument grading [13]. At this meeting, industry representatives unanimously expressed the need for objective grading systems [13]. Despite the success of the initial VIA system that utilized chilled, ribbed carcasses, industry representatives decided to take a different direction and pursue the development of technologies that function on unribbed, unchilled carcasses [13]. Multiple technologies were discussed at this meeting including: 1) nuclear magnetic resonance (NMR), 2) near infrared reflectance (NIR), 3) real-time ultrasound, 4) video imaging and 5) computerized axial tomography (CAT-scan) [13,14]. After consideration of each of these technologies, the group felt that ultrasound technology offered the best chance of success due to the technical ability and durability of the equipment along with recent advances in ultrasound by the medical industry [13,14]. Consequently, research involving VIA systems on ribbed, chilled carcasses was put on hold in the U.S. for over a decade, while most applied efforts to develop on-line, real-time grading systems were focused on the use of ultrasound technology [13,14]. Despite the fact that the use of real-time ultrasound in developing potential carcass Expected Progeny Differences (EPDs) was increasing in popularity and accuracy from 1986 to 1990, a lack of progress was being made towards meeting the requirements for real-time, on-line instrument assessment of beef [13].

In 1989, the need for objective grading was again listed as a top priority by NCA's Grading and Labeling Committee [13]. In 1990, an Instrument Grading Subcommittee was formed by the NCA Grading and Labeling Committee to develop an RFP for instrument grading of beef [13]. NCA's subcommittee felt that the final version of the instrument should meet the following seven requirements to be capable of operating in a commercial application: 1) have ability to predict percentage or kilograms of lean, marbling (or percentage of chemical fat) and skeletal maturity with a high level of accuracy; 2) have a high level of precision (repeatability) on individual, independent variables; 3) be totally automated; the interpretation of the image or output should not require a human subjective evaluation; thus, it must be interfaced with a computer; 4) be capable of evaluating all carcass traits and computing the dependent variables (percentage or kilograms of lean, marbling and skeletal maturity) at projected industry production rates; 5) have ability to withstand extremes in temperature (0 to 40°C) and humidity (up to 100%) without losing accuracy and precision; 6) be tamper-proof to prevent errors in assessment; and 7) have mechanism for precise, quick and easy recalibration [13].

In 1994, a National Livestock and Meat Board subcommittee convened to create the first National Beef Instrument Assessment Plan (NBIAP). The first NBIAP plan identified VIA technologies as first in research priority and funding, which was instrumental in the pivot from ultrasound research [36]. VIA grew in popularity to become regarded as the most useful technology to aid the grading system in the development of a value-based marketing system [24,26,43]. Extensive research in recent years has shown VIA systems to be effective for cutability, USDA yield grade, marbling score and tenderness prediction [8,32,44,47,55,60]. Despite the fact that no instrument technology has exhibited the ability to replace USDA graders completely, VIA systems have been shown to be useful to augment graders to generate more accurate and consistent grades for beef carcasses [4,7,8,44,48,49]. As a result, the USDA-Agricultural Marketing Service (AMS) released performance standards for VIA technologies to determine ribeye area (REA) in 2003, USDA yield grade (YG) in 2005 and marbling score in 2006, as well as approving the first VIA instrument for YG application in 2007 [35]. Past and current research indicates that VIA systems will continue to exhibit value for instrument assessment of beef.


The primary focus of NBIAP meetings held in 2002 and 2007 was instrument assessment of beef tenderness [33,35]. It was determined at the 2002 meeting that "technology to classify carcasses based on tenderness must be accurate, fast, durable, reasonably priced and have the ability to reflect tenderness of the various cuts after advanced aging" [33]. Slice shear force (SSF) was recommended by the 2002 NBIAP as a rapid objective measure of tenderness that produced more accurate results than existing VIA and colorimetric methods [33]. Despite the previous recommendation, the 2007 NBIAP reported that the SSF method had not been universally adopted by researchers in academia, and the industry remained in need of indirect, non-invasive methods to objectively predict tenderness that are as reliable as the existing vision grading systems [35]. In the latest NBIAP (2007), USDA, academia and industry personnel extensively discussed existing and potential non-invasive instrument assessments of beef tenderness [35]. Specifically, instruments utilizing NIR technology, high-resolution imaging, the principle of fluorescence resonance energy to detect calpastatin and VIA technology were all discussed [35].

With a focus on the next five years in regard to instrumentation, the 2007 NBIAP concluded that research needs included the following: 1) to establish a uniform tenderness threshold; 2) to conduct a large collaborative study comparing tenderness instrumentation technologies; 3) to integrate technologies with regard to tenderness instrumentation and standardization of interfaces and reference measures; 4) to develop new technologies to predict tenderness; 5) to utilize instrumentation to increase the likelihood of delivery of a tender product; and 6) to develop tenderness instrumentation to a point where it can play a role in third-party verification [35]. Industry representatives present at the meeting determined that the most important issue is raising confidence in instrument assessment technologies currently in use, rather than how to utilize instrument data [35]. As a result, it was concluded that there was an immediate need to publicize successful research in the area of the instrument assessment of beef to ensure the implementation and acceptance of using instrumentation for USDA yield and quality grading processes [35]. Additionally, it was concluded that "without the acceptance of the use of instrumentation in augmenting the USDA grades, work on tenderness instrumentation will not be applicable to the industry" [35] (Figure 1. See page 4).



## Summary of Recent Instrument Assessment of Beef Yield Traits

Carcass yield and/or cutability make reference to the percentage of boneless, closely trimmed retail products or retail product yield obtained from an individual beef animal. For graded beef, USDA yield grades are routinely applied to carcasses to represent estimated individual carcass yield. Assigned yield grades range in numerical value from 1.0 to 5.9 and are often calculated to the nearest tenth of a YG unit. Assignment of YG to beef carcasses can be determined somewhat objectively with the use of measuring devices. When assigned by trained evaluators allowed ample time to measure and precisely determine YG factors accurately, USDA YG accounts for 70 to greater than 80% of the variation in beef carcass cutability [1,7,8]. Nonetheless, current production practices with chain speeds in excess of 450 carcasses per hour do not permit precise YG assignment. Research has shown that in actual application, yield grades are often applied in error [10,12]. Therefore, it is imperative that instrument assessment be utilized for yield estimation and the application of YG to enhance a value-based marketing system. Belk et al. (1996) concluded that without an instrument that is completely capable of calculating YG and replacing USDA graders, the ability of technologies to augment the application of carcass yield grades should be evaluated.

