OPEN

Original article

Nuclear Medicine Communications

Prognostic factor analysis in 325 patients with Graves' disease treated with radioiodine therapy

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Introduction **^{131}I therapy is a choice for Graves' hyperthyroidism. Several factors that affect the success of ^{131}I treatment in Graves' disease (GD) patients have been put forward. The aim of this retrospective study was to evaluate the factors influencing the success of ^{131}I therapy and the occurrence of hypothyroidism after ^{131}I therapy.**

Patients and methods **We reviewed 325 GD patients, who were well documented out of 779 cases, treated with ^{131}I in the First Affiliated Hospital of Xi'an Jiaotong University between 2010 and 2016. We collected the potential influencing factors, including demographic data (age, sex, family history), iodine intake state, antithyroid drugs (ATD) taking, thyroid texture, complications of hyperthyroidism, physical and laboratory examinations [thyroid weight, effective ^{131}I half-life time (T_{eff}), 24-h iodine uptake rate, tri-iodothyronine, thyroxine, free tri-iodothyronine (FT3), free thyroxine, thyroid-stimulating hormone, thyroglobulin antibody, thyroid microsome antibody, thyrotropin receptor antibody], and final administered dosages according to Quimby formula. The correlations between the prognosis of GD patients and these factors were analyzed by logistic regression analysis.**

Results **Out of 325 patients, 247 (76.00%) were treated successfully with radioiodine. GD patients who were cured by ^{131}I therapy were more likely to have smaller thyroid [odds ratio (OR) = 0.988, 95% confidence interval (CI) = 0.980–0.996, $P = 0.002$], lower FT4 levels (OR = 0.993, 95% CI = 0.988–0.997, $P = 0.002$), and shorter time of ATD withdrawal before ^{131}I treatment (OR = 0.985, 95% CI = 0.975–0.996, $P = 0.002$). Hypothyroidism occurred in 132 (41.00%) out of 325 patients. There was an increased risk of early hypothyroidism in patients with lower 24-h iodine uptake (OR = 0.964, 95% CI = 0.941–0.988, $P = 0.004$), and treated with a lower total dose of iodine (OR = 0.892, 95% CI = 0.824–0.965, $P = 0.005$) and a higher iodine dose per garm of thyroid tissue (OR = 5.414E + 14, 95% CI = 45.495–6.444E + 27, $P = 0.027$).**

Conclusion **Our results showed that ^{131}I treatment was more successful in patients with lower weight of the thyroid, lower free thyroxine level, and shorter ATD taking period. Furthermore, early hypothyroidism after radioiodine treatment was more likely to occur in patients with lower 24-h iodine uptake, lower total dose of iodine, and higher iodine dose per garm of thyroid tissue.** ***Nucl Med Commun*** **39:16–21 Copyright © 2017 The Author(s). Published by Wolters Kluwer Health, Inc.**

Nuclear Medicine Communications 2018, **39**:16–21

Keywords: Graves' disease, hypothyroidism, ^{131}I therapy, logistic regression analysis

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Received 26 July 2017 **Revised** 11 September 2017
Accepted 12 September 2017

Introduction

Graves' hyperthyroidism is an organ-specific autoimmune disease characterized by abnormal increased thyroid hormone secretion, which is the result of genetic and environmental factors [1,2]. The incidence rate of Graves' disease (GD) in China is about 1.2% and the majority of patients are in the age range of 20–50 years [3]. There are three main methods of treatment for Graves' hyperthyroidism: antithyroid drugs (ATD), radioactive iodine (^{131}I) (RAI), and surgery [4,5]. Surgery is the most successful definitive treatment [6], but it is associated with the risk of recurrent laryngeal nerve injury or hypoparathyroidism [7]. ^{131}I therapy has been used successfully for the treatment of hyperthyroidism since 1940 [8]. It is an effective, practical, and inexpensive agent to permanently control hyperthyroidism. The objective of ^{131}I therapy is to cure Graves' hyperthyroidism by destroying enough thyroid tissue with a single ^{131}I dose and it is considered successful if euthyroidism or hypothyroidism is achieved after ^{131}I therapy. However, so far, there is no general consensus on the determination of ^{131}I dose. Some doctors suggested that ^{131}I should be administered at a fixed dose [9] and others

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proposed that the dose of ^{131}I can be calculated according to the formula [10]. The national guidelines in China for the treatment of GD proposed that the doctors should follow the principle of individual treatment when choosing a treatment regimen [11]. Antithyroid drugs are the first-line treatment for the first episode of GD in China. However, many patients cannot adhere to long-term medication, which may lead to a poor clinical outcome. China's endocrinologists have a relatively conservative approach toward ^{131}I treatment of hyperthyroidism [11].

