Effects of the 60-d Window Around the Time of Weaning on Subsequent Quality Grade and Eating Quality of Beef

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Introduction

Marbling influences beef's ultimate eating satisfaction, and has resulted in development of premium beef products that require a high degree of marbling. Recent research at Colorado State University (CSU) indicates that beef from carcasses with modest marbling (equivalent to average Choice) provides an 82% probability of a positive sensory experience (Figure 1; Emerson et al., 2013), which is greater than the probability of a positive sensory experience associated with small marbling (equivalent to low Choice; 62%). Probability is maximized at 99% in steaks from carcasses with slightly abundant marbling (equivalent to low Prime).

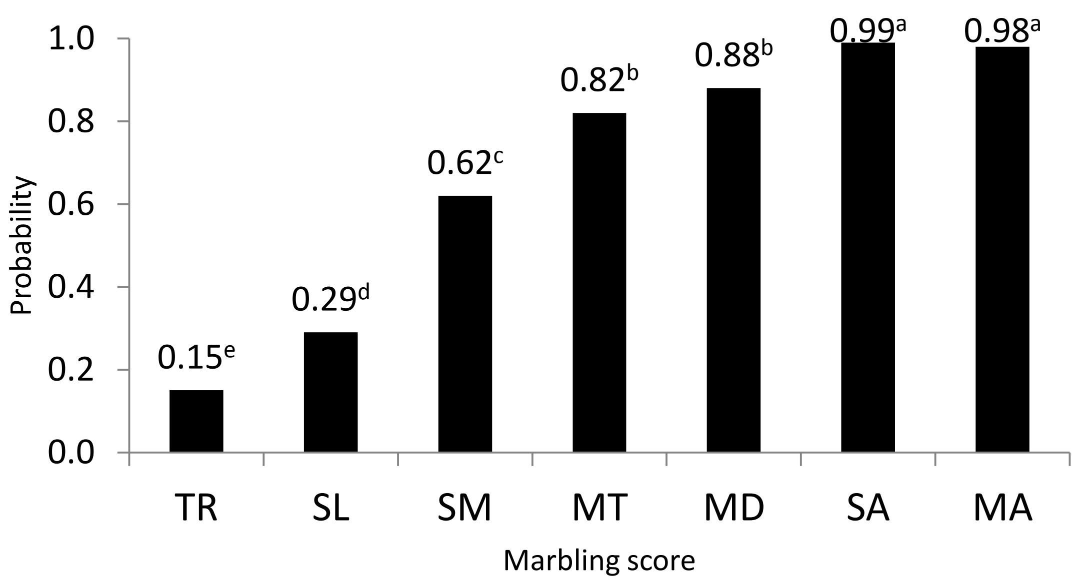

Figure 1. Effect of marbling degree on probability of a steak receiving a positive sensory experience rating (>7.5 on a 15-cm scale; TR = traces, SL = slight, etc.; Emerson et al., 2013). [a-e]Means without common superscripts differ ($P < 0.05$).

Thus, ensuring that consumers have a positive eating experience requires creation of highly-marbled beef carcasses. Unfortunately, the U.S. beef industry continues to struggle with this, as evidenced by limited industry-wide progress in marbling deposition based on National Beef Quality Audit (NBQA) data from the 2 most recent audits. According to the 2011 NBQA, industry experts estimated the "ideal" consist of beef carcasses was 69.0% Choice or higher, based on demand by retailers, food service companies, etc. (Figure 2; NCBA, 2011). However, in the 2011 NBQA only 61.0% of carcasses actually graded Choice or higher. Progress up until that point had been limited, based on the fact that the percent of carcasses grading Choice or Prime increased only 6.5% percent (just 3.7 percentage points) from 57.3 to 61.0% during the previous 6-year period (2005 to 2011; NCBA 2005, 2011).

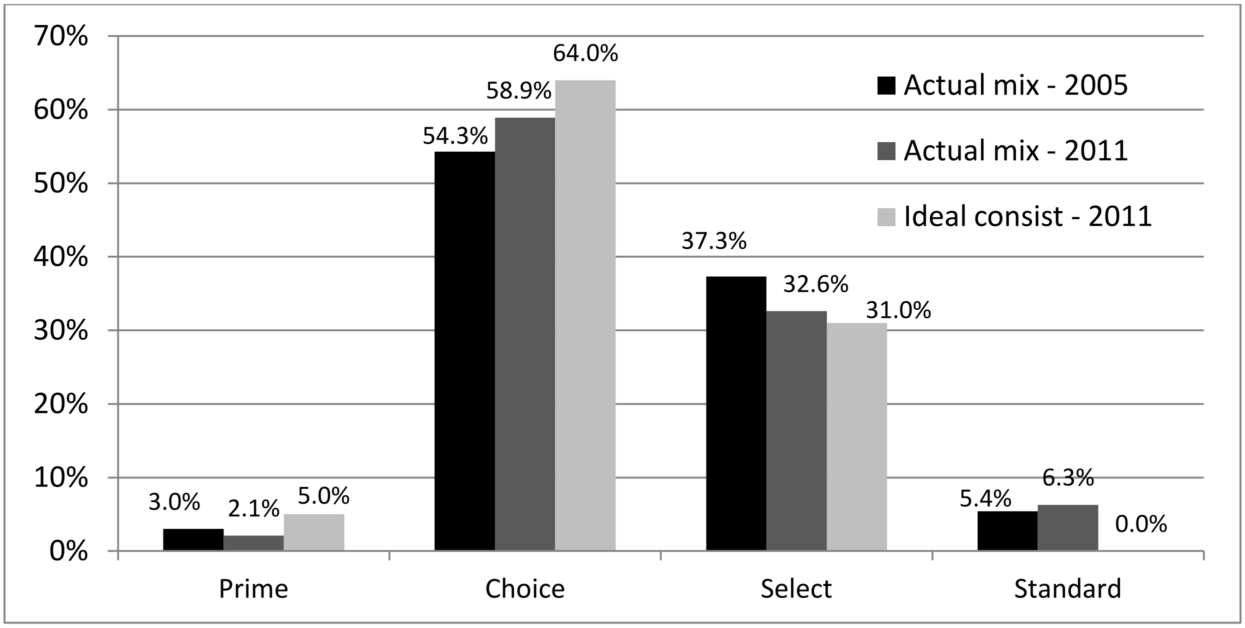

Figure 2. Comparison of actual quality grade consist in 2005 and 2011 vs. ideal harvest mix desired in 2011, according to National Beef Quality Audit results (NCBA, 2005, 2011).

Marbling deposition is moderately to highly heritable (h^2 range = 0.30 to 0.57; Utrera and Van Vleck, 2004), which has enabled great strides in marbling improvement due to genetic selection alone. Conversely, the remaining variation in marbling (about half, or more, of total variation) is due to the environment, including how cattle are managed. Recent research suggests that deposition of marbling can be influenced much earlier in a beef animal's life than previously believed, indicating an opportunity for changes to be made via management. *Thus, the objective of this paper is to provide a synopsis of factors around the time of weaning that have been shown in the scientific literature to influence eating quality and/or marbling deposition in beef cattle.*

In a recent comprehensive review, Du et al. (2013) provided an overview of fat tissue development in beef cattle. Cells that become fat (adipocyte) or muscle (myocyte) tissue originate during embryonic development as "progenitor" cells (i.e. forbearers of future body cells). Promotion of one or the other of these early cell lines results in either enhanced muscle growth (via bolstered myogenesis and creation of muscle cells) or fat cell formation including marbling deposition (via increased adipogenesis and creation of fat cells). Influencing progenitor cells via nutrition or management early in development (vs. later) is more effective due to the declining number of these cells as an animal gets older (Du et al., 2013).

Creation of fat cells begins in an embryo during mid-gestation when visceral fat develops, which continues into the newborn stage. This is followed by the start of subcutaneous, intermuscular (seam), and intramuscular (marbling) adipogenesis, which continues through pre-weaning (for both subcutaneous and intermuscular) and as late as 250 days of age (for intramuscular) as indicated by Du et al. (2013). The authors reported that intramuscular adipogenesis can be influenced via dietary and/or management intervention during a "marbling window", which is the timeframe from pre-weaning through about 250 days of age in which fat deposition processes may be altered (Figure 3).

