CLINICAL STUDY

Presentation of a kindred with familial medullary thyroid carcinoma and Cys611Phe mutation of the RET proto-oncogene demonstrating low grade malignancy

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Abstract

Objective: Both multiple endocrine neoplasia type 2A (MEN 2A) and familial medullary thyroid carcinoma (FMTC) are caused by germline mutations of the RET proto-oncogene. A broad spectrum of malignancy within and between families has been described with no clear genotype–phenotype correlation due to a scarcity of available data of large kindreds.

Design: Here we present the only known family with a germline mutation of codon 611 TGC to TTC (exon 10) in the RET proto-oncogene leading to a replacement of cysteine by phenylalanine (Cys611Phe or C611F).

Results: Twenty family members of this large kindred are gene carriers (GCs) and seven (5–13 years old) are potential carriers but have yet to be analysed. The clinical course of medullary thyroid carcinoma (MTC) in this family is characterized by a very slow evolution and progression of the tumour with no MTC-related death to date. Of 11 patients (30–69 years old) having undergone thyroidectomy six were classified as pT1, four as pT2 and one as C-cell hyperplasia according to the TNM system of the International Union Against Cancer. Due to cervical and mediastinal lymph node metastasis one patient (44 years old) had to be operated on a second time. The seven non-operated GCs of the fourth and fifth generation (17–26 years old) are yearly monitored with pentagastrin stimulation tests; one non-operated GC (43 years old) has refused any further investigations. Screening for primary hyperparathyroidism and phaeochromocytoma was negative in all cases.

Conclusion: We suggest from these experiences that the general advice for thyroidectomy in early childhood should be modified in certain families, depending on genotype.

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Introduction

Multiple endocrine neoplasia type 2A (MEN 2A) is a hereditary syndrome characterized by development of medullary thyroid carcinoma (MTC), phaeochromocytoma and hyperparathyroidism. Familial MTC (FMTC) presents with MTC only (1). Both MEN 2A and FMTC, are caused by germline mutations of the RET proto-oncogene and show autosomal dominant inheritance (2, 3). Genetic identification of asymptomatic gene carriers now allows the accurate diagnosis of MEN-2 at an early stage of the disease (4–6). Medullary thyroid carcinoma develops in virtually all patients with MEN 2A or FMTC (7). It is the most important manifestation of the syndrome and the most frequent cause of mortality. Cure by operation can only be achieved if the tumour is limited to the thyroid gland and spreading to the local lymph nodes has not occurred. In addition, preoperative calcitonin levels do not distinguish reliably in all cases between C-cell-hyperplasia and carcinoma (7, 8). Microcarcinoma despite normal pentagastrin test has been observed in children 4–9 years old (8, 9). Lymph node metastasis may occur very early in the course of the disease and has been observed at the age of 14 years (10) or even earlier (11). Therefore, prophylactic thyroidectomy before the development of microcarcinoma is usually recommended (8–12).

However, in some studies variable biological activity of MTC was shown (13, 14). The MTC that occurs in FMTC seems to develop later in life and to grow more slowly compared with MTC in patients with MEN 2A. Indeed, specific mutations of the RET proto-oncogene considerably influence the phenotype, but data on the relationship between RET mutations and the clinical outcome in MEN-2A are scarce. It has been
demonstrated by clinical and functional studies that the non-634 cysteine codon mutations are of lower penetrance and the further away from the membrane these codons are, the lower the penetrance (3, 15, 16).

In this study we present the largest kindred described to date with germline codon 611 TGC to TTC mutation (exon 10) in the \textit{RET} proto-oncogene. In affected family members MTC developed relatively late in life and never caused death in any of the hosts.

\section*{Subjects and methods}

\subsection*{Patient population}

A German FMTC kindred of 80 individuals spanning three generations (III to V, Fig. 1) was evaluated for disease expression. Initial screening of the third generation included medical history, physical examination and laboratory tests, which included the pentagastrin test, \textit{RET} gene mutation analysis and thyroid sonography. Members of the fourth and fifth generation were examined similarly if they had an affected parent.