Several factors that affect the success of ^{131}I treatment in GD patients have been put forward, such as the dose of ^{131}I administration, thyroid volume, age, thyroid uptake of ^{131}I, and the use of antithyroid drugs [12]. Some researchers have proven that thyroid volume has a significant influence on the success of treatment and the inefficiency of ^{131}I therapy is closely related to thyroid volume [13,14]. The effect of age on the outcome of ^{131}I treatment is still a matter of debate. Some studies did not find any significant association [15], whereas other studies suggested that older age is a risk factor for the poor outcome of ^{131}I therapy [16]. However, the impact of these factors on the success of ^{131}I treatment on GD patients remains largely unknown.

In the present study, we investigated the treatment condition of Graves' hyperthyroidism within our clinical practice to explore the clinical factors that may affect the outcome of ^{131}I treatment. The correlations between the prognosis of GD patients and these factors were analyzed to further optimize radioiodine treatment for individual patients with hyperthyroidism.

Patients and methods

Ethics statement

This is a retrospective clinical study. It presents a summary and analysis of a large number of clinical data. The study was approved by the Ethics Committee for Medical Research, Xi'an Jiaotong University and was carried out in accordance with the Good Clinical Practice. Informed consent was provided by all patients participating in this study.

Patients

A total of 325 GD patients were enrolled, including 12 patients with hyperthyroidism heart disease, 12 patients with periodic paralysis, and 13 patients with abnormal liver function, and treated with ^{131}I at the First Affiliated Hospital of Xi'an Jiaotong University between 2010 and 2016. Among these 325 patients, 239 were females and 86 were males. The average age of the female and male patients was 41.31 ± 12.42 and 41.73 ± 11.98 years, respectively.

Data collection

Before the administration of therapeutic ^{131}I, the patients had undergone routine eligibility examinations, including the assessment of standard clinical symptoms of GD, effective ^{131}I half-life in thyroid gland (T_{eff}), tri-iodothyronine (T3), thyroxine (T4), free tri-iodothyronine (FT3), free thyroxine (FT4), thyroid-stimulating hormone (TSH), thyroglobulin antibody (TGAb), thyroid microsome antibody (TMAb), thyrotropin receptor antibody (TRAb) as well as iodine uptake tests: 24-h (T_{24}). The therapeutic ^{131}I dose was calculated according to the Marinelli–Quimby formula [17]:

$$A = \frac{\text{Rad/g} \times G \times 8}{T_{\text{eff}} \times T_{24} \times 120},$$

where, A is the ^{131}I dose, G is thyroid weight, Rad/g is iodine dose per garm of thyroid tissue, T_{eff} is effective ^{131}I half-life in the thyroid gland, T_{24} is 24-h iodine uptake, W is thyroid weight), and ^{131}I was administered once according to the calculated dose and the patient's condition. Follow-up was performed at 3 months, 6 months, and 1 year after ^{131}I treatment. Most studies reported that 6 months of RAI administration was sufficient to stabilize thyroid functions [18–20]. Therefore, RAI therapy in the 325 patients with Graves' hyperthyroidism in our study was also administered after 6 months. The efficacy of treatment was presented as the percentage of patients with euthyroidism, hypothyroidism, or persistent hyperthyroidism within 6 months since radioiodine administration. We defined complete euthyroidism and hypothyroidism as 'cured' (cured group) and persistent hyperthyroidism as 'uncured' (uncured group). Similarly, we defined hypothyroidism as the hypothyroidism group, and euthyroidism and persistent hyperthyroidism as the nonhypothyroidism group.

