Introduction

Conventional U.S. cattle-production systems are designed to provide consumers with a consistent supply of high-quality, grain-fed beef, which is preferred in current mainstream U.S. beef markets (both domestic and export). In grain-fed beef production systems, beef calves (steers and heifers) typically are reared on pastures with their dams until they are five- to eight-months old. After weaning, calves either are placed in feedlots immediately for grain finishing (as “calf-feds”) or grown for a period of time on forage-based diets, until they are 12 to 18-months old, before placement in feedlots for finishing (as “yearlings” or “long-yearlings”). Grain-finished cattle produced in the United States normally are harvested between 12 and 24 months of age. Calf-feds typically are 12- to 16-months old at harvest, depending upon length of the finishing period, whereas most cattle fed as yearlings or long-yearlings are harvested between 16 and 24 months of age.

When beef carcasses are presented for quality grading, USDA graders examine visible indicators of physiological maturity (i.e., size and shape of the ribs and ossification of the bones and cartilages along the vertebral column of the split carcass, together with the color and texture of the lean at the 12th-13th rib interface), which are used to classify carcasses into maturity groups designated A through E (USDA, 1997; Table 1). Approximate chronological ages corresponding to each physiological maturity classification are: A – 9 to 30 months, B – 30 to 42 months, C – 42 to 72 months, D – 72 to 96 months, and E – older than 96 months (Tatum, 2007).

Table 1. Descriptions of USDA physiological maturity indicators

<table>
<thead>
<tr>
<th>Maturity</th>
<th>Sacral vertebrae</th>
<th>Lumbar vertebrae</th>
<th>Thoracic vertebrae</th>
<th>Ribs</th>
<th>Chine bones</th>
<th>Lean color</th>
<th>Lean texture</th>
</tr>
</thead>
<tbody>
<tr>
<td>A0⁰</td>
<td>Distinct separation</td>
<td>No ossification</td>
<td>No ossification</td>
<td>Slight tendency toward flatness</td>
<td>Soft and very red in color</td>
<td>Light grayish red</td>
<td>Very fine</td>
</tr>
<tr>
<td>B0⁰</td>
<td>Completely fused</td>
<td>Nearly completely ossified</td>
<td>Some evidence of ossification</td>
<td>Slightly wide and slightly flat</td>
<td>Slightly soft, slightly red</td>
<td>Light red to slightly dark red</td>
<td>Fine</td>
</tr>
<tr>
<td>C0⁰</td>
<td>Completely fused</td>
<td>Completely ossified</td>
<td>Partially ossified</td>
<td>Moderately wide and slightly flat</td>
<td>Tinged with red</td>
<td>Slightly dark red to moderately dark red</td>
<td>Tends to be fine to moderately fine</td>
</tr>
<tr>
<td>D0⁰</td>
<td>Completely fused</td>
<td>Completely ossified</td>
<td>Show considerable ossification, outlines of cartilage are plainly visible</td>
<td>Moderately wide and flat</td>
<td>Moderately hard, rather white</td>
<td>Moderately dark red to dark red</td>
<td>Slightly coarse</td>
</tr>
<tr>
<td>E⁰</td>
<td>Completely fused</td>
<td>Completely ossified</td>
<td>Ossified, outlines of cartilage are barely visible</td>
<td>Wide and flat</td>
<td>Hard and white</td>
<td>Dark red to very dark red</td>
<td>Coarse</td>
</tr>
</tbody>
</table>

Carcasses classified as A-maturity typically would qualify for the Prime, Choice, Select, or Standard grades; those classified as B-maturity usually would grade Prime, Choice, or Standard; and those classified as C-, D-, or E-maturity, if graded, would be identified as Commercial, Utility, Cutter, or Canner (USDA, 1997). In most commercial fed-beef plants, carcasses that would grade Standard because they have been classified as B-maturity and carcasses that are classified as C-, D-, or E-maturity (often referred to as “hard-bone” carcasses because the cartilages in their vertebrae are moderately to completely ossified) typically are not assigned USDA quality grades. If prices for finished cattle are determined using one of several value-based grid pricing systems, these ungraded (“no roll”) carcasses receive substantial price discounts (USDA, 2011).

