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1 **Thyroid and Renal Function in Cats Post Low-dose (111Mbp) Radioiodine Therapy**

2

3 **Objectives:** To describe the effect of low-dose (111MBq) radioiodine therapy (RAI) on thyroid and
4 renal function in hyperthyroid cats over a 12 month follow-up period.

5 **Methods:** Client-owned hyperthyroid cats underwent treatment with low-dose RAI and were followed
6 for 12 months post-RAI treatment. Immediately prior to RAI treatment, and subsequently at one, six
7 and 12 months post-RAI treatment, thyroid function was evaluated using total thyroxine (TT4) and
8 thyroid stimulating hormone (TSH) and renal function was evaluated using serum creatinine
9 concentration and glomerular filtration rate (GFR).

10 **Results:** Fifteen of the 24 (63%) cats achieved euthyroidism following low-dose RAI treatment. The
11 incidence of development of overt hypothyroidism was 25% (6/24 cats). Of the cats developing overt
12 hypothyroidism, 3/6 (50%) had decreased renal function, with decreased GFR preceding development
13 of azotaemia in 2 out of 3 of these cats. Transient overt or subclinical hypothyroidism prior to
14 restoration of euthyroidism was not observed in any cats.

15 **Clinical Significance:** Low-dose RAI is effective for most cats with hyperthyroidism, however, overt
16 hypothyroidism may develop in some. Concurrent early decline in renal function may only be detected
17 by measuring GFR rather than serum creatinine in some patients. Monitoring of patients post-RAI
18 treatment should include TT4 and TSH with consideration of GFR measurement in non-azotaemic cats.

19

20 **Introduction**

21 Hyperthyroidism is the most commonly diagnosed endocrinopathy in cats with a reported prevalence of
22 8.7% in cats over 10 years old (Stephens and others 2014). Radioactive iodine (RAI) treatment is
23 widely considered the gold standard treatment of hyperthyroidism. The aims of RAI treatment are two-
24 fold; firstly to cure hyperthyroidism and secondly, to prevent the development of iatrogenic
25 hypothyroidism by administering the minimum effective RAI dose.

26 Between 15-51% of hyperthyroid cats develop azotaemia following restoration of euthyroidism
27 (Williams and others 2010, Reinsche and others 2008). Thyroid activity directly impacts renal function;
28 the hyperthyroid state increases glomerular filtration rate (GFR) and may consequently mask any prior
29 loss of renal filtration function, restoration of euthyroidism reduces GFR (Boag and others, 2007) and
30 hypothyroidism decreases GFR further (Panciera and Lefebvre, 2009).

31 Excessive thyroid suppression can lead to the development of subclinical hypothyroidism (increased
32 thyroid stimulating hormone [TSH] concentrations with total thyroxine [TT4] concentrations within the
33 normal reference interval) and overt hypothyroidism (increased TSH concentration and low TT4
34 concentrations) whilst clinical signs of hypothyroidism may not be apparent (Peterson and Becker,
35 1995).

36 Serum or plasma creatinine is routinely used as a marker of renal function, however, it is affected by
37 non-renal factors, principally muscle mass. The catabolic effects of hyperthyroidism cause muscle
38 atrophy and therefore creatinine may be an unreliable indicator of renal function in hyperthyroid cats.
39 Additionally, endogenous creatinine production is reduced in hypothyroid dogs (Panciera and
40 Lefebvre, 2009).

41 The greatest reduction in TT4 concentration is expected in the first month following RAI treatment
42 (Boag and others 2007, van Hoek and others 2008). Opposing activities may occur post-RAI treatment
43 to cause on-going changes in TT4 and TSH concentrations. These include atrophy of thyrocytes due to
44 sublethal RAI damage resulting in a gradual decrease in TT4 concentrations (Mooney, 1994) and
45 recovery of function of residual thyroid tissue resulting in an increase in TT4 concentrations.

46 Continued change in TT4 and TSH concentrations may occur over months to years, however this has
47 not been well documented in conjunction with renal function beyond six months in cats.

48 The aim of this study was to describe the effect of low-dose (111MBq) RAI therapy on thyroid and
49 renal function in hyperthyroid cats over a 12-month follow-up period.

