The Effects of Fasting and Increased Feeding on Plasma Thyroid Hormones, Glucose, and Total Protein in Sea Turtles

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The Effects of Fasting and Increased Feeding on Plasma Thyroid Hormones, Glucose, and Total Protein in Sea Turtles

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ABSTRACT—The effects of fasting and increased feeding on plasma thyroid hormones, glucose, and total protein levels were investigated in immature greens (Chelonia mydas) and Kemp’s ridley (Lepidochelys kempi) sea turtles. Under constant temperature, nutritional status affected plasma thyroid hormones and glucose level, but not protein level in green and Kemp’s ridley turtles. Plasma T4 in green turtles decreased with deprivation of food, but did not do so in Kemp’s ridleys. Increased feeding did not affect circulating levels of plasma T4 in either species. Plasma T3, in contrast, tended to decrease during fasting and increase with refeeding or increased feeding. Blood glucose level fell with deprivation of food, but remained constant during increased feeding. Sea turtles may use glycogen or lipid during short-term fasting as in endothermic vertebrates.

INTRODUCTION

In various vertebrates, alterations in the quantity and quality of ingested food influence thyroid function (Eales, 1988). Many studies demonstrated that the thyroid system is especially sensitive to carbohydrate content in diets (Harvey et al., 1981; Young et al., 1982, 1983; Danforth, 1986; Himick and Eales, 1990). Glucose in diet may stimulate the secretion of thyroid hormones (Hughes et al., 1984; Himick and Eales, 1990), especially T3, or may act to enhance T4 deiodination peripherally (Decuyper and Kuhn, 1984).

Alternatively, other nutritional components of diet, possibly protein, may be involved in the regulation of thyroid function. Lipid on the other hand, did not appear to modify thyroid function in rainbow trout under isocaloric conditions (Eales et al., 1990). The plausible function of dietary protein on the thyroid system may be related to the observations that food intake also influences T3, 5’ monodeiodinase (which converts T4 to T3) as well as blood protein binding to circulating thyroid hormones (Eales, 1988).

Even though much research has been performed on the temperature related changes in plasma thyroid hormones, glucose, or protein (Hutton and Goodnight, 1957; Sellers et al., 1982; Bona-Gallo et al., 1984; Abdel-Raheem et al., 1989), the influence of nutritional status on those factors has rarely been investigated in reptiles. There have been a few experiments conducted on the effects of starvation on blood glucose or protein level in turtles (Bonnet, 1979; Da Silva and Migliorini, 1988). In freshwater turtles, starvation did not affect blood glucose level (Machado et al., 1989; Da Silva and Migliorini, 1988). However in sea turtles, starvation reduced blood glucose concentration and maintained constant protein level (Bonnet, 1979). From these studies, further research is suggested to develop a more detailed understanding of the effect of nutritional status on blood glucose and protein in reptiles. Additionally, thyroid hormone, as one of the metabolically important hormones in reptiles as well as in other classes of vertebrates, needs to be understood in relation to nutritional status. No documentation or data on thyroid-nutrition relationships in reptiles are available for this purpose. From previous study (Moon, 1992), it was found that plasma thyroid hormones decreased significantly in cold water. Either temperature or temperature and nutrition were suggested as the causes of the decrease in thyroid hormones, since sea turtles stopped feeding in cold water. To determine if thyroid hormones are influenced by nutritional status, the effect of nutritional manipulation on thyroid function of sea turtles need to be examined under constant temperature condition.