The majority of conventionally produced grain-finished steers and heifers produce carcasses that are classified as A-maturity when USDA quality grades are determined (Garcia et al., 2008). Occasionally, however, cattle known to be less than 30-months old exhibit premature skeletal ossification causing them to be classified as B-maturity or older, which not only reduces their final carcass quality grade, but also limits their marketability and lowers their value in the U.S. beef trade. Results of in-plant audits conducted during the 2005 National Beef Quality Audit revealed that, at that time, about 3% of the U.S. fed-steer and heifer population produced carcasses that were classified as B-maturity or older (Garcia et al., 2008). Packing company employee surveys conducted during the same 2005 National Beef Quality Audit, however, suggested the percentage of B-maturity or older carcasses produced by fed steers and heifers was much higher, averaging approximately 14% when evaluated on an annual basis (NCBA, 2006).

Advanced carcass maturity represents a producer-controllable quality shortfall; however, very little information is available to assist cattle producers in developing management strategies for preventing production of cattle whose carcasses exhibit advanced physiological maturity characteristics. The purpose of this review is to examine and summarize existing scientific information concerning production-level effects on physiological maturation processes in cattle and examine the relationships of these effects to the occurrence of advanced beef carcass maturity characteristics. Relationships among animal age, physiological maturity, and beef tenderness also are examined.

### Relationship of Physiological Beef Carcass Maturity to Animal Age

The relationship between chronological age of cattle and physiological maturity classification of beef carcasses is not well documented in the scientific literature. Data summarized in Table 2 were reported by O’Connor et al. (2007) and have been re-analyzed and presented here in an effort to quantify the effect of chronological age on USDA carcass maturity classification among cattle ranging in age from 12 to 24 months. In the study conducted by O’Connor et al. (2007), more than 4,300 beef carcasses produced by cattle of known ages were evaluated by USDA grading experts, who assigned both skeletal and lean maturity scores to each carcass and, then, combined the two scores classifying the carcasses into physiological maturity groups (A, B, and C or older). As expected, most (96.7%) of the cattle within the 12- to 24-month-age range produced carcasses that were classified as A-maturity. Among cattle that were 18-months old or younger, the odds of an animal producing a B-maturity carcass were approximately one in 100. However, past 18-months of age, the likelihood of producing a B-maturity carcass became significantly greater and, among cattle 22- to 24-months old, approximately one of every 11 animals produced a carcass classified as B maturity (Table 2). The probability of an animal producing a carcass classified as C-maturity or older was extremely low (odds of about one in 1,000) among cattle 12- to 21-months old (Table 2). Among cattle 22- to 24-months old, however, the predicted incidence of carcasses classified as C-maturity or older was 3.1% (Table 2). Though the dataset compiled by O’Connor et al. (2007) included observations for both steers and heifers, information included in their report did not permit comparison of age-maturity relationships for the two sex classes.

### Table 2. Relationship of chronological age to USDA carcass maturity and the probability of an animal producing a carcass with A, B, or ≥ C maturity characteristics

<table>
<thead>
<tr>
<th>Animal age, mo</th>
<th>N</th>
<th>Mean USDA carcass maturity score</th>
<th>Probability of producing an A-maturity carcass</th>
<th>Probability of producing a B-maturity carcass</th>
<th>Probability of producing a C-maturity or older carcass</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 to 15</td>
<td>1003</td>
<td>58.6 ± 0.42</td>
<td>0.985 ± 0.003</td>
<td>0.013 ± 0.003</td>
<td>0.002 ± 0.001</td>
</tr>
<tr>
<td>16 to 18</td>
<td>1381</td>
<td>60.1 ± 0.52</td>
<td>0.990 ± 0.003</td>
<td>0.009 ± 0.003</td>
<td>0.001 ± 0.001</td>
</tr>
<tr>
<td>19 to 21</td>
<td>1454</td>
<td>71.1 ± 0.45</td>
<td>0.968 ± 0.005</td>
<td>0.030 ± 0.004</td>
<td>0.001 ± 0.001</td>
</tr>
<tr>
<td>22 to 24</td>
<td>164</td>
<td>80.5 ± 1.33</td>
<td>0.878 ± 0.026</td>
<td>0.091 ± 0.023</td>
<td>0.031 ± 0.013</td>
</tr>
</tbody>
</table>

