# Optimizing carcass value and the use of anabolic implants in beef cattle

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**ABSTRACT:** The historical use of implants in ruminants dates to 1947 with the first implanting of Hereford heifers with diethylstilbestrol. Since that time, several different implants have been developed with varying degrees of commercial success. It is recognized that the use of anabolic implants in beef cattle offers the greatest return on investment outside of ensuring adequate nutrition. Although this may be true with respect to increased weight gain and improved feed efficiency, the influence of anabolic implants on carcass characteristics has not all been positive. Since the early use of diethylstilbestrol, packers have been concerned about the influences of implants on meat tenderness and carcass value as indicated by quality grade. This concern has been renewed and amplified with the increased use of anabolic implants and the introduction of combination implants. Estrogenic, trenbolone acetate, and combination implants used today have been shown to increase live performance, rate of empty body protein gain, carcass weight, ribeye area, and closely trimmed boxed beef weights. The use of anabolic implants has resulted in varying decreases in marbling score and infrequent increases in skeletal maturity of carcasses, thus decreasing the proportion of carcasses grading Choice. Factors not commonly measured can influence marbling score. Moreover, the inherent variation in intramuscular fat distribution along the loin should be considered in determining influences of implants on marbling score and(or) quality grade. An increased proportion of dark cutters and in Warner-Bratzler shear force values have occasionally been reported in combination with the use of anabolic implants. It should be noted that these results are limited and need to be treated with caution due to the large number of extraneous factors that can affect the proportion of dark cutters at slaughter and decreased tenderness after chilling. Implant strategies are available to alleviate concerns with carcass quality and their final value.

Key Words: Carcass Quality, Cattle, Composition, Growth, Implantation

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## Introduction

Since the first use of anabolic implants 53 yr ago, it has been well recognized that anabolic implants improve growth rate, feed conversion, and protein deposition in cattle under both experimental and commercial conditions (Samber et al., 1996; Duckett et al., 1997). The use of anabolic implants has also resulted in increased carcass weight (Roeber et al., 2000; Hermesmeyer et al., 2000) and increased longissimus muscle area and carcass muscle yield in cattle (Johnson et al., 1996a,b; Roeber et al., 2000). Despite these positive responses, concern exists that carcass and eating quality may be sacrificed through the use of anabolic implants.

Industry concerns have been highlighted regarding the use of implants and their negative effects on marbling, skeletal maturity, the incidence of dark cutters (Belk, 1992), and the subsequent effect on meat tenderness (Morgan, 1991). Reviewing the literature, Morgan (1997) concluded that the percentage of carcasses grading USDA Choice was decreased 5% with a mild estrogen implant and decreased 25% when cattle were implanted with a trenbolone acetate-containing implant (**TBA**). Moreover, recent conflicting reports suggest that the use of implants may decrease intramuscular fatty acid content (Duckett et al., 1999) or not alter total lipid content of the longissimus muscle (Foultz et al., 1997). Data (Blumer et al., 1962) suggest that the inherent variation in intramuscular fat distribution along the loin should be considered in determining influences of implants on marbling score and(or) quality grade.

The objective of this paper is to highlight the development in the use of anabolic implants in the United States beef industry, to examine the effect of various implant strategies available to optimize carcass value, to discuss their influence on tissue growth and development and carcass traits, and to offer suggestions for future research.

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## History of Anabolic Implants

It has long been recognized that naturally produced hormones in humans and other animals play an important role in the physiological, biochemical, and behavioral changes associated with growth and development. It is also well recognized that hormones associated with the intact male animal will result in an increased proportion of lean, and greater rate and efficiency of growth compared to the female animal. However, behavioral problems associated with intact males of domestic meat-producing animals such as cattle have led to the practice of castration and eliminated the benefit of endogenous production of testosterone. Moreover, approximately one-half the offspring produced will be female which have lower efficiencies of meat production compared to intact males. It is therefore not surprising that humans have attempted to improve efficiency of growth and carcass composition of cattle through the use of naturally occurring and synthetic estrogens and androgens.

Although the use of anabolic implants today is almost exclusively associated with beef production, the benefits of utilizing implants in meat production were first noted in poultry. Lorenz (1943) reported that implanting cockerels with diethylstilbestrol (**DES**) increased fat content of the breast and legs 300% compared with nonimplanted cockerels. It was not until 1947 that the first beef cattle were used in an experiment to determine the effects of DES on growth rate of heifers (Dinussion et al., 1948, 1950). Results from these experiments showed that the use of DES improved rate of BW gain (12 to 17%) and feed conversion efficiency (4 to 11%). Other effects noted with the use of DES included increased appetite, increased body length and width, increased carcass maturity, and a pronounced increase in sexual behavior.

