

Effects of Synovex-S[®] and Recombinant Bovine Growth Hormone (Somavubove[®]) on Growth Responses of Steers: III. Muscle Growth and Protein Responses^{1,2,3}

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ABSTRACT: We conducted this study to determine whether the growth responses of specific skeletal muscles in crossbred beef steers were differentially affected by treatment with recombinant bovine growth hormone (Somavubove[®], SbV, .1 mg/kg BW, i.m., daily), Synovex-S[®] (200 mg progesterone + 20 mg 17- β estradiol benzoate, SYN, ear implant), or a combination of the two. Starting body weights of steers averaged 182 ± 1.8 kg. Five steers were used at this average BW to obtain data on weight and composition of individual muscles at d 0, and 20 other steers were assigned in equal numbers to control (C, no implant and placebo daily injection), SYN, SbV, and SYN + SbV treatment groups. After 56 d of treatment with placebo or growth promoters, complete rectus femoris (RF), triceps brachii (TB), supraspinatus (SS), psoas major (PM), and semitendinosus (ST) muscles were dissected, weighed, and then ground for determination of moisture, total

protein, and fat. To calculate the average daily muscle wet weight, protein, and fat gains, the initial weight, protein content, and fat content of a muscle were subtracted from those obtained at slaughter and the difference divided by 56. Muscle weight was increased over C in TB and SS by SYN ($P < .1$); in TB by SbV ($P < .09$); and in RF ($P < .05$), TB ($P < .03$), and SS ($P < .03$) by SYN + SbV. Overall average daily wet tissue gain was increased over C by SbV + SYN ($P < .05$) in RF, TB, and SS. Average daily protein gain in RF and TB was increased by SYN ($P < .1$), SbV ($P < .06$), and SYN + SbV ($P < .01$) over that calculated for C. For RF, TB, and SS, average daily protein gain was greater ($P < .1$) in SbV + SYN than that obtained with SbV or SYN alone. These data suggest that administration of growth promoters, such as somatotropin and Synovex, to cattle differentially affects growth characteristics in certain muscles and can have additive effects on protein gain when used together.

Key Words: Cattle, Muscles, Protein, Somatotropin, Estrogens, Growth

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Introduction

Muscle protein accretion, the net result of greater synthetic than degradative processes, is modulated by a variety of growth factors in domestic animals (Eisemann et al., 1989; Hancock and Preston, 1990; Beermann and DeVol, 1991). The effects of hormones that modify metabolism to enhance growth, like somatotropin (GH) or Synovex (progesterone + estradiol benzoate), of specific muscles are poorly defined for cattle. Previous studies using GH alone (Early et al., 1990) or the combination of GH and estrogen (Enright et al., 1990) in long-term growth trials in cattle demonstrated limited specific effects of

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these repartitioning compounds on carcass protein accretion. Work reported by Eisemann et al. (1989) suggested that GH stimulated specific protein fractional synthesis rates in certain muscles, but the effect was not uniform in all muscles characterized. Even though the data are not extensive, exogenous growth promoters (GH and β -adrenergic agonists, specifically) have been shown to have differential effects on specific muscles and fiber types within muscles (Pell and Bates, 1987; Maltin et al., 1990; Pell et al., 1990). Endocrine regulation of muscle accretion response to GH is directed through specific receptors for GH, and GH receptor characteristics are modulated by steroids in cattle (Breier et al., 1988; Beermann and Devol, 1991). There are no data that address the potential for GH-mediated protein accretion to be modulated in different muscles by coadministration of GH and steroid-based growth promoters. The present study was performed to assess the growth-promoting effects of GH in combination with an estrogen-progesterone-based formulation on protein accretion in several specific muscles in cattle.

Materials and Methods

Animals and Treatments. The experimental protocol for this project was reviewed and approved by the USDA Beltsville Animal Care and Use Committee. Crossbred steers ($n = 25$) obtained from Angus \times Hereford cows (the USDA, Beltsville Agricultural Research Center nutrition herd) bred with semen from a bull of the MARC II composite population (Roman L. Hruska Meat Animal Research Center, Clay Center, NE; Gregory et al., 1991) were used in a growth trial to assess and compare the effects of daily administration of GH (recombinant bovine somatotropin, Somavubove, **SbV**; .1 mg/kg, i.m., daily) and Synovex-S (200 mg progesterone + 20 mg 17 β -estradiol benzoate, **SYN**; 60-d implant, linear release profile; Rumsey et al., 1992) alone and in combination on the growth of specific muscles over a 56-d period. Synovex-S[®] was procured from Syntex Animal Health, West Des Moines, IA, and Somavubove[®] was supplied by Pharmacia & Upjohn, Kalamazoo, MI. The animals reported on here were the same as those used in the previous paper that described the effects of these treatments on the growth performance and composition of gain of the steers (Rumsey et al., 1996). Five steers were slaughtered as the initializing d-0 nontreated control group and averaged 182 ± 1.9 kg BW. These five steers were used to establish estimates for the mass and composition of the individual muscles relative to whole-body and carcass variables as animals entered the experimental period. The 20 remaining steers were blocked by weight to create five replications of the four main treatment groups: control, SbV, SYN, and SbV+SYN.

