

Standard Article

J Vet Intern Med 2016;30:1780–1789**Evaluation of Body Weight, Body Condition, and Muscle Condition in Cats with Hyperthyroidism**

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Background: The contribution of fat loss versus muscle wasting to the loss of body weight seen in hyperthyroid cats is unknown.

Objectives: To investigate body weight, body condition score (BCS), and muscle condition score (MCS) in hyperthyroid cats.

Animals: Four hundred sixty-two cats with untreated hyperthyroidism, 117 of which were reevaluated after treatment.

Methods: Prospective cross-sectional and before–after studies. Untreated hyperthyroid cats had body composition evaluated (body weight, BCS, and MCS). A subset of these cats were reevaluated 3–12 months after treatment when euthyroid.

Results: Pretreatment body weight (median, 4.36 kg; IQR, 3.5 to 5.2 kg) was lower than premorbid weight (5.45 kg; IQR, 4.6 to 6.4 kg, $P < .0001$) recorded 1–2 years before diagnosis. 154 (35.3%) cats were thin or emaciated; 357 (77.3%) had loss of muscle mass. Cats showed increases in body weight (median, 4.1 kg to 5.0 kg), BCS (median, 3/5 to 3.5/5), and MCS (2/3 to 3/3) after treatment ($P < .001$), but mild-to-moderate muscle wasting persisted in 45% of treated cats.

Conclusions and Clinical Importance: Most hyperthyroid cats lose body weight but maintain an ideal or overweight BCS, with only a third being underweight. As in human hyperthyroid patients, this weight loss is associated with muscle wasting, which affects >75% of hyperthyroid cats. Successful treatment leads to weight gain and increase of BCS in most cats, but almost half fail to regain normal muscle mass.

Key words: Body composition; Dietary protein; Feline; Muscle condition; Sarcopenia; Thyroid gland.

Hyperthyroidism is a catabolic state associated with increased energy expenditure,^{1,2} increased lipolysis,^{3,4} and increased protein turnover.^{5,6} These metabolic effects commonly lead to loss of body weight associated with a decrease in both fat stores and lean body mass. In untreated hyperthyroid human patients, initial weight loss is predominantly caused by a decrease in lean body mass (primarily muscle), rather than loss of fat.^{7–9} After successful treatment, lost muscle mass is restored first, before that of the fat deposits.^{7,9–13}

In hyperthyroid cats, weight loss has long been recognized as a classical feature of the disease, but muscle wasting is only rarely mentioned as a clinical feature of feline hyperthyroidism.^{14,15} Furthermore, these descriptions are based on early studies of feline hyperthyroidism, in which most cats were very thin to emaciated.^{16–18} Today, however, clinicians diagnose hyperthyroid cats at an early or mild stage of disease, with only minimal weight loss or other clinical signs,

Abbreviations:

BCS	body condition score
MCS	muscle condition score
T ₄	thyroxine
T ₃	triiodothyronine
fT ₄	free T ₄
TSH	thyroid-stimulating hormone
IQR	interquartile range
CKD	chronic kidney disease

before being treated.^{14,19} If these mildly affected cats are similar to humans, preferential loss of muscle mass over fat mass might be expected. However, the contribution of fat and muscle wasting to the overall loss of body weight in hyperthyroid cats is not known.

Our aim in this study was to investigate the body weight, body condition score (BCS), and muscle condition score (MCS) in a large population of cats with untreated hyperthyroidism to determine the prevalence of an underweight condition and muscle loss in this disease. Our second aim was to prospectively follow-up a subset of these cats to examine the effects of successful radioiodine treatment on their body weights, as well as their body and muscle condition scores.

Materials and Methods**Selection of Animals and Study Design**

This study was conducted in 2 parts. The first was a prospective cross-sectional study conducted from June 2013 to December 2015, and included hyperthyroid cats referred to the Animal Endocrine Clinic for evaluation before radioiodine treatment. The second was a before–after study^{20,21} involving a subset of the cats from the initial study that returned for reevaluation 3–12 months after treatment with radioiodine.

Initial Cross-Sectional Study. To be eligible for inclusion, hyperthyroid cats had to undergo a thorough evaluation that included

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Where Work was Performed: Animal Endocrine Clinic, New York, New York, USA. Animal Endocrine Clinic Institutional Animal Ethics Committee approved the study.

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review of the past medical record, detailed owner medical and dietary history, complete physical examination, routine laboratory testing (CBC and serum biochemical profile), and determination of serum thyroid panel (thyroxine [T₄], triiodothyronine [T₃], free T₄ [fT₄], and thyroid-stimulating hormone [TSH]).^{22,23} All study cats also underwent quantitative thyroid scintigraphy, which was used as the reference standard to confirm hyperthyroidism.^{23–25}

Cats were ineligible for inclusion if their hyperthyroidism had been well controlled, as demonstrated by normalization of serum T₄ concentration with methimazole or a low-iodine diet within the last 3 months, if concurrent nonthyroidal disease, such as azotemia, was detected, if no premorbid weight was available, or if the diagnosis was not confirmed with quantitative scintigraphy. Cats that were resistant or refractory to the effects of methimazole, with persistent and generally severe hyperthyroidism, were not excluded from this study.

On the day of treatment with radioiodine, body weight was determined to 0.05 kg with a calibrated digital scale,^a which was regularly validated for accuracy with test weights (2, 4, and 8 kg). This hyperthyroid body weight was compared to the last known premorbid body weight, extracted from the referring veterinarian's or owner's record. Each cat was then assigned a BCS by 2 investigators (MEP and CAC) who independently scored each cat with a 5-point system (1 = emaciated; 2 = too thin; 3 = ideal weight; 4 = too fat; 5 = obese),^{26–28} with results averaged. Finally, each cat was also assigned a MCS with a 4-point system (0 = severe muscle wasting; 1 = moderate wasting; 2 = mild wasting; 3 = normal muscle mass).^{28–30} This MCS evaluation includes visual examination and palpation of muscle mass over the spine, scapulae, skull, and wings of the ilia, as previously described.^{28–30}

Before–after Study. All owners of cats enrolled in the initial cross-sectional study were encouraged to return to the Animal Endocrine Clinic for a recheck examination at 3–6 months after treatment with radioactive iodine. Only cats available for recheck were included in this before-and-after study. All of these cats again underwent a thorough evaluation, which included a review of the medical and dietary history since time of ¹³¹I treatment, complete physical examination, serum biochemical testing (including creatinine and urea nitrogen), and determination of serum T₄ and fT₄ concentrations. All cats were carefully reweighed and then had BCS and MCS again assigned by the same 2 investigators who independently scored each cat without knowledge of the cats' pre-treatment BCS, MCS, or response to ¹³¹I treatment.