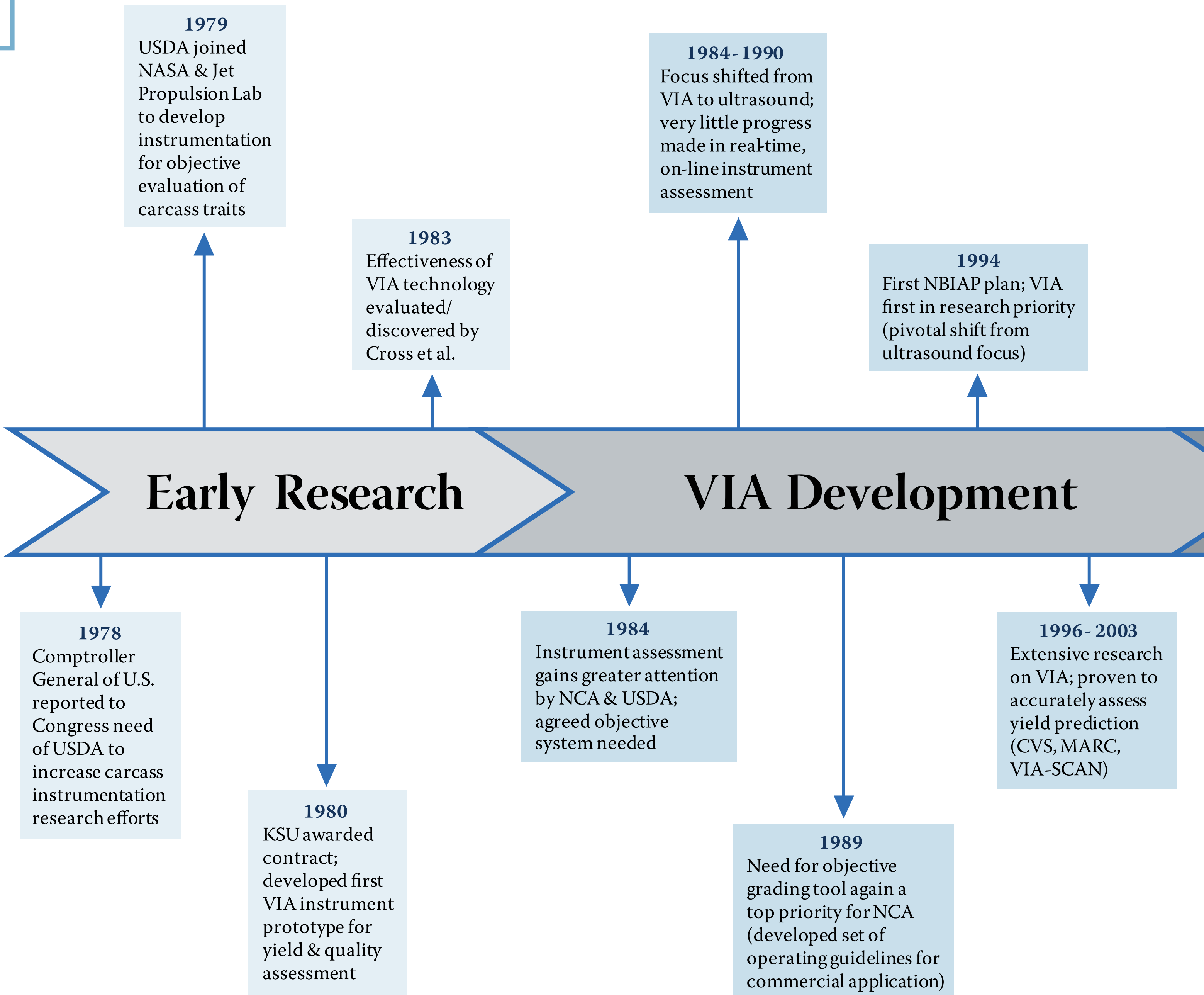
### Video Image Analysis (VIA) for Yield Assessment

VIA systems have been developed and tested in several countries to predict meat yield percentage using output data resulting from the processing of digital images of either the entire side of a hot beef carcass, the cross-section of the rib interface after a beef carcass has been chilled, or by combining data from both digital images [6,7,8,17,25,44,48,49,56]. Cross et al. (1983) and Wassenberg et al. (1986) performed the initial research on the first generation VIA systems that utilized the chilled 12th rib interface and reported considerable potential of VIA as a yield grading device for commercial or research purposes. Both scientists found that VIA had greater or equal success predicting lean muscle, when compared to USDA expert grader evaluations. Cross and Wassenberg also identified actual and adjusted fat thickness as the most important non-instrument traits and concluded that VIA performance could be improved considerably when fat thickness is adjusted subjectively. In retrospect, both Cross and Wassenberg identified the value in using instrumentation and, specifically, VIA technology in an augmented system to predict yield characteristics [11,57].

In recent years, the majority of the research conducted in the scope of yield prediction has been with the use of VIA technologies and has been aimed specifically at augmenting current YG applications and improving carcass cutout estimation and prediction. With the potential for the use of VIA to predict yields with an augmented model by George et al. (1996), Belk et al. (1998) conducted a study to simulate (without the use of instrumentation) and assess the effectiveness of using carcass assessment technology to augment on-line beef carcass USDA YG application to improve accuracy and precision of grade placement. Belk determined that instrument augmentation could be used to increase repeatability, accuracy and precision of on-line graders and would be most beneficial if it could accurately assess muscling characteristics and ribeye area (REA) of beef carcasses [4]. Belk also found that on-line graders were more capable of accurately assessing whole number YG than calling all of the individual YG factors to compute YG to the nearest tenth of a grade [4]. Belk explained that this was not surprising because on-line USDA graders are trained to evaluate carcasses at rapid speeds, but they cannot generally be expected to accurately assess all of the individual factors for YG and compute the final YG at the high rates of speed normally encountered in a commercial packing facility [4]. Therefore, Belk suggested using an augmented YG system to determine YG to the nearest tenth of a grade, offering greater predictive sensitivity, rather than whole number grades [4].