Demographic and related clinical data were recorded, including age (named X_1), duration of Graves' hyperthyroidism (X_2), thyroid weight (X_3), T_{eff} (X_4), 24-h iodine uptake (X_5), the total dose of iodine in patients (X_6), T3 (X_7), T4 (X_8), FT3 (X_9), FT4 (X_{10}), TGAb (X_{11}), TMAb (X_{12}), TSH (X_{13}), the duration of ATD treatment before iodine administration (X_{14}), the number of weeks before ^{131}I administration antithyroid drugs should be withdrawn (X_{15}), iodine dose absorbed per gram of thyroid tissue (X_{16}), administration of iodine dose per gram of thyroid tissue (X_{17}), T4/T3 (X_{18}), FT4/FT3 (X_{19}), sex (X_{20}), family history of thyroid disease (X_{21}), iodine intake peak forward (X_{22}), the number of times of taking iodine (X_{24}), nodules (X_{25}), thyroid texture (X_{26}), hyperthyroidism heart (X_{27}), periodic paralysis (X_{28}), abnormal liver function (X_{29}), and hematological abnormalities (X_{30}). The cured group and the uncured group were named as Y_1. $Y_1 = 1$ implies the uncured group, whereas $Y_1 = 2$ indicates the cured group. The hypothyroidism group and the nonhypothyroidism group were named as Y_2. $Y_2 = 1$ implies the nonhypothyroidism group, whereas $Y_2 = 2$ indicates the hypothyroidism group.

Statistical analysis

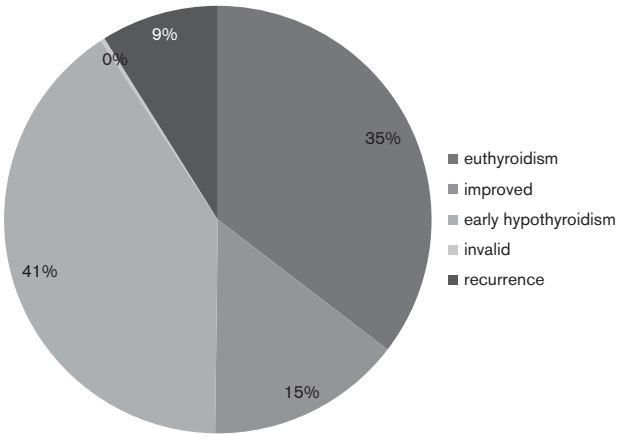
Statistical analysis was carried out using SPSS for windows, version 23.0 (SPSS Inc., Chicago, Illinois, USA). Independent-samples *t*-test was used to investigate the influence of measurement data (X_1–X_{19}). The χ^2-test was applied to investigate the influence of count data (X_{20}–X_{30}). Moreover, logistic regression analysis was used to evaluate the impact that particular parameters had on the success of treatment with ^{131}I (uncured and cured). In addition, logistic regression analysis was also used to evaluate the impact of particular parameters on the occurrence of hypothyroidism after ^{131}I treatment (nonhypothyroidism and hypothyroidism). The logistic regression analysis took into consideration those parameters that were statistically significant for the outcome ($P < 0.1$). Simultaneously, the factors (X_3, X_4, X_5, X_{17}) in the Marinelli–Quimby formula were also incorporated into the regression equation. *P* values less than 0.05 in regression analysis were considered to be statistically significant. All *P* values presented were two tailed.

Results

The clinical characteristics of the patients in this study

The age range of the patients in our study was 13–76 years, and the median age was 41 years. The age range of the female and male patients was 13–76 and 21–67 years, respectively, and the median age of the female and male patients was 41 and 40.5 years, respectively. Overall, as shown in Fig. 1, the ^{131}I therapy was ineffective in 30 patients (9.3% – out of 325 patients). One hundred and fifteen (35.40%) patients achieved euthyroidism, 48 (14.80%) patients showed improvements, and early hypothyroidism occurred in 132 (40.60%) patients. Furthermore, the effective rate of iodine treatment of GD (including euthyroid patients, patients who showed improvement, and early hypothyroid patients) was 90.7%. The cure rate of iodine treatment of GD (including euthyroid patients and early hypothyroid patients) was 76.00%.