Based on results of post-treatment thyroid testing, we classified cats as euthyroid (defined as normal serum T₄ and fT₄ concentrations) or persistently hyperthyroid (high serum T₄ and fT₄ concentrations). Cats were ineligible for inclusion in this part of the study if they had low serum T₄ and fT₄ concentrations (consistent with overt hypothyroidism).

Data and Statistical Analyses

All statistical analyses were performed by proprietary statistical software.^{b,c} Data were assessed for normality by the D'Agostino–Pearson test and by visual inspection of graphical plots.³¹ Data were not normally distributed; therefore, all analyses used non-parametric tests.³² Results are reported as median (IQR, 25th–75th percentile) and are represented graphically as box-and-whisker plots and bar graphs. For all analyses, statistical significance was defined as $P < .05$.

For analysis, the untreated hyperthyroid cats were further categorized into 3 equal-sized groups (quantiles) of disease severity based on total T₄ concentration (i.e., mild, moderate, and severe disease).³³ The cats were also divided into 3 groups based upon their age stage (i.e., mature [7–10 years], senior [11–14 years], or geriatric [≥ 15 years]).^{34,35} Finally, the cats were divided into 4

groups based upon the type of diet fed (i.e., only canned or wet commercial cat food; only dry commercial cat food; both canned and dry food; or home-prepared or raw meat).

Continuous variables were compared between groups by the Mann–Whitney U or Kruskal–Wallis tests; comparisons between 2 or more measurements within a group (before–after) were compared with a Wilcoxon signed ranks or Friedman test,³² followed by the Dunn's multiple comparisons test.³⁶ Categorical variables were compared among groups by the chi-square test (or Fisher's exact test, where appropriate) and within a group for correlated proportions (before–after) by the McNemar's test.³⁷ Correlation testing was performed by Spearman rank correlation coefficient.

Results

Study 1 (Cross-Sectional Study, Untreated Hyperthyroid Cats)

Signalment, Clinical, and Laboratory Findings. During the 2.5-year study period, we evaluated 786 hyperthyroid cats, of which 462 met the eligibility requirements (Fig 1). The 462 study cats ranged in age from 7 to 18 years (median, 13 years; IQR, 11 to 14 years). When divided into 3 groups based on age stage, 91 cats (20%) were mature, 275 (60%) were senior, and 96 (21%) were geriatric.

Breeds included domestic longhair and shorthair ($n = 413$; 89%), Siamese (17), Maine Coon (12), Persian (3), Scottish Fold (3), Burmese (2), Norwegian Forest Cat (2), and one cat of each of 10 other breeds (Abyssinian, American Curl, Bengal, Bombay, Devon Rex, Korat, Oriental, Ragdoll, Russian Blue, and Tonkinese). Of these, 236 (51.1%) were male and 226 were female; all had been neutered.

Common historical signs reported of these cats included weight loss despite an increased appetite, vomiting, increased activity, and polydipsia/polyuria (Table 1). Diet fed consisted of a variety of both moist and dry commercial cat foods to 298 (65%), moist only to 110 (24%), dry only to 46 (10%), and home-prepared or raw meat diet to 8 (1.7%) cats. On physical examination, the most frequent findings included palpable enlargement of one or both thyroid lobes, muscle wasting, and thin body condition.

The most common abnormalities detected on routine laboratory testing were high levels of serum alanine transferase (median, 121 U/L; reference interval [RI], 10–100 U/L) and alkaline phosphatase (median, 57 U/L; RI, 10–100 U/L) activities (Table 1). Median serum concentrations of T₄, T₃, and fT₄ were high, whereas the median serum TSH concentration was undetectable (Table 2). Almost all cats had high serum concentrations of T₄ and fT₄, together with undetected TSH concentrations (Table 1). When subdivided into 3 equal-sized groups (154 each) based on the magnitude of the cats' serum T₄ concentrations, the mild disease group had serum T₄ concentrations ≤ 7.2 $\mu\text{g/dL}$, the moderate group had T₄ concentrations ranging from 7.3 to 11.4 $\mu\text{g/dL}$, and the severe group had serum T₄ concentrations ≥ 11.5 $\mu\text{g/dL}$.

Body Weight. The 462 untreated hyperthyroid cats weighed less (median, 4.36 kg; IQR, 3.5–5.2 kg) than