\subsection*{Genetic screening}

Extraction of genomic DNA and amplification of exons 10, 11 and 16 from the \textit{RET} proto-oncogene were performed as previously described (17). Genomic DNA was isolated using the QIAMP blood kit (Qiagen, Hilden, Germany). PCR amplifications were carried out with the oligonucleotide primer ret19S (5’-GCAGCATTGGTGGGGACA-3’) and ret10Rb (5’-GTCCTGGGCCACCCACT-3’) for exon 10 (size of amplified fragment 140 bp). A total of 100 ng DNA were amplified in a Hybaid Omnigene apparatus (Hybaid, Teddington, UK) in a volume of 25 μl containing 1 μmol/l of each oligonucleotide primer, 1 mmol/l dNTP, 10 mmol/l Tris–HCl (pH 8.3), 2.5 mmol/l MgCl$_2$, and 1 U Taq polymerase (Appligen, Heidelberg, Germany). The PCR was started with 1 min of denaturation at 95 °C and, finally 5 min at 72 °C. The amplified DNA was analysed on a 2% agarose gel and purified with a Quickspin kit (Qiagen). PCR-amplified DNA was sequenced using fluorescently labelled dideoxy terminators (Prism Ready Reaction, Applied Biosystems kit, Foster City, CA, USA). After identification of the MTC-causing mutation, the amplified DNA-fragments from other members of the family were analysed by restriction enzyme analysis (MboI, New England Biolabs, Frankfurt, Germany) only. Restriction enzyme digests were carried out according to the instructions of the supplier. Analysis of the DNA fragments was performed by PAGE with subsequent silver staining.

\subsection*{Biochemical testing}

Family members positive for the \textit{RET} mutation underwent biochemical analysis for MTC by radioimmunoassay measurement of plasma calcitonin levels following intravenous pentagastrin (0.5 μg/kg body weight/10 s). The patients were studied in a fasting state. Blood samples were collected before and at 2 and 5 min after the intravenous injection of pentagastrin (Pentagastrin BP, Cambridge Laboratories, Newcastle upon Tyne, UK). We used two different calcitonin

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Figure1.pdf}
\caption{Pedigree of the FMTC kindred with a Cys611Phe mutation of the \textit{RET} proto-oncogene. Members of each generation are numbered consecutively (grey numbers above the symbols). The numbers below the symbols represent the present age of the kindred member.}
\end{figure}
assays. Until 1997 the test used (dsl, Diagnostics Systems Laboratories, Webster, TX, USA) was regarded positive when detecting elevated (>100 pg/ml) levels of plasma calcitonin (CT) either in the basal or stimulated state (intra-assay variation 4.5%, inter-assay variation 7.5%). Using a more sensitive assay (Nichols Institute Diagnostics, San Juan Capistrano, CA, USA) the normal plasma CT levels were less than or equal to 4.6 pg/ml in females and less than or equal to 11.5 pg/ml in males (intra-assay variation 3.8%, inter-assay variation 8.6%).

Primary hyperparathyroidism (pHPT)
To assess parathyroid function, total calcium was determined using routine diagnostic testing. Serum parathyroid hormone (PTH1–84) was determined by immunoradiometric assay with carboxy-terminal specific antisera (DPC Biermann, Bad Nauheim, Germany). Testing for pHPT was repeated every year in patients positive for the RET proto-oncogene.

Phaeochromocytoma
Evaluation for phaeochromocytoma included determination of 24 h urinary excretion of adrenaline, noradrenaline and vanillylmandelic acid. Testing for phaeochromocytoma was repeated every year in patients positive for the RET mutation.

Surgery
Medullary thyroid carcinoma was treated by total thyroidectomy with resection of the lymph nodes in the central zone of the neck. The TNM system of the International Union Against Cancer (1997) was used for tumour classification. Postoperatively, 1-thyroxine was given as replacement therapy.

Postoperative evaluation
All affected members have been screened annually by physical examination, determination of serum calcium, urinary catecholamine, basal and stimulated plasma CT levels and an ultrasound examination of the thyroid compartment and the neck.

Evaluation of gene carriers
Operated and non-operated gene carriers (GCs) are followed up at yearly intervals.

Results
Evaluation of GCs
The index case is a female now 74 years old (Fig. 1, III14). In 1982 at the age of 56 she had a thyroidectomy followed by radiation therapy. In 1986 she underwent further surgery due to tumour recurrence and lymph node metastasis. Ever since, calcitonin levels have been elevated due to mediastinal lymph node and suspected bone metastasis. Until now she has not had any symptoms attributable to the tumour.