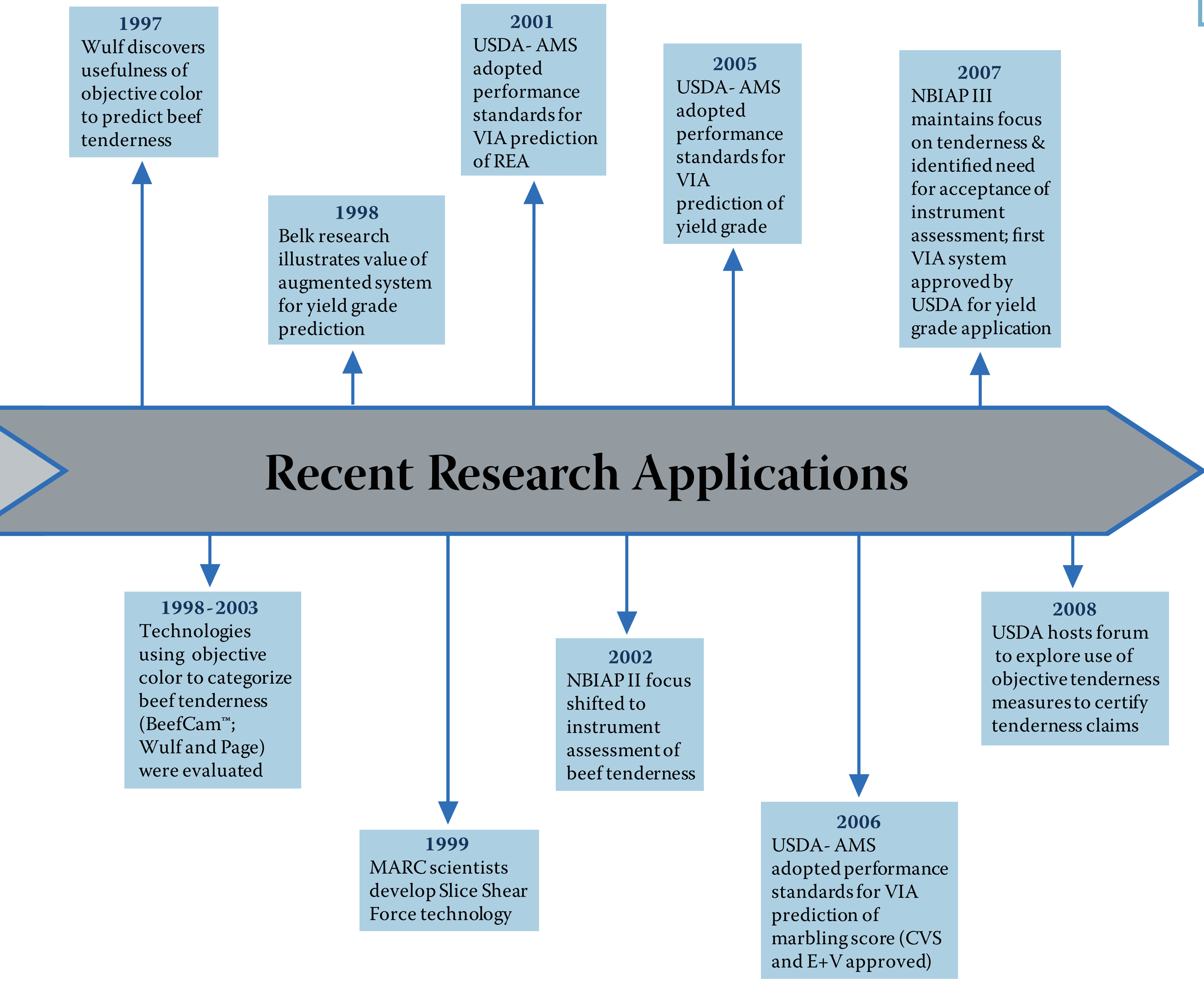

With a significant amount of research suggesting that USDA graders serve as the best evaluators of adjusted (overall) carcass fatness [2,4,11,57], Belk et al. (1998) evaluated differences between measured preliminary yield grades (PYG) and adjusted preliminary yield grade (APYG), as determined by an expert panel at their leisure, to determine

**Figure 1.** Instrumentation history timeline.

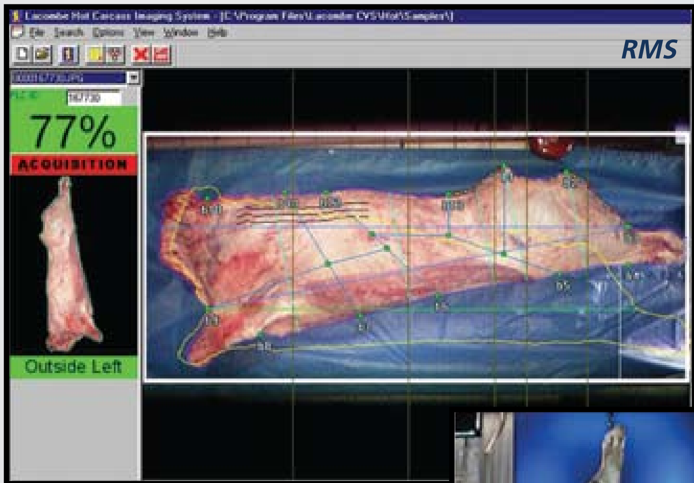



why on-line graders may be able to determine levels of carcass fatness more accurately than instruments. Belk determined that 94.4% percent of the sample population required PYG adjustments to better represent overall carcass fatness, and 11.0% of the population required an adjustment to the measured PYG of over 0.5 YG units. Therefore, the primary reason that USDA graders are more accurate at assessing adjusted or overall fatness of beef carcasses is that there is a certain level of subjectivity that instruments were not capable of estimating to determine the effects of slaughter defects and other irregularities to the exterior of beef carcasses for a significant percentage of the entire population. Considering USDA graders' superior ability to determine APYG and the need for a more accurate assessment of REA, combined with the instruments' ability to accurately assess REA and quickly calculate yield grade factors to a final YG to the nearest tenth, Belk determined that the most realistic estimate of how instrument augmentation could be expected to improve the accuracy and precision of YG determination included: 1) on-line graders' determination of APYG and 2) instrument-measured values for all other yield grade factors [4].