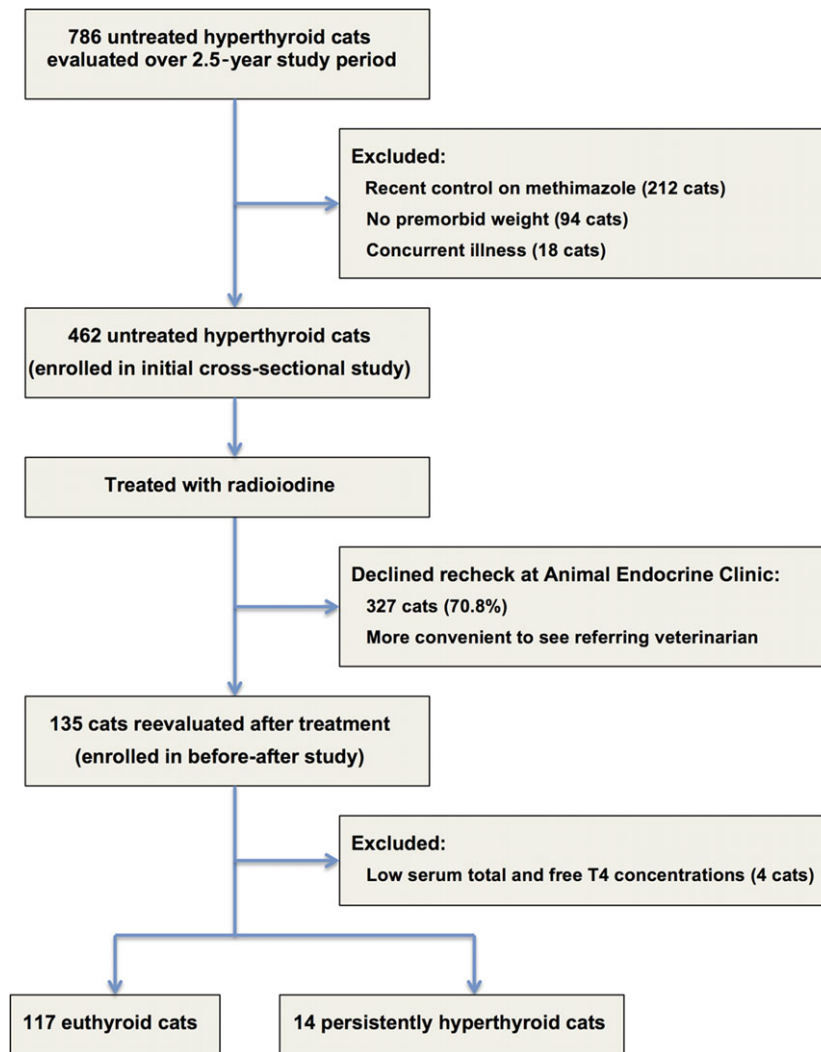


Fig 1. Flowchart for enrollment of hyperthyroid cats into study 1 (cross-sectional study of untreated cats) and study 2 (before–after treatment).

they had 1–2 years before diagnosis of hyperthyroidism (5.45 kg; IQR, 4.6–6.4 kg; $P < .0001$). The most severely hyperthyroid cats weighed less (4.1 kg) than the cats with mild or moderate hyperthyroidism (4.6 kg or 4.4 kg; $P = .025$).

Similarly, geriatric cats weighed less (median, 3.7 kg) than did the senior or mature cats (4.4 kg or 4.5 kg; $P = .0003$). This difference in body weight between the 3 age groups was unrelated to severity of hyperthyroid disease because the serum T_4 concentrations in the lighter geriatric cats (7.9 $\mu\text{g/dL}$) was significantly lower than concentrations in the heavier senior or mature cats (8.6 $\mu\text{g/dL}$ or 10.1 $\mu\text{g/dL}$; $P = .022$). Finally, diet type (canned, dry, both canned and dry, or home-made or raw) had no detectable effect on bodyweight ($P = .25$).

Body Condition Scores. Of the 462 cats with untreated hyperthyroidism, 160 (35%) had a low BCS (i.e., thin to emaciated), 228 (49%) had an ideal BCS, and 74 (16%) had a high BCS (too fat to obese). Serum T_4 correlated negatively (but weakly) with BCS

($r = -0.152$; $P < .001$). When the 462 cats were subdivided into 3 groups of disease severity based on the magnitude of the serum T_4 value, prevalence of low BCS (too thin) increased with severity of disease ($P = .008$, Fig 2A).

Age also correlated negatively and weakly with BCS ($r = -0.247$, $P < .0001$). When the 462 cats were subdivided into 3 groups based on their life stage (mature, senior, or geriatric), prevalence of low BCS was significantly higher in geriatric cats than the senior or mature groups ($P = .009$; Fig 2B). However, diet type (canned, dry, both canned and dry, or home-made or raw) had no association with prevalence of any BCS ($P = .21$).

Muscle Condition Scores. Of the 462 cats with untreated hyperthyroidism, 105 (23%) had a normal MCS, whereas mild, moderate, and severe muscle loss was recorded in 176 (38%) 140 (30%), and 41 (9%), respectively. Serum T_4 concentrations correlated negatively but weakly with MCS ($r = -0.156$, $P = .008$). When the 462 cats were subdivided into 3 groups based

Table 1. Common historical signs, physical examination, and laboratory findings in 462 cats with untreated hyperthyroidism

Finding	Number of Cats	Percent of Cats (%)
Historical signs:		
Weight loss	425	92.0
Increased appetite	253	54.8
Vomiting	216	46.8
Hyperactive	190	41.1
Polydipsia/polyuria	152	32.9
Diarrhea/increased fecal volume	95	20.6
Decreased activity	60	13.0
Heat intolerance	59	12.8
Physical examination findings:		
Palpable thyroid nodule	450	97.5
Muscle wasting	356	77.1
Thin body condition	160	34.6
Dental disease	206	44.6
Tachycardia (≥ 240 bpm)	145	31.4
Cardiac murmur	134	29.0
Laboratory findings:		
High alanine aminotransferase	261	56.5
High alkaline phosphatase	107	23.2
High aspartate aminotransferase	52	11.3
High hematocrit (PCV)	50	10.8
High serum T ₄	444	96.1
High serum fT ₄	450	97.4
High serum T ₃	281	60.1
Low serum TSH	453	98.1

on the magnitude of the serum T₄ value, the prevalence of moderate to severe muscle wasting increased with increasing severity of disease ($P = .0002$; Fig 3A).

Similarly, age correlated negatively but weakly with MCS ($r = -0.229$; $P < .001$). When the 462 cats were subdivided into 3 groups based on their life stage (mature, senior, or geriatric), prevalence of moderate to severe muscle wasting was higher in geriatric cats than the younger groups ($P < .0001$; Fig 3B). However, diet type showed no association with the prevalence of normal or low MCS ($P = .42$).

Study 2 (Hyperthyroid Cats, Before-and-After Treatment with Radioiodine)

Signalment and Serum Thyroid Hormone Findings. We were able to reevaluate 135 hyperthyroid cats 3–12 months after radioiodine treatment, of which 131

met the eligible requirements for this study (Fig 1). Of these, 117 were euthyroid and 14 were persistently hyperthyroid.