50 **Materials and methods**

51 *Study population*

52 Client-owned hyperthyroid cats presenting to a University referral hospital for RAI therapy were
53 recruited prospectively into the study. The study was of observational cohort design with longitudinal
54 follow-up. Only cats that received a low dose of 111MBq RAI were included in the study. Cats were
55 excluded from the study if they required a different dose of RAI therapy (e.g. high dose carcinoma
56 treatment), were not amenable to handling for repeated blood sampling, had received anti-thyroid
57 medications within two weeks of presentation, had documented azotaemia prior to RAI therapy or were
58 fed a restricted iodine diet. Informed consent was obtained from the owners and the study was
59 conducted with approval from the University Animal Welfare and Ethics Review Board (UIN
60 UB/12/025).

61

62 *Longitudinal study design*

63 At recruitment into the study all cats were hyperthyroid. Cats were re-evaluated at one, six and 12
64 months post-RAI therapy. At recruitment into the study and at each subsequent time point the
65 following were performed; full clinical examination, pertinent history, systolic blood pressure
66 measurement by Doppler technique, blood sampling by jugular venepuncture for biochemistry and
67 haematology and urine sampling via either cystocentesis or free catch collection.

68

69 *Measurement of thyroid function markers*

70 Serum TT4 was measured at a commercial reference laboratory using the Immulite 1000
71 chemiluminescent immunoassay.ⁱ Serum TSH was measured at a commercial reference laboratoryⁱⁱ
72 using a previously validated canine assay (Wakeling and others 2008). Thyroid function was
73 categorised at the one, six and 12 month follow-up visits according to the following criteria: overt
74 hypothyroid TT4 <15 nmol/l, TSH >0.15 ng/ml (Wakeling and others 2011); subclinical hypothyroid
75 TT4 ≥15 – 60 nmol/l, TSH >0.15 ng/ml (Wakeling and others 2011); euthyroid TT4 ≤60 nmol/l, TSH
76 ≤ 0.15 ng/ml; hyperthyroid TT4 > 60 nmol/l, TSH <0.03 ng/ml.

77

78 *Measurement of renal function markers*

79 Glomerular filtration rate was determined using a previously described slope-intercept iohexol
80 clearance method (Finch and others 2011). Briefly, a bolus dose of iohexol (Omnipaque™ [647mg/ml;
81 300mg of iodine/ml]) was administered intravenously (0.5ml/kg). Blood samples were collected at 120,
82 180 and 240 minutes post-injection. Iohexol concentrations were determined at an external commercial
83 laboratory using a high performance capillary electrophoresis HPCE methodⁱⁱⁱ. Clearance was
84 determined as dose/AUC, where AUC is area under the plasma concentration versus time curve
85 determined using a one-compartment model. A previously validated cat specific correction formula for
86 slope-intercept clearance was applied to correct for the one compartment assumption (Finch and others
87 2011). In addition, serum creatinine concentrations were determined from a sample collected at the
88 same time as GFR measurement and measured at a commercial reference laboratoryⁱ. Decreased renal
89 function was defined as decreased GFR (<0.92 ml/min/kg; Finch, 2014) and/or azotaemia (serum
90 creatinine >175 µmol/l, the upper limit of laboratory reference interval for feline serum creatinine).

91

92 *Data analysis*

93 Descriptive statistics only were performed due to the small numbers of cats included in the study and
94 the high variability between cats that would limit the statistical power if performing inferential
95 statistics. Change in renal function over time was calculated by subtracting the measurement (serum
96 creatinine or GFR) at one time point from the previous time point (e.g. baseline – one month). The
97 within-individual coefficient of variation (CV) % was determined from measurements in individual
98 cats at all four time points and calculated as (SD/mean) x 100.

99

100 **Results**

101 A total of 27 cats were recruited to the study. Twenty-five cats completed the one and six-month
102 follow-up visit and 21 cats completed the 12-month follow-up visit. The median (range) age at
103 recruitment to the study was 11 (7 – 16) years. Of the 27 cats, 15 were female neutered, 11 were male