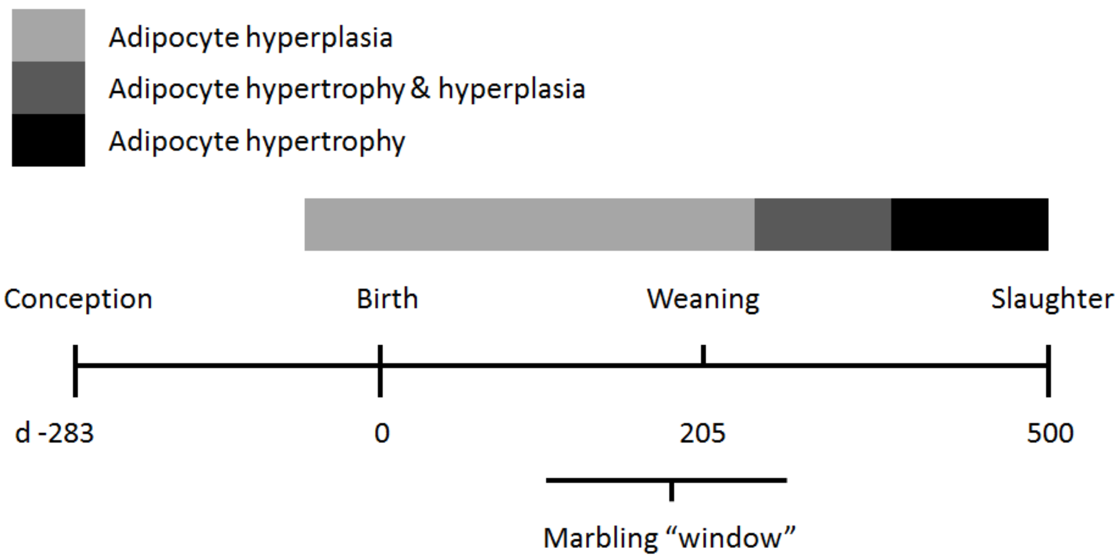

Figure 3. Suggested "marbling window" and approximate timing of adipocyte hypertrophy (increase in cell size) and hyperplasia (increase in cell number) activity associated with intramuscular fat during a beef animal's lifetime (adapted from Du et al., 2013).

Review of Lipogenesis

It's important to discuss the process of lipogenesis associated with intramuscular fat deposition prior to reviewing possible nutritional or management strategies that may influence it. An animal's adipocyte development is influenced by many things, including nutrient intake. Nutrient intake in a young animal beyond nutrient requirements for maintenance and muscle and bone development is necessary to stimulate marbling deposition (including preparation for deposition).

A good background on adipogenesis is available via an extension fact sheet (Fluharty, 2000). Fat tissue mass is created via adipocyte hyperplasia (increase in cell number), hypertrophy (increase in cell size), or both. And, fat tissue development requires 2 raw materials: 1) fatty acids, and 2) glycerol 3-phosphate (which comes predominantly from glucose). In ruminants, fatty acids are supplied by volatile fatty acids (VFAs) created in the rumen by microbes, which consist of acetate, propionate, and butyrate. The ratio of these VFAs to each other varies based on feedstuff type. For instance, the amount of propionate generally doubles when grain is fed compared to forage, due to increased presence of readily-fermentable carbohydrates (Table 1).

Table 1. Typical distribution of volatile fatty acid (VFA) production in beef cattle by feedstuff type

	VFA		
Feedstuff type	Acetate	Propionate	Butyrate
Forage diet	65-70%	15-25%	5-10%
Grain diet	50-60%	35-45%	5-10%

Adapted from Fluharty (2000).

The VFA ratio is important when considering marbling deposition, since increased propionate leads to increased insulin concentration, which results in increased uptake of nutrients by cells from the bloodstream. Increased nutrient uptake ultimately increases fat and protein synthesis (Fluharty, 2000). When the notions of a marbling window (Du et al., 2013) and VFA distribution (Fluharty, 2000) are combined, it's evident that both an animal's age and diet can influence both the timing of lipogenesis onset and its relative amount of activity. This situation was shown by Smith et al. (1984) when lipogenesis was evaluated in cattle fed either a grain- or forage-based diet. Grain-fed cattle had greater backfat as well as activity of enzymes associated with lipogenesis, yet energy intake was slightly higher for the forage-based diet due to increased feed intake. This was an important finding, since it indicated that end-products of ruminal fermentation influence adipocyte development beyond total energy intake.

More specific to intramuscular fat, Smith and Crouse (1984) evaluated the effect of VFA source on enzyme activity associated with fatty acid synthesis. Cattle were fed either a low (corn silage) or high (corn grain) energy diet, which resulted in high energy cattle having greater carcass weight, backfat, and internal fat but no difference in intramuscular fat amount, fat cell diameter, fat cell number, or intramuscular fat enzyme activity. However, cattle receiving the low energy diet generated acetate that provided 70 to 80% of the acetyl units needed for lipogenesis of subcutaneous fat, but only 10 to 25% for intramuscular fat. In contrast, cattle receiving the high energy diet only provided 1 to 10% of the acetyl units needed for subcutaneous fat via propionate, but 50 to 75% for intramuscular fat.

It's clear that deposition of marbling is a "lifetime event", in which there are several critical points during an animal's life when the process can be influenced. And, as described above, nutrients accessible to an animal at different points in life, including the acetate-to-propionate ratio, influence the type of adipose tissue that is deposited (subcutaneous vs. intramuscular). It has been suggested that the time period around weaning appears to be one of these critical control points (Figure 3), due to the animal's physiological status – adipocyte activity is beginning to transition from increasing cell number (hyperplasia) to increasing cell size (hypertrophy; Du et al., 2013) – and the fact that weaning time is likely the most stressful event for a beef animal in between birth and harvest.

Management activities associated with weaning can influence a calf's physiology (Corah and McCully, 2006). Activities that may be influential will be discussed in this paper in detail, including the weaning process (age at weaning and weaning method used), dietary intervention (dietary energy and protein density and source), as well as exposure to growth-promoting implants, castration, and health challenges.

1. Weaning Age, Nutrition, and Methods

One of the biggest challenges with interpreting published research on the effects of weaning age, nutrition, and management on end-product quality is that most research includes the evaluation of several main effects simultaneously – variables such as calf age, breed, energy or protein source, diet nutritional content, use of supplemental/creep feeding, etc. Thus, clearly identifying, and concluding, that specific events or treatments truly influence marbling and end-product quality can be difficult. Regardless, an effort has been made here to focus on individual traits shown convincingly to affect carcass quality.

Age at Weaning

Early Weaning. Conventional weaning by cow/calf producers typically occurs around 205 days of age (nearly 7 months). Early weaning is generally defined as occurring at 100 to 150 days of age (Lake, 2009b), or simply less than 150 d (Loy et al., 1999), but has most often been referred to as occurring between 2.5 and 5 months of age (Ritchie, 2005). Historically, early weaning has been used primarily to improve cowherd fertility when grass is only seasonally available. Removing a cow's energy requirement for lactation when she is able to store body condition prior to winter and the following year's calving and breeding seasons can be beneficial. Yet, it has rarely been viewed as a method of enhancing calf value or carcass quality. If anything, calf value due to early weaning was seen as declining based on a reduction in saleable weaning weight (at the expense of increasing the dam's weight). And, most research has focused on evaluating possible negative consequences of early weaning more so than opportunities to add value (i.e. through enhanced end-product quality).

Early weaning can result in cattle harvested at a younger age, which may benefit carcass maturity and tenderness. Less total feed input may also result, simply due to a shortened time that an animal is alive and needs to be maintained. However, early weaned calves are often lighter at harvest, and often can be on feed for a longer period of time due to a lighter in-weight. This is an important consideration when deciding to early wean, particularly since carcass weight impacts carcass value substantially more than any other trait, including marbling (Tatum et al., 2006).