The 117 euthyroid cats ranged in age from 7 to 18 years (median, 12 years; IQR, 10–14 years). When these 117 cats were divided into 3 groups based on age stage, 30 cats were mature, 65 were senior, and 22 were geriatric. Breeds included domestic longhair and shorthair (109 cats), Siamese (2 cats), Maine Coon (2 cats), and 1 cat each of the following breeds (American Curl, Bombay, Devon Rex, Persian). Of these, 62 (53%) were female and 55 were male; all had been neutered. When these 117 cats were subdivided based on their severity of disease (when untreated), hyperthyroidism was mild (≤ 7.2 $\mu\text{g/dL}$) in 37, moderate in 38, and severe (≥ 11.5 $\mu\text{g/dL}$) in 42 cats. When reevaluated after treatment, the median serum T₄ concentration had decreased from 9.2 $\mu\text{g/dL}$ to 1.7 $\mu\text{g/dL}$, whereas the fT₄ concentration had decreased from 95 pmol/L to 17 pmol/L ($P < .0001$). At the time of follow-up evaluation, serum concentrations of T₄ and fT₄ were within reference intervals in all 117 of these euthyroid cats.

The 14 cats with persistent hyperthyroidism ranged in age from 10 to 20 years (median, 14.5 years; IQR, 11 to 17 years). All were domestic longhair or shorthair. Of these, 7 were female and 7 were male. When these 14 cats were subdivided based on their severity of disease (when untreated), hyperthyroidism was mild in 2, moderate in 4, and severe in 8 cats. When reevaluated after treatment, the median serum T₄ concentration had decreased from 13.2 $\mu\text{g/dL}$ to 5.9 $\mu\text{g/dL}$, whereas the fT₄ concentration had decreased from 100 pmol/L to 64 pmol/L ($P = .002$). However, post-treatment serum concentrations of T₄ and fT₄ remained high in all 14 of these cats with persistent hyperthyroidism.

Body Weight. In the 117 euthyroid cats reevaluated 91–358 days (median, 204 days; IQR, 178–234 days) after treatment, median body weight increased from 4.1 kg (IQR, 3.5–5.2 kg) to 5.0 kg (IQR, 4.1–6.1 kg) ($P < .0001$; Fig 4), with a median weight gain of 0.6 kg (IQR, 0.4–1.0 kg; range, 0.0–3.0 kg). Fifty-three (45%) of the 117 cats regained $>90\%$ of the weight lost when hyperthyroid; only 4 cats (3.4%) showed $<15\%$ weight gain. Although higher than the hyperthyroid weight, the median post-treatment body weight remained lower than pre-morbid body weight (5.3 kg; IQR, 4.3–6.3 kg; $P < .001$) (Fig 4).

In contrast to the euthyroid cats, the 14 cats with persistent hyperthyroidism showed no significant change

Table 2. Median (IQR) serum concentrations of T₄, T₃, fT₄, and TSH in 462 cats with untreated hyperthyroidism (divided into 3 quantiles of disease severity based on T₄ concentrations)

Cat Group	Serum T ₄ ($\mu\text{g/dL}$)	Serum T ₃ (ng/dL)	Serum fT ₄ (pmol/L)	Serum TSH (ng/mL)
Hyperthyroid (462)	8.7 (6.5–12.9)	139 (89–224)	80 (68–100)	<0.03 (<0.03 – <0.03)
Mild (154)	5.7 (4.8–6.5)	76 (59–90)	64 (57–69)	<0.03 (<0.03 – <0.03)
Moderate (154)	8.7 (7.8–10.0)	141 (123–167)	81 (78–94)	<0.03 (<0.03 – <0.03)
Severe (154)	16.6 (12.9–20.9)	284 (232–372)	100 (100–100)	<0.03 (<0.03 – <0.03)
Clinically normal (131)	2.1 (1.7–2.6)	49 (40–60)	32 (26–38)	0.04 (<0.03 –0.07)

Reference intervals: T₄ = 0.9–3.8 $\mu\text{g/dL}$; T₃ = 35–120 ng/dL; fT₄ = 10–51 pmol/L; and cTSH = <0.03 –0.3 ng/mL.