104 neutered and one was female entire. Twenty-six cats were domestic shorthair and one was domestic
105 longhair. One cat was excluded from longitudinal data analysis due to uncertain thyroid status. It was
106 thought this cat may have had euthyroid sick syndrome post-RAI therapy but a final diagnosis was not
107 available at euthanasia. Median (range) thyroid and renal function markers are presented in **Table 1**.
108 At recruitment to the study all cats were hyperthyroid with normal renal function (**Table 2**). Fifteen
109 (63%) cats achieved euthyroidism over the 12-month follow-up period. Two cats (8%) were
110 persistently hyperthyroid and required second RAI treatments. Five cats (21%) classified as
111 hyperthyroid at one-month post-RAI therapy were euthyroid by six months. Six cats (25%) developed
112 overt hypothyroidism (two at one month, two at six months, two at 12 months) and of these cats, none
113 regained thyroid function by the study end point or last follow-up visit. In two cats, development of
114 overt hypothyroidism was preceded by subclinical hypothyroidism. No cats developed transient overt
115 or transient subclinical hypothyroidism before euthyroidism, however, one cat had subclinical
116 hypothyroidism at 12 months and it is unknown whether this resolved. A summary of the longitudinal
117 data is presented in **Figure 1**. A total of seven cats (29%) developed decreased renal function. Of the
118 cats that developed overt hypothyroidism (n = 6), three (50%) developed decreased renal function and
119 one had borderline renal function (GFR 0.99 ml/min/kg, serum creatinine concentration 175 µmol/l).
120 Decreased GFR preceded development of azotaemia in 2/3 (67%) cats. The cat with subclinical
121 hypothyroidism at 12 months (n = 1) had decreased GFR and azotaemia at the six and 12-month revisit.
122 Of the cats that became euthyroid (n = 15), three (20%) had decreased GFR and normal creatinine at 12
123 months. Of these three cats, one had decreased GFR and normal creatinine at one, six and 12 months.
124 There was no decreased renal function in the cats that remained persistently hyperthyroid (n = 2). Mean
125 ± SD change coefficient of variation (CV) in renal function in the hyperthyroid, euthyroid and overtly
126 hypothyroid cats over each time point is presented in **Table 3**.

127 128 129 130 **Discussion**

131 The present study of cats receiving low-dose (111MBq) RAI that were followed for a maximum of 12
132 months post-RAI therapy identified development of overt hypothyroidism in 6/24 (25%), transient
133 overt or transient subclinical hypothyroidism before euthyroidism in 0% and persistent
134 hyperthyroidism in 2/24 (8%). All of the cats with subclinical hypothyroidism progressed to overt
135 hypothyroidism however, one cat (4%) developed subclinical hypothyroidism at the 12-month time
136 point and it is unknown whether this progressed to overt hypothyroidism or resolved. Of the six cats
137 that developed overt hypothyroidism, three (50%) developed decreased renal function, with decreased
138 GFR preceding azotaemia in 2/3 (67%) cats.

139
140 Variable RAI dosing enables individual dosing tailored to the patient, although this is not used in all
141 clinics treating cats with RAI; this study evaluated a standard fixed 'low' dose of 111MBq that was
142 used to treat cats at the clinic (however, since completion of the study, the protocol at the clinic has
143 changed to employ variable dosing). Published scoring schedules use the severity of hyperthyroid
144 clinical signs, TT4 concentrations and goiter size to guide doses, with low doses previously classed as
145 74-130MBq and 80-120MBq (Mooney, 1994; Peterson and Becker, 1995). In addition, some clinics
146 use scintigraphy for thyroid gland volume estimation to guide doses, however the optimal method is
147 undecided (Morre and others 2018).

148
149 A recent study comparing low (defined as 74 MBq) and standard dose (defined as 148 MBq) RAI
150 treatment for hyperthyroidism in cats reported the incidence of overt hypothyroidism to be 18% with
151 standard dose RAI and 1% with low dose RAI. It is important to note that a higher cut off for TSH
152 to define overt hypothyroidism was used compared to the present study (0.3 ng/ml versus 0.15 ng/ml)
153 (Lucy and others 2017). In the same study, the incidence of subclinical hypothyroidism was 46% in
154 cats treated with standard dose RAI and 21% in cats treated with low dose RAI. In the present study,
155 the incidence of development of overt hypothyroidism was higher (25%) and subclinical
156 hypothyroidism lower (4%). In two out of six (33%) of the cats that developed overt hypothyroidism in
157 the present study, it was preceded by subclinical hypothyroidism. Therefore, although the earlier study
158 (Lucy and others 2017) reported a much higher incidence of subclinical hypothyroidism, the study
159 period was only six months and it is possible that had the cats been followed longer, they could have
160 progressed to overt hypothyroidism. Conversely, 4/6 overtly hypothyroid cats in the present study
161 could be classed as mildly hyperthyroid at baseline (Petersen and Becker 1995), and these cats were
162 potentially excessively treated with 111MBq. Indeed, 111MBq may not be considered 'low-dose' when
163 compared to low doses used in other studies. The incidence of development of overt hypothyroidism