Fig. 1



The outcome of treatment with ^{131}I.

Analysis of factors affecting the successful treatment of hyperthyroidism with ^{131}I

The characteristics of the GD patients in this study, including clinical and physiological parameters and the results of ^{131}I treatment (hyperthyroidism, euthyroidism, or hypothyroidism) that they had undergone, are shown

Table 1 Characteristics of patients under study with respect to clinical and physical parameters and ^{131}I therapy outcomes: hyperthyroidism, euthyroidism, or hypothyroidism

Factors	Hyperthyroidism ($n = 78$) (mean ± SD)	Euthyroidism or hypothyroidism ($n = 247$) (mean ± SD)	*P*
X_1 (years)	40.83 ± 12.29	41.61 ± 12.30	0.628
X_2 (months)	66.17 ± 64.25	53.37 ± 63.76	0.124
X_3 (g)	86.28 ± 41.61	67.63 ± 29.07	< 0.001
X_4 (day)	5.57 ± 0.68	5.54 ± 0.71	0.754
X_5 (%)	72.97 ± 10.95	70.34 ± 12.05	0.087
X_6 (mCi)	9.29 ± 4.10	7.68 ± 3.35	0.001
X_7 (ng/ml)	5.37 ± 2.00	4.60 ± 1.94	0.002
X_8 (μg/dl)	20.68 ± 5.00	20.38 ± 12.39	0.837
X_9 (pmol/l)	38.83 ± 24.66	28.08 ± 19.29	< 0.001
X_{10} (pmol/l)	96.65 ± 66.59	66.24 ± 48.03	< 0.001
X_{11} (%)	27.77 ± 17.19	24.44 ± 18.34	0.572
X_{12} (%)	18.94 ± 11.28	18.12 ± 12.04	0.595
X_{13} (μIU/ml)	0.17 ± 0.78	0.08 ± 0.06	0.100
X_{14} (months)	42.68 ± 37.01	33.76 ± 39.43	0.078
X_{15} (weeks)	16.10 ± 38.67	7.51 ± 16.12	0.005
X_{16} (mCi/g)	6.58 ± 1.21	6.53 ± 1.07	0.722
X_{17} (mCi/g)	0.08 ± 0.01	0.08 ± 0.01	0.991
X_{18}	4.26 ± 1.55	4.91 ± 2.71	0.043
X_{19}	2.56 ± 0.94	2.46 ± 0.85	0.381
X_{20} (%)			
Male	32.05	24.70	0.199
Female	67.95	75.30	
X_{21} (%)			
Existence	11.54	11.34	0.961
Not to exist	88.46	88.66	
X_{22} (%)			
No	70.51	78.54	0.144
Yes	29.49	21.46	
X_{23} (%)			
Pyrimidine	10.26	14.17	0.770
Imidazole	73.33	78.54	
Pyrimidine + imidazole	6.41	7.29	
X_{24} (%)			
Single time	98.72	96.76	0.601
Repeatedly	1.28	3.24	
X_{25} (%)			
Without nodules	71.79	67.61	0.488
With nodules	28.21	32.39	
X_{26}			
Soft	30.77	31.58	0.838
Hard	19.23	21.86	
Tough	50.00	46.56	
X_{27} (%)			
(%	92.31	97.57	0.071
Yes	7.69	2.43	
X_{28} (%)			
(%	96.15	96.36	0.934
Yes	3.85	3.64	
X_{29} (%)			
No	97.44	95.55	0.681
Yes	2.56	4.45	
X_{30} (%)			
No	93.59	93.12	0.885
Yes	6.41	6.88	

in Table 1. Independent-samples *t*-test was used to compare the measurement data (X_1–X_{19}) between the uncured and the cured groups. The χ^2-test was used to compare the count data (X_{20}–X_{30}) between the two groups. The results in Table 1 show that the ^{131}I therapy outcomes were influenced by X_3, X_5, X_6, X_7, X_9, X_{10}, X_{13}, X_{14}, X_{15}, X_{18}, X_{27} ($P<0.1$).