Use of DES was not considered beneficial in cattle production until the idea of oral administration or delivery was studied by Hale and Burroughs in 1953 (as cited by Raun and Preston, 1997). It was concluded from these studies that oral administration of DES increased rate of BW gain by 35%, decreased feed costs by 20%, and carcass fatness and meat quality did not differ. Oral DES had been approved by the FDA in late 1954 for cattle; by the end of 1955 it was estimated that six million cattle were being fed DES. By 1957, DES implants received FDA approval. Throughout development, DES continually struggled with poor press and misconceptions related to its effect on animal sexual behavior and complaints and discounts from packers regarding reduced carcass quality. However, the use of DES increased until 1972 when it was published in Science that DES was "a spectacularly dangerous carcinogen" and a report in *New England Journal of Medicine* suggested that high doses of DES caused adenocarcinoma in the first generation of females (as cited by Raun and Preston, 1997). Despite unclear findings in both of these cases, the FDA was forced to ban the use of oral DES in 1972 and DES implants in 1973.

Although the banning of DES may not have been totally objective, removal of DES from the marketplace likely facilitated the development of other anabolic implants. There are currently 24 different anabolic implants registered with the FDA as suitable for use in cattle (Table 1). These implants can be classified according to the nature (estrogens, androgens, or progestins) and dosage of active ingredient(s). The use of anabolic implants is common today through all stages of growth of beef animals: from the use of approved low-dose combination implants in young suckling calves to the use of various multiple implant strategies in the feedlot. The implementation of these strategies seems to have come about as beef producers attempt to maximize return on investment through all stages of the production cycle. However, the mode of action of these various agents on muscle tissue growth, adipose tissue deposition, and skeletal development is not fully understood.

## Influence of Anabolic Implant Strategies on Carcass Characteristics

The influence of anabolic implants on carcass characteristics and carcass value is directly related to the extent of change in total carcass lean, carcass fat deposition, degree of marbling, and meat tenderness. The extent of these changes in carcass traits as influenced by the type of implant used and the type of implant strategy employed will be discussed for varying production systems including, yearling steers and heifers, and calf feds; the effect of lifetime implanting also will be explored. For the purposes of this discussion, implant strategies will be defined as the selection of implants and their sequence as determined by animal sex, weight, and age. Previously introduced nomenclature (Duckett et al., 1997; and Morgan, 1997) was used to classify the available implants according to active ingredient and its relative potency (Table 2). The reader is referred to reviews by Dolezal (1997), Duckett et al. (1997), and Morgan (1997) for the effects of implants on carcass yield, live performance and carcass traits, and carcass quality, respectively.

It is recognized that marbling is and will be for some time an important aspect of value-based marketing of fed cattle and is currently the practical measure available. However, it is important to discuss relevant issues regarding inherent variation in the subjective measurement of marbling score. Blumer et al. (1962) found that marbling score could vary up to one and one-third of a USDA grade within a 6.35 mm. This variation could conceivably have a marked influence on marbling score data for carcasses near the slight$^{100}$/small$^{00}$ line. Bartle and Preston (1992) indicated that the decrease in carcasses grading Choice was greatest when the average marbling score of carcasses is near the Select/Choice grade in uniform sets of implanted cattle. The decrease

**Table 1**. List of hormonal growth promotants currently registered with FDA for use in beef cattle in the USA, by active ingredient, dosage, registered trade name, and beef group suitable for use

| Ingredient | Dosage, mg | Trade name | Suitable beef group |
|---|---|---|---|
| Single ingredient implants | | | |
| Estradiol[a] | 25.7 | Compudose 200[f] | Steers and heifers |
| | 43.8 | Encore[g] | Steers and heifers |
| Zeranol[a] | 36 | Ralgro[h] | Cattle |
| | 72 | Ralgro Magnum[h] | Steers |
| Trenbolone acetate[b] | 140 | Component T-S[eg] | Steers |
| | 200 | Finaplix-H[i] | Heifers |
| | | Component T-H[eg] | |
| Combination ingredient implants | | | |
| Estradiol benzoate[bd] | 10 | Synovex-C[j] | Steers and heifers |
| Progesterone[c] | 100 | Component E-C[eg] | |
| | | Implus-C[g] | |
| Estradiol benzoate[ad] | 20 | Synovex-S[j] | Steers |
| Progesterone[c] | 200 | Component E-S[eg] | |
| | | Implus-S[g] | |
| Estradiol benzoate[ad] | 20 | Synovex-H[j] | Heifers |
| Testosterone propionate[b] | 200 | Component E-H[eg] | |
| | | Implus-H[g] | |
| Estradiol[a] | 24 | Revalor-S[i] | Steers |
| Trenbolone acetate[c] | 120 | Component TE-S[eg] | |
| Estradiol[a] | 14 | Revalor-H[i] | Heifers |
| Trenbolone acetate[b] | 140 | | |
| Estradiol[a] | 16 | Revalor-IS[i] | Steers |
| Trenbolone acetate[b] | 80 | | |
| Estradiol[a] | 8 | Revalor-IH[i] | Heifers |
| Trenbolone acetate[b] | 80 | | |
| Estradiol[a] | 8 | Revalor-G[i] | Steers and heifers |
| Trenbolone acetate[b] | 40 | Component TE-G[eg] | |
| Estradiol benzoate[ad] | 20 | Revalor-200[i] | Steers |
| Trenbolone acetate[c] | 200 | | |
| Estradiol benzoate[ad] | 28 | Synovex Plus[j] | Feedlot steers and heifers |
| Trenbolone acetate[b] | 200 | | |

[a]Estrogen group.
[b]Androgen group.
[c]Progestin group.
[d]Estradiol benzoate contains 71.4% estradiol as calculated on formula weight (Herschler et al., 1995).
[e]Available with Tylosin Tartate at 29 mg (Tylan; Elanco Animal Health, Indianapolis, IN).
[f]Elanco Animal Health.
[g]Vet life (Winterset, IA).
[h]Schering Plough (Madison, NJ).
[i]Intervet Inc. (Flemmington, NJ).
[j]Fort Dodge Animal Health (Overland Park, KS).