1. Pooled data for steers and heifers (O’Connor et al., 2007).
2. Overall USDA carcass maturity score based on combined assessments of skeletal and lean maturity indicators (USDA, 1997). Maturity was scored by USDA expert graders in 10% increments: 40 = A10, 50 = A20, 60 = A30, 70 = A40, 80 = A50, etc.
Skeletal Maturation of Heifers vs. Steers

It is well documented that estrogen promotes skeletal ossification and that adolescent females of various mammalian species exhibit more advanced skeletal maturity when compared with male contemporaries of the same age (Grumbach and Auchus, 1999). Correspondingly, beef carcasses produced by heifers are much more likely to be classified as B-maturity or older than are carcasses produced by steers when the two sexes are compared at a common age.

Data analyzed and presented in Figures 1 and 2, comparing skeletal maturation of heifers (n = 3,095) and steers (n = 3,671), originated from a 2004 beef checkoff study (unpublished) in which carcasses produced by cattle of known ages were assigned skeletal maturity scores by USDA grading experts. Age-maturity relationships presented in Figures 1 and 2 show that as chronological age increased from 16 to 27 months, skeletal maturation progressed at a much faster rate in heifers than in steers. As a result, heifers 16- to 27-months old were about seven times more likely to produce carcasses with B-maturity skeletal characteristics (Figure 1) and almost 11 times more likely to produce carcasses with C-maturity or older skeletal characteristics (Figure 2) than were 16- to 27-month-old steers.

When cattle were harvested beyond 20 months of age, the risk of producing a carcass with B-maturity or older skeletal characteristics increased rapidly in heifers, but not in steers (Figures 1 and 2). In Figures 1 and 2, about one in four carcasses produced by heifers 21- to 27-months old had B-maturity skeletal characteristics and one in 16 had C-maturity or older skeletal characteristics, whereas across the same age interval, only one of every 29 steer carcasses was classified as B-maturity and just one in 200 steer carcasses had C-maturity or older skeletal characteristics (Figures 1 and 2).
Effect of Reproductive Status on Skeletal Maturation of Heifers

It is not uncommon for heifers placed in feedlots for finishing as yearlings or long-yearlings to be pregnant at the time of harvest. Published estimates of the pregnancy rate among feedlot heifers at slaughter have ranged from just less than 4% to as high as 17% (Laudert, 1988; Kreikemeier and Unruh, 1993; McKenna et al., 2002). Kreikemeier and Unruh (1993) compared carcasses of commercially finished, pregnant and non-pregnant heifers of unknown ages and determined that carcasses produced by pregnant heifers had significantly more advanced maturity characteristics than did carcasses produced by non-pregnant heifers. In that study, the frequency of B-maturity or older carcasses was 7.5% among pregnant heifers harvested during the last trimester of gestation compared with 3.5% among non-pregnant heifers (Kreikemeier and Unruh, 1993).