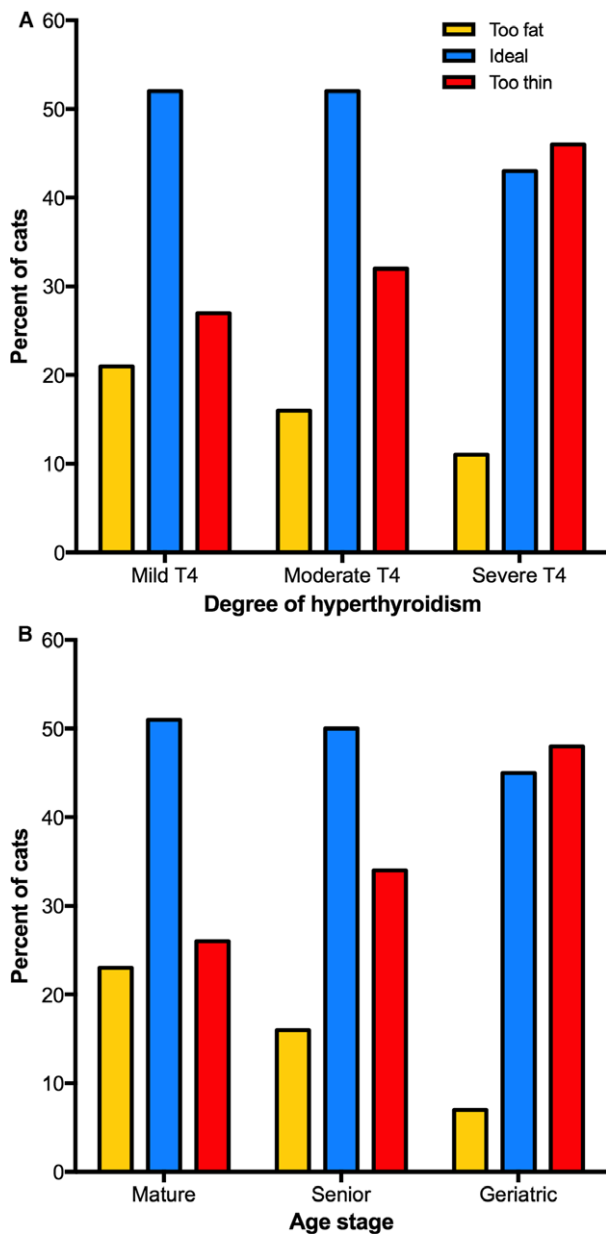


Fig 2. (A) Bar graphs depicting the BCSs of the 462 untreated hyperthyroid cats categorized into 3 equal-sized groups ($n = 154$) of disease severity based on total T_4 concentration (i.e., mild, moderate, and severe disease). In each of the 3 groups, the percentage of hyperthyroid cats with low (too thin), ideal, and high (too fat) BCSs is depicted. As the severity of hyperthyroid disease increases, notice that the prevalence of too-fat and ideal cats decreases, whereas prevalence of thin cats increases ($P = .008$). (B) Bar graphs depicting the BCSs of the 462 untreated hyperthyroid cats categorized into 3 groups based on their life stage (mature, senior, or geriatric). As the age stage of the cats increases from mature to geriatric, notice that the prevalence of fat cats decreases, whereas the prevalence of thin cats increases ($P = .0087$).

in median body weight (4.2 kg vs. 3.9 kg; $P = .14$) when reevaluated 70–280 days (median, 171 days) after treatment with radioiodine. Only 3 of the 14 cats showed >15% weight gain, and none reached their pre-morbid body weight.

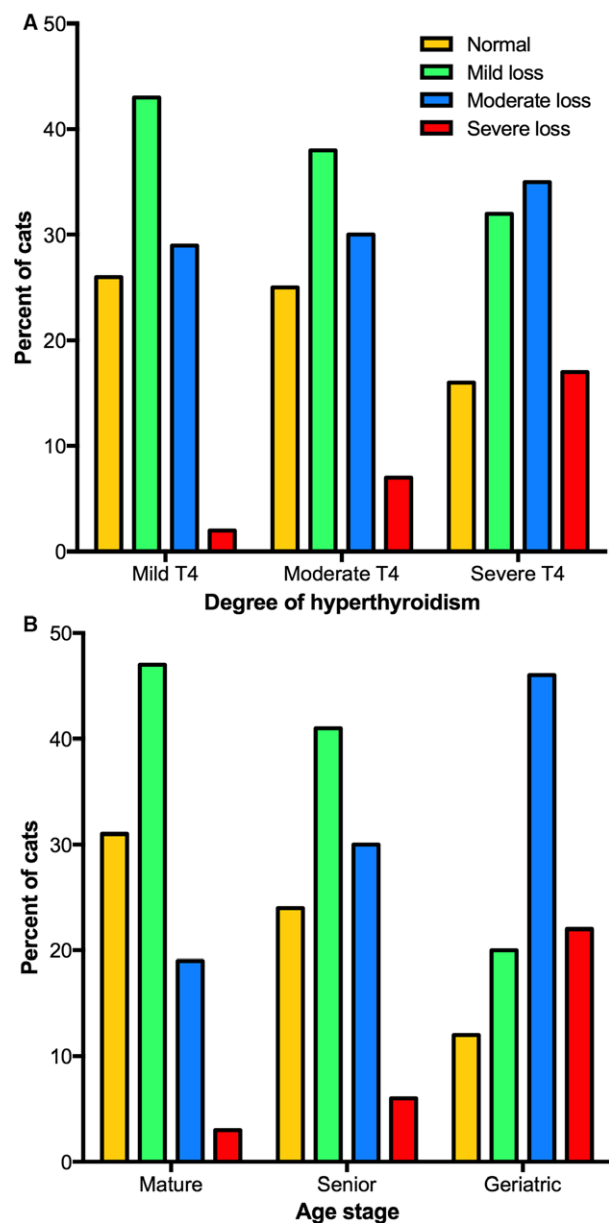


Fig 3. (A) Bar graphs depicting the MCSs of the 462 untreated hyperthyroid cats categorized into 3 equal-sized groups ($n = 154$) of disease severity (i.e., mild, moderate, and severe disease). In each of the 3 groups, the percentage of hyperthyroid cats with normal muscle mass, and mild, moderate, and severe muscle loss is depicted. As the severity of hyperthyroid disease increases, notice that the prevalence of normal muscle mass cats decreases, whereas the prevalence of moderate to severe muscle wasting increases ($P = .0002$). (B) Bar graphs depicting the MCSs of the 462 untreated hyperthyroid cats categorized into 3 groups based on their life stage (mature, senior, or geriatric). As the age stage of the cats increases from mature to geriatric, notice that the prevalence of normal muscle mass decreases, whereas the prevalence of moderate and severe muscle wasting increases ($P < .0001$).

Body Condition Scores. In the 117 euthyroid cats reevaluated after treatment, BCS increased after treatment ($P < .001$). After treatment, the proportion of cats having an ideal or high BCS increased as those with low

BCS decreased ($P < .001$; Fig 5A). Of 43 cats (37%) that were considered too thin at time of hyperthyroidism, 37 increased BCS (to ideal BCS in 31), whereas 5 failed to increase BCS and remained thin despite a slight weight gain (0.15, 0.3, 0.5, 0.5, and 0.65 kg, respectively). Of the 11 (9%) euthyroid cats that remained thin after treatment, overt chronic kidney disease (CKD) was detected in 7 (serum creatinine concentrations, 2.2–3.4 mg/dL). The median age of the cats that had persistent low BCSs was significantly higher than the age of the cats with normal or high BCSs (14 vs. 12 years; $P = .016$). However, there was no significant difference between the prevalence of mature, senior, or geriatric age stage ($P = .15$) or type of diet fed ($P = .15$) in cats with normal or high BCSs vs those with persistent low BCSs.