We were able to test eight other members of the same generation and found six gene carriers (GCs) (Fig. 1). Of these subjects five underwent total thyroidectomy with neck dissection between 1992 and 1997. When classified three (aged 68–72 years) had pT1N0M0 (two continued to have a positive pentagastrin stimulation test postoperatively), and two (aged 59 and 67 years) had pT2N0M0 (Table 1). A 67-year-old male with positive pentagastrin stimulation test could not be operated on because of concomitant diseases. Four members of this generation refused investigation of themselves or their families.

Among the 23 members of the fourth generation, 17 were tested and nine were found to be GCs (Fig. 1). Six of these had total thyroidectomy with neck dissection between 1989 and 1997. When classified three (aged 45–51 years) had pT1N0M0, and one (aged 34 years) had hyperplastic C-cells (Table 1). All had negative pentagastrin stimulation tests postoperatively. One (aged 50 years) had pT2N1M0 (two operations) and postoperatively continues to show raised CT levels. The three non-operated GCs (aged 23–43 years) have had negative pentagastrin stimulation tests until now and refuse thyroid surgery. One member of this generation (IV17) has refused further testing so far.

The fifth generation has 34 known members. We tested all but six of those with a GC parent. Of nine tested subjects four (aged 17–26 years) were GCs (Fig. 1). All had negative pentagastrin stimulation tests and none have undergone thyroidectomy to this point. The six members not tested to date, children under 13 years old, are planned to have gene analysis as soon as possible.

All GCs repeatedly tested negative for pHPT and phaeochromocytoma.

Evaluation of operated patients
At the time of the initial pentagastrin testing all patients who subsequently underwent surgery had established or advanced disease. The youngest operated patient (30 years old) showed only C-cell hyperplasia. The youngest patient with histologically established disease was 34 years old. Only three patients showed persistent disease postoperatively according to pentagastrin testing: one is the index patient (III14, Table 1) with advanced disease but with slow progression in the control visits. The second, a 69-year-old man at time of operation (III9, Table 1), showed only local tumour and postoperatively normal basal calcitonin but stimulated levels remain above normal. The third, a 44-year-old woman (IV4, Table 1) with lymph node metastasis,
presented the most aggressive form of the tumour yet observed under our surveillance. Therefore, all three patients with persistent disease were more than 40 years old and, with one exception, had tumours $>pT_2N_0$. The main difference between the ‘cured’ and the ‘persistent’ disease groups was the more advanced age in the persistent disease group. All other patients who underwent surgery and whose tumours were classified between CCH and $pT_{2B}N_0M_0$ were cured.

**Discussion**

In this paper, we present a large kindred with germline codon 611 TGC to TTC mutation (exon 10) in the RET proto-oncogene which results in the substitution of phenylalanine for cysteine (C611F). The MTC developed relatively late in life, progressed slowly and never caused death in any of the hosts. The presence of hyperparathyroidism and phaeochromocytoma was excluded by extensive testing.

To date 13 different mutations at codon 611 in Exon 10 have been described (3); six of them were characterized according to their phenotype (17–21), leading to both the MEN 2A and FMTC phenotype (Table 2). Due to small family size or incomplete screening information, the other seven mutations were not further classified (3). So far this is the largest reported family with a codon 611 mutation and the only family with a phenylalanine substitution at this codon. A C611G kindred in the north of Spain with nine members, three of them with FMTC, showed a rather benign disease progression (21). Furthermore, Wells et al. (8) reported on a C611T kindred with eleven members, three of them with proven clinical disease, and six at risk of inheritance but with no data on the clinical course of the disease. In other families with a mutation of codon 611 (Table 2) a genotype to phenotype correlation has not been established because of the small number of kindred members. Cysteine mutations of codon 611, as well as codons 609, 618 and 620, are most likely to be associated with FMTC, are less frequent in families with MEN 2A and show weaker RET activity (22–24). In this context a large kindred of 150 members with a C618S mutation in exon 10 and clinically or biochemically proven MTC in 44 patients is of great scientific interest. The C618S mutation shows a later age of conversion of the pentagastrin testing ($18 \text{ versus } 6$ years), higher cure rates and a life expectancy of 60 years compared with 48 years in families with C634 mutation. This demonstrates a distinct clinical course of MTC with the C618S mutation (25), similar to the findings in our C611F kindred.