Moreover, the above factors ($P<0.1$) and factors in the Marinelli–Quimby formula were incorporated into the logistic regression model. The results (Table 2) showed that X_3 (g), X_{10} (pmol/l), and X_{15} (weeks) were more likely to be associated with ^{131}I therapy outcomes. The regression equation is $Y_1=2.95-0.013X_3-0.007X_{10}-0.015X_{15}$. This equation is tested by the likelihood ratio: $X_2=37.014$, $P<0.01$. Thus, the equation has obvious significance and the model of the degree of fit is better. This equation shows that GD patients who were cured by ^{131}I therapy were more likely to have smaller weight of the thyroid, lower FT4 levels, and shorter time of ATD withdrawal before ^{131}I treatment.

Analysis of factors affecting the occurrence of early hypothyroidism after radioiodine treatment for Graves' hyperthyroidism

The characteristics of the GD patients in this study, including clinical and physiological parameters and the results of the treatment with ^{131}I (euthyroidism or hyperthyroidism, hypothyroidism) that they had undergone, are shown in Table 3. Independent-samples *t*-test was used to compare the measurement data (X_1–X_{19}) between the two groups (group 3: euthyroidism and hyperthyroidism, group 4: hypothyroidism). The χ^2-test was used to compare the count data (X_{20}–X_{30}) between the two groups. The results in Table 3 show that the ^{131}I therapy outcomes was influenced by X_3, X_5, X_6, X_{10}, X_{14}, X_{22} ($P<0.1$).

Moreover, the above factors ($P<0.1$) and factors in the Marinelli–Quimby formula were incorporated into the logistic regression model. The results (Table 4) showed that X_5 (%), X_6 (mCi), and X_{17} (mCi/g) were more likely to be associated with the occurrence of hypothyroidism. The regression equation is $Y=0.51-0.035X_5-0.1X_6+32.11X_{17}$. This equation is tested by the likelihood ratio: $\chi^2=17.26$, $P=0.002$. Therefore, the equation has obvious significance and the model of the degree of fit is better. This equation shows that there was an increased risk of early hypothyroidism in patients with lower 24-h iodine uptake, and treated with a lower total dose of iodine and a higher iodine dose per garm of thyroid tissue.

Table 2 Variables and constants of the regression equation: the chances of ^{131}I cure Graves' disease

					95% CI	
Factors	*B*	Wald	*P*	OR	Lower	Upper
X_3 (g)	−0.013	9.764	0.002	0.987	0.979	0.995
X_{10} (pmol/l)	−0.007	9.369	0.002	0.993	0.988	0.997
X_{15} (weeks)	−0.015	7.189	0.007	0.985	0.974	0.996
Constant	2.95	59.934	0	19.103	–	–

CI, confidence interval; OR, odds ratio.

Table 3 Characteristics of patients under study with respect to clinical and physical parameters and ^{131}I therapy outcomes: euthyroidism or hyperthyroidism, hypothyroidism