Positive benefits of early weaning on end-product quality have been reported by a number of researchers. Using 167 steers over 2 years, Myers et al. (1999a) indicated that marbling score and percent cattle grading average Choice or higher were both greater for early vs. normal weaned calves. Steers were weaned early (158 or 177 days old) and then placed on a finishing diet, or weaned at a normal age (213 or 231 days old). The effect of creep feeding in this study will be discussed later. Addition of the early weaning treatment increased the rate that steers graded average Choice or higher by 38%, although early weaned calves were in the feedyard longer, had a lower rate of respiratory morbidity, and in year 2 had greater carcass weights. These 3 factors could have secondarily influenced ability to deposit intramuscular fat (beyond age and diet factors).

Meteer (2011) reported that marbling score, and percent of carcasses grading average Choice or higher, low Prime, or Certified Angus Beef (CAB) were greater in early weaned calves (133 days) vs. normal weaned calves (233 days), regardless if pre- or post-weaning supplementation occurred (Table 2). The authors evaluated 200 Angus and Angus x Simmental calves, and early weaned calves were placed into the feedlot at weaning time.

Table 2. Effects of calf weaning age, creep feeding, and energy source on carcass traits (adapted from Meteer, 2011)

	Treatments[a]					Contrasts (P-value)[b]			
Item	EWS (1)	EWF (2)	CFS (3)	CFF (4)	CON (5)	1 vs. 2	3 vs. 4	1-2 vs. 3-4	1-4 vs. 5
Marbling score[b]	574	598	506	493	476	NS	NS	< 0.01	< 0.01
≥ Low Choice, %	91.9	100.0	89.2	91.7	75.0	NS	NS	NS	< 0.01
≥ Avg Choice, %	78.4	81.6	51.4	41.7	40.0	NS	NS	< 0.01	< 0.01
≥ Low Prime, %	13.5	23.7	8.1	0.0	0.0	NS	NS	< 0.01	0.02
% CAB	75.7	76.3	45.9	41.7	35.9	NS	NS	< 0.01	< 0.01

[a]EWS = early wean starch; EWF = early wean fiber; CFS = normal wean starch creep; CFF = normal wean fiber creep; CON = normal wean no creep.

[b]NS = not significant ($P > 0.10$).

[c]Marbling score: 400 = small^{00}; 500 = modest^{00}; 600 = moderate^{00}, etc.

Loy et al. (1999) reported that calves weaned at a very young age (67 days) had greater intramuscular fat (5.7 vs. 5.1%), marbling score (small^{78} vs. small^{20}), and percent Choice or higher (38 vs. 14%) or Prime carcasses (10 vs. 0%) vs. calves weaned at closer to a normal weaning age (147 days). Steer calves (n = 120) were sired by Angus or Simmental bulls. The early weaned calves received a concentrate mixture and alfalfa hay for 94 days. Although confounded by dietary treatment, the early weaning treatment altered lifetime intramuscular fat deposition but not backfat, and also probably influenced cow cyclicity and fertility more than normal weaning (although not measured in this study) since the early weaned calves were weaned at about the time of rebreeding (67 days post-calving).

In one of the largest experiments conducted on this topic (n = 554 calves at 2 locations), marbling deposition was influenced by weaning age, but not consistently by location (Waterman et al., 2012). At one location, marbling tended to be greater in normal (213 days) vs. early weaned (80 days) calves, while at the second location marbling, percent of cattle grading upper two-thirds Choice, and backfat were all greater in early vs. normal weaned calves. Steer age at harvest was similar across treatments at the first location, but at the second location normal weaned steers were older. Also, Warner-Bratzler shear force (WBSF) was evaluated but was not affected by age at weaning.

Similarly, Meyer et al. (2005) reported no change in tenderness (as measured by WBSF) due to weaning age. However, marbling scores were greater (modest^{13} vs. small^{63}), and more carcasses graded Choice or higher (57 vs. 37%) among early- (90 days) vs. normal-weaned (174 days) calves in Angus x Gelbvieh steers (n = 140). Cattle were harvested at 2 age end-points (404 or 442 days of age), and interestingly the variation in WBSF was greater in younger EW vs. older NW steers.

In one of few studies to evaluate the effect of weaning age on beef quality as measured by a taste panel, Schoonmaker et al. (2001) found that steaks from early weaned calves had more desirable taste panel tenderness and juiciness ratings vs. normal weaned calves (Table 3). However, weaning age did not affect quality grade or marbling score. The authors used 143 Angus x Simmental steers, and also studied the effects of an implant regimen (and the resulting interaction; discussed later). Weaning age was early (108 days) or normal (202 days), and cattle were harvested at a similar weight (1,200 lbs) and all treatments graded at least 85% Choice or better. It should be noted that early weaned steers were younger at harvest (355 vs. 372 days) than normal weaned calves, but also on feed longer (247 vs. 170 days).

Table 3. Effect of weaning time on carcass traits and end-product palatability (adapted from Schoonmaker et al., 2001)

Item	Early wean	Normal wean	P-value[a]
Marbling score[b]	444.3	440.0	NS
Quality grade[c]	4.0	3.9	NS
Select, %	6.3	14.8	NS
≥ Choice, %	93.7	85.2	NS
≥ Average Choice, %	60.3	69.1	NS
≥ High Choice, %	34.5	34.1	NS
Prime, %	8.5	3.9	NS
Shear force, kg	4.8	5.1	NS
Tenderness[d]	5.8	5.4	0.05
Juiciness[d]	5.7	5.4	0.04
Flavor intensity[d]	5.5	5.4	NS

[a]NS = not significant ($P > 0.10$).

[b]Marbling score: 300 = small^{00}; 400 = modest^{00}; 400 = moderate^{00}, etc.

[c]Low Choice = 3.0; average Choice = 4.0; high Choice+ = 5.0; etc.

[d]1 = extremely tough, dry, bland; 8 = extremely tender, juicy, intense.

While limited data indicate a benefit of early weaning on eating quality, and none reported any improvement in WBSF, several datasets indicate that there are clear benefits of weaning early on marbling deposition and percent of cattle grading Choice or higher. Generally, the studies placed early weaned cattle directly into a feedlot and compared them to normal weaned calves at harvest.

In contrast, several other studies have indicated no effect of early weaning. In research that strictly evaluated the effect of weaning age (90, 152, or 215 days) on carcass quality, Myers et al. (1999b) observed no difference in degree of marbling or percent of carcasses grading Choice (Table 4). The study involved Simmental x Angus x Hereford steers (n = 168) placed directly into the feedyard at weaning and fed to constant backfat of 0.32 inches. Interestingly, over 90% of cattle in every treatment group graded Choice even though they were harvested at a fairly lean backfat endpoint.

Table 4. Effect of weaning age on carcass traits (adapted from Myers et al. 1999b)

Item	Weaning age, days			P-value[a]	
	90	152	215	Linear	Quadratic
Marbling score[b]	1,140	1,121	1,115	NS	NS
≥ Choice, %	98	96	92	NS	NS
≥ Average Choice, %	65	53	56	NS	NS
≥ Prime, %	11	9	6	NS	NS

[a]NS = not significant ($P > 0.10$).

[b]Marbling score: 1,000 = small^{00}; 1,100 = modest^{00}; 1,200 = moderate^{00}, etc.

Similarly, in 2 experiments where cattle also graded a high percent Choice (≥78.6% in every treatment), Fluharty et al. (2000) reported that neither quality grade distribution nor backfat thickness were influenced by weaning age (marbling score was not measured). Weaning age was either early (93 or 103 days) or normal (203 or 210 days), and experiments included 78 and 64 calves (respectively). Early weaned calves received a 75% whole corn diet beginning at weaning. The authors did suggest that providing early weaned calves access to a high concentrate diet accelerated fat deposition early in the feeding period, although a direct ultrasound comparison between early- and normal-weaned calves was not reported.

Lusby et al. (1990) also reported no effect of weaning age on marbling and quality grade using 58 calves where weaning was early (at 2.5 to 4.5 months) or normal (at 6 to 8 months). Early weaned calves were fed a grain-based diet to achieve varying levels of gain (1.0 or 1.5 lbs/day via limit-feeding, or full-feeding), and all calves were harvested at about 1 year of age (343 to 379 days old) when they reached 0.5 inch of backfat. There was no influence of weaning age or level of concentrate fed to early weaned calves on carcass quality. However, cattle had relatively low marbling, since cattle graded Select on average, with mean marbling scores ranging from slight^{26} to slight^{58} for the 4 treatments.