Steers were randomly assigned to treatments within the replicate groups. Live body weights of the 20 steers assigned to experimental treatments averaged 182 ± 1.7 kg on d 0 of treatment. Steers were fed and maintained in individual 24-m² pens. Steers were fed a diet composed of concentrate (80% of diet dry matter, based on cracked corn and soybean meal) and silage (an equal wet weight mixture of orchardgrass and corn silages, 20% diet dry matter), and fed at a constant proportion to metabolic body weight (20 g CP and 252 kcal ME per kilogram BW^{.75}). Steers were fed once daily; no orts were present during the study. Steers assigned to main treatments were slaughtered, and tissues were obtained for analysis on d 56 of treatment.

Tissue Collection and Component Analysis. Steers were stunned with a captive bolt and exsanguinated at the USDA abattoir at Beltsville. Processing the carcass through the evisceration, dehiding, and muscle dissection required an average of 24 min per steer. Rectus femoris (**RF**), triceps brachii (**TB**), supraspinatus (**SS**), semitendinosus (**ST**), and psoas major (**PM**) were dissected in toto from the left carcass half. Muscles were chosen on the basis of reports of differences in fractional protein synthesis rate (Eisemann et al., 1989) with further consideration to anatomical location, apparent physiological function, and the cleanness with which the muscles could be obtained between tendons of origin and insertion. Muscles were trimmed free of obvious adhering fat and loose connective tissue, weighed, and vacuum-packed in heat-shrink plastic, and frozen at -40°C until processed. To determine fat, moisture, and protein content, each muscle was thawed, ground in a screw-type meat grinder fitted with a .48-cm die, mixed, reground five times using a .25-cm die, and subaliquotted. Samples of this matrix were digested for determination of Kjeldahl N (with protein estimated as $\text{N} \times 6.25$; Rumsey et al., 1981), extracted with petroleum ether for fat content (AOAC, 1990), and heated in a 100 to 105 $^{\circ}\text{C}$ oven for 24 h or to constant weight for moisture content; three 1-g samples were used to estimate variable. For additional confirmation and validation of the protein values, three random samples of each muscle (duplicate 3-g aliquots) were assayed for N using the LECO[®] nitrogen analyzer (LECO, St. Joseph, MI), calibrated with EDTA standards. The mean value of each muscle and subcomponent as a percentage of carcass and the carcass percentage of live weight were determined for the five initial d-0 steers, and this percentage was used to estimate the muscle weight and composition of each experimental treatment steer at its respective starting weight. Therefore, at the end of the 56-d period, the estimated starting values for each steer were subtracted from the measured mass and composition of the muscles, and the values were divided by 56 to obtain a measure of the average daily

Table 1. Single-degree-of-freedom comparisons used for the development of contrast statements in the general linear model (SAS, 1985)

Contrast	Treatments			
	Control	Synovex	Somavubove	Combination
1	1	-1	0	0
2	1	0	-1	0
3	1	0	0	1
4	0	0	1	-1
5	0	1	0	-1

gain of each muscle and subcomponent (Pell and Bates, 1987; Early et al., 1990). Further validation of this procedure was obtained from Butler-Hogg and Whelehan (1987), in which the estimation of initial muscle mass as a percentage of live weight was demonstrated to be constant for a given muscle.

Statistics. The data were analyzed using the GLM procedure of SAS (SAS, 1985) with SbV and SYN as main effects. Comparisons of treatment means with control means was performed using specific individual contrast statements as shown in Table 1. Probability values less than .05 were considered significant.

Results

Carcass and RF, TB, SS, PM, and ST weights, as a percentage of live weight, averaged 53.3, 1.461, 2.064, .990, 1.119, and 1.696%, respectively, with less than 5% variation (SE) around each mean for the five d-0 steers slaughtered as an initial control baseline group. Muscle protein averaged 19.6, 19.5, 19.0, 19.1, and 19.5% for RF, TB, SS, PS, and ST, respectively, again with less than 5% (SE) variation around the mean. These component percentages were then used as numerical constants for estimating the same d-0 component weights of the respective experimental steers.