Factors	Euthyroidism or hyperthyroidism ($N=193$) (mean ± SD)	Hypothyroidism ($N=132$) (mean ± SD)	*P*
X_1 (years)	41.05 ± 12.05	41.96 ± 12.65	0.513
X_2 (months)	58.97 ± 58.26	52.74 ± 71.66	0.39
X_3 (g)	76.97 ± 36.44	65.00 ± 27.02	0.001
X_4 (day)	5.58 ± 0.68	5.49 ± 0.75	0.24
X_5 (%)	72.16 ± 11.59	69.24 ± 12.00	0.028
X_6 (mCi)	8.50 ± 3.87	7.42 ± 3.77	0.008
X_7 (ng/ml)	4.85 ± 1.91	4.68 ± 2.06	0.444
X_8 (μg/dl)	21.05 ± 12.67	19.59 ± 5.29	0.245
X_9 (pmol/l)	31.68 ± 21.04	29.17 ± 21.34	0.292
X_{10} (pmol/l)	78.12 ± 57.73	66.83 ± 48.95	0.067
X_{11} (%)	26.32 ± 17.64	27.42 ± 18.69	0.59
X_{12} (%)	18.15 ± 11.62	18.56 ± 12.22	0.758
X_{13} (μIU/ml)	0.12 ± 0.50	0.08 ± 0.07	0.441
X_{14} (months)	39.26 ± 38.74	30.99 ± 38.98	0.061
X_{15} (weeks)	10.65 ± 27.15	7.99 ± 17.76	0.321
X_{16} (mCi/g)	6.62 ± 1.18	6.42 ± 0.96	0.109
X_{17} (mCi/g)	0.08 ± 0.01	0.08 ± 0.01	0.546
X_{18}	4.77 ± 2.92	4.73 ± 1.68	0.904
X_{19}	2.51 ± 0.89	2.43 ± 0.85	0.413
X_{20} (%)			
Male	26.42	26.52	0.986
Female	73.58	75.30	
X_{21} (%)			
Existance	11.92	10.61	0.715
Not to exist	88.08	89.39	
X_{22} (%)			
No	73.06	81.82	0.067
Yes	26.94	18.18	
X_{23} (%)			
Pyrimidine	13.99	12.12	0.472
Imidazole	80.31	78.79	
Pyrimidine + imidazole	5.70	9.09	
X_{24} (%)			
Single time	98.45	95.45	0.107
Repeatedly	1.55	4.55	
X_{25} (%)			
Without nodules	71.50	64.39	0.175
With nodules	28.50	35.61	
X_{26} (%)			
Soft	31.61	31.06	0.994
Hard	21.24	21.21	
Tough	47.15	47.73	
X_{27} (%)			
No	95.85	96.97	0.823
Yes	4.15	3.03	
X_{28} (%)			
No	97.41	94.70	0.33
Yes	2.59	5.30	
X_{29} (%)			
No	96.89	94.70	0.322
Yes	3.11	5.30	
X_{30} (%)			
No	93.78	92.42	0.632
Yes	6.22	7.58	

Discussion

The hyperthyroidism treatment program preferred to use high-dose ^{131}I one time and hypothyroidism is considered acceptable in some countries. However, in China, it is strongly

Table 4 Variables and constants of the regression equation: the chance of early hypothyroidism

					95% CI	
Factors	*B*	Wald	*P*	OR	Lower	Upper
X_5 (%)	−0.035	7.63	0.006	0.966	0.943	0.99
X_6 (mCi)	−0.1	6.66	0.01	0.905	0.838	0.976
X_{17} (mCi/g)	32.109	4.55	0.033	8.81E+13	13.513	5.74E+26
Constant	0.511	0.33	0.567	1.802	–	–

CI, confidence interval; OR, odds ratio.

suggested that doctors should use an acceptable minimum dose ^{131}I to curing hyperthyroidism while the hypothyroidism is not occurred. Calculated ^{131}I doses according to the formula are still the main method used. These clinical experiences emphasize the importance of evaluating the corresponding influence factors during ^{131}I treatment. The aim of this study was to analyze the factors that could have a potential influence on the effects of therapy with ^{131}I.