In a 5-yr study using 60 calves/treatment weaned at 150 (early), 210 (normal), or 270 (late) days of age, Story et al. (2000) reported no effect of calf weaning age on marbling. Interestingly, when percent of cattle grading Choice or higher among normal and late weaned calves was adjusted to the backfat of early weaned calves, no difference was observed for marbling.

In heat adapted cattle, Arthington et al. (2005) observed no influence of weaning age on carcass quality in 40 Brahman x English steers weaned at a normal (300 days) or early (at 89 days) age. During the experiment, both treatments were allowed to graze, but on different grass types, and early weaned calves received a supplement (1% of body weight) after weaning on-site until shipping at the time of normal weaning (thus, normal weaned calves were subjected to transport stress at weaning). Ultimately, there were no differences in marbling or quality grade, but on average both treatments averaged Select.

The reasons that a number of researchers observed no influence of weaning age on marbling deposition are unclear. However, it should be noted that most of these studies – with the exception of Myers et al. (1999b) and Story et al. (2000) – utilized much smaller numbers of cattle per treatment than studies that noted an effect. And, the average quality grade reported was relatively low (Lusby et al. 1990; Arthington et al., 2005) compared to researchers who reported an effect of weaning age. Finally, only one study (Story et al., 2000) adjusted marbling deposition based on backfat. As will be discussed later in this paper, it appears that when early weaned cattle are harvested at a similar backfat to normal weaned calves [as was the case with

Myers et al. (1999b) and Lusby et al. (1990)], early weaned calves have not deposited as much marbling as anticipated since they often deposit backfat early (due to receiving a higher energy diet starting earlier in life), and thus are physiologically more "advanced" than normal weaned calves (Shike et al., 2003; Schoonmaker et al., 2003).

Late Weaning. Several researchers evaluated the effect of late weaning (later than the typical 6 to 7 months of age) on carcass quality, including determination if any "risk" is associated with weaning late. Marbling, quality grade, and backfat were not affected by weaning age (212 vs. 300 days) in a 3-year study using 139 fall born steers (Hudson et al., 2010). Thus, the authors concluded there was no net benefit or loss associated with late weaning.

Sexton et al. (2012) also reported that late weaning did not alter carcass traits using 33 steers either normal (210 days) or late (300 days) weaned. Hot carcass weight was greater for late weaned calves, but marbling score and backfat thickness did not differ. Worthy of note, the fatty acid profile was influenced by age at weaning, including mono- and poly-unsaturated fatty acids, as well as the omega-6 to omega-3 fatty acid ratio.

Ultimately, placing cattle on feed at a younger age vs. as yearlings improves intramuscular fat deposition, based on an Ohio State University study evaluating age at feedyard entry and castration status in 70 Angus x Simmental calves (Schoonmaker et al., 2002; Table 5). A 3 x 2 factorial design was used, in which factors were age (early weaned = 111 days, normal weaned = 202 days, or yearling = 371 days) and castration status (steers vs. bulls) at feedyard entry. Time on feed increased as age at feedyard entry decreased, but fat thickness, carcass percent lipid, and WBSF did not differ across treatments. Marbling score and quality grade were greater in early and normal weaned calves vs. yearlings, but did not differ between early and normal weaned calves, indicating that weaning early and placing on feed (prior to 202 days) did not benefit marbling deposition. Yet, placing cattle on feed at an older age (371 days) detracts from marbling.

Table 5. Effect of age at feedlot entry on carcass traits (adapted from Schoonmaker et al., 2002)

	Feedlot entry age, days			
Item	111	202	371	P-value[a]
Marbling score[b]	370.4[x]	393.0[x]	319.3[y]	0.02
Quality grade[c]	3.2[x]	3.5[x]	2.7[y]	0.01
Select, %	25.0[x]	12.9[x]	48.1[y]	0.03
Low Choice, %	41.7	34.5	34.5	NS
Avg Choice, %	25.0	43.6	17.4	NS
High Choice, %	8.3	9.0	0.0	NS
Shear force, kg	4.9	4.8	5.1	NS

[a]NS = not significant ($P > 0.10$).

[b]Marbling score: 300 = small^{00}; 400 = modest^{00}; 400 = moderate^{00}, etc.

[c]Select = 2.0; low Choice = 3.0; average Choice = 4.0; high Choice+ = 5.0; etc.

[x,y]Within a row, means without a common superscript differ ($P < 0.10$).

Data in the literature do not suggest a negative impact of late-weaning on carcass quality. However, cattle placed on feed earlier (as early or normal weaned calves) will have greater marbling than those placed on feed as yearlings.

Nutrition Around the Time of Weaning

Beyond studying the effects of calf age at weaning, a large amount of research has also evaluated the effects of nutritional supplementation around the time of weaning – including as creep feed to normal weaned calves concurrent with early weaning – on animal performance, including carcass quality.

Creep Feeding. The effect of creep feeding normal weaned calves on carcass quality was evaluated by Deutscher and Slyter (1978) in which greater marbling score and quality grade resulted in creep-fed calves (receiving corn/oats combination) nursing their dams in a dry-lot situation vs. nursing calves not receiving creep feed either on pasture or in a dry-lot. In addition to greater marbling, creep-fed dry-lot calves had less backfat than pasture-based calves. This was a 6-year experiment involving 90 cows, and dry-lot cattle were provided a forage-based ration consistent with NRC recommendations that calves could also access.

In another study, Faulkner et al. (1994) evaluated the effects of limit-feeding supplemental creep feed and source of supplemental feed (soyhulls vs. corn) in 90 Angus x Hereford 5-month old steer calves nursing their dams on pasture. Treatments included no supplement (control), limited corn (2.2 lbs/day), unlimited corn, limited soyhulls (2.2 lbs/day), and unlimited soyhulls. At harvest at 14 months, unlimited creep calves had greater quality grade vs. controls, and corn supplementation resulted in greater marbling vs. soyhulls. Thus, creep feed source affected carcass quality when creep feed gains were similar.

In contrast, Myers et al. (1999a) reported no effect of creep feeding on marbling in calves provided with creep feed for 55 days prior to being normal weaned (213 or 231 days). However, when recognizing that these authors observed an effect of early weaning on marbling deposition, their data indicate that when early weaned calves received a high energy diet post-weaning, marbling deposition was changed. However, a high energy pre-weaning diet provided to normal weaned calves did not influence marbling deposition.

In a master's thesis, Meteer (2011) saw no influence of creep feed source (starch- vs. fiber-based supplement) on marbling deposition in normal weaned calves. Ultimately, in that study both early weaned and creep fed (normal weaned) calves had greater marbling deposition than normal weaned non-creep fed calves, indicating the benefits to marbling of either early weaning or creep feeding and normal weaning.

Comparisons have also been made between creep-fed normal weaned calves vs. those weaned early. Although not discussed earlier in the "age at weaning" section, Shike et al. (2003) reported that early weaning (65 days) improved marbling deposition and percent of carcasses grading average Choice or higher and Prime vs. normal weaning (189 days) with creep feeding (Table 6). This result was not discussed earlier since the normal weaned calves were also creep-fed, and thus results were confounded. However, the authors reported that neither presence of creep feed (vs. none in control calves) nor type of creep feed (corn- or fiber-based) influenced marbling-related traits in normal weaned calves. Angus x Simmental steers (n = 168) were used, and early weaned calves were program-fed restricted corn to match gain of normal weaned calves receiving creep feed. Interestingly, backfat tended to be greater in early weaning vs. creep-fed normal weaned calves, which supports the concept that early-weaned calves deposit subcutaneous fat earlier. These data indicate that high energy intake with early weaning altered marbling but dietary energy level (high vs. low) via creep feeding and normal weaning did not.