**Table 2**. Classification of various implant types by category and relative potency[a]

| Implant | Category | Relative potency | Abbreviation[b] |
|---|---|---|---|
| Compudose, Ralgro, Encore, Implus-C, Synovex-C, Component E-C | Estrogen | Mild | ME |
| Implus-S, Synovex-S, Component E-S, Ralgro Magnum | Estrogen | Strong | SE |
| Component T-S, Finaplix-H, Component T-H | Androgen | — | A |
| Implus-H, Synovex-H, Component E-H, Revalor-S, Revalor-H, Revalor-G, Revalor-IH, Revalor-IS Component TE-S, Component TE-G | Combination | Mild | MC |
| Synovex Plus, Revalor-200 | Combination | Strong | SC |

[a]Adapted from Duckett et al., 1997; Morgan, 1997.
[b]ME = mild estrogen, SE = strong estrogen, A = androgen, MC = mild combination, SC = strong combination.

in carcasses grading Choice was reduced as the average marbling score shifted from the Select/Choice division and as the uniformity in implanted cattle decreased. In addition, caution should also be exercised when comparing marbling score and percentage Choice data among trials because both cooler temperature (Clavel, 2000) and the time the carcass is allowed to bloom can influence marbling score at the point of grading (Keller, 2000).

In reviewing the literature, it is evident that comment is warranted regarding statistical methods to analyze data that are used to represent carcass quality. The response variable of "percentage Choice" is commonly used to represent the percentage of carcasses assigned a quality grade ≥Choice$^{-}$, which requires an A maturity carcass with a marbling score ≥Small$^{00}$ (USDA, 1997). Carcass quality grade data collected are commonly converted to a numerical scale before statistical analyses, presumably as an extension of the numerical marbling score assigned to the carcass.

According to Dowdy and Wearden (1991) and Stokes et al. (2000), the scale of measurement of data refers to the preciseness of information obtained, and scales of measurement include dichotomous, nominal, ordinal, discrete numerical, and continuous numerical. The scale of measurement of percentage Choice data is defined as dichotomous because there are only two possible outcomes for meeting the previously mentioned criteria (yes or no) by each carcass (Stokes et al., 2000). The scale of measurement of percentage Choice data may be considered either nominal or ordinal; the number of the degrees of marbling are not constant across quality grades and a finite number of quality grades exists (Stokes et al., 2000). This principle also applies to situations where pen is the experimental unit, and data for an individual carcass are summarized to the level of pen. For example, it is not appropriate to increase the scale of measurement of the original dichotomous data to continuous numerical data (Dowdy and Wearden, 1991) by analyzing the percentage of carcasses from a pen that were Choice or not Choice. Thus, percentage Choice and quality-grade data can be appropriately analyzed using nonparametric procedures (Stokes et al., 2000) to evaluate the distribution of percentage of Choice carcasses or quality grades among treatments (Dowdy and Wearden, 1991). The authors recognize that numerical differences in carcass quality grade are of economic importance in production. For the purposes of this review, published data were not excluded from discussion if statistical methods used differed from those previously suggested.

### *Implant Strategies for Yearling Steers*

The use of a single implant at the beginning of the feeding period is the most common implant scenario. In reviewing the literature, Duckett et al. (1997) showed that a single anabolic implant increased ADG by 26.4%, whereas combination implants produced the greatest response. Combination implants were also shown to have the greatest effect in decreasing feed:gain (10.9%), whereas the effect of other single implant strategies on feed:gain was less defined.

The use of a single combination androgen/estrogen implant has been shown to have the greatest effect on increasing carcass weight and ribeye area. Hermesmeyer et al. (2000) found that steers implanted with either a mild combination or strong combination implant and fed to a subcutaneous fat depth of 1.4 cm had both a heavier carcass and larger ribeye area compared to nonimplanted steers. Foutz et al. (1997) indicated that carcass weight and ribeye area were increased for steers given a strong estrogen implant compared with nonimplanted, whereas steers receiving a mild combination implant exhibited a greater increase in carcass weight and ribeye area than steers receiving a strong estrogen implant.

A single implant does not seem to alter final yield grade compared to nonimplanted steers. This would be expected as the yield grade measure is influenced by ribeye area in relation to carcass weight. Therefore, final yield grade would not be expected to change as both of these measures increase with the use of anabolic implants (Roeber et al., 2000).