In MEN 2A patients the clinical course of MTC is highly variable and these experiences have led to the recommendation of prophylactic thyroidectomy in MEN 2A patients as young as 5 years old (9–11, 14) and strict yearly provocation test screening from 1 year old

<table>
<thead>
<tr>
<th>Patient generation (Fig. 1)</th>
<th>Sex</th>
<th>Age at operation (years)</th>
<th>Date of total thyroidectomy (month/year)</th>
<th>Tumour stage (pTNM)</th>
<th>Basal CT preoperatively (pg/ml)</th>
<th>Stimulated CT preoperatively (at 2 min, pg/ml)</th>
<th>Basal CT postoperatively (pg/ml)</th>
<th>Stimulated CT postoperatively (at 2 min, pg/ml)</th>
<th>Normal CT values postoperatively (pg/ml)</th>
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<tr>
<td>III 9</td>
<td>F</td>
<td>59</td>
<td>5/97</td>
<td>69</td>
<td>68</td>
<td>6.8</td>
<td>74</td>
<td>56</td>
<td>0.7</td>
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<tr>
<td>III 10</td>
<td>F</td>
<td>39</td>
<td>6/97</td>
<td>65</td>
<td>65</td>
<td>6.0</td>
<td>21</td>
<td>64</td>
<td>0.7</td>
</tr>
<tr>
<td>III 11</td>
<td>F</td>
<td>40</td>
<td>6/97</td>
<td>64</td>
<td>63</td>
<td>6.2</td>
<td>87</td>
<td>63</td>
<td>0.7</td>
</tr>
<tr>
<td>III 12</td>
<td>M</td>
<td>52</td>
<td>6/97</td>
<td>62</td>
<td>61</td>
<td>5.6</td>
<td>82</td>
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<td>0.7</td>
</tr>
<tr>
<td>III 13</td>
<td>F</td>
<td>49</td>
<td>6/97</td>
<td>60</td>
<td>59</td>
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<td>6/97</td>
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<td>F</td>
<td>49</td>
<td>6/97</td>
<td>60</td>
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<td>5.9</td>
<td>82</td>
<td>60</td>
<td>0.7</td>
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<td>III 16</td>
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<td>51</td>
<td>6/97</td>
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<td>6/97</td>
<td>60</td>
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<td>82</td>
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<td>0.7</td>
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<tr>
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<td>M</td>
<td>51</td>
<td>6/97</td>
<td>60</td>
<td>59</td>
<td>5.6</td>
<td>82</td>
<td>60</td>
<td>0.7</td>
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<tr>
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<td>F</td>
<td>49</td>
<td>6/97</td>
<td>60</td>
<td>59</td>
<td>5.9</td>
<td>82</td>
<td>60</td>
<td>0.7</td>
</tr>
<tr>
<td>IV 6</td>
<td>M</td>
<td>51</td>
<td>6/97</td>
<td>60</td>
<td>59</td>
<td>5.6</td>
<td>82</td>
<td>60</td>
<td>0.7</td>
</tr>
<tr>
<td>IV 7</td>
<td>F</td>
<td>49</td>
<td>6/97</td>
<td>60</td>
<td>59</td>
<td>5.9</td>
<td>82</td>
<td>60</td>
<td>0.7</td>
</tr>
<tr>
<td>IV 8</td>
<td>M</td>
<td>51</td>
<td>6/97</td>
<td>60</td>
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<td>82</td>
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<tr>
<td>IV 9</td>
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<td>6/97</td>
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<td>IV 10</td>
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<td>5.6</td>
<td>82</td>
<td>60</td>
<td>0.7</td>
</tr>
</tbody>
</table>

CCH, C-cell hyperplasia; nd, not determined.
Biochemical or imaging examinations become positive in the C618S or C634R carriers until the conventional M918T genotype carriers, whereas it could be withheld genotype. In their opinion, prophylactic thyroidectomy procedures in patients with MEN 2A according to suggested modification of the timing of operative MTC to mutations 618, 634 and 918 (26). The authors correlate variation in tumour size and clinical course of recently, in genotype–phenotype studies of patients no exception from the rule was proposed (25). More with codon C618S and a very benign clinical course, regard to the previously mentioned MEN 2A family same author agreed with the above-described more are conducted (7). However, in a later publication the same author agreed with the above-described more aggressive management approach (9). Even with regard to the previously mentioned MEN 2A family with codon C618S and a very benign clinical course, no exception from the rule was proposed (25). More recently, in genotype–phenotype studies of patients with MEN 2A in Japan the authors were able to correlate variation in tumour size and clinical course of MTC to mutations 618, 634 and 918 (26). The authors suggested modification of the timing of operative procedures in patients with MEN 2A according to genotype. In their opinion, prophylactic thyroidectomy should be performed at an early age for the C634Y or M918T genotype carriers, whereas it could be withheld in the C618S or C634R carriers until the conventional biochemical or imaging examinations become positive (26).