With the identification of the potential for added



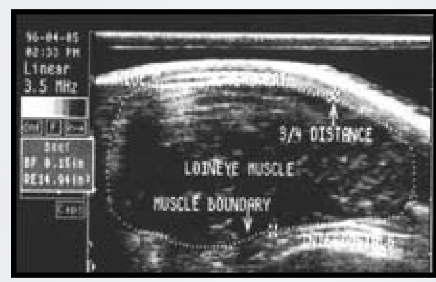

accuracy and precision for an instrument augmented yield prediction system by Belk et al. (1998), subsequent research has evaluated multiple techniques to predict carcass and subprimal yields to increase the viability of, and producer and consumer confidence in, a value-based marketing system. Research conducted in recent years pertaining to the use of VIA as an objective method to assess the yield characteristics of beef carcasses indicated an extremely consistent and unanimous conclusion that VIA technologies are effective. Various VIA instruments and instrument systems estimated overall carcass cutability and predicted subprimal yields with a significant level of accuracy [7,8,11,17,40,44,47,56,57]. Additionally, VIA technology was superior to subjective methods for assessing REA with accuracy and precision [7,8,11,17,40,44,49,56,57]. Despite the fact that some research has shown VIA technology to exhibit considerable ability to predict overall fatness (APYG) of beef carcasses [8,40], it has been well established that VIA instruments have not indicated the ability to assess the overall fatness (APYG) of beef carcasses to the same level as human, subjective measures [7,8,11,40,49,56,57]. With APYG and REA serving as two of the most important factors influencing subprimal yield prediction and USDA YG, researchers have suggested the use of VIA technology in an augmented system to facilitate beef carcass segregation in the U.S. value-based marketing system [4,7,8,11,17,40,44,49,56,57]. Researchers concluded that VIA REA utilized in an augmented system designed to increase accuracy and precision of USDA YG application is the single most effective, objectively measured factor, with a specific focus on applying USDA YG to the nearest tenth of a YG unit [7,8,11,40,49,56,57]. The application of USDA YG to the nearest tenth with VIA augmentation has been shown to more accurately predict carcass cutting yields and as a result, carcass value [7,8,49]. An augmented system for USDA YG application with the use of VIA technology not only provides greater accuracy in the assessment of individual carcasses, but also allows time for USDA-AMS to evaluate or even replace the current method of assessing carcass yield.





## Real-Time Ultrasound for Yield Assessment

Along with VIA technologies, ultrasound technology was identified by USDA and NASA in the late 1970's to have potential to accomplish the goals of USDA – to enhance accuracy in carcass grading, increase speed and efficiency in the grading process and provide more objective means for disseminating information [13,14]. In 1984, it was determined by USDA and industry representatives that objective instrument measures should be focused on unribbed, unchilled carcasses [13]. Consequently, most of the efforts to develop on-line, real-time grading systems during the mid to late 1980's and early 1990's were focused on the use of ultrasound technology. Currently, ultrasound technology is primarily utilized to assess breeding cattle for carcass traits and the development of EPDs. Recently performed research pertaining to the ability of real-time ultrasound (B-mode scanning) to assess beef carcass yield characteristics has primarily utilized off-the-shelf instrumentation. With this technology, ultrasonic signals are ultimately digitalized, displayed and stored as an image. Digitalized images allow for the development of quantitative models from which ultrasound instrument outputs are derived. Recently published research has evaluated the ability of ultrasound to assess beef carcass characteristics on live animals and hide-on carcasses. Published research indicates that the use of ultrasound technology to assess live animal yield characteristics is a viable method to explain variation in beef carcass yield [19,29,50]. Real-time ultrasound assessment of live animal fatness has determined actual carcass fatness with a high level of accuracy and explained a substantial amount of variation in retail product yield and percent retail fat trim [19,29,50]. Additionally, real-time ultrasound assessment of live animal muscling, via the measurement of REA and *gluteus medius* muscle dimensions, significantly contributed to the explanation of variance associated with retail product weight [19,29,50]. Furthermore, ultrasound measured REA and 12th rib fat (PYG) were considerably correlated with actual carcass measurements [29,50]. Nonetheless, real-time ultrasound assessment of unchilled, hide-on carcasses at commercial production speeds was not a considerable option for determining carcass yield characteristics in a value-based marketing system. In addition, VIA instrument assessment has been shown to more accurately assess REA [7,8,40,49,56], PYG [7,8,44,49], and closely-trimmed retail product yield [7,8,40,44]. Therefore, real-time ultrasound has not been widely adopted by the U.S. beef industry to assess yield characteristics at commercial production speeds and research has continued to focus on alternative methods for objective assessment of beef.




## Bioelectrical Impedance Analysis (BIA) for Yield Assessment

Bioelectrical impedance analysis (BIA) has shown promise as a non-destructive, objective method to assess yield characteristics including total muscle mass, fat-free muscle and subprimal weights of beef [27,28,45]. BIA technology measures resistance and reactance of constant alternating current passed through tissue, and composition can be estimated due to the conductivity of lean tissue and insulation properties of fat [14]. BIA technology is simple, portable and shows potential for use as a robotic device for cattle producers, processors and retailers [27,28,45].

Multiple studies conducted by Marchello and Slanger have shown BIA to be highly effective at predicting total muscle mass and saleable product weights of beef [27,28,45]. Despite this, BIA has not been widely adopted by researchers and processors as an objective means of beef yield prediction in the U.S. beef industry. It should be noted that for each of the aforementioned studies pertaining to BIA assessment of beef [27,28,45], a large amount of the variance explained by predictions, including BIA assessed traits, were explained by the actual weight of the animal, carcass, or primal. A lack of research explaining the ability of BIA technology to augment or replace current yield assessment systems or to predict individual beef carcass yield characteristics exists. Further research involving BIA technology is warranted prior to the application of this technology to assess beef yield characteristics in the U.S. beef industry. (Table 1.)

**Table 1.** Instrument technologies for prediction of carcass and primal yield characteristics.

| Type | Technology | Mode of Action | Predictive Accuracy ($R^2$ as % or correlation as r) | Comments | Reference |
|---|---|---|---|---|---|
| **VIA** | Initial VIA technology developed by Kansas State | Chilled, 12th/13th rib interface camera image | Kg of lean – 93.6%<br>% of lean – 88.7%<br>Kg of fat – 86.1%<br>% of fat – 83.8% | 9th, 10th, 11th rib sections fabricated for predictive accuracy | Cross et al. (1983) |
| | VIA system developed by research team at Kansas State | Chilled, 12th/13th rib interface digital image | Closely trimmed boxed beef yields (instrument only) – 54.8%<br>Closely trimmed boxed beef yields (using VIA muscling and expert-determined fat) – 74.9% | These results initiated Belk et al's (1998) idea for VIA augmentation for YG application and yield prediction | George et al. (1996) |
| | MARC-developed system | Digital image of 12th rib cross-section | Retail product yield – 89%<br>Retail product wt. – 95%<br>REA – 88% | | Shackelford et al. (1998) |
| | Dual-component VIAscan | Chilled, 12th/13th rib interface (CAS) and hot side digital image (HAS) | CAS and HAS determined wholesale cut yield (WY)- 71%<br>CAS WY – 68% | CAS more accurately predicted individual yield factors and WY prediction | Cannell et al. (1999) |
| | Dual-component Computer Vision System (CVS) | Chilled, 12th/13th rib interface (CAS) and hot side digital image (HAS) | CAS and HAS combined factors for WY- 64% | CAS more accurately predicted individual yield factors and WY prediction | Cannell et al. (2002) |
| | Computer Vision System (CVS) | Chilled, 12th/13th rib interface digital image | REA – 94%<br>Augmented YG – 89% | Augmented YG improved accuracy of subprimal yield prediction 5 to 8% | Steiner et al. (2003b) |
| | VIAscan cold assessment (VIAscan CAS) | Chilled, 12th/13th rib interface digital image | REA – 88%<br>Augmented YG – 81% | VIA augmentation increased accuracy of YG placement | Steiner et al. (2003b) |
| | MARC beef carcass image analysis | Chilled, 12th/13th rib interface digital image | REA – 88%<br>APYG – 88%<br>YG – 90% | | Shackelford et al. (2003) |
| **Ultrasound** | B-mode scanning | Live animal measures (L)<br>Hide-on carcass measures (C) | APYG – r = .81 (L)<br>REA – r = .61 (L)<br>Subprimal yield - 57% (L)<br>APYG – r = .73 (C)<br>REA – r = .55 (C)<br>Subprimal yield - 31% (C) | Live animal ultrasound more effective than real-time carcass ultrasound | May et al. (2000) |
| | B-mode scanning | Live animal measures | REA – r = .86<br>Retail product yield – 61%<br>Retail product wt. – 84% | Ultrasound-measured fat more highly related to retail product yield than actual carcass fat | Greiner et al. (2003) |
| | B-mode scanning | Live animal measures | PYG – r = .68<br>REA – r = .56<br>Retail product yield – 45.4% | Yields predicted from four major primals instead of entire carcass | Tait et al. (2005) |
| **BIA** | Four-terminal BIA analyzer | Hot and cold carcasses | Kg of muscle – 92%<br>Total fat-free muscle – 87% | A considerable amount of accuracy attributed to product weight; minimal accuracy added from BIA assessment | Marchello and Slanger (1994) |

