分娩1週間前から泌乳期間の母豚へのL-カルニチン補給が
母乳中カルニチン濃度、発情回帰および子豚の発育に及ぼす
影響
Effects of L-Carnitine Supplementation 1 week prior to Farrowing and during Lactation on Its Concentration in Milk, Return of Estrus and Growth Performance of Piglets

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(Received : April 13, 2007, Accepted : October 23, 2007)

Summary: L-carnitine stimulates the transport of long-chain fatty acids across the inner mitochondria membrane to produce energy. It is synthesized with lysine and methionine as precursors. During lactation, the potential for biosynthesis of L-carnitine in piglet has not yet developed and so its supply depends on milk. The effects of L-carnitine supplementation to the feed of sows during pregnancy and lactation were demonstrated in earlier studies. The present study aimed to evaluate the effect of short-term L-carnitine supplementation in the following: on its concentration in milk during lactation, on the return of estrus, and on the growth performance of piglets. Fourteen crossbred sows with similar farrowing days were used at a commercial farm. They were classified into 2 groups: a control group in which sows were fed normal commercial feed and an L-carnitine-treated group, in which the feed included 50 ppm of L-carnitine. Milking was conducted on days 0, 2, 3 and 11 after farrowing and the concentration of total, free and acetyl-form L-carnitine in milk were quantitatively analyzed. Milk yield was determined on days 1, 7, 14 and weaning by the weigh-suckle-weigh method. The number of piglets born, birth weight, deaths due to weakening, weaning weight, and the return date of estrus were recorded. The individual birth weight of piglets in the L-carnitine-treated
group was significantly higher than that in the control group, but there was no significant difference in the litter weights at birth. Daily gain in the L-carnitine-treated group tended to be higher than the control group. For milk yield, the L-carnitine-treated group tended to be higher than the control group during week 1 with a decrease on the weaning day. On day 11 free L-carnitine concentrations in the L-carnitine-treated group were significantly (P < 0.10) higher than that in the control group. Return of estrus tended to be earlier in the L-carnitine-treated group. The following results have been suggested: 50 ppm supplementation of L-carnitine, even for short periods, positively affects the growth of piglets and return of estrus. This seemed to be due to the increase in the L-carnitine level in sow milk, and the better growth performance of piglets contributes to lessening the burden of lactation on sows.

**Key words**: sows, carnitine, lactation, growth of piglets, return of estrus

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**Introduction**

The bio-function of L-carnitine is similar to vitamins; at one time it was called vitamin B₅. However, it was found later on that L-carnitine was endogenously synthesized with lysine and methionine as precursors, and it is no longer classified as a vitamin but as a conditionally essential nutrient. In investigating the bio-function of L-carnitine many trials have been carried out under various conditions. It plays a role in the transport of long-chain fatty acids across the inner mitochondrial membrane to produce energy. Endogenous products such as acetyl-carnitine are excreted from mitochondria under intense stress, i.e., L-carnitine plays a two-way role in material uptake (normal energy requirement status) and acetyl residue release (under acute anaerobic stress) for energy metabolism modulation (Fig. 1-3). For human nutrition, various kinds of functional foods containing L-carnitine have been developed and commercialized. Large amounts of L-carnitine are found in the muscles and tissues of mammals, whereas it seldom occurs in plants. The intake of animal foodstuff increases the L-carnitine intake amount, however recently, restriction of animal feedstuff utilization has decreased the intake amount. Studies on the roles of L-carnitine have been performed on different domestic animals under different conditions. The effects of L-carnitine supplementation in the feed of sows on milk production, various hormone secretions, and growth performance of piglets were evaluated. In these studies the supplementation of L-carnitine was carried out over a long period through pregnancy to lactation. The present study began 1 week prior to farrowing and the effects of short-term supplementation on its concentration in milk, milk yield, growth performance of piglets and return of estrus were evaluated.