In contrast to the euthyroid cats, the 14 cats with persistent hyperthyroidism showed no significant change ($P = .5$) in median BCS after treatment with radioiodine. All 7 cats that were too thin at time of initial reevaluation remained thin after treatment. In addition, 1 cat that had an ideal BCS on initial evaluation developed a low BCS after treatment.

Muscle Condition Scores. In the 117 euthyroid cats reevaluated after treatment, MCS increased significantly ($P < .001$). After treatment, the number of cats having a normal MCS increased, whereas the number of cats with muscle wasting decreased ($P < .001$; Fig 5B). Of the 117 cats, 93 (80%) cats originally had a low MCS; after treatment, MCS normalized in 42 (45%) of the 93 cats, increased but remained low in 35, and showed no change in 16. Of the 51 euthyroid cats that remained muscle wasted after treatment, overt CKD was detected in 17. Of the 93 cats that had originally had a low

MCS, there was no difference in median follow-up times between the 42 treated cats that normalized muscle mass and the 51 cats with persistent muscle wasting (203 vs 210 days; $P = .36$).

Compared to the 67 treated cats with normal MCSs, the cats with persistent muscle wasting were older (13 vs 12 years; $P < .01$) and had a higher proportion of senior and geriatric age stages ($P < .0001$). However,

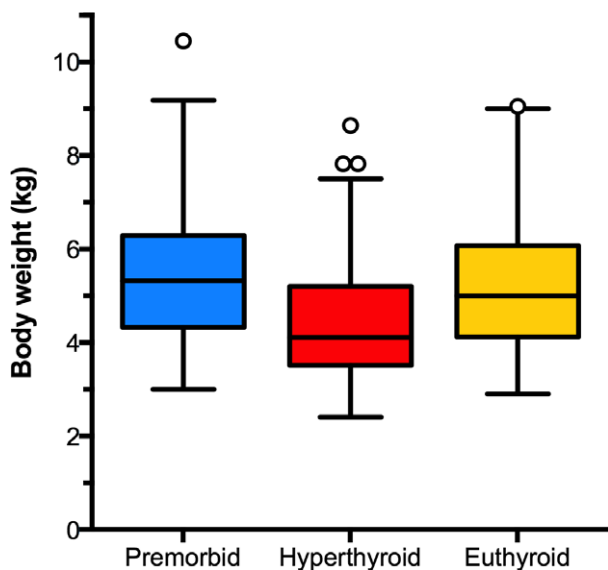


Fig 4. Box plots of premorbid, hyperthyroid, and post-treatment (euthyroid) body weights in 117 cats evaluated before and after the successful treatment with radioiodine. Notice that the cats' premorbid body weight fell significantly ($P < .0001$) when hyperthyroid, whereas the post-treatment, euthyroid weight increased significantly ($P < .001$) to levels similar to premorbid weight.

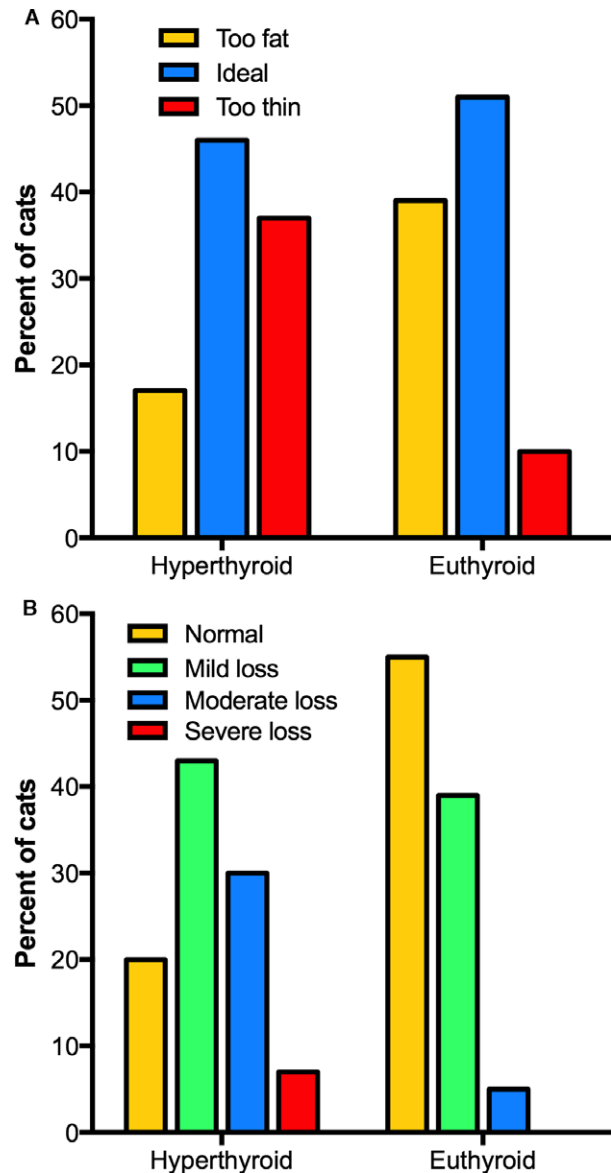


Fig 5. Before and after BCSs and MCSs of 117 cats reevaluated after successful treatment with radioiodine. (A) Bar graphs depicting the percentage of cats with low (too thin), ideal, and high (too fat) body condition scores. After treatment, notice that the prevalence of normal and overweight cats increased, whereas underweight cats decreased ($P < .001$). (B) Bar graphs depicting the percentage of cats with normal muscle mass, and mild, moderate, and severe muscle wasting. After treatment, notice that the prevalence of normal muscle mass increased, whereas mild, moderate, and severe muscle wasting decreased ($P < .001$). Severe muscle wasting did not persist in any of the cats after treatment.

there was no significant difference ($P = .34$) between the types of diet fed to cats with normal or low MCSs.