# Summary of Recent Instrument Assessment of Beef Tenderness

Prediction of cooked beef palatability has long relied on USDA marbling scores combined with physiological maturity (USDA QG). The decision to include marbling as a primary value-determining characteristic in beef carcass assessment was based on the premise that marbling is associated with eating quality [15,23,30,51]. Smith et al. (1987) illustrated how marbling effectively sorts carcasses on the basis of expected eating quality when the sample population spans the entire range of possible quality grades experienced in the U.S. beef supply. However, over 75% of U.S. beef carcasses today grade USDA Select or low Choice (Slight and Small degrees of marbling) [34]. Within this narrow range of marbling scores, marbling does not do an adequate job of sorting beef carcasses into palatability groups reflecting differences in value at the consumption level [47,58]. As a result, in recent years, the beef industry has shifted its focus to the instrument assessment of beef tenderness [33,34]. Therefore, new technologies with the ability to more precisely assess beef carcasses for tenderness are necessary, particularly as branded beef programs continue to make "guaranteed tender" claims.

Warner-Bratzler shear force (WBSF) has been widely accepted and adopted as the standard for objective measurement of beef tenderness. However, the WBSF method was intended to be used as a laboratory research tool and not to assess beef tenderness in a non-invasive manner at commercial production speeds. To fit the needs of today's beef industry, an ideal system to assess beef tenderness would involve an objective, non-invasive, tamper-proof, accurate, rapid and robust technology. Therefore, recently conducted research pertaining to instrument assessment of beef tenderness has been aimed at minimally invasive techniques targeted to explain differences in WBSF and could be potentially integrated into a beef carcass assessment system at commercial speeds. With rapid advances in imaging technology and technologies utilized in the medical field, a great deal of promise is evident for future research in this area.

### Slice Shear Force (SSF) as an Objective Method for Assessing Beef Tenderness

The slice shear force (SSF) method was developed by scientists at USDA's Roman L. Hruska Meat Animal Research Center (MARC) as a system for measuring beef *longissimus* muscle tenderness under commercial processing conditions using a simplified method of shear force determination. The same scientists had found WBSF measured at the traditional time of beef carcass grading (1 to 2 days postmortem) was an accurate predictor of beef *longissimus* steak tenderness at 14 days postmortem [39]. Based on these findings, MARC scientists designed SSF to serve as a more rapid objective measurement (compared to WBSF methods) to quantify and classify beef carcass tenderness immediately following carcass ribbing. By classifying carcass tenderness at the time of carcass grading, SSF was expected to facilitate the use of tenderness classification in a value-based marketing system and result in clearer economic signals in the beef production chain.

Despite the fact that SSF has been shown to be technically less difficult, more rapid, more repeatable and more accurate technique than WBSF [41,42], it has not been utilized in a commercial production setting to assess the tenderness of beef carcasses at the time of grading. The mechanically invasive nature of the SSF technique and the monetary loss associated with removing a single steak from each carcass has left the beef industry searching for more indirect, non-invasive technologies to assess beef tenderness in a real-time commercial setting. Nonetheless, the positive attributes of SSF have attracted the attention of researchers and, along with WBSF, it is routinely utilized to assess beef tenderness in academic and industry research. In fact, many individual companies currently utilize SSF in an off-line, laboratory setting to verify branded beef and tenderness claims.

### Tendertec Tenderness Probe as an Objective Measure to Assess Beef Tenderness

Many researchers have attempted to develop probe systems that are moderately invasive, believing that the industry would much more readily accept a system that performed tenderness measurements on uncooked muscle from intact carcasses. The Tendertec Mark III Beef Grading Instrument (Tendertec; Tendertec International, Bemboka, NSW Australia), an Australian probe developed to measure the amount of connective tissue and other factors that contribute to meat tenderness, was identified by NBIAP meetings in 1994 as a technology that needed to be evaluated as an objective measure of tenderness. Tendertec is an electromechanical penetrometer (probe) that is inserted laterally into the *longissimus* muscle of beef carcasses to measure the amount of force necessary (readings taken every 75 μs) to penetrate the muscle to an ultimate depth of 8 cm.

As a moderately invasive prediction tool assessing raw postmortem muscle to predict cooked beef tenderness, Tendertec is unable to predict *longissimus* steak tenderness differences in youthful beef carcasses [5,18]. Despite the fact that Tendertec may be capable of predicting tenderness differences among beef carcasses from mature cattle [5], Tendertec is inherently limited as a predictor of cooked steak tenderness to evaluate carcasses likely to differ substantially in connective tissue characteristics. Therefore, Tendertec is not a viable instrument to assess tenderness characteristics of the majority of beef ultimately destined for steak and roast cuts, and as a result, this technology has not been implemented in the U.S. beef industry.

### Use of Objective Color Measurement to Assess Beef Tenderness

Due to the limited success of tenderness probes and industry opposition to invasive systems, researchers have also investigated the use of color as a palatability predictor. Hodgson et al. (1992) and Hilton et al. (1997) found that subjective lean and fat color scores for mature cow carcasses were related to subsequent cooked beef palatability. With the concept that lean color explains physiological and postmortem factors known to influence beef palatability, Wulf et al. (1997) used a portable colorimeter to evaluate the ability of objective color measurements obtained from the lean of the exposed 12th rib interface (ribeye) to segregate beef carcasses into tenderness groups. Wulf et al. (1997) found that Commission Internationale de I'Eclairage (CIE) $L^*$, $a^*$, and $b^*$ values, measured on the exposed *longissimus* muscle of beef carcasses, were highly related to beef carcass palatability. Additionally, when compared to marbling scores, objective color scores were more highly related to WBSF and sensory panel tenderness ratings and showed a greater ability to effectively segregate carcasses into tenderness groups [58].