The use of anabolic implants seems to have little influence on subcutaneous fat depth and kidney, pelvic and heart fat percentage (Herschler et al., 1995; Foutz et al., 1997). However, the use of either a mild or strong combination implant has been shown to decrease internal fat as days on feed are increased (Johnson et al., 1996a). This seems most likely due to an increase in carcass weight in relation to total body fat. The use of a single implant has been shown to have variable effects on marbling score. Apple et al. (1991) and Johnson et al. (1996a) indicated that the use of a combination implant did not affect marbling. However, Herschler et al. (1995) found that marbling was decreased when either a mild or strong combination was used in a single implant strategy. Research indicates that a reduction in marbling score may be greatest with the use of a single estrogenic implant (Gerken et al., 1995), while the use of a single androgen implant has not had a significant effect on marbling score (Apple et al., 1991; Gerken et al., 1995).

The effect of a second implant on both feeding performance and carcass characteristics seems to be similar to the use of a single implant of the same potency. Moreover, the use of either a mild or strong combination implant seems to have the greatest effect on previously mentioned factors. Dolezal (1997) indicated that increases in carcass weight and ribeye area were least for steers receiving only an estrogenic implant initially and as a reimplant, while a combination implant used both initially and as a reimplant produced the greatest increase in carcass weight and ribeye area. Decreased marbling score is also evident with reimplantation. Morgan (1997) observed a decrease in marbling score by 26 points and the proportion of carcasses grading at

least low Choice by 24% in steers reimplanted with either a mild or strong combination strategy. In comparing four different reimplant strategies (Synovex-S + Finaplix-S/Synovex-S + Finaplix-S, Ralgro/Revalor-S, Synovex-S/Revalor-S, and Ralgro Magnum/Revalor-S) to a nonimplanted control, Pritchard (1994) found no appreciable differences in carcass traits among strategies. Overall carcass weights were at least 7.4% heavier and ribeye areas 6.4% greater in the implanted steers than the nonimplanted group. Marbling score was reduced for the Synovex-S + Finaplix-S/Synovex-S + Finaplix-S, Ralgro/Revalor-S groups. However, no difference in marbling score was seen among implant strategies.

Meat tenderness decreases (increased Warner-Bratzler shear force values) with the use of implants either as a single implant or in a reimplanting program (Roeber et al., 2000). Morgan (1997) determined that the use of implants increased the Warner-Bratzler shear force value by 0.5 kg over nonimplanted cattle.

It would, therefore, appear that the use of either a mild or strong combination implant will give the greatest returns in terms of feedlot performance and overall lean production, when compared in either a single or reimplant strategy. Relative to carcass traits, Roeber et al. (2000) showed that the use of combination implants as a single implant or as a reimplant improved the USDA yield grade factors for hot carcass weight, ribeye area and kidney, pelvic and heart fat percentage. However, meat quality is more likely to be decreased by the use of combination implants as a function of decreased marbling score and increased shear force values. The use of combination implants in various strategies has resulted in undesirable consumer ratings from taste panel tests due to decreased tenderness and increased Warner-Bratzler shear force values (Roeber et al., 2000).

*Delayed Implanting.* The use of delayed implanting or the use of an initial low-dose implant has been studied in an attempt to improve marbling scores in carcasses while maintaining performance in comparison to aggressive implant strategies. The theory of delayed/low-dose implanting is based on the principle that intramuscular fat development may occur earlier in the feeding period (Bruns et al., 2000) than once thought. Therefore, the use of stronger anabolic implants early in the feeding period partitions dietary energy from intramuscular fat development toward protein accretion. Delaying implanting or using a low-dose implant initially in the finishing stage may allow intramuscular fat development to occur, whereas maximal lean deposition can be achieved with the use of mild or strong combination implant later in the feeding period.

Samber et al. (1996) compared the effects of both delayed implanting (Revalor-S on d 60 + Revalor-S on d 130 and Synovex-S on d 30 + Revalor-S on d 130) and the use of an initial low-dose implant (Ralgro on d 0 + Synovex-S on d 60 + Revalor-S on d 130 and Ralgro on d 0 + Revalor-S on d 60 + Revalor-S on d 130) with the use of an initial mild combination implant strategy (Revalor-S on d 0 + Revalor-S on d 75 + Revalor-S on d 150) and nonimplanted steers fed for 212 d. Average daily gain, gain:feed, carcass weight, and ribeye area were not influenced by treatment. Delayed implanting did not reduce marbling or the percentage of carcasses achieving a Choice quality grade or better when compared to the nonimplanted steers. The use of an initial low-dose implant did reduce both marbling and percentage choice when compared to the nonimplanted steers and the steers receiving the delayed Synovex-S/Revalor-S implants. The use of three mild combination implants resulted in a reduction in both marbling and percentage choice when compared against all treatments except for the low-dose strategy.

Milton et al. (2000) compared use of delayed implanting (Synovex-Plus on d 30; Synovex-Plus on d 70) or an initial low-dose implant (Ralgro on d 1 + Synovex-Plus on d 70) with more conventional implanting strategies (Synovex-Plus on d 1; Synovex-S on d 1 and d 70). No differences among strategies were observed for marbling score or the percentage of carcasses achieving a quality grade of Choice or better. However, a negative control was not used to determine if the use of a delayed/low-dose strategy differed from nonimplanted steers for quality grade.