Therefore, the present study was undertaken to determine the effects of nutrient intake on plasma thyroid hormones, glucose, and total protein levels in sea turtles. To test the hypothesis that a decrease of food intake will lower plasma thyroid hormone, glucose, and total protein levels, the animals were first fasted and then refed thereafter. In a separate experiment, turtles were fed with increased amounts of food to satiate them. These studies may elucidate the metabolic adjustment of sea turtles to fasting periods in nature, a possible adaptation of sea turtles to the ocean environment in which long migrations are achieved away from feeding grounds.
MATERIALS AND METHODS

Laboratory-acclimated immature green (*Chelonia mydas*) and Kemp’s ridley (*Lepidochelys kempi*) sea turtles (8 of each species) were used in this experiment. The green sea turtles were hatched in Florida in 1982 and raised in the laboratory for 8 years. The Kemp’s ridley sea turtles had been hatched at Padre Island National Seashore, Texas, in 1987 and were obtained from the National Marine Fisheries Service Galveston Headstart Program. At the beginning of the experiment, the green turtles were 8 years old and 10–12 kg body weight (BW). The Kemp’s ridley sea turtles were 3 years old and 11–15 kg BW. Each species was randomly divided into two groups of 4, experimental and control, which were put in separate 2,000 gallon artificial sea water raceways (7 m long by 1 m wide by 0.75 m deep) in two separate rooms of the Bioaquatic Facility of the Biology Department, Texas A & M University. Each turtle was kept isolated in its raceway by a plastic pipe divider. Constant water temperature of 25°C was maintained during the study. To examine the effects of fasting, the experimental group was fed diet every day at 4:00 PM for 15 minutes with turtle burgers made of Purina Trout Chow and a squid (twice a week), followed by 2 weeks of fasting (no feeding), then returned to the basal diet (turtle burgers). The control group, in contrast, was fed the same diet during the 5-week period. Blood samples (3 to 4 ml) were collected at 10:00 AM from the dorsal cervical sinus of each turtle as described by Owens and Ruiz (1980). The sampling times were: at 2 weeks after initiation of basal diet, at 24 hr after initiation of fasting, at 1 week of fasting, at 2 weeks of fasting, at 24 hr following the return to the basal diet, and at 1 week after return to the basal diet. The turtles then had a month for recovery after the fasting/ refeeding experiment. During this period the turtles were fed routinely with the basal diet.

For the increased feeding experiment, the experimental groups were fed a basal diet for 2 weeks followed by 2 weeks of increased feeding, and finally 1 week back on the basal diet. During the increased feeding phase, these turtles were given as many burgers as they could consume within 15 minutes, three times a day. The approximate number of burgers consumed by each turtle was counted by observation after 15 min. The control groups were fed the basal diet throughout the experiment. Blood samples (3 to 4 ml) were collected from each turtle. Sampling times were: at 2 weeks after initiation of the basal diet, at 24 hr after increased feeding, at 1 week of increased feeding, at 2 weeks of increased feeding, at 24 hr after return to the basal diet, and at 1 week after return to the basal diet. Blood samples were centrifuged immediately and kept frozen at −70 to −80°C until analyzed for thyroid hormones (T₄ and T₃), glucose, and total protein. To see if there are diurnal changes in plasma thyroid hormones and blood glucose levels in sea turtles, seven serial blood samples were collected form the same turtles during a 2-day period. Bleeding times were: morning (8:30 AM), afternoon (4:30 PM), and midnight (00:30 AM). In the midnight, to eliminate the possible disturbance of turtles by illumination red filter-covered flashlight was used when the turtles were grabbed and bled.

Thyroid hormone radioimmunoassay

A thyroid hormone radioimmunoassay (RIA) (MacKenzie et al., 1977), with modifications described by Denver and Licht (1988)) was used for quantifying plasma thyroxine (T₄) and triiodothyronine (T₃). An important modification was the use of 5% rather than 25% polyethylene glycol for precipitation of bound hormone with second antibody. To validate the assay, parallelism and recovery tests were conducted. Supplemented and non-supplemented samples appeared to parallel to the standard. The average recovery rate was 94±5%.