To emulate a scenario under which a quality grading system would be employed, Wulf and Page (2000) evaluated the effectiveness of objective muscle color, muscle pH and hump height (maximal protrusion of the *rhomboideus* muscle; serves as an indication of *Bos indicus* influence in cattle) to segregate palatable and unpalatable beef from a sample population that was representative of the U.S. cattle population in terms of breed type (including native Brahman and dairy carcasses). Additionally, Wulf and Page (2000) evaluated these factors' ability to augment the current USDA quality grading standards to improve their effectiveness at distinguishing palatable from unpalatable beef.

Wulf and Page (2000) found that $L^*$ and $b^*$ values effectively segregated beef that was especially low in palatability and specifically low in tenderness and flavor desirability, whereas muscle pH was more useful at distinguishing carcasses that have especially tender *longissimus* steaks. It was also determined that a hump height specification of not more than 8.9 cm was effective at sorting out palatability problems associated with *Bos indicus* carcasses. With all things considered, Wulf and Page (2000) proposed two systems to augment the current USDA quality grading standards to improve their effectiveness at distinguishing palatable from unpalatable. The grading systems proposed by Wulf and Page (2000) increased the consistency of palatability by reducing the variation within Choice and Select grades. In addition to reducing variation within quality grades, the proposed systems were able to reduce the incidence of unpalatable carcasses from each grade, as they were applied using current USDA standards [59].

The use of objective color in combination with other carcass characteristics effectively explains variation in beef palatability [21,22,58,59] and could be utilized to augment USDA quality grades to better predict carcass palatability in a value-based marketing system [58]. Objective color measurements are especially effective at identifying and segregating the least palatable carcasses [58,59]. As a result, objective color measurement continues to serve as the foundation in other technologies aimed at predicting beef tenderness in a non-invasive manner.

### Use of BeefCam™ Technology to Assess Beef Tenderness

Researchers at Colorado State University initiated pilot work with Hunter Associates Laboratory (manufacturers of the HunterLab MiniScan portable spectrophotometer) to develop a VIA system that could measure beef carcass lean and fat color using the $L^*$, $a^*$ and $b^*$ color scale. A bench-top VIA system first was used to obtain images of beef *longissimus* steaks for the purpose of objective color analysis. Belk et al. (1997) reported that the pilot study data confirmed that: (1) color is related to subsequent cooked palatability of beef carcasses, independent of differences in marbling or carcass maturity, and (2) VIA technology is capable of ascertaining color attributes of beef ribeyes, using the color information to augment USDA quality grades, and thereby improve the accuracy of

quality grades in sorting carcasses based on expected eating palatability across narrow ranges of marbling scores. Based on the results of the pilot study, Colorado State University and Hunter Associates Laboratory began development of a prototype portable video imaging system (BeefCam™), which contained hardware and software that were specifically designed for the analysis of beef carcass lean and fat color in a packing plant environment [3].

Using the BeefCam™ technology to segregate and certify carcasses as being tender provides a clear advantage to not sorting carcasses based on tenderness [55,60]. However, a significant percentage of carcasses that are actually tender are not certified by BeefCam™ technology [55,60], and BeefCam™ has not been shown to identify tough steaks with 100% accuracy. At minimum, branded beef programs that are willing to establish thresholds for tenderness and BeefCam™ outputs could utilize this technology to increase the consistency and tenderness of their products [55,60]. However, further research to increase the accuracy of BeefCam™ is warranted before it could be widely adopted by the U.S. beef industry as an objective measure of tenderness.

## Use of Near-Infrared Reflectance (NIR) to Assess Beef Tenderness

Near-infrared reflectance technology (NIR) utilizes spectroscopic methods to measure the quantity of reflectance in the near-infrared region of the spectrum (from about 705 nm to 2,500 nm). NIR measurements are based on differential light absorption of material which have been used as a non-invasive method to predict the 31 physical and chemical characteristics of meat, including beef tenderness [20,37,38]. The most current NBIAP meetings identified NIR technology as a rapid, non-destructive, accurate and precise method that requires little sample preparation and is easy to operate [35]. Therefore, NIR technology has been the focus of recent research pertaining to the prediction of beef tenderness. NIR has been shown to effectively segregate beef carcasses into tenderness categories and to segregate the toughest beef carcasses [37,38,56].

However, NIR technologies have not been shown to quantify tenderness for individual carcasses or beef cuts. Despite this, both color measured in the visible range of the spectrum [55,55,59,60] (CIE *L**, *a**, *b**) and reflectance measured in the NIR range of the spectrum have shown similar ability to segregate tough and tender beef [37,38,56]. Currently in the beef industry, the primary focus is to reduce the incidence of a tough eating experience by beef consumers, as evidenced by the increase in certified or guaranteed branded beef programs. Therefore, the ability of non-invasive techniques, including NIR, could be useful in identifying tender beef and to increase the probability of a positive beef eating experience. Still, further research is warranted for the improvement of NIR to fully assess beef carcass tenderness. (Table 2.)

## Summary of Recent Instrument Assessment of USDA Marbling Score



USDA marbling score is the most variable factor influencing the value of graded beef carcasses in the U.S. today. Unlike the determination of USDA YG where at least some of the factors used to assess overall carcass yield can be objectively measured using a tool, determination of marbling score is quite different because no true measuring device is used to aid expert determination. Marbling photographs prepared by (and available from) NCBA and USDA illustrating standards for individual marbling scores are utilized heavily by USDA graders today. However, an overwhelming amount of variation in the volume and distribution of marbling in carcasses requires USDA graders to rely on subjective judgment to determine marbling score. The subjective nature of a human's visual assessment of marbling can lead to discrepancies in quality grade assignment between USDA graders when exposed to different environmental conditions and cattle populations [12]. A limited amount of published research