For a frame of reference, the effects of the hormone treatments on whole animal growth are summarized from Rumsey et al., (1996). Initial mean BW for steers assigned to experimental treatments were 182.1 ± 3.9 , $181.1 \pm .9$, 184.2 ± 4.9 , and 181.0 ± 3.9 kg for control, SbV, SYN, and the SbV+SYN combination, respectively ($P > .5$). Final body weights were 252 ± 3.3 , 263 ± 3.4 , 272 ± 4.7 , and 279 ± 4.0 kg for control, SYN, SbV, and the combination, respectively ($P < .1$, effect of SYN; $P < .01$, effect of SbV).

Total wet weights of the RF, TB, SS, PM, and ST muscles were determined in steers administered saline placebo, SYN, SbV, and SYN+SbV (Figure 1). Synovex treatment alone tended to increase muscle weight in TB ($P < .06$) and SS ($P < .05$). Somavubove administered alone tended to increase muscle weight only in TB ($P < .09$). The combined treatment

increased muscle weight ($P < .05$) by 14, 20, and 13% in RF, TB, and SS, respectively. The PM and ST muscles were not affected by any treatment.

When average daily wet weight gain was calculated, it was revealed that SYN alone tended to increase total wet weight gain in TB ($P < .09$), ST ($P < .1$), and SS ($P < .05$), respectively (Figure 2). Somavubove treatment tended to increase wet weight gain only in TB ($P < 0.1$). The combined treatment increased wet weight gain in RF ($P < .03$), TB ($P < .02$), and SS ($P < .02$). There were no significant effects of treatment on PM or ST, although the numeric mean of daily wet weight gain of the muscles in the combined treatment steers averaged 22% greater than control, SYN, and SbV.

Average daily protein gain in the various muscles is presented in Figure 3. Average daily protein gain was increased by SYN treatment in RF ($P < .05$), with a trend for positive effects on protein gain in TB ($P < .1$), compared with the control. Somavubove treatment increased daily protein gain in RF ($P < .03$) and TB ($P < .06$), compared with control. The combined SbV and SYN treatment increased daily protein gain in RF ($P < .006$) and in TB ($P < .01$), when compared with controls. The additive effect of SYN and SbV was evident in RF, in which the daily protein gain was greater with the combination than SbV alone ($P < .05$) and tended to be greater than that obtained with SYN alone ($P < .06$). Collectively, these data demonstrate that some muscles, such as RF and TB, are capable of responding to SYN, SbV, or SYN+SbV with increases in daily protein gain, but in other muscles, such as the SS, PM, or ST, the protein gain response

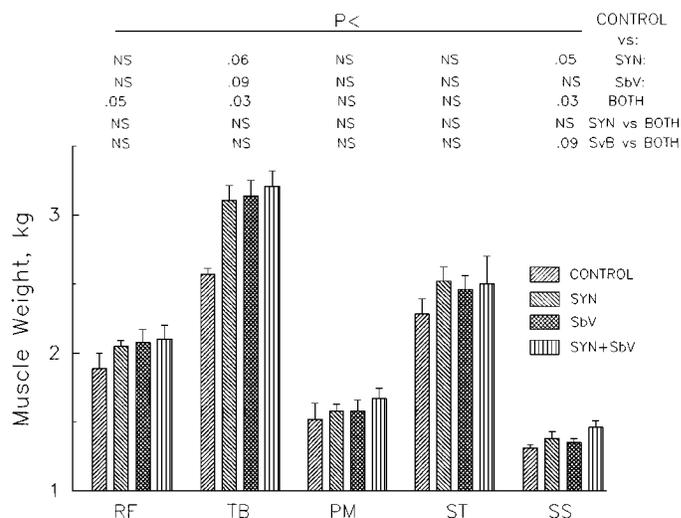


Figure 1. Effects of Synovex-S (SYN), recombinant bovine GH (Somavubove, SbV), and the combination treatment on total wet weight of specific muscles in steers ($n = 5$ /treatment). RF, rectus femoris; TB, triceps brachii; PM, psoas major; ST, semitendinosus; SS, supraspinatus.