### *Implant Strategies for Yearling Heifers*

A single implantation with an androgen, mild combination or strong combination implant has been shown to improve ADG and gain:feed in heifers when compared against nonimplanted controls (Duckett et al., 1997; Popp et al., 1997; Mader, 2000). However, the use of a single estrogen implant has been found to have no effect on these factors (Stobbs et al., 1988; Duckett et al., 1997; Mader, 2000).

Mader (2000) observed that carcass weight was heaviest for heifers given either a single androgen or strong combination implant, whereas the use of a single estrogen implant had no effect on carcass weight when compared to nonimplanted heifers. Increases in ribeye area have been greatest for heifers implanted with either an androgen (Mader, 2000) or strong combination implant (Popp et al., 1997; Mader 2000). The ribeye area of heifers implanted with estrogen-based implants was unaffected when compared to nonimplanted heifers, and lower than those heifers implanted with the strong combination (Popp et al., 1997; Mader 2000). However, Stobbs et al. (1988) found that the use of an estrogen implant increased both carcass weight and ribeye area. Indeed, the effect of implant on ribeye area would be strongly correlated to the finished carcass weight of these animals. The use of a strong combination implant has also been shown to improve yield grade (Popp et al., 1997; Mader, 2000).

Single implantation with an estrogen, androgen, or strong combination implant has decreased marbling score in heifers (Mader, 2000). Nichols et al. (1996)

reported that marbling score and percentage of Choice did not differ between heifers implanted with either an androgen or mild combination and nonimplanted heifers. Duckett et al. (1997) also observed that neither marbling score nor quality grade was altered in heifers receiving a single implant.

The influence of anabolic implants on meat tenderness in heifers is limited. Nichols et al. (1996) reported that tenderness as determined by Warner-Bratzler shear force was decreased in heifers receiving a mild combination implant. Sensory panel ratings also determined that steaks from implanted heifers were less tender compared with nonimplanted heifers. Even though tenderness was compromised through the use of implants, the authors deemed the differences as being of little practical importance because no steaks exceeded the shear force value of 4.5 kg.

The reimplantation of yearling heifers utilizing a combination implant has resulted in heavier carcass weight and increased ribeye area when compared with nonimplanted controls (Mader et al., 1994). The use of two androgen implants was also found to increase ribeye area when compared to nonimplanted heifers (Crouse et al., 1987). However, Lehman et al. (1996) observed similar final carcass weight and final yield grade between three reimplant strategies (Revalor-H/Revalor-H, Synovex-H + Finaplix-H/Revalor-H, Synovex-H + Finaplix-H/Finaplix-H). Although the use of a single implant does not alter final yield grade, the reimplanting regardless of implant type seems to improve yield grade; this improvement is primarily due to decreased fat thickness in relation to carcass weight (Duckett et al., 1997).

The effect of reimplanting on carcass-quality aspects is less defined than the effect on carcass-yield aspects. The use of combination implants and estrogen implants has been shown to decrease marbling, and androgen implants alone appear to have little effect on final marbling score (Duckett et al., 1997). Crouse et al. (1987) found that reimplantation with androgen implants numerically increased marbling score.

### *Implant Strategies for Calf-Feds*

The number of calf-fed animals seems to be increased over the last 20 yr as a result of an increasing supply of male calves from the dairy industry and through an attempt to maximize rate of production of both beef and dairy calves. Galyean (1996) defined calf-fed animals as those on feed more than 180 d and determined in a survey of six consulting nutritionists (Arizona, Kansas, Oklahoma, Nebraska, and Texas, representing 3.6 million cattle) that calves accounted for 33 to 50% of cattle on feed. These animals will typically enter a finishing facility at approximately 140 kg of BW at the lightest and care must prevail in use of implant strategies because the use of potent implants too early in the feeding period of younger animals may result in a reduced response to later implants (Mader et al., 1994).

In feeding calf-fed Holstein steers for 326 or 350 d, Milton et al. (1998) compared a progressive implant strategy (CSR, Synovex-C on d 1, Synovex-S on d 109, and Revalor-S on d 201) to two more aggressive implant strategies (SSS, Synovex-S on day 1, day 109, and day 201; and CRR, Synovex-C on day 1, and Revalor-S on days 109 and 201). Steers implanted with the CSR or CRR strategy gained faster and were more efficient than the SSS strategy, indicating that use of an initial low-dose implant improved live performance. Carcass weight was also greater for these strategies, and marbling score was found to be greater for the CSR strategy when compared against the two more aggressive strategies.

In designing implant strategies for calf-fed steers, it also appears that differences in the length of time between reimplanting will affect carcass characteristics. Increasing the length of time between implanting from 70 to 98 d has been shown to improve marbling score under a number of implant strategies (Zinn et al., 1999).