Blood glucose assay

Blood glucose levels were determined using a blood glucose test kit (Sigma colorimetric test kit No. 635). For the standard curve, 50 µl of glucose standard solution (No. 63500) was added. For unknowns, 50 µl of duplicate plasma was added to each tube. To each tube, 2.5 ml of toluidine reagent was added followed by shaking to mix. All tubes were put into a vigorously boiling water bath for exactly 10 min. Treated samples were read for absorbance at 635 nm using spectrophotometer (LKB NOVASPEC Biochrom 4049) within 30 min.

Blood total protein assay

Blood total protein level was determined using a protein test kit (Pierce colorimetric test kit No. 23236X). This protein test is based on the Bradford method that utilizes the absorbance shift in Coomassie Brilliant Blue G50 solution. The standard curve was prepared with 100 µl of BSA (bovine serum albumin) standard at the range of 20 to 1.25 g/dl. To sample tubes in duplicate, 100 µl of diluted plasma (1:100) in distilled water was added followed by 3.0 ml of protein assay reagent. After mixing, these samples were read for absorbance at 595 nm using the same spectrophotometer as above.

Statistical analysis

One-way ANOVA (repeated measures) was used to determine if there were significant changes in plasma thyroid hormone, glucose, and total protein levels over the experimental period. The significant differences were determined at the level of p<0.05. The paired t-test was used to determine if there are significant differences between control and experimental groups. The ANOVA and t-test were performed using the University SAS system at Texas A & M University.

RESULTS

Fasted/refeed experiment

Plasma thyroid hormones — The ANOVA showed significant differences (p<0.05) in plasma T₄ levels over the study period in green turtles. T₄ was reduced from 9.8 ± 1.1 (mean ± SE) to 6.7±1.3 ng/ml as green turtles were deprived of food during the first week (Fig. 1). In the second week of food deprivation, T₄ remained depressed as in the first week. When

![Fig. 1. Blood glucose (top) and T₄ (bottom) levels in green turtles, Chelonia mydas, in fast/refeed experiment. Vertical bars represent standard errors of the mean. The asterisks represent significant differences between control (solid line) and experimental (dotted line) groups by t-test. F: feeding, S: starving.](https://bioone.org/journals/Zoological-Science on 28 Jul 2019 Terms of Use: https://bioone.org/terms-of-use)
fasted turtles were refed, the concentration of plasma T4 increased to 100% of control level within 24 hr. However, refed greens after one week had decreased again to 68% of control level. 

Fig. 2 shows the changes in plasma T4 levels in fasted and refed ridley turtles. There were no significant differences between control and experimental groups. Plasma T4 in the experimental group was consistently higher than in the control group except at one point at which T4 decreased to lower than control group levels after refeeding for a week. This decrease by refeeding for 1 week was also observed in green turtles.

Plasma T3 levels were very low, ranging from 0.6 to 1.0 ng/ml (mean 0.8 ± 0.1 ng/ml) when green turtles were fed but decreased to 0.4 ± 0.1 ng/ml when they were fasted (Table 1). Any significant changes in T3 by fasting were not observed even though significant differences existed between control and experimental groups at 24 hr and 1-week fasting. Plasma T3 levels in Kemp’s ridley turtles were low and relatively constant, always less than 0.5 ng/ml (Table 1). Table 2 shows the changes in the ratio of T3 to T4 during the period fasted. Both species did not show significant differences in the ratio of T3/T4.

Blood glucose — Blood glucose level in fasting green turtles varied significantly (p<0.001). There were no significant changes in blood glucose level after 1 day of starving, whereas continuous fasting for 1 week and 2 weeks decreased profoundly blood glucose level by 22% and 29%, respectively (Fig. 1). However, refed greens exhibited a rapid increase in glucose to the control level within 24 hr. Thereafter, glucose remained at about 90% of the control levels for the week of refeeding with a basal diet.

Kemp’s ridleys presented a similar pattern in blood glucose changes relating to diet. Food deprivation decreased blood glucose level to 76% of initial level after the first week and to 64% after the second week, while refeeding increased glucose to 90% of the control level at the end of this experiment (Fig. 2).