Beef females that produce their first calf when they are approximately two-years old and, then, fail to rebreed often are grain-finished, and eventually enter the U.S. fed-beef supply. When compared at similar ages, females that have calved once (often described as “heiferettes”) produce carcasses with more advanced skeletal maturity characteristics than do females that have never calved (Waggoner et al., 1990). Field et al. (1996) compared maturity characteristics of carcasses produced by 31- to 35-month-old beef females, either spayed, virgin, or once-calved, fed high-concentrate finishing diets for 100 days before harvest and found significant differences in skeletal maturity among the three groups (Figure 3). In that study (Field et al., 1996), percentages of carcasses that were classified as B-maturity or older were 5.6%, 37.5%, and 77.8% for spayed, virgin, and once-calved heifers, respectively. The authors attributed the observed differences in skeletal maturation to among-group differences in estrogen production associated with biological events such as estrus, late gestation, parturition, and lactation (Field et al., 1996).

Effect of Implanting on Skeletal Maturation

Anabolic implants, which are used routinely in conventional U.S. beef production systems to improve growth rate and feed conversion in growing/finishing steers and heifers, have been shown to accelerate skeletal maturation in cattle. Primary active ingredients contained in commercially available cattle implants include one of the following: an estrogen, an androgen, or an estrogen and an androgen combined in the same implant (combination implant).

Estrogenic implants contain estradiol-17β (E2β), estradiol benzoate (EB), or zeranol (a non-steroidal mycoestrogen that mimics the effects of estradiol), whereas androgenic implants contain trenbolone acetate (TBA, a synthetic androgenic steroid with eight to ten times greater anabolic activity than testosterone). The most frequently used combination implants contain various dosages of TBA and estradiol (either E2β or EB). Steer-specific combination implants usually contain a 5:1 ratio of TBA to estradiol, whereas heifer-specific combination implants typically contain a 10:1 ratio of TBA to estradiol. Some estrogenic implants contain either progesterone (for steers) or testosterone propionate (for heifers) as a secondary
ingredient; however, as used, these two compounds have little, if any, direct effect on growth or carcass traits.

Acceleration of skeletal maturation due to implanting appears to be directly associated with the estrogenic effects of zeranol or estradiol. Implants that contain zeranol or estradiol (either alone or in combination with TBA) all have been found to increase skeletal maturity (Turner et al., 1981; Vanderwert et al., 1985; Apple et al., 1991; Foutz et al., 1997; Reiling and Johnson, 2003). On the other hand, androgenic implants that only contain trenbolone acetate do not seem to affect skeletal maturation rate (Apple et al., 1991; Crouse et al., 1987). The extent to which implanting increases skeletal maturity is determined by the dose of estrogen delivered by the implant (Turner et al., 1981) and the number of estrogen-containing implants the animal receives prior to harvest (Scheffler et al., 2003).

Administering estrogen-containing implants sequentially throughout an animal’s lifetime promotes skeletal maturation (Pritchard et al., 2003). Platter et al. (2003) found that administering estrogen-containing implants to steers repetitively, in sequential phases of production (i.e. branding, weaning,backgrounding, and finishing), significantly increased beef carcass maturity when the cattle were later harvested at 16 to 18 months of age. In that study, steers that received four or five lifetime implants produced carcasses with more advanced maturity characteristics compared with carcasses of steers implanted zero, two, or three times (Platter et al., 2003).

When cattle are harvested at or before 20 months of age, implant effects on carcass maturity usually are inconsequential, because most carcasses produced by implanted cattle 20-months old or younger remain within the A-maturity classification when USDA grades are determined. However, when cattle are implanted multiple times and harvested at ages greater than 20 months (which would be common for cattle grown for extended periods on forages and, then, finished as long-yearlings), implant effects on skeletal maturation rate can result in a substantial increase in the incidence of B-maturity or older carcasses (Paisley et al., 1999).