The above results showed that the cure rate of ^{131}I therapy in GD patients depends on the thyroid weight, FT4, and the time of ATD withdrawal before ^{131}I treatment. Markovic and colleagues reported that the chances of recovery are much greater for the patients with thyroids smaller than 62 g (9.6% of unsuccessful attempts) as opposed to patients with thyroids larger than 62 g (44% of cases of persistent hyperthyroidism) [13]. Szumowski *et al.* [14] have proven that the volume of the thyroid gland has a significant ($P < 0.002$) effect on the success of treatment, and the larger the thyroid volume, the worse the treatment efficiency. Similar to the results of other studies, our study showed that the lower weight of the thyroid led to greater success of treatment ($P = 0.002$). Our study showed that a lower FT4 level and greater chances of ^{131}I cured incidence. This was supported by some studies in which FT4 levels had a negative impact on the ^{131}I therapy success rate [16,21–23]. The serum levels of FT4 at the onset of GD can reflect the severity of hyperthyroidism. Lower FT4 serum levels, suggesting a less severe GD condition, may lead to a better treatment result. However, some studies found that FT4 levels had no such influence on the ^{131}I therapy success rate [24–26]. We found that the shorter the ATD withdrawal time before ^{131}I treatment, the greater the chances of ^{131}I curing GD. It is frequently discussed in the medical literature that how many days anti-thyroid drugs should be stopped before ^{131}I administration [27]. However, so far, the answers to this question are varied. Most of the results show that at least 2 weeks of antithyroid drugs withdrawal are suggested. In this study, withdrawal of less than 2 weeks in some patients was because of special conditions, such as severe complications, including heart disease, liver damage, etc. The therapeutic goal in these patients is to relieve symptoms as soon as possible or induce hypothyroidism as a final treatment result. The disease situation of these patients may result in differences between our study and other studies. Other factors included, such as sex, age, and duration of the antithyroid treatment before ^{131}I treatment, did not affect the cure rate of ^{131}I in GD in our study. This result is similar to the reports of other authors [15]. We found that there was no impact of the FT4/FT3 ratio on the success of ^{131}I treatment [16]. The FT4/FT3 ratio is an indicator of the severity of hyperthyroidism, but it is also affected by antithyroid drugs. Our observation is that the rate of iodine absorption did not significantly affect the outcome of ^{131}I treatment, which is consistent with some other studies [16,24,28]. However, another study showed that higher thyroid uptake may be the cause of ^{131}I treatment failure [26,29], possibly owing to a higher iodine turnover.

In general, the greater the total dose of iodine in patients, the higher the incidence of hypothyroidism [21]. Ogunjobi and colleagues found that on using a small total dose of iodine in patients, the incidence of hypothyroidism increased, but no statistically significant difference was observed [30]. The chances of hypothyroidism are much greater in the patients receiving low RAI doses than those receiving higher RAI doses in patients with multinodular goiter or adenoma in the study of Saara Metso. However, they also found that the RAI doses did not have any effect on the development of hypothyroidism in patients with GD [31]. Our study used a smaller total dose of iodine in patients and observed a greater likelihood of early hypothyroidism, and logistic regression analysis showed that the low total dose of iodine in patients was a contributing factor toward the development of hypothyroidism (odds ratio = 0.966, 95% confidence interval: 0.943–0.990, $P = 0.006 < 0.05$). Moreover, we found that the higher iodine dose per gram of thyroid tissue administered to patients increased the risk of early hypothyroidism (odds ratio = 8.808E + 13, 95% confidence interval: 13.513–5.741E + 26, $P = 0.033 < 0.05$). The reason may be that when using the individual dose method to calculate the ^{131}I dose in clinic, the thyroid weight is more likely to be overestimated and a dose larger than the actual required dose was administered, resulting in hypothyroidism. However, some studies have shown that individual radiosensitivity is regulated by specific genes such as Bc1-2 and Egr-1, which is an important factor affecting the efficacy of ^{131}I treatment [32,33] and also affects the therapeutic outcome. Meanwhile, our study showed that with lower 24-h iodine uptake, a higher chance of early hypothyroidism was observed. The reason may be that the calculated dose increases with the decrease in 24-h iodine uptake, and the iodine absorption rate varies during the therapy period [34].

^{131}I therapy costs less compared with other treatments for GD in China. Patients need to receive ^{131}I treatment only once or twice, and euthyroidism or hypothyroidism can be achieved. At the same time, they do not have to be followed up regularly for thyroid function. If the

patients are treated with long-term antithyroid drugs, they need to be followed up regularly for thyroid function and there may be some side effects such as leukopenia, liver damage, and drug rash, which can sometimes lead to severe consequences. From this point of view, more money and time can be saved if patients are treated with ^{131}I treatment compared with antithyroid drugs.

Conclusion

The results of our retrospective study indicated that the cure rate of ^{131}I treatment in GD was higher in patients with smaller weight of the thyroid, lower FT4 levels, and shorter time of ATD withdrawal before ^{131}I treatment, and early hypothyroidism after radioiodine treatment for Graves' hyperthyroidism is more likely to occur in patients with lower 24-h iodine uptake, lower total dose of iodine, and higher iodine dose per gram of thyroid tissue.

Acknowledgements

Conflicts of interest

There are no conflicts of interest.

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