### *Effect of Lifetime Implanting in Steers and Heifers*

The use of implants throughout the lifetime of both steers and heifers is common practice as animals move through the production chain from weaning, to growing and finishing. Mader (1998) indicated that steers and heifers being finished in feedlots could possibly receive six or more implants in their lifetime. Therefore, knowledge of implants used along the production chain and their carry-over effects on future implant efficacy is critical.

It appears that strategies for lifetime implanting should closely follow those suggested for calf-fed animals with use of lower implant strengths preweaning followed by implants with a higher relative strength for both steers and heifers (Mader et al., 1994). The effect of lifetime implanting has been greatest for heifers when compared to steers with larger increases in ADG, final weight, hot carcass weight and ribeye area (Mader et al., 1994). Marbling score and percentage choice and prime did not differ between implanted steers or heifers; implanted steers and heifers displayed reduced quality-grade measurements against nonimplanted controls. The greater growth response to lifetime implanting seen in heifers compared to steers may be due to a reduction in reproductive function in these animals. Kniffen et al. (1999) indicated that the number of heifers reaching puberty was decreased with continual implantation of a mild estrogen. No difference among treatments was observed for carcass weight or ribeye area. However, quality grade did decrease with implantation compared to nonimplanted controls. These observations for carcass measurements would be expected when using an estrogenic implant in heifers, as previously discussed.

*Dark Cutters*

The use of combination implants in an aggressive implant strategy has been reported to increase the proportion of dark cutters (Scanga et al., 1998). This was particularly evident for intact heifers compared with steers or spayed heifers. The effect of sex in this interaction is believed to be due to nulliparous females having a more excitable temperament due to a higher level of estrogen secretion in combination with the implanted exogenous estrogen (Voisinet et al., 1997). Scanga et al. (1998) further reported that reimplanting steers with combination implants and heifers with estrogen implants increased the incidence of dark cutters. This aggressive use of implants was shown to be moderated if the time from reimplantation to slaughter was greater than 100 d. Caution should be exercised in using this figure because dark cutting in beef is caused by a number of interactive factors. For example, it has been observed that the withdrawal of melengesterol acetate from the diet 72 h prior to slaughter may increase the incidence of dark cutters (Montgomery et al., 1992). Morgan (1997) indicated that anabolic implants alone do not cause dark cutting beef and that other stress-inducing factors including transport, climatic conditions, and handling should also be considered.

## Influence of Anabolic Implants on Tissue Growth and Development

The administration of anabolic implants to cattle has been shown to increase muscle mass and protein deposition and to alter the rate of empty body tissue gain (Hayden et al., 1992; Johnson et al., 1996a; Dayton et al., 1997). Anabolic implants also have been shown to increase skeletal maturity (Foutz et al., 1997; Paisley et al., 1999) and skeletal growth (Hutcheson et al., 1997).

Chaudhary et al. (1985) and Unruh et al. (1986) reported that bulls implanted with zeranol from birth had decreased measures of bone weight and growth and increased skeletal maturity when compared to nonimplanted bulls. This increase in bone maturity was attributed to the estrogens in the implant contributing to the aging process of skeletal tissue through decreasing bone and cartilage growth. Estrogen is known to be a major inhibitor of osteoclast formation (Roodmann, 1996). Therefore, elevated levels of estrogen in the blood due to the use of estrogenic implants could result in decreased bone turnover and decreased bone resorption, as seen in animals reaching maturity.

Hutcheson et al. (1997) harvested nonimplanted cloned steers and cloned steers implanted initially (Synovex-S, Finaplix-S, Revalor-S [120 mg TBA]) after 112 d of feeding. Final empty body fat ranged from 31.9 (Synovex-S) to 33.8% (nonimplanted). Rate of empty body protein gain was increased for Synovex-S and Finaplix-S compared with nonimplanted steers (Table 3), and further increased for Revalor-S compared with the remaining two implants. Rate of empty body fat gain did not differ among treatments. Johnson et al. (1996a) harvested steers either nonimplanted or implanted initially (Revalor-S, 120 mg of TBA) after 40, 115, or 143 d of feeding. Final carcass fat averaged 31.9 and 31.4% for nonimplanted and implanted steers, respectively. Rate of carcass protein gain was increased at each harvest date, and the magnitude of the increase numerically decreased with increasing days of feeding. Rate of carcass fat gain, marbling score, and average carcass quality grade did not differ. Loy et al. (1988) harvested nonimplanted steers and steers implanted initially (Ralgro or Synovex-S), or implanted initially and on day 84 (Ralgro or Synovex-S) after 189 d. Final carcass fat ranged from 31.9 (Synovex-S twice) to 34.3% (nonimplanted). Rate of empty body protein gain was increased by implanting, and rate of empty body fat gain and average carcass quality grade did not differ.