Blood total protein — There were no significant effects of food deprivation on blood total protein levels in green turtles.

### Table 1. Plasma T3 and total protein levels in green and Kemp’s ridley turtles in fast/refeed experiment

<table>
<thead>
<tr>
<th>Species</th>
<th>Group</th>
<th>Day 0</th>
<th>1</th>
<th>7</th>
<th>14</th>
<th>15</th>
<th>21</th>
</tr>
</thead>
<tbody>
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<td>C</td>
<td>0.8</td>
<td>0.8</td>
<td>0.6</td>
<td>0.4</td>
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<td>T3 (ng/ml) (mean±SE)</td>
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<td>±0.1</td>
<td>±0.1</td>
<td>±0.1</td>
<td>±0.1</td>
<td>±0.2</td>
</tr>
<tr>
<td>E</td>
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<td>±0.3</td>
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<td>0.2</td>
<td>0.4</td>
<td>0.5</td>
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</tr>
<tr>
<td>L. kempi</td>
<td>C</td>
<td>0.3</td>
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<tr>
<td>(mean±SE)</td>
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<td>±0.1</td>
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<td>±0.1</td>
<td>±0.1</td>
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<td>E</td>
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</tr>
<tr>
<td>Total Protein (g/dl) (mean±SE)</td>
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<tr>
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<td>L. kempi</td>
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<td>3.5</td>
<td>4.5</td>
<td>3.8</td>
<td>3.9</td>
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<tr>
<td>(mean±SE)</td>
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<td>±0.1</td>
<td>±0.6</td>
<td>±0.3</td>
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<td>±0.6</td>
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<td>3.9</td>
<td>3.7</td>
</tr>
</tbody>
</table>

C: control group  E: experimental group  SE: standard error of the mean

The asterisks represent significant differences between control and experimental groups.
protein ranged from 3.2 ± 0.5 to 4.2 ± 0.5 g/dl in greens during the study (Table 1). As in greens, blood protein in ridleys was not strongly affected by fasting. Individual variations and small number of animals reflected fluctuations in protein level.

**Increased feed experiment**

To determine the effect of increased feeding, greens and ridleys received about 254% of the basal diet (17.0 g/day/kg body weight) (data not shown). After feeding as much food as they could, the turtles either ignored or spit food out.

**Plasma thyroid hormones** — Plasma T₄ levels in green turtles decreased significantly as the turtles fed more (p<0.05). Within 1 day of increased feeding, greens recorded 30.0% increase in plasma T₄ level while consuming about 300% of the usual basal diet (Fig. 3). However, despite an average 200% increase in feeding over the 1 week, the T₄ decreased thereafter from 9.4 ± 0.7 ng/ml to 6.2 ± 1.3 ng/ml at day 7, which is a 34.7% decrease from the initial readings. Continual increased feeding returned T₄ to control levels, followed by a 22.9% increase within 1 day after returning to a basal diet. It is noticeable that there is a significant difference between control and experimental groups only at the first week of increased feeding.

In Kemp's ridley turtles, plasma T₄ levels followed a different pattern of change from greens in that after the first day of increased feeding T₄ decreased by 23.0% rather than increasing (Fig. 4). However as in greens, returning to a basal diet increased T₄ markedly in ridleys (40.1%).

Increased feeding did not affect significantly plasma T₃ in either species (Table 3). In greens, T₃ increased to 1.1 ± 0.5 ng/ml after 1 week of increased feeding and remained constant during the second week, but no significant differences between groups were found. In ridleys, the patterns of T₃ changes were not similar to those in greens and T₃ in experimental group remained relatively constant during the study period. The ratio of T₃ to T₄ changed significantly (p<0.05) by increased feeding in greens, whereas it did not in ridleys (Table 4).

**Blood glucose** — Unlike the food deprived/refeeding experiment, no significant changes in blood glucose levels with increased feeding were observed in either species (Figs. 3, 4). While the control group in greens maintained a stable glucose level, ranging from 91 ± 9.5 to 95 ± 4.7 mg/dl, during the study, ridleys showed relatively more variable glucose levels ranging from 84 ± 1.6 to 107 ± 6.5 mg/dl.