**Table 2.** Instrument technologies for prediction of beef tenderness.

| Technology | Mode of Action | Effectiveness of determining tenderness (correlation as r) | Comments | Reference |
|---|---|---|---|---|
| **Slice Shear Force (SSF)** | Mechanical shearing perpendicular to muscle fibers | WBSF – r = .84<br>Sensory panel – r = -.81<br>Correctly predict 93% of tender steaks at 14 d aged | Highly accurate and repeatable, but invasive/destructive in nature | Shackelford et al. (1999a and 1999b) |
| **Tendertec Tenderness Probe** | Electromechanical penetrometer (probe) inserted laterally into *longissimus* muscle | Connective tissue amount–r = -.17<br>Unable to predict tenderness in youthful carcasses | Moderately invasive; inherently limited as predictor of cooked steak tenderness | Belk et al. (2001) |
| **Objective Color** | Commission Internationale de l'Eclair age (CIE) *L**, *a**, *b** values of exposed *longissimus* muscle | b* value and WBSF – r = -.38<br>b* value and trained sensory panel – r = .37 | Meaningful relationship between objective muscle color and tenderness | Wulf et al. (1997) |
| **Wulf and Page system** | Combined CIE *L**, *a**, *b** with muscle pH and hump height | Distinguished palatable from unpalatable<br>Reduced variation in USDA Choice – 39%<br>Reduced variation in USDA Select – 37% | Objective color and breed type reduced variation and incidence of unpalatable carcass within Choice and Select quality grades | Wulf and Page (2000) |
| **BeefCam™** | *L**, *a**, *b** color scale on exposed *longissimus* lean and fat color | Able to certify up to 80% of carcasses as tender<br>Effectively reduced the chance of encountering a tough steak versus an unsorted population | Offers clear advantage to not sorting carcasses, but a significant % of tender carcass are not certified | Vote et al. (2003) |
| **Near Infrared Reflectance (NIR)** | Measures quantity of reflectance in NIR region of spectrum | Explains 67% of variation in WBSF<br>Effectively segregated extremely tough carcasses(> 6 kg) with 89% accuracy | Unable to predict WBSF<br>Effectively segregate extremely tough and tender carcasses | Park et al. (1998) |
| **VIS-NIR** | Measures quantity of reflectance in the visible and NIR regions of spectrum | Not related to actual tenderness values<br>Unable to classify carcasses into tender and intermediate categories<br>Correctly classified 92.9% of tough carcasses | Does not appear to be any added advantage in combining the visible and NIR spectrums | Price et al. (2008) |

has been aimed directly at assessing marbling score with the use of instrumentation. However, technological advances in VIA have made the concept of instrument assessment of beef carcass marbling scores a readily approaching reality.

### Video Image Analysis (VIA) Assessment of USDA Marbling Score

Early studies assessing only the amount of marbling in the 12th rib interface with the use of VIA demonstrated very little association between expert assigned marbling scores and VIA predictions [11,24]. Researchers have noted that in addition to the amount of marbling in the assessment of marbling score, expert evaluators take into account the size and distribution of marbling depots [24], as well as lean and fat color [16]. Marbling score prediction using VIA technology would need to utilize multiple variables in an equation, which actually defines how expert evaluators see marbling. Researchers have recently utilized VIA outputs indicating amount of marbling and other visible attributes of beef carcass ribeyes in regression analysis to predict marbling score with considerable accuracy. Studies have shown the ability of VIA systems to be moderate to high in explaining variation in marbling score with a high level of repeatability [44]. Nonetheless, scientists determined that VIA systems were unable to assign USDA quality grades with an acceptable level of accuracy [44]. Therefore, scientists concluded that VIA systems were not a viable option to replace or augment the application of USDA marbling scores [44].



With previous research indicating that VIA systems' prediction abilities lacked the accuracy needed for assignment of USDA marbling scores for quality grade determination, Moore (2006) assessed the improvements in predictive capabilities for the Computer Vision System (CVS; Research Management Systems, USA, Inc., Fort Collins, CO), in conjunction with the evaluation of recommendations regarding USDA approval requirements for instruments to augment the current quality grading system. Moore (2006) conducted a study in three phases for prediction equation development as well as testing for accuracy, precision and repeatability. Moore reported that the current CVS VIA system exhibited much greater accuracy (greater than 89%) and precision than any other instrument previously used to predict marbling score with an extremely high level of repeatability (greater than 99.5%) [32].

Following suggestions made by Moore [32], USDA published performance requirements for instrument marbling evaluation (PRIME I) [52] using a method comparability approach. Final instrument performance criteria were established as a result of consultation with an industry working group comprised of representatives of USDA, the NCBA, beef processing companies, cattle producers, technology providers and academia. The instrument approval process as outlined in PRIME I [52] involved two phases: Phase I: Demonstration of the repeatability of marbling score prediction on stationary beef carcasses; Phase II: Demonstration of the accuracy and precision of marbling score prediction at line speeds. A USDA instrument trial was conducted in 2006 to test two VIA systems seeking USDA approval in the determination of marbling score using VIA, the CVS system and the VBG2000 (E+V Technology, Oranienburg, Germany).


Utilizing the approved prediction equation, the CVS system was over 98% repeatable at commercial production speeds. The most accurate (approved) CVS equation utilized 14 variables relating to the amount, size and distribution of fat present within the exposed ribeye, as well as variables describing color of lean and fat. The approved CVS technology exhibited a high degree of accuracy and precision across all degrees of marbling, and variance in CVS marbling score remained fairly constant across all degrees of marbling [32].

In summary, as an objective measure, modern VIA technologies exhibit the greatest ability to provide an assessment of the amount of marbling, lean and fat color measurements, as well as some quantification of the spatial characteristics of marbling in determining marbling score. Additionally, alternative techniques have been established to better determine the accuracy and precision of instruments' ability to objectively predict expert marbling scores [32]. Once these techniques were identified, USDA was able to establish reasonable standards for assessing the ability of VIA instruments to determine marbling score. Based on proven accuracy and precision in marbling score assignment, two VIA technologies have been approved for the determination of marbling score by USDA [53]. If implemented, approved VIA systems to assign marbling score will increase the consistency of grade placement within individual packing facilities and between facilities. The reproducibility and objectiveness gained through the use of VIA technology in the assignment of quality grade will bring the beef industry closer to a true value-based marketing system.

## Major Achievements with USDA

With an interest in improving the accuracy and precision of beef carcass evaluation within a value-based marketing system, USDA has been instrumental in the development and evolution of instrument systems designed to assess beef carcass traits. USDA has recognized that grading accuracy, precision and consistency benefits all segments of the beef production and consumption supply chain [54]. With the proven abilities of VIA instruments to assess beef carcasses for yield and quality traits, USDA-AMS Livestock and Seed Program (LS) has established a series of standards for the use of VIA technologies in current grading procedures. USDA-AMS LS has published standards for instruments to determine REA in 2001 (later revised in 2003), USDA YG in 2005, fat thickness in 2005 (later revised in 2007) and USDA marbling score in 2006 (Table 3.). Additionally, USDA-AMS LS is currently considering the use of non-invasive techniques to certify *longissimus* muscle tenderness in branded beef programs making "guaranteed tender" claims. (Table 3.)