Table 6. Effects of weaning age, creep feeding, and type of creep feed on carcass traits (adapted from Shike et al., 2003)

	Treatments[a]				Contrasts (P-value)[b]		
Item	EWP (1)	NWC (2)	NWF (3)	CON (4)	1 vs. 2-3	2 vs. 3	1-3 vs. 4
Marbling score[c]	663	588	609	615	0.01	NS	NS
≥ Low Choice, %	90.0	79.5	80.0	73.0	NS	NS	NS
≥ Avg Choice, %	72.5	33.5	45.0	46.5	0.00	NS	NS
≥ Low Prime, %	12.5	2.5	2.5	7.5	0.03	NS	NS

[a]EWP = early wean program fed; NWC = normal wean creep; NWF = normal wean fiber creep; CON = normal wean no creep.

[b]NS = not significant ($P > 0.10$).

[c]Marbling score: 500 small00, 600 modest00, 700 = moderate00

In addition to evaluating the effect of weaning age on carcass traits, Fluharty et al. (2000) observed no effect of feed strategy (programmed vs. ad libitum) or protein level [at NRC (1984), or above NRC] on quality grade distribution or backfat thickness in 2 experiments (marbling score was not measured). These experiments evaluated a relatively small number of cattle, including a 2 x 2 x 2 factorial arrangement assessed on 78 animals in experiment 1, and 27 normal vs. 37 early weaned calves in experiment 2.

Although data are inconsistent among normal weaned calves, it appears that creep feeding prior to weaning likely benefits marbling deposition. And, creep feed source (starch- vs. fiber-based) can influence marbling among normal weaned calves, although results are inconclusive.

Post-weaning Nutrition. The effects of post-weaning diet content among early weaned calves have been evaluated, including comparisons of grain- vs. forage/pasture-based diets provided to calves after weaning. In a 2-year study, Myers et al. (1999c) compared the ad libitum feeding of a high concentrate diet with pasture grazing for 82 days using 74 early weaned (at 117 days) steers. Neither marbling score nor sensory attributes differed; however, percent of carcasses grading average Choice or higher tended (P = 0.11) to be greater for concentrate-fed steers (56 vs. 38%).

Using calves weaned at 119 days old in 2 experiments, 4 treatments were compared by Schoonmaker et al. (2003): ad libitum high concentrate, limit-fed concentrate for 1.76 lbs/day limit-fed concentrate for 2.64 lbs/day, and ad libitum high fiber. Intramuscular fat measured by ultrasound at 218 days was greatest, and serum insulin was increased, in ad libitum high concentrate steers in experiment 1. In experiment 2, the growing phase diet did not influence marbling score. The authors reported that although marbling was deposited at a faster rate in ad libitum high concentrate-fed vs. forage-fed cattle from 119 to 218 days of age, subcutaneous fat was also deposited at a faster rate. Thus, if cattle are harvested at a constant backfat endpoint, those that deposit more subcutaneous fat early – like calves fed the ad libitum high concentrate diet – would have less opportunity to deposit marbling.

In a similar study, Schoonmaker et al. (2004) compared calves weaned at 119 days old and treated with: 1) a 50% grain diet fed ad libitum, 2) limit-fed a 70% grain diet to achieve a specific rate of gain (1.76 lbs/day from 199 to 192 days of age, 2.64 lbs/day from 193 to 259 days of age), or 3) 60% haylage diet ad libitum (from 119 to 192 days) and 25% haylage diet ad libitum (193 to 259 days), with normal weaned (204 days of age) calves fed a silage diet until day 259. There was no difference in marbling score, but ad libitum grain calves had lowest percentage fat in the ribeye muscle. And, WBSF was highest for grain-fed steers (ad libitum and limit-fed), and lowest for haylage-fed and normal weaned steers. Ultimately, the authors concluded that feeding high grain diets hastened physiological maturity, decreased ribeye lipid content, and decreased tenderness vs. forage feeding.

Waterman et al. (2012) also evaluated the effect of the rumen degradability (69 or 57%) of a 17.5% crude protein post-weaning diet among early weaned calves (80 days). Marbling score was not influenced by rumen protein degradability at either location. Also, the effect of post-weaning diet source (starch- vs. fiber-based) fed to early weaned calves for 100 days was evaluated by Meteer (2011). No influence of source on marbling score or quality grade distribution was observed.

McCurdy et al. (2010) evaluated the effects of post-weaning growing programs in 256 normal weaned calves on carcass traits. Calves were fed to maximize gain via an ad libitum high concentrate diet, or to gain similarly via grazed wheat pasture, sorghum silage-based diet, or program fed high concentrate diet. Sorghum silage-based cattle had greater marbling scores vs. ad libitum high concentrate and wheat pasture calves, and program-fed concentrate calves were intermediate.

In summary, marbling deposition can be changed in early weaned calves that receive a high energy diet post-weaning. It appears that feeding a high concentrate diet will increase intramuscular and subcutaneous fat deposition vs. forage- or limit-feeding. But, dietary energy source (starch- vs. fiber-based) among early weaned calves does not influence marbling. It should be noted that if cattle receiving a high concentrate diet are harvested at a backfat similar to others, no difference in marbling will be observed vs. forage-fed calves. Along these lines, even normal weaned calves fed a high concentrate diet to maximize gain will not deposit more intramuscular fat than calves receiving a limit-fed grain or ad libitum forage-based diet. Data suggest that feeding high grain diets to early weaned calves hastens physiological maturity vs. forage feeding. Finally, there is no effect of rumen degradability of protein on marbling in the post-weaning diet of early weaned calves.

Possible Mechanisms of Action. Generally, providing high energy diets to calves at a young age (less than typical weaning age) enhances deposition of intramuscular fat, more so than simply weaning at an early age. In a comprehensive review, Berger and Faulkner (2005) conveyed 2 major points related to the influence of lifetime events on beef quality and profitability, notably: 1) marbling deposition may be affected early in development, and 2) diet composition during the growing period may influence marbling deposition. The authors summarized the likely mechanisms involved.

As discussed initially in this paper, diet influences VFA profile which alters lipogensis. This is the case in early weaned calves fed a high energy diet. Also, animals primarily undergo intramuscular adipocyte hyperplasia (increasing number) pre-birth through approximately weaning, followed predominantly by hypertrophy (increasing size) until harvest (Du et al., 2013). Early research by Prior (1983) indicated that a grain diet promoted hyperplasia vs. a forage diet. The author reported that grain-fed steers had more fat cells that were smaller, and also had more total adipose tissue mass, compared to forage-fed steers.

Lake (2009b) provided a discussion about possible mechanisms responsible. He suggested that greater marbling in early weaned calves is likely due to propionate and insulin concentration. Of VFAs produced in the rumen, propionate is the primary gluconeogenic precursor – which enables glucose to be supplied to a ruminant. Further, glucose is the predominant provider of acetyl units for intramuscular fat (supplying 50 to 70% of acetyl units). When propionate is produced by grain-fed steers, serum insulin increases and thus early weaned calves fed grain have greater glucose uptake from blood into cells. Also occurring is increased lipogenic precursors (including methlymalonyl-CoA) which causes increased glucose and insulin concentrations, resulting in increased intramuscular fat vs. subcutaneous fat deposition. Intramuscular fat deposition requires insulin while subcutaneous fat does not. Thus, glucose increases gluconeogenesis substrates and insulin enables more cellular uptake and use of glucose for marbling.

Many researchers reference earlier work by Cianzo et al. (1985) and Hood and Allen (1978) regarding fat cell number and size. Fat cell number, which has been reported to be more associated with marbling than fat cell size (i.e. diameter), was increased at 11 to 15 months of age in cattle creep fed prior to receiving a concentrate diet (Cianzo et al., 1985). And, Hood and Allen (1978) reported that the longissimus dorsi (ribeye) contains a greater proportion of small fat cells.

It appears that intramuscular adipocytes benefit from rumen products generated via a grain- vs. grass-based diet. These products are dietary substrates for lipogensis, and serve as the source of acetyl units for lipogenesis in adipocytes. Smith et al. (1984) found that acetate provided the majority of acetyl units for lipogenesis in subcutaneous adipocytes (70 to 80%) compared to the minority in intramuscular fat cells (10 to 25%). Thus, the authors reported that most of the remaining substrates for intramuscular fat cell synthesis come from glucose (50 to 60%). As reported in Table 1 above, grain results in more propionate vs. forage. And, propionate is converted to glucose in the liver of a ruminant. Dr. Scott Lake at the University of Wyoming helped to capture this comparison, in terms of comparing forage- vs. grain-based diets, rumen products, and how those products are used in lipogenesis of subcutaneous and intramuscular fat cells (Figure 4).