To determine if there are diurnal changes in plasma T₄ and blood glucose levels and to see the effects of multiple sampling for a short period on these, greens and ridleys were bled seven times repeatedly during a 2-day period. Fig. 5 shows diurnal changes in plasma T₄ and glucose, respectively. T₄ was variable but did not show significant changes in the morning, afternoon (after a meal), and midnight, ranging from 8.1 ± 0.7 to 10.5 ± 0.6 ng/ml in greens and 3.7 ± 0.4 to 4.6 ± 0.7 ng/ml in ridleys. Greens seemed to have more variable T₄ than ridleys, but no significant changes were found over a 2-day period (Fig. 5). No significant diurnal changes in blood glucose were observed in either species (Figs. 3, 4).

**Table 2.** Changes in the ratio of T₃/T₄ (%) in fast/refeed experiment

<table>
<thead>
<tr>
<th></th>
<th>C. mydas</th>
<th>L. kempi</th>
</tr>
</thead>
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<tr>
<td></td>
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<tr>
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<tr>
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<td>1 week refeed</td>
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C: control group  E: experimental group
Table 3. Plasma T₃ and total protein levels in green and Kemp’s ridley turtles in increased feed experiment

<table>
<thead>
<tr>
<th>Species Group</th>
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<th>14</th>
<th>15</th>
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</tr>
</thead>
<tbody>
<tr>
<td>C. mydas</td>
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<tr>
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C : control group  E : experimental group
SE: standard error of the mean

Table 4. Changes in the ratio of T₃/T₄ (%) in increased feed experiment

<table>
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<th>Species Group</th>
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<th>15</th>
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<tr>
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<tr>
<td>L. kempi</td>
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</tr>
</tbody>
</table>

C : control group  E : experimental group

Blood glucose were observed in greens and ridleys. Blood glucose levels in ridleys were consistently lower (70.6±1.7 mg/dl) than those in greens (82.1±2.4 mg/dl) over a 2-day period. There seems no feeding or multiple sampling effect on glucose level.

Blood total protein — As in the fasted/refed experiment, no significant changes were observed in blood total protein levels in green or Kemp’s ridley turtles (Table 3). Large standard error represented great individual variation in protein level. During the study, blood protein ranged from 3.0±0.5 to 4.2±0.8 g/dl in the control and 2.9±0.2 to 3.6±0.7 g/dl in the experimental group in greens, while protein in ridleys ranged from 2.5±0.2 to 3.4±0.4 g/dl in the control and from 2.7±0.2 to 3.3±0.3 g/dl in the experimental group.