In contrast to the euthyroid cats, the 14 cats with persistent hyperthyroidism showed no significant change ($P = .5$) in median MCS after treatment with radioiodine. These 14 cats had mild ($n = 6$) or moderate ($n = 8$) muscle wasting at time of initial reevaluation, and all had persistent muscle wasting after treatment, with no improvement in MCS.

Discussion

Our results indicate that most hyperthyroid cats lose body weight but maintain an ideal or high (overweight) BCS, with only a third being too thin. As in human hyperthyroid patients, this weight loss appears to be largely because of muscle wasting, affecting >75% of hyperthyroid cats. Resolution of hyperthyroidism leads to weight gain and increased BCS in most cats, but many fail to completely regain normal muscle mass. Severe hyperthyroidism and geriatric age both appear to contribute independently to the prevalence of low BCSs and MCSs in these cats.

Our findings are similar to those observed in human hyperthyroid patients. Skeletal muscle is an important target of thyroid hormone action.³⁸ In humans and experimental animals, hyperthyroidism accelerates whole body protein turnover and catabolizes muscle tissue.^{5,39-43} This leads to loss of muscle mass, which has long been recognized as an important clinical feature in human hyperthyroid patients.⁴⁴⁻⁴⁶ In fact, human hyperthyroid patients lose body weight mainly caused by loss of muscle mass, with loss of fat mass playing only a modest role.^{7,9-13} After treatment, weight is regained primarily by restoring lost muscle mass, together with a lesser gain in fat mass.^{7,9-13} In hyperthyroid cats, loss of muscle mass may also be of greater importance than fat loss, especially in the earlier stages of the disease. The importance of muscle wasting to overall weight loss was not well appreciated in early publications of feline hyperthyroidism,¹⁶⁻¹⁸ probably because cats of those reports generally had more chronic and severe disease in which marked loss of fat as well as muscle mass would be expected.

Hyperthyroid cats are currently being diagnosed at an earlier and milder stage than they were over two decades ago when we last reported an update on the prevalence of clinical and laboratory findings in untreated hyperthyroid cats examined in the New York City area.⁴⁷ Weight loss remains a very common sign (92%), but the prevalence of thinness (low BCS) has essentially halved, from 65% in 1993 to only 35% in this study.⁴⁷ In fact, a considerable number of hyperthyroid cats diagnosed today are overweight or even obese (16% in the present series), a finding never reported in earlier case series.^{16-18,47}

Clinically, body weight is a precise, repeatable, and objective measurement.^{48,49} When body weight is monitored regularly over months to years, it is a highly sensitive measure (especially when the same calibrated scale is consistently used), allowing one to detect even slight

weight loss (e.g., as cats develop early or mild hyperthyroidism). For a primary care practitioner who lacks confidence in performing body condition scoring (which is both subjective and imprecise), or for a multidisciplinary hospital in which different veterinarians examine a cat over time, use of body weight as an early warning indicator for health status is arguably the best approach. Finding subtle changes in body weight can alert the clinician to take a closer look (especially at BCS and MCS), as well as to exclude underlying disease. Finally, body weight is also very useful in documenting expected weight gain on follow-up evaluation after treatment of hyperthyroidism; if the expected weight gain does not occur despite cure of the hyperthyroidism, concurrent nonthyroidal disease should be considered.

Despite the advantages of body weight measurement, our study shows that body weight alone fails to accurately reflect body composition or muscle-to-fat mass ratio. Furthermore, body weight comparisons across cat populations might fail to reflect body condition differences. Although cats have a more uniform body conformation than either dogs or humans, the ideal body weight of an adult cat can range between 2 and 7 kg, depending on breed, sex, and individual variation.^{50,51} Therefore, clinicians should combine body weight with body condition scoring, a widely accepted method that uses both visual observation and palpation of key anatomic features (e.g., fat cover over ribs, abdominal tuck) to assess the amount of body fat. Either a 5-point or 9-point BCS system is used to classify cats as too lean, ideal, or too fat.^{26-28,50,52,53}

However, it is important to realize that BCS classifications are designed to evaluate body fat, but not muscle mass.²⁶⁻²⁸ One might expect muscle wasting to only develop in lean cats (low BCS), but loss of muscle mass can also occur in cats with ideal or even high BCS. Our study supports this hypothesis, because only 35% of these cats were thin but over 75% displayed muscle wasting. Therefore, along with evaluation of body fat with BCS, one should also evaluate muscle mass, especially if the cat is losing weight. Clinically, this is performed most easily with a 4-point muscle scoring system in which muscle mass is accessed at four sites: the skull (temporal muscles), the scapulae, the spine (epaxial muscles), and the wings of the ilia—areas that are relatively devoid of fat and therefore tend to reflect muscle mass rather than fat mass.^{28-30,54}

In these hyperthyroid cats, both increasing disease severity and age were associated with a lower body weight, as well as a higher prevalence of low BCS (thinness) and low MCS (muscle wasting). The finding that cats with severe hyperthyroidism weighed less, were thinner, and were more muscle wasted might be predicted, given the known physiological effects of thyroid hormone excess on energy expenditure and muscle and fat loss.^{2,4,6} Studies suggest that older cats (especially those >15 years) tend to lose body weight as they age,^{55-57,d} which may at least partially explain why these geriatric cats were thinner and had more muscle wasting than the younger hyperthyroid cats. This aging process might also explain why many of these treated cats failed

to return to their pre-morbid weight, recorded one to two years earlier. Even though severity of disease and older age were independently associated with thinness and muscle wasting, the median serum T_4 concentration in these geriatric cats was actually lower than T_4 concentrations in the younger cat groups, suggesting that age and severity of disease are independent risk factors for fat and muscle loss in hyperthyroid cats.