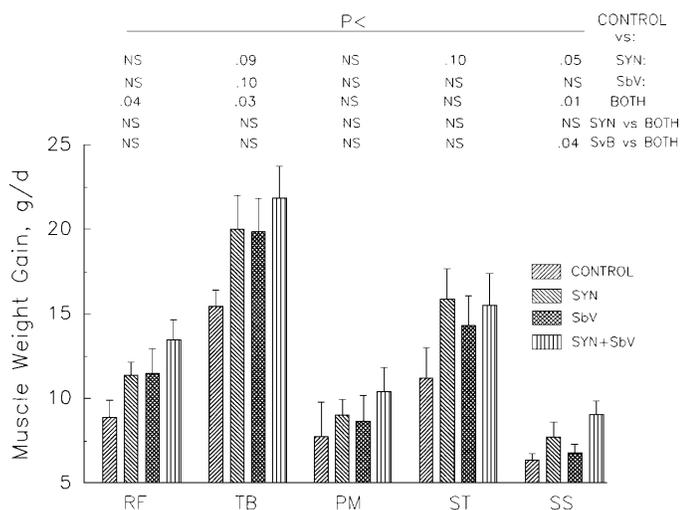


Figure 2. Effects of Synovex-S (SYN), recombinant bovine GH (Somavubove, SbV), or the combination treatment on average daily wet tissue gain for selected muscles in steers (n = 5/treatment). RF, rectus femoris; TB, triceps brachii; PM, psoas major; ST, semitendinosus; SS, supraspinatus.

to these hormone preparations was less evident with the conditions under which the growth trial was conducted. Even though it was not always statistically significant with the animal numbers used in the present treatment groupings, the combination treatment with SbV + SYN always resulted in a response value numerically greater than that measured in control steers.

The effects of treatments on individual muscle percentage fat and the estimate of the average daily muscle fat gain (ADFG) are presented in Table 2. The percentage fat and ADFG were not affected by treatment of steers with either SYN, SbV, or the combination. Across all muscles sampled and treatments applied, means for intramuscular fat ranged between 1.2 and 2.75%. Mean ADFG was highly variable between muscles and treatments without any indication of a uniform response to treatment and ranged between 220 and 474 mg/d.

Discussion

The present paper demonstrates that the growth response of individual muscles to hormonal growth promoters is not uniform, and the interpretation of such data can change according to the end point that is quantified. Certain muscles seem overtly responsive to repartitioning agents; muscle protein and muscle mass increase (triceps brachii and rectus femoris). Other muscles seem refractory to manipulation by these compounds (psoas major) in steers of this age group. The data extend the findings presented by

Rumsey et al. (1996) and Ono et al. (1996) and further demonstrate the additivity of SYN and SbV in growth responses of specific muscles. Average daily body weight gain for these animals was 1.27, 1.47, 1.63, and 1.78 kg/d for C, SYN, SbV, and SYN + SbV, respectively (Rumsey et al., 1996). These rates of gain were 15.7, 26.3, and 40% greater for these respective treatments than that measured in control steers and demonstrate the singular and additive effects of SYN and SbV on the whole-body growth response to treatment. Aspects of specific muscle growth response to the treatments were often not in proportion to the percentage change of the whole-body response. For example, even though average daily wet weight gain of the TB increased 33, 32, and 53% for SYN, SbV, and SYN + SbV, respectively, the effects of these treatments on PM were not apparent or, perhaps, were not detectable with the number of animals sampled. This phenomenon has also been observed in the muscle growth data of others (Rathmacher et al., 1997).

Collectively, the present data also complement and extend observations on regionally specific protein synthesis in ruminants treated with GH. Using radiolabeled leucine incorporation, Eisemann et al. (1989) suggested that increases in protein fractional synthesis rate (FSR) effected with GH varied depending on the muscle studied. In agreement with the earlier findings that showed a positive effect of GH on FSR in RF and TB, but not the ST (based on 19 to 20 d of GH treatment), our data (based on a 56-d treatment) also identified positive effects of hormonal growth compounds on average daily protein