DISCUSSION

The relationship between nutrition and thyroid hormones, or blood chemical components including glucose and protein has been investigated mainly in endothermic vertebrates, such as birds and mammals. In ectotherms, the most effort has been focused on salmonid fishes, whereas a very few studies have been conducted in reptiles. In the present study, nutritional effects on plasma thyroid hormones, glucose, and total protein levels were observed in captive greens, but not in Kemp’s ridleys under constant temperature and photoperiod. In greens, plasma T₄ level changed significantly with deprivation of food. This finding agrees with that of Flood and Eales (1983) and Eales (1985) for salmonid fish. After an initial decrease during 1 week of fasting, T₄ level remained at a steady state which may be a result of decreased metabolic rate in green turtles as found in fish (Flood and Eales, 1983; Vijayan and Leatherland, 1989). In both species we found that when fasted turtles were re-fed, plasma T₄ concentration initially
increased but then decreased after a week. This long-term
decrease may be explained by the increased conversion of \( T_3 \)
to \( T_4 \) peripherally (Klandorf and Harvey, 1985). Therefore, more
available \( T_3 \) would be produced from \( T_4 \) when the turtles
receive more food. Unexpectedly, plasma \( T_4 \) also decreased
as turtles consumed more food, as well as when they returned
to a basal diet. This is inconsistent with a salmon study by
McCormick and Saunders (1990) in which \( T_4 \) increased pro-
portionally to increasing ration level. The possible factors which
decrease plasma \( T_4 \) are increased clearance rate of \( T_4 \) in blood
and increased secretion of \( T_4 \) from the gland (Eales, 1988). In
the satiated state with increased diet, the clearance rate of \( T_4 \)
in blood may be higher than thyroidal secretion rate of \( T_4 \) in
turtles. Another possible factor is that the increased diet may
induce an increase in \( T_4 \) secretion from the gland (Dauncey et
al., 1983). In both experiments, thyroid hormones appeared
to be influenced by nutritional status within 24 hr. After this
acute response to altered ration, the sea turtle thyroid system
seemed to adjust to maintain baseline-circulating concentra-
tion of its hormones. In green turtles, \( T_3 \) returned to approxi-
ately 10 ng/ml after 2 weeks of fasting or increased feeding
after an initial transient change, implying regulation of basal
level around 10 ng/ml. It is assumed that decreased nutrients
may cause decreased \( T_4 \) secretion that results in decreased
conversion of \( T_4 \) to \( T_3 \). As greens take in more nutrients, there
may be a transient increase in \( T_4 \) secretion, possibly followed
by readjustment of the thyroid system through alterations in
clearance rate. The thyroid system in ridleys appears more
resistant to altered ration since basal \( T_4 \) levels were more
variable than in greens. The reason that ridleys were different
in their response is not certain, but genetic differences be-
tween two species may explain this discrepancy.

In the present study, blood glucose level was affected by
fasting in sea turtles. The results agree with those in Bonnet's
green turtle study (1979) in which blood glucose concentra-
tion dropped significantly as they starved for 5 days. Similar
results were also found by Cherel et al. (1988) in birds. How-
ever, the present finding seems to contradict a freshwater turtle
study by Da Silva and Migliorini (1988) in which no significant
change was seen after fasting for 30 days followed by
refeeding for 3 days. Da Silva and Migliorini (1988) found that
maintenance of a constant glucose level in the blood was due
to a high liver gluconeogenic activity for animals fed protein-
rich and carbohydrate-poor diets. In fact, freshwater turtles
were fed on a fresh meat diet, which possibly provided higher
protein concentration than our pellet-diet for sea turtles. Simi-
lar results in which blood glucose level remained constant
during fasting were found in mammals (Kettelhut et al., 1980).
In this study, cats and rats fed a protein-rich diet (63% pro-
tein) maintained a constant glucose level, whereas animals
fed a carbohydrate-rich diet (70% carbohydrate) showed sig-
ificantly lower glucose level than controls or animals fed the
high-protein diet. Catfishes fed a carbohydrate-rich diet also
showed a progressive decline in blood glucose level as they
were starved (Machado et al., 1989). After 2 weeks of starva-
tion, glucose reached about 80% of controls. In our turtles,
either diet (protein content about 44%) or other internal fac-
tors, such as lower gluconeogenesis may have caused the
decrease in blood glucose. Increasing the ration to 200% of
the baseline did not cause any significant change in glucose,
indicating that the liver or muscle acted as a reservoir for con-
verting excess glucose into glycogen, as in refed fresh water
turtles (Da Silva and Migliorini, 1988).