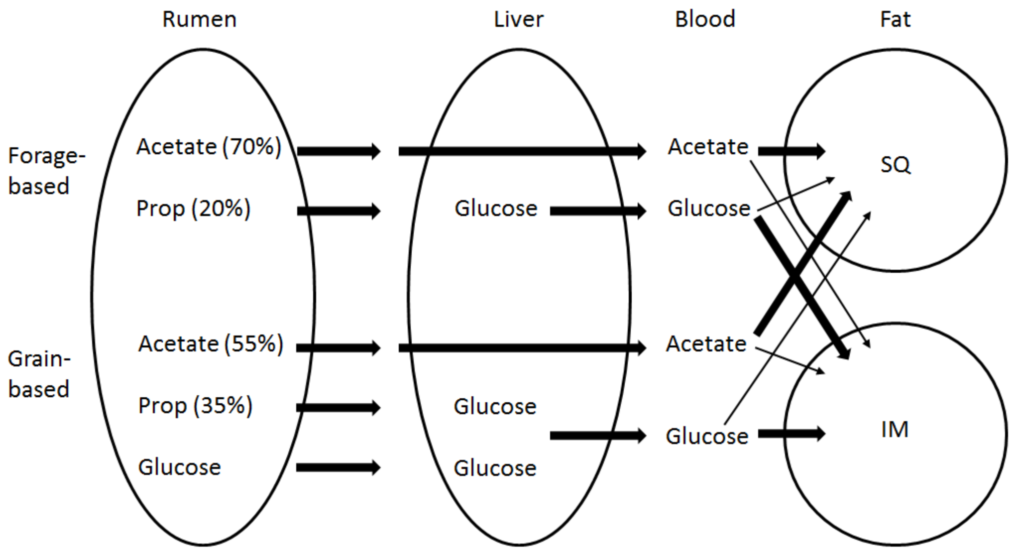

Figure 4. Influence of diet on rumen products and fat stores in cattle
Adapted from Lake (2009a) presentation

Lake (2009b) has reported preliminary data related to feeding calves a high concentrate diet beginning at 120 days old. Such a diet, provided through traditional weaning age and then followed by a low plane of nutrition prior to a high concentrate finishing diet, resulted in higher quality grades with similar hot carcass weights to traditional weaning. This led to development of a feeding strategy that includes feeding a high concentrate diet from 4 to 7 months of age, followed by slow plane of nutrition to reduce input costs while allowing for skeletal and muscle gain, and then followed by a high concentrate finishing ration. This method may increase marbling score in early weaned calves at a similar carcass weight to normal weaned calves, which has been a limitation to early weaning in some scenarios.

In a recently published manuscript, a team of researchers explored early postnatal metabolic imprinting (MIP) events that might be influenced via short-term high energy dietary interventions (Scheffler et al., 2014). The authors evaluated normal weaned (at 253 days) and MIP calves (weaned at 105 days followed by a 20% crude protein, 1.26 Mcal/kg NEg diet to gain 1.39 lbs/day). At 253 days of age all cattle were grazed for 156 days prior to entering the feedyard at 407 days of age on a corn silage-based finishing diet. The MIP calves were heavier at normal weaning age, the normal calves gained more during the grazing period, and traits including backfat thickness and feedlot performance were not different. Ultimately, the MIP calves had greater marbling score (645 vs. 518; where 400 = small^{00}), more desirable quality grade distribution (41.6% had marbling scores equivalent to prime vs. 0%), heavier carcass weights, and more days on feed vs. normal weaned calves. When accounting for carcass weight, MIP calves had less backfat at the same carcass weight. Scheffler et al. (2014) speculated as to why marbling score was greater (due to enhanced intramuscular lipogenesis), and provided 4 possible options: 1) increased production of pre-adipocytes during imprinting results in more pre-fat cells that mature during the finishing phase, 2) more mesenchymal stem cells that eventually become fat cells, 3) cells are "metabolically programmed" to be more aggressive and/or efficient at converting raw materials to fat, and/or 4) intramuscular fat deposition is driven by total energy consumed

The authors proposed that metabolic imprinting may be an ideal strategy for fall-calving herds. This would include weaning early at 90 to 100 days (after lactation has peaked and when forage availability is declining), feeding a high energy diet over the winter (limited grazing forage may be available), grazing calves on forage during spring for cheap gain, and ending with a relatively shortened finishing phase.

Trace Minerals. A lengthy review of the effects of nutrition and management during the background/stocker phase on carcass quality is available (Krehbiel et al., 2012). The authors provided a sound meta-analysis of dietary starch and placement weights; thus, those topics will not be discussed here. However, additional classes of nutrients fed early in life and shown to influence end-product quality, including trace mineral supplementation, will be reviewed here briefly.

Very limited research has focused exclusively on trace mineral supplementation during the immediate pre- or post-weaning period on carcass traits. However, during the growing and finishing phase, Zn supplementation and source have been shown to influence quality grade and marbling in steers (Spears and Kegley, 2002). And, relative to Cu, Engle et al. (2000) reported that Cu source, but not Cu supplementation, altered marbling score and quality grade in finishing steers.

The influence of injectable trace minerals early in life on carcass traits have been reported, with mixed results. Genther and Hansen (2014) reported that feeder cattle (weighing 711 lbs before a mineral depletion phase) given a combined injection of Cu, Zn, Mn, and Se had greater marbling score than steers receiving saline. However, Kegley et al. (2011) reported no benefit of injecting a trace mineral product 28 days pre-weaning on carcass characteristics, among calves already supplemented with dietary trace minerals.

Evidence clearly indicates that several trace minerals influence marbling deposition, but almost all research has been done in heavier cattle on growing or finishing diets. Limited data indicates that there is no effect of pre-weaning trace mineral administration on carcass traits. This is an area that would benefit from more research focused on the effects of specific minerals (e.g. Cu, Zn) supplemented pre- and post-weaning on fat deposition.

Weaning Methods

Although weaning is likely the most stressful event during an animal's life, at least in between the processes of birth and harvest, the scientific literature related to management of the weaning process and end-product quality is very limited. Most studies were conducted from weaning through part of the growing or finishing phases, and rarely incorporated carcass traits as response variables.

Boyles et al. (2007) explored pasture-weaning calves to reduce stress and its possible negative impacts on performance and health status upon arrival to the feedyard. The authors assigned 280 crossbred steers to treatments including weaning at shipping, weaning 30 days before shipping and placing in a dry lot, and weaning 30 days before shipping via fence-line weaning on pasture. Drylot steers gained less during the first 4 weeks in the feedlot compared to other treatments. Fence-line calves had lower morbidity vs. other treatments during the receiving period. Carcass traits were not evaluated.

The use of nose flaps to implement a "two stage" weaning process is increasing in the cow/calf industry, and appears to be more widespread outside of the U.S. The 2 stages include prevention from nursing the dam (stage 1) and separation from the dam (stage 2; Haley et al., 2005). The goal of the nose flap device is to avoid dietary change and abrupt separation from occurring on the same day.

Boland et al. (2008) evaluated weaning methods on post-weaning beef calf performance by assigning calves to fence-line weaning, nose flaps, or nothing (control) 7 days prior to weaning. Before weaning, calves with nose flaps spent less time eating, more time close to dams, and had less gain compared to other treatments. After weaning and transport, control calves spent less time eating and walked more than the other treatments. Fence-line calves had greater gain than calves with nose flaps. Blood metabolites indicated that nose flap calves had a negative energy balance prior to weaning. Ultimately, nose flaps were not comparable to fence-line weaning, and are probably more beneficial to dam body condition than to reducing calf stress. Again, carcass traits were not evaluated.