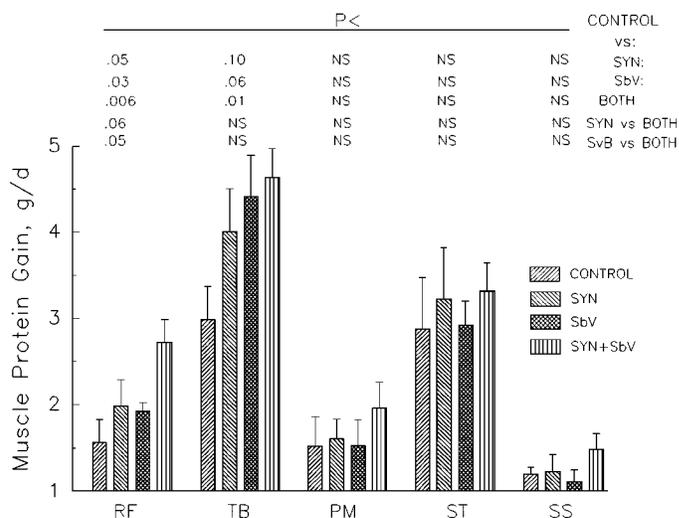


Figure 3. Effects of Synovex (SYN), recombinant bovine GH (Somavubove, SbV), and the combination treatment on average daily protein gain of selected muscles in steers (n = 5/treatment). RF, rectus femoris; TB, triceps brachii; PM, psoas major; ST, semitendinosus; SS, supraspinatus.

Table 2. Effects of Synovex-S (SYN) and Somavubove (SbV) on relative fat content and average daily fat gain (ADFG)^a in steer skeletal muscles

Muscle	Treatment				SEM
	Control	SYN	SbV	SYN + SbV	
Rectus Femoris					
% Fat	1.52	1.68	1.69	1.17	.18
ADFG, mg/d	278	377	396	220	67
Triceps Brachii					
% Fat	1.56	1.72	1.65	1.71	.19
ADFG, mg/d	394	445	413	474	12
Psoas Major					
% Fat	2.75	2.7	2.52	1.84	.35
ADFG, mg/d	397	227	362	186	119
Semitendinosus					
% Fat	1.54	1.51	1.53	1.21	.14
ADFG, mg/d	396	411	408	284	56
Supraspinatus					
% Fat	1.81	1.92	2.14	1.91	.31
ADFG, mg/d	243	290	340	317	81

^aValues represent means of five steers.

gain (**ADPG**) in the RF and TB, but not the ST. It was also apparent that the ST was not responsive to somatotropin treatment on the basis of whole-muscle growth in other long-term GH treatment studies (Early et al., 1990). Pell and Bates (1987) correctly pointed out that it was possible for some muscles to seem less responsive to one repartitioning agent than to another if those muscles appearing less responsive were, in fact, already at a point of maximum rate of growth or protein accretion. In this regard, the use of the term *responsive* could be misleading because it is partnered with attempts to quantify or describe the capacity for a given muscle to grow faster under the influence of hormonal stimulation. What might be a more accurate characterization is that muscles such as the PM and ST may be near their maximum capacity for growth already (under the influences of the stated diet and genetic capacity for growth in this study) and cannot be forced to increase their growth much further with the use of the exogenous hormone treatments.

Our data and similar data from experiments with steers by others that used different growth-regulating hormones suggest that the additivity of growth-promoting hormones remains particular to the specific combination. Even though Rathmacher et al. (1997) demonstrated a more than 100% increase in ST weight gain in cattle treated with a recombinant somatotropin preparation (Posilac[®], Protiva, St. Louis, MO), the response was not significant ($P = .12$), which suggests a large degree of animal-to-animal variation in response. Interesting, and in line with the conclusions of this paper, however, was their observation that the longissimus muscle (**LM**) in the same cattle responded with only a 17% increase in weight gain ($P = .51$) with somatotropin treatment. In these same animals, Revalor-S[®] increased weight gain

in both muscles. Interestingly, when Revalor-S[®] was combined with somatotropin, not only were the effects not additive, but the effect of the Revalor-S[®] on LM was lost.

Most muscles are heterogeneous in fiber-type makeup. Using an estimation-slaughter balance technique similar to that used here, Pell and Bates (1987) suggested that red-type muscles were more responsive to enhanced accretion rates by exogenous repartitioning agents. Ono et al. (1996) assessed the effects of SYN, SbV, and the combination of these agents on the fiber-type makeup of individual muscles from the same animals reported on in this paper. Use of the repartitioning agents was associated with specific changes, by muscle, on 1) conversions between distribution population of fiber types and 2) changes in the cross-sectional areas of fiber types. The data suggested that the response of fiber type to repartitioning compounds also varies between muscles.

However, some discrepancy exists between the assessment of muscle response to the SbV and SYN treatments presented in the current paper and the conclusions reached by Ono et al. (1996), which based the assessment on microscopic examination of fiber staining characteristics. Based on pure weight change and estimated daily protein accretion of the entire muscle, our data suggest that the RF and TB were most responsive and the PM least responsive to treatment with the hormonal compounds. Based on fiber area analysis, Ono et al. (1996) concluded the opposite. The differences in conclusion may reside in the interpretation of the data based on the analysis used. Fiber area changes may not represent the total hypertrophic response uniformly throughout the entire muscle. Furthermore, measures of the muscle growth and protein accretion in the present paper were

obtained by measured differences in calculated starting and measured finishing weights of muscles in the growth trial, whereas observations of Ono et al. (1996) pertained to only terminally acquired samples of muscle. Also, longitudinal growth of the muscle was not calculated. The difference between the finding of Ono et al. (1996) and the current results suggest that longitudinal growth of muscle and number of sarcomeres (Goldspink, 1991) should be considered in characterizing the overall growth response of a muscle.