There are many reasons why senior and geriatric cats might lose weight, including higher daily energy requirements, reduced ability to digest fat and protein, and increased protein turnover.^{55-59,d} In addition, changes in olfaction or taste or presence of dental disease may lead to a decrease in appetite and subsequent weight loss. Approximately half the cats in our study had dental disease, but it did not appear to decrease their appetite, at least while hyperthyroid. Old cats also tend to lose muscle mass and develop sarcopenia,⁶⁰⁻⁶² which is also likely related to their decreased ability to digest protein and increased protein turnover, leading to a negative protein balance. Again, hyperthyroidism would be expected to accelerate this age-related loss of muscle mass caused by the catabolic effects of thyroid hormone excess on muscle tissue.^{5,6}

Inadequate protein intake by older cats could play a role in pathogenesis of aged-related sarcopenia. Recently, Laflamme and Hannah⁶³ reported that young adult cats (aged 2–8 years) require >5 g protein/kg body weight per day ($\approx 34\%$ of daily caloric intake as protein) to maintain lean body (muscle) mass. Older senior and geriatric cats appear to require amounts of protein even higher than this to support total body protein turnover and maintain normal muscle mass.^{64,c} In our study, most pet owners fed their cats a combination of both canned and dry foods, generally with multiple flavors or brands of cat food, or both. Therefore, it was impossible to estimate the exact protein intake of these cats; however, as most over-the-counter cat foods only contain moderate amounts of protein, it is highly unlikely that most cats ingested a protein intake even close to the recommended amount of >5 g/kg/d. Very few of our owners fed diets known to contain high amounts of protein, as would be needed to fulfill the protein requirements and maintain normal muscle mass, especially in aging cats.

After successful treatment, many of these cats regained both lost fat and muscle mass. However, not all of these treated, euthyroid cats returned to their pre-morbid weight; some remained thin (about 10%), and almost half remained muscle wasted. In human hyperthyroid patients, lost muscle mass can take several months to recover after successful treatment, so it is possible that additional increases in body weight or muscle mass might occur in these treated cats if studied over a longer time. However, median follow-up time in the 131 treated cats was >6 months, with no difference in follow-up time between cats that normalized muscle mass and those that did not. Therefore, failure to completely regain lost weight or restore lost muscle mass is also likely related to aging per se, and not all because of the prior hyperthyroid state alone. In addition, daily

dietary protein intake in most of these cats was below that recommended to maintain lean body mass, so relative protein deficiency likely played a role in the failure of some cats to fully recover lost muscle mass. Finally, about 25% of these treated cats developed evidence of chronic kidney disease (CKD) at time of follow-up, which may have contributed to failure to completely regain weight or restore lost muscle.⁶⁰

One limitation of our study was our use of subjective, semiquantitative methods to determine both BCS and MCS. Several other more objective techniques can be used to estimate body composition, including carcass composition analysis (not ideal for pet cats), deuterium oxide dilution, bioelectrical impedance analysis, quantitative magnetic resonance, ultrasonography, and dual-energy X-ray absorptiometry (DXA)^{53,65-69} Of these, DXA analysis is generally considered as the reference standard for estimating body composition for cats.^{52,66,67,69} However, the imaging equipment for DXA is not widely available, with its use generally limited to larger research institutions, and we do not have DXA at the Animal Endocrine Clinic. Regardless, DXA analysis measures overall lean body mass, which includes both visceral organs and smooth and skeletal muscle; skeletal muscle tissue accounts for only half of lean body mass,^{29,70,71} making the changes detected on DXA less specific for evaluation of muscle wasting. Nevertheless, additional studies to objectively quantitate muscle mass in hyperthyroid cats are warranted to verify the results of our study.

Another limitation of our study was its possible inherent bias, especially in the cats evaluated before and after the treatment. In our clinic situation, we were not blinded to the fact that the cats had been treated, and therefore, it is possible that this knowledge unconsciously biased our post-treatment MCSs (making them better than they actually were). We tried to compensate for this potential bias in 2 ways: first of all, we did all of our follow-up evaluations (body weight, BCS, and MCSs) without prior knowledge of the pretreatment body weight or body and muscle condition scores (i.e., we did not look up their pretreatment data until after our follow-up examination was completed). Additionally, we compared our follow-up results of these euthyroid cats to those of 14 cats with persistent hyperthyroidism, evaluated during the same period and at similar intervals as the 117 euthyroid cats, in which the radioiodine treatment failed to induce cure. Based on our results, the results clearly show that the changes in body weight, BCS, and MCS were caused by the cure of the hyperthyroidism, because little to no improvement in any of these parameters occurred in the cats with persistent hyperthyroidism. We do not believe we were biased in these evaluations, as we did not have the results of the serum thyroid function tests for 2–3 days, long after our physical examinations had already been completed.

Finally, other limitations include the questionable reliability of the pre-morbid weight measurements, which were recorded in hundreds of veterinary clinics on different scales, most of which were likely not calibrated.

We also had a wide range of follow-up times after treatment, ranging from 3 to 12 months. Although we had recommended that cats return for reevaluation between 3 and 6 months, many owners did not return until many weeks or even months later. Because this was a clinical study involving pet cats, we had limited control concerning which cats were reevaluated or the time period of when this evaluation took place.

In conclusion, most hyperthyroid cats evaluated in this study had evidence of weight loss but only a third were thin. However, muscle wasting was very common, suggesting that this contributed to a large proportion of the weight loss commonly reported in cats with hyperthyroidism. After successful treatment, not all cats returned to their premorbid weight, and about half remained muscle wasted. Future studies that use objective methods (e.g. DXA) to quantitate muscle mass in hyperthyroid cats, both before and after the treatment, are warranted to verify the results reported in this study.

Footnotes

- ^a Ohaus Digital Scale, Model ES30R Parsippany, NJ
^b GraphPad Prism, version 6.0; GraphPad Software, La Jolla, CA
^c MedCalc, version 14.12.0, MedCalc Software, bvbv, Ostend, Belgium
^d Cupp C, Perez-Camargo G, Patil A, et al. Long-term food consumption and body weight changes in a controlled population of geriatric cats (abstract). *Compend Contin Educ Vet* 2004;26(2A):60
^e Laflamme D. Protein requirements of aging cats based on preservation of lean body mass (abstract). In: 13th Annual American Academy of Veterinary Nutrition (AAVN) Clinical Nutrition & Research Symposium, Seattle, Washington 2013;17

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Off-label Antimicrobial Declaration: Authors declare no off-label use of antimicrobials.

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