Use of nose flaps was compared to controls by Haley et al. (2005) where treated calves received a nose flap for 3- or 14-day periods before separation. After separation, nose flap calves vocalized less, spent less time walking, and spent more time eating and resting than controls. Coupled with this, the nose flap calves had reduced gains while they were prevented from nursing, but greater gains during the 7-d post-separation period compared to controls. Two-stage weaning causes less stress upon separation, but only for the first 2 days after separation. Longer-term differences in gain or performance have not been shown.

Stress can influence carcass quality, and weaning methods have been shown to differ in the amount of stress they cause. However, the ultimate effects on carcass traits have not been evaluated. Further research is needed in this area, including more focus on end-product quality.

2. Health, Disease, and Stress

Morbidity

In a very large study using data from 17,919 Angus steers fed in one feedyard during a 10-year period, Reinhardt et al. (2012) evaluated several factors that influenced ultimate quality grade of an animal. The authors reported that quality grade declined in a linear fashion with the number of times an animal was treated (0, 1, 2, and 3+). Similarly, percent of cattle grading premium Choice or Choice declined linearly and quadratically with the number of times treated. However, this study was not isolated to the receiving or immediate post-weaning period.

Similarly, a large number of studies have evaluated the effects of morbidity in newly weaned calves on carcass characteristics. Marbling scores have been shown to be negatively affected by bovine respiratory disease (BRD; Montgomery et al., 1984; Roeber et al., 2001). In receiving cattle in particular, Stovall et al. (2000) reported that marbling scores were lower among sale barn heifers treated for BRD during a 42-day receiving period, resulting in a 38% drop in heifers grading Choice or higher.

Incidence of BRD and number of treatments explained a significant amount of variation in marbling scores according to Schneider et al. (2009) when they evaluated records from 5,976 cattle in feedyards. In particular, marbling score was reduced by 0.13 among BRD-treated cattle, and marbling decreased as the number of BRD treatments increased.

In contrast, Step et al. (2008) found that previously-weaned single-source calves had less receiving phase morbidity than commingled cattle or those weaned directly to a feedyard. However, the authors reported that quality grade was not different based on weaning management. McBeth et al. (2001) reported that carcass quality did not differ among heifers treated once or not treated at all during a 42-day receiving period. It should be noted that the authors did not treat any cattle more than once during the receiving period. Snowder et al. (2007) reported no effect of BRD on marbling score using health records on 18,112 feedlot cattle, including carcass data on 1,637 steers. The authors reported that neither marbling score nor palatability of steaks were different between healthy and treated calves.

Several large studies have shown clear relationships between morbidity (e.g. treatment rate) and marbling and/or quality grade. Further, the more times an animal is treated the more detrimental to intramuscular fat deposition. Cattle treated for BRD, including newly weaned and high risk cattle, are particularly susceptible to lower quality carcasses as a result. However, decreased carcass quality was not apparent in low risk cattle (including previously-weaned single-source calves) that had been treated.

Presence of Worms

Using a relatively small number (n = 43) of steer calves, Clark et al. (2014) evaluated the effect of internal parasite burden at feedyard arrival on performance and carcass traits. Cattle with more significant worm burdens (≥100 eggs/gram), even though they tended ($P = 0.06$) to have more days on feed, also tended ($P = 0.08$) to have reduced marbling scores (modest^{12}) vs. lowly infected cattle (≤99 eggs/gram; small^{64}). However, quality grade did not differ. It should be noted that age at entry, or timing relative to weaning, were not known.

In 2 experiments, Reinhardt et al. (2006) evaluated the impacts of combining fenbendazole oral drench and ivermectin pour-on upon feedyard arrival in 1,106 newly received yearling heifers on parasite burden and performance. In experiment 1, the authors reported tendencies for marbling to be greater in fenbendazole-treated cattle ($P = 0.13$), and percent of carcasses grading Standard to be lower ($P = 0.09$). However, in experiment 2 no differences in carcass marbling or quality grade distribution were observed.

Marbling deposition can be influenced by parasite burden at feedyard arrival. And, treatments including fenbendazole in combination with ivermectin may influence carcass marbling, but results are inconsistent. However, limited research on the influence of parasite load around the time of weaning has been reported.

Castration

An early comprehensive review clearly indicated the negative traits of carcasses from bulls vs. steers, including decreased marbling, lower quality grade, less desirable tenderness, and undesirable meat color (Seideman et al., 1982). However, the effects of castration method and timing on carcass traits are not as clear.

In Europe, Marti et al. (2013) studied the effect of castration and timing of castration, as well as age at harvest, in 132 Holstein bulls on meat quality including use of a taste panel (Table 7). An interaction between castration and harvest age was present for intramuscular fat. However, separable intramuscular fat was greater in early vs. late castrated calves. Initial and overall "hardness", as well as juiciness, were more desirable in early vs. late castrated. However, flavor did not differ. Castration age influenced WBSF on d 0 of aging, in which values were more desirable among early vs. late castrates. In France, Micol et al. (2009) castrated Charolais steers at 2 or 10 months of age, and then harvested them at 19 or 26 months of age, and did not observe any effect of time of castration on tenderness or taste panel evaluation scores.

Table 7. Effect of age at castration on carcass traits and sensory panel (adapted from Marti et al. 2013)

	Castration age			
Item	Bulls	3 mo	8 mo	P-value[a]
Separable intramuscular fat (rib), %	8.3^{z}	11.1^{y}	12.6^{x}	< 0.001
Intramuscular fat, %	1.6^{z}	2.3^{y}	2.9^{x}	< 0.001
WBSF (d 0), kg	6.6^{x}	6.3^{xy}	5.7^{y}	0.05
WBSF (d 7), kg	5.0	5.2	5.3	NS
Initial hardness[b]	5.9^{x}	5.8^{x}	5.5^{y}	< 0.001
Overall hardness[b]	6.0^{x}	5.9^{x}	5.6^{y}	< 0.001
Juiciness[b]	2.7^{x}	2.5^{y}	2.6^{x}	0.01
Flavor	2.6	2.5	2.4	0.09

[a]NS = not significant (*P* > 0.10).

[b]10-point scale; 0 = least intensity, 10 = greatest intensity of the attribute.

[x-z]Means within a row without a common superscript differ (P < 0.05).

Heaton et al. (2004) evaluated time of castration on carcass traits and consumer preference. Treatments included early (233 lbs), mid (535 lbs), and late (803 lbs) band castration concurrent with an implant. Late castrates had lower marbling score and regular beef-eating older panelists identified the early castrates as more tender, juicy, and flavorful and with better overall acceptability than the others. Younger panelists who ate beef less indicated early were less juicy than others, but no difference in other traits. The authors did note that no steaks in any treatment were considered unacceptable.

Early research by Worrell et al. (1987) using Angus x Hereford steers harvested at 15 months of age indicated that calves castrated at lighter weights (154 lbs = small^{00} and 506 lbs = small^{40}) had greater marbling vs. calves castrated heavier (704 lbs = slight^{20} and 902 lbs = slight^{00}). Further, results of a trained taste panel indicated that calves castrated at the lightest weight (154 lbs) were more tender than heavy castrates (902 lbs) and bulls left intact, but tenderness scores did not differ among calves castrated at 506, 704, or 902 lbs. Interestingly, intact males had the lowest mean marbling score but were not different from calves castrated at heavier weights (704 or 902 lbs).

Research data clearly indicate that castration improves marbling and end-product palatability. Further, data suggest that in high marbling breeds of cattle (e.g. Angus, Holstein) early castration of bulls can improve marbling, tenderness, and other palatability traits. And, possibly the most important finding is that there is a benefit to end-product quality when late castration can be avoided.

3. Growth-promoting Technologies

Implants

Researchers at CSU conducted a large study using 550 steer calves and 10 implant strategies or a control to evaluate the effects of repetitive use of anabolic implants on beef carcass palatability (Platter et al., 2003). Implanting occurred at branding, weaning, backgrounding, feedyard entry, and/or re-implant time. The authors reported that as the number of implants a steer received increased, marbling decreased, shear force value increased, and consumer acceptability decreased. Further, steaks from steers that received 2 or more implants had less desirable eating quality than steaks from non-implanted controls. Most importantly, marbling scores were not affected by implanting at branding, weaning, or backgrounding. However, implanting at backgrounding (vs. controls) increased shear force value.