Few data in the literature address the effects of somatotropin and estrogen-progesterone treatments on intramuscular fat in specific muscles from steers, and difficulty was encountered in finding appropriate literature citations that reported data for a treatment time frame and animal age similar to those used in the present study. The present data indicate that the effect of SYN and(or) SbV treatments was not significant in terms of altering the fat content or daily fat gain of the five muscles studied. These results, obtained by direct proximate analysis of the muscle tissue samples, were consistent with the results arrived at by Ono et al. (1996), in which the percentage fat of the five muscles was estimated as the residual difference between the sum of the measured protein and water contents subtracted from 100%. Ouali et al. (1988) demonstrated that there were no significant effects of the combined treatment of estradiol and trembolone acetate on lipid content of either the LM or the TB; however, the animals were 20 to 22 mo old. McBride and Moseley (1991) summarized the effects of somatotropin on the anatomical sites of action regarding fat distribution in the carcass of steers. Even though significant reductions in subcutaneous and intermuscular fat were apparent with somatotropin treatment and the magnitude of effect varied with location (hip/loin vs flank/chuck, etc.), no data were presented specifically for intramuscular fat. The data from Rumsey et al. (1996) demonstrated a significant effect of hormone treatments on lipid (decreased by SbV) in these same animals, and further demonstrated that the location of effect was not uniform. The data here are consistent with the suggestion by McBride and Moseley (1991) that the effects of somatotropin on fat and lipid biochemistry vary with the location of the tissue source.

The contribution of longitudinal aspects of specific muscle growth as affected by repartitioning agents needs to be researched further. Longitudinal growth occurs at the ends of muscle fibers (Griffin et al., 1971; Williams and Goldspink, 1971). The greatest increases in weight gain and daily protein accretion in the present study were observed with some aspect of muscles associated with locomotion or stabilization of long bones, particularly with what are characterized as "antigravity" and extensor muscles. Rectus femoris,

TB, and SS fall within this classification as regards extension of the hindleg, foreleg, and shoulder, respectively. Conversely, the ST is characteristically a hindlimb flexor, and the PM is a vertebral postural muscle. In regard to the need for total-muscle growth response to include aspects of longitudinal growth, one theory suggests that a significant component of the observed increased muscle growth imparted by the use of metabolic hormones like GH and IGF-1 results from the muscle tissue response to the direct effects of these hormones to increase the rate of cell division at the bone growth plate (Baldwin et al., 1991). Thus, as muscles accommodate to stretch between the origin and insertion on the bone, they respond with increases in growth rate (Goldspink and Goldspink, 1986).

The entire relationship among muscles and response to hormones was more complex than anticipated. Lack of uniformity of fiber type within the same muscle may contribute to differences in conclusions about the effects that repartitioning compounds have on muscle growth for obvious anatomical reasons but also as affected by the methodological sampling procedure. For example, the medial and lateral heads of the triceps brachii have different inherent growth impetus and responsiveness (as classified by Butterfield and Berg, 1966). Furthermore, Watt et al. (1982) demonstrated that the relationship between induced changes in protein synthesis and degradation vary according to fiber type. Even though these data were more relevant to the effects of exercise on protein deposition by specific fiber types, they do point out the propensity for muscles more directly associated with locomotion to respond to growth stimuli in a fashion different from the responses of more static postural muscles. Sorting out specific effects of hormones on muscle growth then becomes even more difficult because of the heterogeneity in fiber type at the onset and the significant effect of repartitioning compounds to alter proportions of fiber types (Ono et al., 1996).