**Materials and Methods**

Experimental protocol was approved by the Animal Experiment Committee in Tokyo University of Agriculture.
Fig. 1. Energy metabolic pathway under normal energy requirement status

Fig. 2. Energy metabolic pathway under acute anaerobic stress where carbohydrate is used as major energy source resulting in stagnancy for ATP generation

Fig. 3. Possible energy metabolic pathway under acute anaerobic stress with sufficient L-Carnitine supply which buffers acetyl group to maintain free CoA level resulting in ad hoc intracellular optimization against the intense stress

Animals and feeding

Fourteen crossbred sows were used in this study. They were fed at a commercial farm (Uchimodori Shuton Kumiai). The animals were classified into two groups of 7 sows each, a control-group and an L-carnitine-treated group, according to their reproductive cycles and performances. Artificial control of sexual cycle using hormonal materials was not carried out in this study. The sows were kept in a single farrowing pen and they consumed a set amount of commercial feed (guaranteed CP 14.0% and TDN 74.0%) twice a day. Chemical compositions of basal commercial feed are shown in Table 1. This feed was used for both groups, while the supplementation of 50 ppm L-carnitine in the treated groups was started 7 days before farrowing. Chemical compositions were determined by usual methods. Until weaning, sows in the L-carnitine-treated group consumed the feed supplemented with 50 ppm L-carnitine. The dosage of L-carnitine was based on an earlier study by Owen et al. Feed amount for sows varied in accordance with their development stage; during week 1 before farrowing, the amount was 3.0 kg/d; during days 2 to 3 after farrowing, 1.6 kg/d; day 4 after farrowing, 2.4 kg/d; days 5 to 6 after farrowing, 3.0 kg/d; days 7 to 9 after farrowing, 4.5 kg/d, and the period from day 10 to weaning was 7.2 kg/d. The L-carnitine used was Carniking, a commercial type from Lonza Japan Co.Ltd., which contains 50% L-carnitine.

Milk samples

On days 0, 2, 3, and 11 of farrowing, milk was collected by hand milking to determine amounts of total, free, and acetyl-type carnitine. Determination of all types of carnitine
was entrusted to SRL Co.Ltd. The concentrations of each type of carnitine were determined according to an enzymatic cycling method using carnitine dehydrogenase by Takahashi et al. Milk output was measured daily from 0900 h to 1500 h on days 1, 7, 14, and the day of weaning (from about days 18 to 22) for all sows using the "weigh-suckle-weigh" method. Daily milk output was calculated according to the mean of piglet gain for each suckling and litter size.

Data collection

The number of piglets born (total, number born alive and number of death due to weakening) was recorded. Individual piglets were weighed at birth (not later than 6h after birth), and at weaning day. Weaning day was decided according to the customary standard for the commercial farm. The first day of estrus return after weaning and the performance of artificial insemination were recorded.

Statistical analysis

Data were treated using t-Test method. For statistically significant F-values, means of the groups were compared by the multiple range test. Means were considered significantly different at \( P < 0.10 \).

Results

L-carnitine intake

Each L-carnitine intake derived from feed and/or supplementation is shown in Table 1. Actual intakes of L-carnitine are included in Table 2.

Birth performance and weight gain of piglets during suckling (Table 3)

Litter size in the L-carnitine-treated group was slightly higher than the control group, but the alive ratio of piglets did not differ between both groups. Although body weight of piglets at birth in the L-carnitine-treated group was significantly \( (P < 0.10) \) lower than the control

<table>
<thead>
<tr>
<th>Table 2. Actual intakes (mg/d) of L-carnitine</th>
</tr>
</thead>
<tbody>
<tr>
<td>One week prior to farrowing and on farrowing day</td>
</tr>
<tr>
<td>2–3(^{th}) days</td>
</tr>
<tr>
<td>4(^{th}) day</td>
</tr>
<tr>
<td>5–6(^{th}) days</td>
</tr>
<tr>
<td>7–9(^{th}) days</td>
</tr>
<tr>
<td>10(^{th})-weaning day</td>
</tr>
</tbody>
</table>

1: Guaranteed value
Table 3. The effect of L-carnitine supplementation in sows on the piglet during the suckling period