It was expected that stress, such as multiple sampling,
might influence plasma thyroxine or glucose levels. In the
present study, multiple sampling (7 times for 2-day period)
did not affect on \( T_4 \) and glucose, indicating that changes in
these are not likely caused by stress. Therefore, increased \( T_4 \)
or glucose levels at 24 hr were not due to sampling on previ-
ous day. Blood total protein content did not change signifi-
cantly during the study period, suggesting that blood protein
in sea turtles may be under precise control during fasting,
refeeding, and increased feeding. Despite no significant dif-
ferences between groups, protein ranged from 2.9 to 4.2 g/dl
and 2.5 to 4.7 g/dl in greens and ridleys, respectively. This
range falls within the levels for other reptiles reported
(Dessauer, 1970); being similar to that in some chelonians,
but lower than that for other reptilian species, including
Bonnet (1979) obtained similar results to the present study in
that juvenile green turtles showed only slight variations in blood
protein level during fasting. Changes in blood protein have
been observed in several reptilian species. Most of this work
revealed that blood protein level changes seasonally; lower
in winter than summer. It can be assumed that during winter
months animals do not feed well, resulting in low protein lev-
els. In the present study, 2 weeks of fasting or increased feed-
ing may not have been enough to observe substantial changes
in serum protein level, since both greens and ridleys exhib-
ited significant decreases in protein concentration when they
stopped feeding when exposed to cold temperature for one
or two months (Moon, 1992). This finding parallels that of
Cherel et al. (1988) that fasted penguins maintained constant
serum protein level for approximately 30 days and decreased
thereafter. A protein sparing strategy such as this may be also
rely on internal regulatory factors including hormones, such
as thyroid hormones, insulin, or corticosterone (Cherel et
al., 1988; Vijayan and Letherland, 1989). Among these possible
endocrine factors, thyroid hormones are known to activate
protein synthesis in liver and muscle cells (Narayansingh and
Eales, 1975; Medda and Ray, 1979). In contrast to anabolic
effects, the catabolic effect of thyroid hormones on protein
has also been seen in mammals and fish (Tata, 1974; Goldberg
et al., 1980). In our sea turtles, thyroid hormones tended to be
negatively associated with protein as has been seen in lizard
species (Mishra and Ahsan, 1988). The maintenance of a rela-
tively constant protein level during starvation also can be seen
in water snakes (Wasser, 1990) in which no seasonal varia-
tions in protein occurred. Glycogen or lipid may be possible
factors to be utilized by sea turtles during short-term starva-
tion as has been seen in hibernating snakes and mammals
(Wasser, 1990) or other reptilian species (Derickson, 1976).
It may be hypothesized that our sea turtles use glucose from glycogen or lipid during the first phase of starvation for a month or so and thereafter they catabolize spared protein for the later phase of starvation. Reptiles, like fishes, are known to be able to survive prolonged periods of starvation, whether or not they hibernate (Bonnet, 1979). Starvation may induce a slower decline in glucose level so that the animals can prepare for long periods of starvation with a gradual decrease in glucose utilization (Machado et al., 1989). From results of the experiments in which animals fed a high-protein diet maintained constant blood glucose level, it is assumed that the rate of glucose utilization may be related to protein content in a diet. Other factors involved in glucose metabolism in response to starvation or increased feeding are temperature, season, or sex (Sheridan and Mommesen, 1991). It is not known which one affects glucose metabolism in sea turtles. Whether they store protein, glycogen, or lipid, no doubt depends on the life history of the animals. Their activity and the usual duration of fasting may determine which nutrient system they mobilize to best advantage (Sheridan and Mommesen, 1991).

In summary, it is concluded that in sea turtles, nutritional status affects plasma thyroid hormones and glucose level, but not protein level. As for the thyroid function, plasma T<sub>3</sub> level and the ratio of T<sub>3</sub>/T<sub>4</sub> did not change in consistent ways in relation to nutrition. Plasma T<sub>3</sub> tended to decrease during starvation and increase with refeeding or increased feeding, suggesting that deiodination of T<sub>4</sub> is facilitated by food intake (Eales, 1988). Further studies on deiodination activity in sea turtle thyroid system will be of interest. Blood glucose level falls with deprivation of food, but remains constant during increased feeding. No significant changes in blood protein level between control and experimental groups were observed under any nutritional condition in the present study. Sea turtles may use glycogen or lipid for energy during short-term starvation.

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