Solis et al. (1989) fed steers calves 182 d that were nonimplanted or implanted initially and at 90-d intervals (Ralgro, Ralgro Magnum, Synovex-S, or Ralgro + Synovex-S). Final empty body fat ranged from 21.3 (Synovex-S) to 24.8% (nonimplanted). Rate of empty body protein gain was increased by implanting, whereas rate of empty body fat gain did not differ. Lemieux et al. (1988) harvested nonimplanted steers and steers implanted initially and at 90-d intervals (Ralgro or Synovex-S) at a similar final BW (214 to 236 d of feeding). Final empty body fat ranged from 22.7 (Synovex-S) to 26.1% (nonimplanted). Rate of empty body protein gain was increased by implanting and rate of empty body fat gain did not differ. In a subsequent study (Lemieux et al., 1990) using the same treatments, steer calves were fed for 229 to 242 d and harvested at a similar final BW. Final empty body fat ranged from 21.7 (Ralgro) to 24.4% (nonimplanted). Rate of empty body protein gain was increased by implanting and rate of empty body fat gain tended to decrease 24 to 27%. Rumsey et al. (1992) fed nonimplanted steers and steers implanted (Synovex-S) on d 1 only, on d 1 and d 60, or on d 30 only for 112 d. Rate of empty body protein gain was increased by implanting, whereas rate of empty body fat gain and average carcass quality grade did not differ.

Perry et al. (1991) fed nonimplanted beef steers or beef steers implanted initially (Revalor-S, 140 mg of TBA) to an estimated ribfat thickness of approximately 1.0 cm (123 to 152 d of feeding). Final carcass fat was 31.3 and 31.9% for nonimplanted and implanted steers. Rate of empty body protein gain was increased by implanting, whereas marbling score and percentage of Choice carcasses did not differ. Loy et al. (1988) reported that marbling score was decreased by implanting when steers were harvested at a time-constant endpoint, whereas average quality grade did not differ. However, marbling score did not differ when nonimplanted and implanted steers were compared using final carcass fat as a covariate. In a recent study, Hermesmeyer et al. (2000) finished implanted and nonimplanted steers to two endpoints based on estimated subcutaneous fat thickness. Although final carcass fat

**Table 3**. Effect of anabolic implants on the percentage increase in rate of empty body protein gain (EBPG) of beef steers compared to nonimplanted beef steers

| Anabolic implant | Days on final implant | Number of occasions implanted | Average days per implant[a] | EBPG (%) | Citation |
|---|---|---|---|---|---|
| Ralgro | 189 | 1 | 189 | 12 | Loy et al. (1988) |
| | 105 | 2 | 95 | 16 | Loy et al. (1988) |
| | 93 | 2 | 92 | 19 | Solis et al. (1989) |
| | 62 | 3 | 81 | 22 | Lemieux et al. (1990) |
| | 36 | 3 | 72 | 31 | Lemieux et al. (1988) |
| Ralgro Magnum | 92 | 2 | 91 | 26 | Solis et al. (1989) |
| Ralgro + Synovex-S | 84 | 2 | 87 | 37 | Solis et al. (1989) |
| Synovex-S | 189 | 1 | 189 | 26 | Loy et al. (1988) |
| | 112 | 1 | 112 | 27 | Hutcheson et al. (1997) |
| | 112 | 1 | 112 | 59 | Rumsey et al. (1992) |
| | 105 | 2 | 95 | 23 | Loy et al. (1988) |
| | 90 | 2 | 90 | 30 | Solis et al. (1989) |
| | 82 | 1 | 82 | 53 | Rumsey et al. (1992) |
| | 59 | 3 | 80 | 38 | Lemieux et al. (1990) |
| | 52 | 2 | 56 | 53 | Rumsey et al. (1992) |
| | 34 | 3 | 71 | 46 | Lemieux et al. (1988) |
| Finaplix-S | 112 | 1 | 112 | 36 | Hutcheson et al. (1997) |
| Revalor-S[b] | 143 | 1 | 143 | 25 | Johnson et al. (1996a) |
| | 133 | 1 | 133 | 24 | Perry et al. (1991) |
| | 115 | 1 | 115 | 34 | Johnson et al. (1996a) |
| | 112 | 1 | 112 | 62 | Hutcheson et al. (1997) |
| | 40 | 1 | 40 | 82 | Johnson et al. (1996a) |

[a]Calculated as number of doses divided by total duration of the feeding period.
[b]Contained 120 mg trenbolone acetate in all studies except that of Perry et al. (1991), which contained 140 mg trenbolone acetate.

percentage was not determined, the overall percentage of Choice carcasses did not differ (92.2, 87.5, and 88.9 ± 2.8 % for nonimplanted, Revalor-S, and Synovex-Plus, respectively), and the overall percentage of average Choice carcasses was decreased for Synovex-Plus steers compared with those nonimplanted (31.7, 40.9, and 44.3 ± 3.1% for Synovex-Plus, Revalor-S, and nonimplanted, respectively; L. L. Berger, personal communication). Byers et al. (1994) slaughtered nonimplanted steers and steers implanted on d 1 and 56 (d 1/d 56) with Synovex S + Finaplix S/Synovex S, Synovex S/Synovex S + Finaplix S, or Synovex S + Finaplix S/Synovex S + Finaplix S after 56, 112, 126, 145, or 154 d of feeding. Daily empty body protein gain at each slaughter date and final empty body fat were not reported. However, empty body protein gain averaged across slaughter dates was increased 45, 85, and 133%, whereas empty body fat gain was decreased 19, 37, and 40% for steers receiving Synovex S + Finaplix S/Synovex S, Synovex S/Synovex S + Finaplix S, or Synovex S + Finaplix S/ Synovex S + Finaplix S, respectively.