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>+L-carnitine</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sows, n</td>
<td>7</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Piglets, n</td>
<td>70</td>
<td>74</td>
<td></td>
</tr>
<tr>
<td>Piglets born/litter, n</td>
<td>11.8±0.5</td>
<td>12.4±0.6</td>
<td>0.5016</td>
</tr>
<tr>
<td>Alive ratio of piglets at birth, %</td>
<td>84±4</td>
<td>86±5</td>
<td>0.5859</td>
</tr>
<tr>
<td>Weight of piglets at birth, kg</td>
<td>1.43±0.11</td>
<td>1.26±0.15</td>
<td>0.0474*</td>
</tr>
<tr>
<td>Weight of piglets at birth/litter, kg</td>
<td>16.8±1.0</td>
<td>15.9±0.9</td>
<td>0.4905</td>
</tr>
<tr>
<td>Suckling period, days</td>
<td>22±0.7</td>
<td>22±0.4</td>
<td>0.6338</td>
</tr>
<tr>
<td>Daily gain, g/d</td>
<td>204±30</td>
<td>211±13</td>
<td>0.6305</td>
</tr>
<tr>
<td>Daily gain, kg/litter/d</td>
<td>1.98±0.10</td>
<td>2.23±0.13</td>
<td>0.1593</td>
</tr>
</tbody>
</table>

Mean±S.E.

Table 4. The effect of L-carnitine supplementation in sows on their milk production on days 0, 7, 14 and weaning and return of estrus

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>+L-carnitine</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sows, n</td>
<td>7</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Milk production, kg/d</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>day 0</td>
<td>5.27±0.99</td>
<td>6.08±1.24</td>
<td>0.2337</td>
</tr>
<tr>
<td>day 7</td>
<td>4.72±0.53</td>
<td>5.21±0.91</td>
<td>0.2805</td>
</tr>
<tr>
<td>day 14</td>
<td>4.11±0.46</td>
<td>3.99±1.40</td>
<td>0.8396</td>
</tr>
<tr>
<td>weaning day</td>
<td>4.34±0.66</td>
<td>3.84±0.48</td>
<td>0.1656</td>
</tr>
<tr>
<td>Sows, n</td>
<td>7</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Return of estrus, d</td>
<td>8.1±2.4</td>
<td>4.7±0.2</td>
<td>0.1722</td>
</tr>
</tbody>
</table>

Mean±S.E.

group, there was no significant difference in the litter weights at birth. Daily gain and daily gain per litter in the L-carnitine-treated group tended to be higher.

**Milk production, L-carnitine and its derivative concentration in milk, and return of estrus (Table 4 and Fig. 4-6)**

Although sows in the L-carnitine-treated groups tended to produce large amounts of milk on days 0 and 7, milk yield decreased at weaning day when compared to the control group. Total L-carnitine content in milk tended to be higher in the L-carnitine-treated group during the suckling period. Free L-carnitine content in the L-carnitine-treated group showed a significantly (P<0.05) higher value than that of the control group on day 11. Acetyl-carnitine content tended to be higher during the early suckling period from days 0 to 3, but on day 11 it decreased. Before determination of the return of estrus, a sow in the L-carnitine-treated group was sacrificed due to an accident in its hind leg. Return of estrus tended to be earlier in the L-carnitine-treated
Fig. 4. Total L-carnitine contents in the milk from sows in both groups. There is no significant difference between the control and +L-carnitine groups.

Fig. 5. Free L-carnitine contents in the milk from sows in both groups. There is significant difference ($P < 0.05$) between the different superscript letters.

Discussion

In a review of the use of L-carnitine supplements in domestic animal feed (HARMEYER, 2003), investigations were more actively conducted in experiments using pigs than with the other domestic animal species. In these studies using pigs, dietary supplements of L-carnitine ranged from dose rates of 25 to 1250 mg/kg feed. These studies were conducted under various conditions. Positive effects on daily gains in piglets were shown in almost all reports. These studies using sows and piglets were started from the early period of gestation, while this study began 1 week prior to farrowing and the effects of short-term supplementation on its concentration in milk, milk yield, growth performance of piglets and return of estrus were evaluated. Basal feed normally used contained 4.4 mg/kg of naturally occurring L-carnitine per feed. For reference, we determined the L-carnitine content in several commercial feeds that ranged from 2.5 to 6.6 mg/kg. Supplementation of 50 mg/kg feed is about 11 times the value found in usual feed, but it is still much lower than that used for humans nutrition. Actual intake of L-carnitine in the experimental group was about 12.4
times higher than that of the control group as shown in Table 2.