Growth responses to hormonal repartitioning agents are in large measure dictated by the feeding regimen supplied to support growth (Rumsey and Hammond 1990; NRC, 1994). Differences between the data reported for these animals here and in Rumsey et al. (1996) with earlier reports published by others may relate to the feeding strategy employed in the respective studies. The possibility exists that the protein and energy requirements needed for somatotropin to direct greater increases in carcass and muscle deposition rather than viscera were not optimized in some of the earlier studies by others. We fed a diet, per unit of metabolic size, sufficiently high in protein and energy and included a sufficient forage component to ensure that dietary components were not (by calculation) a limitation to the effectiveness of either SYN or SbV (Clark et al., 1992; Collier et al., 1992), as suggested in the strategies summarized by the Subcommittee on Effects of Metabolic Modifiers on

the Nutrient Requirements of Food Producing Animals (NRC, 1994). The animals in this study averaged 5.5 kg DM intake/d for the 56-d treatment period (Rumsey et al., 1996). The diet was formulated to provide 21% CP on a DM-basis, and animals averaged approximately 1,150 g CP intake daily. Because 20% DM of the diet was derived from silage sources to maintain adequate microbial protein in the gut, it was unlikely that dietary protein was a limiting factor, compromising the utility of the hormone preparations.

The data herein suggest that the function and location of muscles may affect the propensity to respond to repartitioning agents with increased protein deposition. Enhanced protein deposition in selected muscles is consistent with treatment-associated increases in carcass protein reported for the same steers in Rumsey et al. (1996). The SYN and SbV can be used in combination to increase muscle mass. In cattle, efficacy of treatment to increase protein deposition and muscle size may be related to specific muscles and therefore specific retail cuts of beef.

Implications

The use of recombinant bovine somatotropin, Synovex-S, and the combination of these two growth promoters was effective in increasing the average daily protein gain of selective muscles. The combination was particularly effective in that protein gain could be increased by the combination when either somatotropin or Synovex alone might have been ineffective. The combination was also effective in some muscles beyond the response obtained with either treatment alone. The data suggest that combination treatments may be more effective in increasing overall protein gain in steers fed appropriately and that the protein subcomposition of muscle is not greatly altered by these treatments.

Literature Cited

- AOAC. 1990. Official Methods of Analysis (15th Ed.) Association of Official Analytical Chemists, Procedures 24.3 and 24.5. Arlington, VA.
- Baldwin, R. L., C. C. Calvert, and A. M. Oberbauer. 1991. Growth control in the future. In: A. M. Pearson, and T. R. Dutson (Ed.) Growth Regulation in Farm Animals. Advances in Meat Research, Volume 7. pp 609-612. Elsevier Press, New York.
- Beermann, D. H., and D. L. DeVol. 1991. Effects of somatotropin, somatotropin releasing factor, and somatostatin on growth. In: A. M. Pearson and T. R. Dutson (Ed.) Growth Regulation in Farm Animals. Advances in Meat Research, Volume 7. pp 373-426. Elsevier Press, New York.
- Breier, B. H., P. D. Gluckman, and J. J. Bass. 1988. The somatotropic axis in young steers: Influence of nutritional status and 17 β -estradiol on hepatic high- and low-affinity somatotropic binding sites. *J. Endocrinol.* 116:169-177.
- Butler-Hogg, B. W., and O. P. Whelehan. 1987. Muscle growth and distribution of muscle weight in Clun and Southdown sheep. *Anim. Prod.* 44:133-142.
- Butterfield, R. M., and R. T. Berg. 1966. A classification of bovine muscles, based on their relative growth patterns. *Res. Vet. Sci.* 7:326-346.
- Clark, J. H., T. H. Klusmeyer, and M. R. Cameron. 1992. Microbial protein synthesis and flows of nitrogen fractions to the duodenum of dairy cows. *J. Dairy Sci.* 75:2304-2323.
- Collier, R. J., J. L. Vicini, C. D. Knight, C. L. McLaughlin, and C. A. Baile. 1992. Impact of somatotropins on nutrient requirements of domestic animals. *J. Nutr.* 122:855-860.
- Early, R. J., B. W. McBride, and R. O. Ball. 1990. Growth and metabolism in somatotropin-treated steers: I. Growth, serum chemistry and carcass weights. *J. Anim. Sci.* 68:4134-4143.
- Eisemann, J. H., A. C. Hammond, and T. S. Rumsey. 1989. Tissue protein synthesis and nucleic acid concentrations in steers treated with somatotropin. *Br. J. Nutr.* 62:657-671.
- Enright, W. J., J. F. Quirke, P. D. Gluckman, B. H. Breier, L. G. Kennedy, I. C. Hart, J. F. Roche, A. Coert, and P. Allen. 1990. Effects of long-term administration of pituitary-derived bovine growth hormone and estradiol on growth in steers. *J. Anim. Sci.* 68:2345-2356.
- Goldspink, G. 1991. Perspectives for the manipulation of muscle growth. In: A. M. Pearson and T. R. Dutson (Ed.) Growth Regulation in Farm Animals. pp 557-588. Elsevier Applied Science, New York.
- Goldspink, G., and D. F. Goldspink. 1986. The role of passive stretch in retarding muscle atrophy. In: W. A. Nix and G. Vrbova (Ed.) Electrical Stimulation and Neuromuscular Disorders. pp 91-100. Springer-Verlag, Berlin.
- Gregory, K. E., L. V. Cundiff, and R. M. Koch. 1991. Breed effects and heterosis in advanced generations of composite populations for preweaning traits of beef cattle. *J. Anim. Sci.* 69:947-960.
- Griffin, G., P. E. Williams, and G. Goldspink. 1971. Region of longitudinal growth in striated muscle fibers. *Nat. New Biol.* 232:28-29.
- Hancock, D. L., and R. L. Preston. 1990. Titration of the recombinant bovine somatotropin dosage that maximizes the anabolic response in feedlot steers. *J. Anim. Sci.* 68:4117-4121.
- Maltin, C. A., M. I. Delday, S. M. Hay, G. M. Innes, and P.E.V. Williams. 1990. Effects of bovine pituitary growth hormone alone or in combination with β -agonist clenbuterol on muscle growth and composition in veal calves. *Br. J. Nutr.* 63:535-545.
- McBride, B. W., and W. M. Moseley. 1991. Influence of exogenous somatotropin on the components of growth in ruminants. *Biotechnology for Control of Growth and Product Quality in Meat Production: Implications and Acceptability. Proceedings of an International Symposium, Washington, DC.* pp 91-133.
- NRC. 1994. *Metabolic Modifiers: Effects on the Nutrient Requirements of Food-Producing Animals.* National Academy Press, Washington, DC.
- Ono, Y., M. B. Solomon, T. H. Elsasser, T. S. Rumsey, and W. M. Moseley. 1996. Effects of Synovex-S and recombinant bovine growth hormone (Somavubove[®]) on growth responses of steers: II. Muscle morphology and proximate composition of muscles. *J. Anim. Sci.* 74:2929-2934.
- Ouali, A., M. Zabari, J. P. Renou, C. Touraille, J. Koop, M. Bonnet, and C. Valin. 1988. Anabolic agents in beef production: Effects on muscle traits and meat quality. *Meat Sci.* 24:151-161.
- Pell, J. M., and P. C. Bates. 1987. Collagen and non-collagen protein turnover in skeletal muscle of growth hormone-treated lambs. *J. Endocrinol.* 115:R1-R4.
- Pell, J. M., C. Elcock, R. L. Harding, D. J. Morrell, A. D. Simmonds, and M. Walls. 1990. Growth, body composition, hormonal and metabolic status in lambs treated long-term with growth hormone. *Br. J. Nutr.* 63:43-445.
- Rathmacher, J. A., F. J. Bonilla, C. Coats, D. C. Beitz, A. Trenkle, and S. L. Nissen. 1997. Effect of bovine somatotropin and