A subset of the same data records that were used to develop relationships depicted in Figures 1 and 2 were used to quantify the effect of implanting on the occurrence of B-maturity or older skeletal maturity characteristics among 16- to 27-month-old steers and heifers. Results of these analyses are summarized in Figures 4 and 5 and show very clearly that, among cattle harvested at 21 to 27 months of age, implanting greatly increases the risk of an animal producing a B-maturity or older carcass, especially in heifers. On average (within sex and across the entire age interval of 16 to 27 months), implanted cattle were more than three times as likely to produce a B-maturity carcass and twice as likely to produce a C-maturity or older carcass than were non-implanted cattle (Figures 4 and 5).
Possible Effects of Naturally Occurring Estrogens

Estrogenic hormones are produced by several forage plants and by certain species of fungi (molds) that live on forage plants and cereal grains. Consumption of feeds that contain estrogens produced either by fungi (mycoestrogens) or plants (phytoestrogens) has been linked to impaired reproductive performance and other clinical signs of hyperestrogenism in several livestock species (Galey et al., 1993).

Zeranol, the non-steroidal estrogen contained in Ralgro implants, is produced commercially by reduction of zearalenone, a mycoestrogen produced by several species of Fusarium (Caldwell et al., 1970). Zearalenone and its derivatives have been detected in several common livestock feeds that have been infected with Fusarium molds including corn, corn silage, wheat, barley, sorghum, oats, and hay (Gromadzka et al., 2008). Moreover, studies have shown that zeranol can be formed in vivo by animals that have ingested feeds contaminated with zearalenone and α-zearalenol (Dickson et al., 2009). Particularly noteworthy is the fact that zeranol has been detected in untreated, pasture-fed cattle at amounts comparable to those resulting from deliberate treatment with a zeranol-containing Ralgro implant (Erasmuson et al., 1994). Therefore, exposure to feeds that have been infected with Fusarium molds may provide an explanation for some cases of premature skeletal ossification in cattle.

Additionally, many common forage legumes such as alfalfa and various clovers contain phytoestrogens (i.e., coumestans in alfalfa and isoflavones in clover) that are able to bind with estrogen receptors and mimic the effects of estradiol (Adams, 1995). Forage-based diets containing phytoestrogens have been reported to cause various symptoms of hyperestrogenism in female cattle and sheep (Galey et al., 1993). In cattle, the physiological effects of phytoestrogens are believed to be additive to those elicited by estrogen-containing implants (Adams, 1995). Correspondingly, symptoms of hyperestrogenism stemming from consumption of forages containing phytoestrogens are more likely to occur in implanted cattle compared with cattle that have not been implanted.

It is plausible that unintentional exposure of cattle to estrogens occurring naturally in the environment may accelerate skeletal ossification, resulting in greater frequency of carcasses with advanced maturity characteristics. However, a review of the current literature revealed no published scientific reports specifically linking mycoestrogens or phytoestrogens to premature skeletal ossification in cattle.

Animal Age, Physiological Maturity, and Beef Tenderness

Animal Age and Beef Tenderness

As cattle become older, the beef they produce becomes tougher, due to increased mechanical and thermal stability of collagen – the primary connective-tissue protein that provides the structural framework within skeletal muscles. Beef produced by youthful cattle (12- to 18-months old) contains immature, soluble, intramuscular collagen, which is characterized by a high proportion of reducible, heat-labile crosslinks that interconnect collagen molecules. During cooking, collagen containing these immature crosslinks readily hydrolyzes to form gelatin, which minimizes collagen’s effect on meat tenderness when beef cuts are prepared using cooking techniques that are appropriately matched to the total concentration of collagen within the cut (e.g., dry heat, high-temperature, brief cooking time for cuts with low levels of collagen vs. moist heat, low-temperature, extended cooking time for cuts with high levels of collagen). As collagen matures, however, the crosslinks gradually stabilize to an insoluble, heat-resistant form so that less collagen is solubilized during cooking. The greater concentration of thermally stable collagen in muscles of mature cattle contributes to their greater toughness compared with muscles from youthful animals (Bailey, 1985; McCormick, 1994, 1999; Purslow, 2005). Shorthose and Harris (1990) examined the effect of animal age (ranging from one to 60 months) on tenderness of 12 different beef muscles and determined that age-associated toughening of beef was more pronounced among collagen-rich muscles (such as the Biceps femoris) than among muscles with lesser concentrations of collagen (such as the Psoas major). Similar results recently were reported by Schönfeldt & Strydom (2011).