164 (25%) in the present study is in line with that of cats receiving medical management alone or in
165 combination with thyroidectomy (See Table 4). The incidence of development of subclinical
166 hypothyroidism (4%) is in line with the study by Williams and others (Williams and others 2010a) but
167 lower than the studies by Aldridge and others (Aldridge and others 2015) and Lucy and others (Lucy
168 and others 2017) (See Table 4). Differences in the incidence of subclinical and overt hypothyroidism
169 may partly be explained by the use of different assays to measure TSH in the studies and also the upper
170 reference limit of TSH and lower limit for TT4 used to define a cat as being hypothyroid (subclinical or
171 overt). Standardisation of both measurement of TSH and the definition of subclinical and overt
172 hypothyroidism would be helpful for on-going research into this important and evolving area of feline
173 hyperthyroid management.

174
175
176 In the present study, 4/6 (67%) of cats that developed overt hypothyroidism did so within the first six
177 months post-RAI therapy. Spontaneous recovery of thyroid function was not observed in any of the
178 overtly hypothyroid cats. In human patients developing hypothyroidism post-RAI, 86% do so in the
179 first 6 months and the rate is low after 12 months (3%/year) (Peacey and others 2012). Changes in
180 thyroid function in cats may occur longer than 12 months post-RAI therapy. Normalization of TSH and
181 TT4 has been reported over 3-21 months (median 6 months) and development of hypothyroidism after
182 18 months (Peterson and Rishniw, 2017). The rate of development of overt or subclinical
183 hypothyroidism and also recovery of thyroid function beyond 12 months in cats warrants further
184 studies.

185
186 Previous studies have reported the incidence of development of azotaemia within six months of
187 initiating medical management, RAI therapy or thyroidectomy for hyperthyroidism to be between 15%
188 and 51% (Becker and others 2000, Boag and others 2007, Graves and others 1994, Lucy and others
189 2017, Williams and others 2010a, Williams and others 2010b, Reinsche et al, 2008). In a previous
190 study of cats treated with standard dose RAI (148MBq) the incidence of azotaemia was 46% versus
191 29% in cats treated with low dose RAI (74MBq) (Lucy and others 2017). In cats with normal renal and
192 thyroid function at baseline, the incidence of development of azotaemia over 12 months is reported to
193 be between 11% (Finch and others 2016) and 30.5% (Jepson and others 2009). The present study found
194 the incidence of reduced renal function over 12 months to be 29%. Cats with iatrogenic
195 hypothyroidism are at increased risk of developing azotaemia compared to cats that remain euthyroid
196 (Williams and others 2010a). Of the overtly hypothyroid cats in the present study, 50% had reduced
197 renal function compared to 20% of euthyroid cats. In the overtly hypothyroid cats, decreased GFR
198 preceded development of azotaemia in 2/3 of the cats. However, as one of the hypothyroid cats had
199 both decreased GFR and azotaemia at the one-month time point when first identified to be overtly
200 hypothyroid, it is unknown whether a decline in GFR preceded azotaemia in this cat and therefore, it is
201 possible up to 100% of the overtly hypothyroid cats had a decline in GFR prior to development of
202 azotaemia. Of all of the cats in the study with reduced renal function, 71% remained non-azotaemic
203 despite having reduced GFR. These findings are unsurprising given the lack of sensitivity of creatinine
204 at detecting early decline in renal function (Finch 2014). However, in cats with hypothyroidism,
205 decreased endogenous creatinine production may also influence circulating creatinine concentrations.
206 This has been shown in dogs with experimentally induced hypothyroidism (Pancieria and Lefebvre
207 2009). The present study highlights the importance of measuring GFR rather than serum creatinine
208 concentration to accurately assess renal function in non-azotaemic cats with the potential to be
209 hypothyroid. Further studies are required exploring other markers of GFR such as SDMA.