As discussed earlier, Schoonmaker et al. (2001) evaluated the effect of implant regimen and weaning age (and the resulting interaction) on carcass performance and beef palatability using 143 Angus x Simmental steers. In a 2 x 2 factorial, factors included implant strategy (aggressive or non-aggressive) and weaning age. Cattle were harvested at a similar weight, and all treatments graded at least 85% Choice or better. Implants did not influence quality grade, and ultimately did not negatively impact carcass traits in early weaned calves.

Implanted EW steers had more backfat (0.55 vs. 0.48 inches) than non-implanted EW steers, but this difference was not present in normal weaned steers (Meyer et al., 2005). But, marbling was not influenced by implant presence in EW steers. The authors used 140 Angus x Gelbvieh steers early (90 days) or normal weaned (174 days) and harvested at two age end-points (404 or 442 days of age). Both EW and TW were implanted with Synovex-S at weaning and after 80 days in feedlot.

Literature discussing the influence of growth-promoting implants given very early in life on end-product palatability is minimal, with the exception of studies involving veal calves. Wilson et al. (1999) evaluated 443 intact veal calves given various implant protocols at days 0, 42, and 84 after arrival. Treatments included control and varying combinations and concentrations of zeranol, estradiol, testosterone, progesterone, and/or trenbalone acetate (TBA). Although veal carcasses were not ribbed, no differences were seen related to fat cover, marbling, or carcass conformation. However, two implant regimens [control (day 0), estradiol-progesterone (days 42 and 84); control (day 0), estradiol-progesterone (day 42), estradiol-TBA (d 84)] had less desirable shear force values than controls. Based on these data, aggressive implant regimens may have little effect on veal carcass quality; however, increasing shear force values via implants may result.

Although later than traditional weaning age, results reported by Bruns et al. (2005) are worthy of note as 182 Angus x Limousin steers were evaluated for the effect of implant timing on carcass traits. In addition to a non-implanted control, treatments included an estradiol-TBA implant 47 (680 lbs) or 104 (847 lbs) days after weaning. Days on feed was constant across treatments. The early implant caused a decrease in carcass marbling score and percent of premium Choice carcasses (modest^{00} and higher), but the delayed implant did not. It appears that intramuscular fat deposition was negatively impacted by implants during the early post-weaning growth stage.

Research data summarized above indicate that implants given at branding or weaning time do not influence marbling deposition. Rather, frequency of implants (i.e. implantation of a steer with 2 or more implants in its lifetime) had negative impacts on end-product quality vs. non-implant controls. Among early weaned calves, data suggest that implants do not affect marbling. Data in veal calves suggests that aggressive implant regimens may not influence fat deposition (at least when evaluated in un-ribbed veal carcasses), but shear force values may be impacted. And, implants given post-weaning early during the growing period can negatively intramuscular fat deposition when days on feed is constant, compared to a delayed implant.

Items Not Discussed

The original intention of this paper was to be a near-exhaustive evaluation of all activities and processes around the time of weaning that may contribute to marbling deposition and end-product palatability. Unfortunately, such a review would be extremely lengthy and cumbersome if done properly. Therefore, an effort was made to emphasize aspects in which a large amount of literature were available, and/or an influence could be explained biologically. However, there are many items that were not covered, including the effects of:

- **Preconditioning.** Vaccination administration and protocols, including use of preconditioning programs that combine preventative health care and weaning prior to shipment to a feedyard.
- **Minerals.** Macro mineral status and supplementation as well as trace mineral status, source (organic vs. inorganic), and mineral interactions associated with elevated levels of antagonists.
- **Interactions.** Genetic × environment interactions, including how different management approaches discussed in this paper apply to different breeds (e.g. British, Continental, heat-adapted, etc.), management schemes, environments, etc.
- **Other practices.** Traditional management practices associated with the time around weaning, including dehorning, branding, and long-distance transportation.

Conclusions

For more than a decade, the beef industry has been unable to supply the amount of highly marbled beef (Choice or higher) consumers are demanding. And, through genetic progress alone the industry has been unable to make adequate progress. Elevated feed costs and increased concerns over the effect of beef production on the environment will further pressure marbling deposition in cattle to be a more energy efficient process. Thus, the industry must place increased emphasis on management efforts, particularly those prior to arrival at a feedyard, that promote intramuscular fat deposition. This paper reviewed research data associated with these processes. Unfortunately, the scientific literature in many areas is very limited since the industry's historical focus on increasing marbling has been on the feedyard phase of cattle production. Further, many studies that evaluated weaning-time activities were unable to avoid confounding effects on marbling due to the long time period from weaning to harvest, and due to experimental design (i.e. age at weaning and plane of nutrition). And, extramural funding to support research in these areas is very limited, at least from government agencies. However, it is clear that substantial influence on marbling deposition and eating quality of beef can be achieved by changes in the management of calves around the time of weaning.

10 Key Take-Home Points

1. Diet influences the volatile fatty acid (VFA) ratio, and a grain diet increases propionate (from 15-25 to 35-45% of total VFA) at the expense of acetate vs. a forage diet. Acetate provides the majority of raw materials (70 to 80% of acetyl units) for subcutaneous fat synthesis, while the liver generates glucose from propionate. In turn, glucose provides the majority of raw material (50 to 60%) needed to produce intramuscular fat.

2. Weaning calves early can increase marbling deposition but doesn't necessarily enhance eating quality, and has not been shown to affect cattle that are heat adapted, grade a low percent Choice, or harvested at a backfat thickness similar to normal weaned cattle. Since early weaned cattle have accelerated fat synthesis early in life (including increased backfat deposition), they are more physiologically advanced than normal weaned calves at harvest.

3. Although data are limited, there is no evidence of decreased marbling deposition resulting from calves weaned late (i.e. 300 days of age). However, the earlier that cattle can be placed on feed (as early or normal weaned calves vs. yearlings), the greater their marbling potential.

4. Creep feeding calves weaned at a normal age (e.g. 205 days) can increase marbling deposition, but results are not consistent. Similarly, the effect of creep feed source (i.e. fiber- vs. starch-based) on marbling is not convincing. However, it is clear that providing a high energy post-weaning diet to early weaned calves will increase marbling, but neither feed source (i.e. fiber- vs. starch-based) nor rumen degradability of protein appear to matter.

5. Among early weaned calves, a high concentrate post-weaning diet increases fat deposition (both subcutaneous and intramuscular) vs. forage- or limit-feeding. Yet, due to accelerated backfat deposition, differences will not be observed if cattle are harvested at a constant backfat thickness since calves early weaned only grain will not have an opportunity to express their marbling potential.

6. Several trace minerals clearly influence marbling deposition (e.g. Cu and Zn) in the feedyard, but their dietary effect around the time of weaning has not been thoroughly studied. Further research is needed in this area.

7. Weaning method (i.e. abrupt removal, two-stage with nose flaps, fence-line, etc.) influences a calf's level of stress at the time of weaning, based predominantly on differences in short-term performance and behavior during the immediate post-weaning period. However, larger long-term differences in performance have not been shown, and carcass traits have not been studied – further research is needed.

8. Rate of post-weaning morbidity influences marbling deposition, particularly treatment for BRD in high risk cattle. However, cattle morbidity rate in low risk does not appear to influence marbling deposition. Parasite burden at feedyard arrival altered intramuscular fat deposition, and de-worming protocols have been shown to influence carcass quality. Regardless, limited data specific to the effects of morbidity during the immediate post-weaning period are available.

9. It is accepted that castration of male calves improves marbling deposition and end-product palatability. However, in higher marbling breeds of cattle (e.g. Angus, Holstein), early castration at lighter weights improves marbling, tenderness, and palatability. Additionally, there is a benefit to end-product quality if castration at heavy weights can be avoided.

10. Administration of growth-promoting implants at branding or weaning does not hinder marbling deposition, but administering 2 or more implants to a steer during his lifetime will. Among early weaned calves, implants don't appear to affect marbling if given at weaning. However, implants given to heavy calves early in the growing period can negatively impact marbling vs. delaying the implant when days on feed is constant.

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