- Revalor-S[®] on tissue deposition rates in steers. *J. Anim. Sci.* 75 (Suppl. 1):56.
- Rumsey, T. S., T. H. Elsasser, S. Kahl, W. Moseley, and M. B. Solomon. 1996. Effects of Synovex-S[®] and recombinant bovine growth hormone (Somavubove[®]) on growth responses in steers: I. Performance and composition of gain. *J. Anim. Sci.* 74: 2917–2928.
- Rumsey, T. S., and A. C. Hammond. 1990. Effects of intake level on metabolic response to estrogenic growth promoters in beef steers. *J. Anim. Sci.* 68:4310–4318.
- Rumsey, T. S., A. C. Hammond, and J. P. McMurtry. 1992. Response to reimplanting beef steers with estradiol benzoate and progesterone: Performance, implant absorption pattern, and thyroxine status. *J. Anim. Sci.* 70:995–1001.
- Rumsey, T. S., H. F. Tyrrell, D. A. Dinius, P. W. Moe, and H. R. Cross. 1981. Effect of diethylstilbestrol on tissue gain and carcass merit of feedlot steers. *J. Anim. Sci.* 53:589–600.
- SAS. 1985. SAS User's Guide: Statistics (Version 5 Ed.). SAS Inst. Inc., Cary, NC.
- Watt, P. W., F. Kelly, D. F. Goldspink, and G. Goldspink. 1982. Exercise-induced morphological and biochemical changes in skeletal muscle of the rat. *J. Appl. Physiol.* 53:1144–1151.
- Williams, P. E., and G. Goldspink. 1971. Longitudinal growth of striated muscle fibers. *J. Cell Sci.* 9:751–767.