**Table 3.** Progress with USDA. Approved standards for instrument assessment of beef yield characteristics and marbling score.

| Factor/Grade | Standard Date | Instrument/Company | Approval Date |
|---|---|---|---|
| **Ribeye Area** | **February, 2001**<br>**Phase I and II** | CVS/RMS | 02/26/2001 |
| | **Phase III** | via Certified Beef Program (schedule G-NR)<br>Nolan Ryan's Tender Aged Beef (CVS/RMS) | 08/01/2001 |
| | **February, 2003**<br>**Phase I and II** | VBG2000/E+V | 12/16/2003 |
| | **Phase III** | | |
| **USDA Yield Grade** | **March, 2005**<br>**Phase I and II** | CVS/RMS – National Beef<br>VBG2000/E+V<br>CVS/RMS | 06/03/2005<br>08/16/2005<br>09/15/2006 |
| | **Phase III** | CVS/RMS | 03/15/2007 |
| | **March, 2007**<br>**Addendum A – Fat Thickness** | CVS/RMS<br>VBG2000/E+V | 03/09/2007<br>03/14/2007 |
| **Marbling Score** | **June, 2006**<br>**Prime I** | VBG2000/E+V | 11/02/2006 |
| | **Prime II** | CVS/RMS | 11/02/2006 |

Source: USDA-AMS, LS

Before an instrument is implemented in an individual processing facility to assess yield characteristics (REA, YG and fat thickness), instruments and companies seeking approval for the use of individual technologies must comply with each phase in a three-phase process. In Phase I, USDA-AMS LS standards certify instruments that exhibit the ability to assess the given trait(s) with accuracy and precision in an ideal or stationary setting. Phase II evaluates and certifies instruments that have met the requirements of Phase I and exhibit acceptable levels of accuracy and precision at commercial production speeds. Finally, Phase III certifies operational procedures (including procedures for calibration and maintenance) for an individual establishment (plants) utilizing an instrument that has met the requirements of Phase I and Phase II. Once an instrument has been approved in Phase III, the instrument is subsequently approved for use as long as approved procedures set in Phase III are upheld.

Two VIA technologies, CVS (Computer Vision System; RMS Research Management Systems, USA, Inc., Fort Collins, CO) and VBG2000 (E+V Technology, Oranienburg, Germany), have been approved through Phase II for assessment of REA, USDA YG and fat thickness. Additionally, CVS has been approved through Phase III for REA for a certified beef program and for USDA YG with an individual beef company. Even though technologies have been able to meet the requirements set by USDA, they are not currently being utilized to determine official online USDA yield factors or YG. The reason for individual establishments choosing not to utilize instrumentation to assign YG is not well defined. However, it should be noted that some companies have made the decision to change instrument providers and are now currently operating with a technology that will require Phase III approval in their establishments before being approved to assign USDA YG. Despite this, numerous establishments owned by differing companies rely heavily on instrument outputs to segregate carcasses and even utilize instrument outputs as a contractual basis for payment.

Technology providers and companies seeking approval for individual instrument assessment of marbling score must follow USDA-AMS LS standards of Prime I and Prime II. Procedures outlined in Prime I certify the accuracy, precision and repeatability for individual instruments at commercial production speeds. Individual instruments meeting the requirements of Prime I are subsequently approved, but before the instrument can be utilized to assess marbling score in individual establishments, it must be approved in Prime II. Prime II standards provide requirements for operational procedures for individual establishments intending to use an individual instrument previously approved by Prime I. Individual establishments wishing to utilize instrumentation to assess marbling scores for beef carcasses must meet the requirements of Prime II.

In June of 2006, CVS and VBG2000 met the requirements for Prime I to determine official USDA marbling score. However, as a result of companies not applying for Prime II approval in their individual establishments, neither of these technologies has been approved by USDA for Prime II. Packers have expressed that the implementation of the approved instruments would drastically reduce the number of cattle grading USDA Prime and Choice in their facilities. Therefore, packers have been hesitant in seeking approval for Prime II due to significant monetary losses associated with reduced grading performance. To address this issue, USDA conducted two studies to identify and/or quantify the divergence between USDA field grader and instrument marbling scores [54]. Study 1 confirmed that a divergence existed between graders in the field and the instrument. In agreement with packer concerns, Study 1 also identified that the percentage of carcasses grading Prime and Choice would be significantly reduced. Perhaps the most noteworthy finding was that as a result of the reduced grade utilizing instrumentation, the U.S. beef industry would have suffered a loss in excess of 375 million dollars for all cattle graded in 2006. In a second study (Study 2), USDA attempted to identify the source of divergence among field graders, instruments and a four member expert panel. Expert panel and instrument marbling score were found to be in reasonable agreement with each other; thus, USDA identified that field graders were the source of divergence. Specifically, USDA identified significant inconsistencies in field grader marbling scores among individual establishments [54].

Despite the fact that USDA has identified field graders as the source of divergence and the realization that the transition to instrumentation would resolve issues of inconsistency, it is the USDA's intention to ensure that the transition to instrument grading is seamless and transparent. USDA has acknowledged that the fiscal ramifications associated with an immediate shift to instrument grading could be devastating to the industry's faith in value determinants based on carcass grades and could drastically disrupt the sale of beef in wholesale, retail and export markets. Therefore, USDA is considering the following three options for implementing augmented instrument assessment of quality grades: 1) utilize the current approved instrument grade line; 2) utilize the current USDA field grade pattern for adjusting instrument performance; or 3) establish an offset that is a compromise between the USDA field grade pattern and the current approved instrument grade line (VBG2000 suggested adjustment) [54].

The most current issue facing USDA-AMS LS is certifying tenderness in branded programs wishing to make "guaranteed tender" claims. USDA hosted a Tenderness Forum in June of 2008 to properly define tenderness for a branded beef program. In the future, objective assessment of tenderness, including the use of non-invasive prediction technologies, will be considered to certify the tenderness of beef.

## Summary

With significant contributions from USDA, The Beef Checkoff, beef processing companies, cattle producers, technology providers and academia, significant progress in the use of instrumentation for the assessment of beef has been made in the last 30 years. Specifically, The Beef Checkoff has supported instrument research with contributions exceeding 2.5 million dollars in the past ten years. As a result of these contributions and commitments, multiple instrument technologies have been evaluated for the assessment of beef yield and quality traits in the interest of establishing and improving a true value-based marketing system for beef. Advancements in the accuracy and precision of yield and quality assessment using instrument technologies have been, and will continue to be, advantageous to all parties along the supply chain -- producers, packers and consumers.

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**Advancements in the accuracy and precision of yield and quality assessment using instrument technologies have been, and will continue to be, advantageous to all parties along the supply chain -- producers, packers and consumers.**

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