Rate of empty body fat gain has generally not been influenced by anabolic implants, whereas rate of empty body protein gain has been markedly increased for implanted compared with nonimplanted steers harvested at a time- or BW-constant endpoint. Duckett et al. (1999) reported that implanting/reimplanting (Synovex Plus initially, Synovex Plus on d 1 and 62, or Synovex-S on d 1 and Synovex Plus on d 62) of steers harvested after 126 d of feeding decreased extractable fatty acids per unit of mass of longissimus steaks. These data seem to support observations from production studies that decreased average quality grade or percentage of Choice carcasses seems to result from "diluting" longissimus intramuscular fat with increased longissimus protein if cattle are harvested at a time- or BW-constant endpoint. However, the dilution effect may be diminished or abolished by increasing final BW and days on the final implant and finishing steers to an empty body fat- or carcass fat-constant endpoint.

Reviewing the literature, Owens et al. (1995) determined that feedlot cattle seem to reach mature BW (BW when empty body protein mass reaches a plateau) when the empty body contains approximately 36% fat. Employing the definition of relative maturity introduced by Owens et al. (1995; observed empty body fat percentage divided by 36% empty body fat at mature size), implanted steers in the previously discussed composition of gain studies except those of Perry et al. (1991) were less mature at harvest than nonimplanted steers. Limited data suggest that final BW at 28% empty body fat may be increased 40 to 85 kg for implanted compared with nonimplanted steers (Hutcheson et al., 1997). Further research is needed to describe growth, carcass characteristics, and days on the final implant needed when implanted cattle are finished to an empty body- or carcass fat-constant endpoint similar

to nonimplanted cattle with current implant/reimplant programs.

Recent studies have shown that protein accretion due to anabolic implants has resulted from the activation and proliferation of muscle satellite cells, which are responsible for the growth of existing muscle fibers (Dayton et al., 1997; Johnson et al., 1998a). Although anabolic implants are not directly responsible for the activity of these muscle satellite cells, they have been shown to increase circulating, tissue, and in vitro concentrations of IGF-I and indirectly play a major role in the differentiation and proliferation of satellite cells. Johnson et al. (1998b) reported that IGF-I concentrations increased in both the liver of sheep implanted with Revalor-G and in the muscle tissue of steers implanted with Revalor-S, indicating a strong local effect of anabolic agents on muscle tissue. The use of combination implants has also been shown to increase serum concentrations of both IGF-1 and insulin-like growth factor binding protein-3 (IGFBP-3), in feedlot steers (Johnson et al., 1996b). Insulin-like growth factor binding protein-3 is thought to increase cellular responsiveness to IGF-1, through increased receptor reactivity to IGF-1 (Conover, 1992). Therefore, increases in protein deposition due to the use of combination implants could be due to increased circulating concentrations of either IGF-1 or IGFBP-3.

Isaacson et al. (1993) found that cortisol synthesis was decreased in steer adrenal gland cells in the presence of testosterone, dihydrotestosterone, trenbolone acetate, and zeranol. Decreased serum cortisol concentration also has been shown in bulls and steers when implanted with either trenbolone acetate or zeranol (Jones et al., 1991). Thus, decreased circulating cortisol concentrations have been suggested to aid protein accretion by decreasing protein catabolism.

## Future Research

There is still much to be understood regarding the use of implants in beef production. A thorough understanding of the mode of action of these repartitioning agents is needed. Moreover, efforts to understand the mode of action of anabolic implants on protein accretion and lipid metabolism are of vital economic importance, particularly in reference to intramuscular fat deposition. Further research should be dedicated to developing optimum implant strategies for a particular group of cattle; factors such as breed, body condition score, mature body weight, and nutrition need to be more closely related to implant use and the final effect on meat production and quality. Further research is needed to describe growth, carcass characteristics, and days on the final implant needed when implanted cattle are finished to an empty body- or carcass fat-constant endpoint similar to nonimplanted cattle with current implant/reimplant programs. Finally, a better understanding of the role anabolic implants play in the incidence of dark cutters in heifers is needed so that preventative practices can be developed.

## Implications

With 24 different anabolic implants available, opportunities are available for producers to target a particular end response. In steers, combination implants have been shown to improve feeding performance while having only minor influence on reducing carcass or meat quality. The use of estrogen-based implants is less likely to increase feeding performance and may not adversely affect measures of meat quality. In heifers, a single dose of an estrogen-based implant does not seem to improve feeding performance and has decreased carcass quality grade. Androgen-based and combination implants result in the greatest increase in feeding performance of heifers and may have little influence on carcass quality. Limited data suggest that finishing implanted cattle to an empty body fat or carcass fat-endpoint similar to nonimplanted cattle may diminish or alleviate decreases in quality grade. Some studies have shown that the use of implants injudiciously will most likely result in reduced marbling scores and decreased tenderness. Implant strategies are available to minimize these effects.

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