Although long-term supplementation of L-carnitine to sows affects the number of piglets born and birth weights, when the present experiment began, the embryos had already developed in the uterus. In this study, the significant differences recognized in individual birth weight of piglets may be caused by litter size, because there was no significant difference in the litter weights at birth. L-carnitine supplementation to the sows' feed might affect the weight gain of piglets due to the large amount of milk production in sows in the early period of suckling. Furthermore its milk contained a higher value of L-carnitine. This effect was recognized in the phenomenon that small body weight piglets born in the L-carnitine-treated group reached weaning weight within the same number of days from birth. Stimulation of growth performance of piglets in the L-carnitine-treated group was also obtained in an earlier report. Furthermore, in the later period of suckling, milk production amount in the L-carnitine-treated group tended to be less in comparison with the control group. This tendency seemed to affect the return of estrus. Although there was no significant difference, the return of estrus in the L-carnitine-treated group tended to be earlier in these results. On the other hand, the return of estrus in some sows in the control group was later in comparison with the usual data. Therefore supplementation of L-carnitine might affect the stability rather than the brevity of the return period of estrus. L-carnitine content in milk in the L-carnitine-treated group was higher than that in the non-treated control group, especially for acetyl-carnitine, which tended to have higher value on days 0 to 3 then decreasing on day 11. These results suggest that sows appropriated L-carnitine for energy production during lactation in the early period after farrowing when physical stress increased, and specifically while great energy demand reached a lower level on day 11, i.e., sows in the L-carnitine-treated group recovered earlier from the stressful conditions to a normal state than the untreated group did. Furthermore, it was reported that higher levels of acetyl-carnitine in the milk were reduced again in the tissues of piglets and/or incorporated into the TCA cycle by its transfer from acetyl group to CoA to produce acetyl CoA, followed by energy production. The results of this study suggest that the continuous supplementation of L-carnitine played an important role in milk production of sows. The details of hormonal balance and other mechanism, however, remain to be studied in future work.

Acknowledgements

The authors would like to thank the members of Uchimodori Shuton Kumiai and Mr. T. Akaike of Fuji Farm of Tokyo University of Agriculture for their kind help in this study.

References


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(2007年4月13日受付, 2007年10月23日受理)

要 約  カルニチンがエネルギー生産を促すことや、メチオニン、リジンを前駆物質として体内で生成されることが知られている。しかし、哺乳期の子豚はその生成能力が低いため、母乳に含まれるものを利用する。これまでに妊娠期から泌乳期間の長期に母豚にカルニチンを給与し、その効果を認めていている報告がある。本試験は母豚への給与を分娩後1週間前から泌乳期間の短期間とし、母乳中のカルニチン濃度、母豚の発情回帰への影響、および子豚の発育に及ぼす影響を検討した。供試母豚は、協力養豚場において同時期に分娩予定となった14頭の交雑種を用いた。これらを7頭ずつに分け、対照群の母乳には市販飼料を、試験群の母豚にはカルニチンを50ppm添加して給与した。分娩後0, 2, 3および11日目に搾乳し、乳汁中総カルニチン、遊離カルニチンおよびアシルカルニチンの濃度を測定した。泌乳量は分娩後1, 7, 14および離乳日に哺乳前後の子豚の体重差から算出した。出生子豚の頭数、出生体重、生存率、離乳体重と母豚の発情回帰日を記録した。一腹の出生子豚が多かったためにカルニチン給与区で出生時体重が低かったが、一腹総体重には差は認められなかった。試験区の子豚の増体重は大きい傾向にあり、分娩後1週間以内の泌乳量は多く、離乳時には少なくなる傾向にあった。総カルニチン濃度は試験区で高くなる傾向にあり、11日目に試験区の乳汁中遊離カルニチン濃度が有意に（P<0.10）高くなった。発情回帰は試験区で短くなる傾向にあったが、有意差は認められなかった。短期間で母豚にカルニチンを50ppm程度補給することが子豚の発育、母豚の発情回帰に対して良好に影響することが示唆された。これは乳汁中のカルニチン増加によるものであり、子豚の発育向上に対母豚の泌乳における負担を軽減したと考えられた。

キーワード：母豚、カルニチン、泌乳、子豚発育、発情回帰