When comparisons involve cattle of widely divergent chronological ages, increased animal age generally is associated with reduced beef tenderness (Hiner and Hankins, 1950; Tuma et al., 1963; Shorthose and Harris, 1990). However, when comparisons involve cattle within an age range that typifies the ages of steers and heifers produced for mainstream U.S. beef markets (12 to 24 months), animal age usually has little effect on tenderness (Arthaud et al., 1977; Bouton et al., 1978; Field et al., 1966). Field et al. (1966) examined the relationship between animal age and beef tenderness among steers and heifers harvested between 300 to 699 days of age and concluded that age was not an important determinant of meat tenderness among steers and heifers less than two-years old.
Physiological Carcass Maturity and Beef Tenderness

Although many U.S. cow-calf producers record individual birth dates for each year’s calf crop, slaughter cattle often are transferred from producer to packer without documentation of actual animal ages (USDA, 2005). Correspondingly, carcass indicators of physiological maturity are considered when assigning USDA quality grades to beef carcasses in an effort to reflect age-related differences in beef tenderness.

Studies conducted to determine the relationship between physiological maturity and beef tenderness across the broad spectrum of cattle and beef carcasses produced in the United States (young vs. old, male vs. female, fed vs. non-fed, beef vs. dairy, etc.) have shown that progressive increases in USDA physiological maturity (from A through E) generally are accompanied by increased concentration of mature crosslinks and greater thermal stability of intramuscular collagen (Smith and Judge, 1991), resulting in greater beef toughness (Smith et al., 1982; Smith et al., 1988; Hilton et al., 1998). Results of most studies have demonstrated substantial negative effects of increased physiological maturity on beef tenderness when youthful (A- and B-maturity) carcasses are compared with carcasses exhibiting advanced (D- or E-maturity) maturity characteristics (Romans et al., 1965; Walter et al., 1965; Breidenstein et al., 1968; Berry et al., 1974). Yet, when only youthful carcasses representing the A- and B-maturity groups are compared, few significant differences in beef tenderness have been observed. A review of nine different studies (Romans et al., 1965; Walter et al., 1965; Breidenstein et al., 1968; Covington et al., 1970; Berry et al., 1974; Smith et al., 1982; Smith et al., 1988; Shackelford et al., 1995; Hilton et al., 1998), involving comparisons of Longissimus tenderness for A-maturity vs. B-maturity beef carcasses, identified just two studies (Smith et al., 1982; Smith et al., 1988) in which tenderness of beef from A- and B-maturity carcasses differed significantly. Weighted mean Warner-Bratzler shear force values for Longissimus steaks from A- (n = 680) and B- (n=503) maturity carcasses, calculated using published results from the nine studies cited above, differed by only 0.12 kg.

Physiological Maturity Effects on Tenderness of Beef from Fed Cattle

Research has failed to demonstrate consistent relationships among carcass maturity, collagen solubility, and beef tenderness when comparisons among physiological maturity groups are restricted to include only carcasses and beef produced by grain-finished steers, heifers, and heiferettes (the classes of cattle that make up the bulk of the U.S. fed-beef supply). Grain-finishing of cattle increases their pre-slaughter growth rate, which has been shown to influence the crosslinking profile and solubility of intramuscular collagen (Aberle et al., 1981; Fishell et al., 1985; McCormick, 1994), even in mature cattle (Miller et al., 1987; Cranwell et al., 1996). Periods of rapid growth are accompanied by synthesis of new, immature collagen that contains a high proportion of heat-soluble crosslinks, whereas periods of slower growth are followed by increased concentrations of mature, thermally stable crosslinks, irrespective of animal age (Wu et al., 1981; McCormick, 1994). As a result, cattle harvested following periods of rapid growth may exhibit evidence of advanced skeletal maturity characteristics and, yet, have comparatively immature intramuscular collagen characteristics and, thus, tender meat.