210 The largest change in renal function was seen in the first month following RAI (see Table 3) and this is
211 in line with findings reported in previous studies (Boag and others 2007, van Hoek and others 2008).
212 The greatest within-individual variation in renal function over time occurred in the overtly hypothyroid
213 cats (see Table 3). This likely reflects that this was the group with the largest number of cats with a
214 decrease in renal function. A recent study reported the mean within-individual CV for GFR and serum
215 creatinine concentration to be 28.94 and 8.82% respectively in non-azotaemic cats and 19.98 and
216 6.81% in azotaemic cats (Finch and others 2018). It is interesting that the within-individual variation
217 for serum creatinine concentration was lower in the previous study compared to the present study. This
218 may reflect differences in the reference laboratories used to measure serum creatinine concentration or
219 may suggest there is greater variability in serum creatinine concentration in previously hyperthyroid
220 cats treated with RAI compared to euthyroid cats. Greater variability in serum creatinine is not
221 unexpected in cats that were previously hyperthyroid as change in muscle mass in such cats will be
222 associated with change in endogenous creatinine production

223 Correction of iatrogenic hypothyroidism resolved azotaemia in 50% of cats (Williams and others
224 2014). However, given that 2/3 (67%) of hypothyroid cats with decreased GFR were non-azotaemic in
225 the present study, it is possible that many cats with resolved azotaemia may still have reduced renal
226 function that is not detected by measuring serum creatinine concentration alone. Indeed, changes in
227 creatinine concentrations may simply be related to changes in endogenous creatinine production.
228 Hyperthyroid cats have been reported not to regain normal muscle mass following treatment for
229 hyperthyroidism, thus impacting on endogenous creatinine concentration (Peterson and others 2016).
230 Therefore, measurement of GFR may prove to be important in not only defining renal function and
231 guiding management of cats with iatrogenic hypothyroidism but also in monitoring renal function once
232 management has been initiated. Development of kidney disease is a predictor of negative outcome
233 following RAI therapy in cats (Slater and others 2001) and cats with iatrogenic hypothyroidism that
234 develop azotaemia have reduced survival compared to non-azotaemic cats without iatrogenic
235 hypothyroidism (Williams and others 2010a). Therefore, identifying a decline in renal function early in
236 cats with iatrogenic hypothyroidism and initiating appropriate management such as L-thyroxine is also
237 likely to be important in improving prognosis.

238
239 In the present study, two cats (8%) remained persistently hyperthyroid despite partial responses
240 necessitating second RAI treatments. This is comparable to a six-month prevalence of hyperthyroidism
241 of 7% reported by Morre and others in a group of cats also treated with 111MBq RAI (Morre and
242 others 2018). Of the two cats that remained persistently hyperthyroid in the present study, one had a
243 very high TT4 concentration pre-RAI (351 nmol/l) whilst the other hyperthyroid cat along with the
244 remainder of the cats in the study had TT4 <250 nmol/l. Based on this and unpublished data from cats
245 undergoing RAI therapy at the University referral hospital, the authors recommend that low dose RAI
246 (111MBq) be reserved for cats with mild to moderate hyperthyroidism (i.e. TT4 <250nmol/l).

247
248 The present study has a number of limitations. Firstly, the small numbers of cats included in the study.
249 Secondly, the follow-up period of only 12 months. However, this is the first study to provide data from
250 cats receiving RAI therapy for longer than six months follow-up using TSH in conjunction with TT4
251 concentrations to define thyroid status and GFR to assess renal function. Finally, the use of iohexol
252 clearance for GFR measurement prior to RAI therapy. Iodine containing contrast agents may interfere
253 with thyroid uptake of RAI. However, it has been shown that although cats pretreated with iohexol as
254 part of GFR measurement have decreased uptake of RAI, the effective half-life of RAI and therapy
255 outcome do not differ from cats not pretreated with iohexol (Peremans and others 2008).

256
257 To conclude, low dose (111MBq) RAI was associated with an incidence of development of overt
258 hypothyroidism of 25%. Thyroid function including TT4 and TSH should be monitored longer-term in
259 all cats that have undergone RAI as hypothyroidism can develop at variable rates in the first year post
260 treatment. In addition, renal function should ideally be monitored by GFR in non-azotaemic cats to
261 ensure early and accurate detection of any decline, particularly in cats with the potential to develop
262 hypothyroidism.

- 263
264 i) Langford Diagnostic Laboratories, Langford Vets, University of Bristol, Bristol, UK
265 ii) Royal Veterinary College Diagnostic Laboratory Services, Hawkshead, Hertfordshire, UK
266 iii) DeltaDOT Ltd, London BioScience Innovation Centre, London, UK

267
268 No conflict of interest has been declared

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