Miller et al. (1983) compared beef from youthful (A- and B-maturity) and mature (C- and D-maturity) carcasses produced by steers finished for 185 days on a high-concentrate diet and found no differences in collagen solubility or meat tenderness between the maturity groups. Similarly, Tatum et al. (1980) found no differences in sensory panel tenderness ratings or Warner-Bratzler shear force when comparing steaks from A- and B-maturity carcasses produced by steers harvested after 100 to 160 days on feed. In fact, in the latter study (Tatum et al., 1980), a small number of C-maturity steer carcasses produced steaks with superior ($P < 0.05$) sensory properties to those of steaks from A- and B-maturity carcasses. Shackelford et al. (1995) compared steaks from A- and B-maturity carcasses produced by heifers (mean age = 22.2 months; mean skeletal maturity score = A80) and heiferettes (mean age = 35.9 months; mean skeletal maturity score = B79), fed a high-energy diet for 90 days before harvest, and found that panel tenderness ratings and Warner-Bratzler shear force did not differ ($P > 0.05$) between the two groups. Field et al. (1997) compared beef from A- and C-maturity carcasses produced by beef females of similar chronological ages (both physiological maturity groups consisted of 31- to 35-month-old cattle), finished on high-concentrate diets for 100 days. In their study (Field et al., 1997), the A- and C-maturity groups had similar concentrations of mature crosslinks in muscle (m. longissimus) samples and produced loin steaks that did not differ ($P > 0.05$) in tenderness. The authors concluded that maturation of collagen in muscle was independent of changes in skeletal maturity (Field et al., 1997). Collectively, results of these studies are noteworthy because they do not support the fundamental grading concept of using skeletal maturity assessments to reflect differences in intramuscular collagen maturity and associated differences in tenderness when applied to carcasses of grain-finished cattle.

Currently, there is a lack of information in the scientific literature concerning the effects of premature skeletal ossification on beef tenderness. As mentioned previously in this review, it is not uncommon for some cattle less...
than 30-months old to produce beef carcasses with B-maturity or older skeletal characteristics, while most of their contemporaries (same age, sex, breed, and management history) produce A-maturity carcasses. In today’s U.S. beef trade, most of those carcasses classified as B-maturity or older would be discounted in price by $20 to $55/cwt. (USDA, 2011), yet if beef from these “more mature” carcasses is comparable in all other respects to beef produced by their A-maturity counterparts, then any discount in price would be unjustified. Additional research is warranted to determine how much, if any, effect advanced skeletal maturity, occurring among grain-finished steers and heifers known to be less than 30-months old, has on beef quality, particularly product tenderness.

**Dentition and Beef Tenderness**

Another method of estimating physiological age in cattle is to determine the animal’s dental age by quantifying the number of erupted permanent incisors (Graham and Price, 1982). Dentition is used in place of skeletal ossification in the South African and Australian (AUS-MEAT) beef grading systems (Strydom, 2011). In the United States, dentition is not used for grading purposes, but has been used since 2004 to verify ages of cattle (< 30 months vs. ≥ 30 months) in an effort to prevent human exposure to bovine tissues (specified risk materials) that could contain the infective agent (prion) that causes bovine spongiform encephalopathy (BSE).

Dental age is more closely related to actual chronological age than is USDA physiological maturity (Raines et al., 2008); however, differences in dentition status do not seem to be consistently related to variation in beef tenderness (Strydom, 2011). Schönfeldt & Strydom (2011) compared tenderness characteristics of 16 beef muscles from cattle representing three different dental maturity groups: A – no permanent incisors, B – two, four, or six permanent incisors, and C – eight permanent incisors. In that study, increased dental maturity was associated with significant reductions in collagen solubility and panel ratings for tenderness in all 16 muscles; however, differences between adjacent dental maturity groups (A vs. B and B vs. C) were not always large enough for statistical significance. Shorthose and Harris (1990) also found that increased number of permanent incisors (from zero to seven) was associated with greater beef toughness. In contrast, however, Wythes and Shorthose (1991) reported no differences in tenderness (peak shear force) among cows with two, four, six, or eight permanent incisors or among steers with four, six, or eight permanent incisors. Lawrence et al. (2001) studied the relationship between dental maturity (zero, two, four, six, or eight permanent incisors) and Longissimus tenderness using a sample of 200 commercially fed cattle harvested at a large, commercial U.S. beef plant. Results of that study showed no relationship between dental age and Warner-Bratzler shear force or sensory panel tenderness (Lawrence et al., 2001).

Even though differences in dental age do not appear to consistently reflect differences in beef tenderness, dentition status is an accepted age-verification tool that potentially could simplify assignment of USDA beef quality grades to carcasses produced by youthful steers and heifers. Currently, carcasses from cattle processed in U.S. federally inspected beef plants are segregated into two groups based on dentition: 1) carcasses from cattle with fewer than three permanent incisors, classified as less than 30-months old and 2) carcasses from cattle with three or more permanent incisors, classified as 30 months of age or older. These two groups of carcasses typically are graded and fabricated separately. When graded, not all cattle with fewer than three permanent incisors produce A-maturity carcasses. In a 2004 beef checkoff study (unpublished), more than 6,600 carcasses produced by fed steers and heifers with fewer than three permanent incisors were assigned maturity scores by USDA grading experts. Most (91.8%) of the carcasses produced by these cattle were A-maturity; however, 6.4% of the carcasses were classified as B-maturity and 1.8% were classified as C- or D-maturity. Whether or not such differences in carcass maturity are related to beef tenderness differences among cattle whose dental age is less than 30 months is an important question that has not been addressed in the scientific literature. However, if fed steers and heifers with fewer than three permanent incisors (i.e., those deemed less than 30-months old) produce beef that provides an eating experience comparable to that of A-maturity beef, irrespective of carcass maturity characteristics, then it could be argued that all carcasses from cattle classified as less than 30-months old on the basis of dental age should be considered A-maturity for grading purposes. Such an approach not only would simplify grading by eliminating the need to examine each carcass for indicators of physiological maturity, but also would provide producers and feeders with a means of determining maturity in live cattle, which would assist them in controlling conformity to desired beef marketing specifications for animal age.

**Summary**

The majority of cattle produced for U.S. mainstream beef markets are grain-finished steers and heifers harvested at 12 to 24 months of age. At these young ages, steers and heifers are expected to produce A-maturity carcasses when they are graded by USDA and, yet, some of these cattle exhibit sufficient degrees of skeletal ossification to cause their carcasses to be classified as B-maturity.
or older, which significantly reduces carcass value and marketability. Skeletal ossification is accelerated by high levels of estrogen, so heifers typically show more advanced skeletal maturity than do steers of the same age. In females, increased estrogen levels associated with pregnancy, parturition, and lactation further promote skeletal maturation. Moreover, cattle that have been treated with estrogen-containing implants tend to produce carcasses with skeletal characteristics that are physiologically more mature than carcasses produced by cattle that have not received estrogenic implants. The effect of implanting on skeletal maturation appears to be dependent upon the estrogenic dose delivered by the implant, the number of estrogen-containing implants that an animal receives prior to slaughter, and age of the animal. Sequentially implanted cattle, particularly heifers, greater than 20-months old are most likely to produce B-maturity or older carcasses. Though it is not well documented in the scientific literature, it is possible that premature skeletal ossification in cattle also may be linked with unintentional exposure of cattle to diets containing estrogenic compounds, such as those produced by certain forage plants (phytoestrogens) or by fungi (mycoestrogens) that infect forages and grains. Additional research would be required to determine what, if any effect, premature skeletal ossification has on eating quality (particularly tenderness) of beef produced by steers and heifers known to be less than 30-months old.

References