In addition to these genotype–phenotype studies, two different mutations in codon 804 in exon 14 were described which also lead to a mild phenotype of FMTC. The replacement of a Val by a Leu (27) in one large family with 12 GCs in three generations revealed MTC after the age of 50 years in three GCs and foci of C-cell hyperplasia but no medullary thyroid carcinoma in a GC aged 30 years. Two GCs had a positive pentagastrin stimulation test but had yet to undergo surgery. Six GCs with negative stimulation tests were 29 to 41 years old and had not yet undergone surgery (27). The replacement of a Val with a Met residue (28) also revealed a mild phenotype. Interestingly, in the two families described the subsequent generations showed an earlier and more aggressive phenotype with MTC occurring at the age of 16 years in one GC. Three young GCs (7–12 years old) had not yet undergone surgery due to negative pentagastrin stimulation tests (28). Recently, Feldman et al. (29) reported on two additional FMTC families with the V804M mutation in exon 14. Some GCs over the age of 70 years had no overt clinical evidence of MTC. However, because of active MTC and metastases in younger members (30 and 32 years) of these families, the authors continued to advocate thyroid surgery in mutation-positive individuals (29).

Here we have presented evidence that the mutation C611F in exon 10 causes FMTC and shows an indolent clinical course of the disease in the affected kindred. All patients described in Table 1 were operated on because of visible tumour and/or pathological pentagastrin testing. So far we have only observed conversion of the normal pentagastrin testing in one patient at the age of 25 years. It is planned to operate on this patient. Bearing this in mind we question whether the general recommendations for early prophylactic thyroidectomy should be followed without modification. In our opinion it seems more appropriate to use serial pentagastrin testing rather than a fixed age in order to decide the time of operation. Because of the low aggressiveness of the MTC in the presented kindred with a C611F germline mutation in exon 10 we adopted the following strategy for screening and follow up. We screen for the mutation between the age of 6 and 10 years. Pentagastrin-stimulated calcitonin testing is started at the age of 10 years and repeated every 2 years until the age of 18 years and then every year thereafter. Thyroidectomy is recommended as soon as the test becomes positive, using the very rigid criteria of the French study group (30) who regarded a stimulated concentration of calcitonin at any level above normal as pathological. We feel that a careful follow-up of the not yet operated GCs is necessary and we would not hesitate to abandon the conservative follow-up approach in case of appearance of a more aggressive course in a younger patient.

In summary, the spectrum of clinical appearance of MEN 2A appears to be so broad that, depending on the genotype, therapeutic recommendations should be

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**Table 2** Correlation of different amino acid substitutions at codon 611 of the RET proto-oncogene with the phenotype (from The Human Gene Mutation Database Cardiff (HGMD)).

<table>
<thead>
<tr>
<th>Codon</th>
<th>Nucleotide</th>
<th>Amino acid</th>
<th>Phenotype</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>611</td>
<td>TGC→TAC</td>
<td>Cys-Tyr</td>
<td>MEN 2A</td>
<td>Landsvater et al. 1996</td>
</tr>
<tr>
<td>611</td>
<td>TGC→TTC</td>
<td>Cys-Phe</td>
<td>FMTC</td>
<td>Frank-Raue et al. 1996</td>
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<tr>
<td>611</td>
<td>TGC→TGG</td>
<td>Cys-Trp</td>
<td>MEN 2A</td>
<td>Donis-Keller et al. 1993</td>
</tr>
<tr>
<td>611</td>
<td>cTGC→AGC</td>
<td>Cys-Ser</td>
<td>MEN 2A</td>
<td>Kambouris et al. 1996</td>
</tr>
<tr>
<td>611</td>
<td>cTGC→GC</td>
<td>Cys-Arg</td>
<td>FMTC</td>
<td>Kambouris et al. 1996</td>
</tr>
<tr>
<td>611</td>
<td>cTGC→GGC</td>
<td>Cys-Gly</td>
<td>FMTC</td>
<td>Oriola et al. 1998</td>
</tr>
</tbody>
</table>

<sup>a</sup>Incorrectly referred to as MEN 2A in the database. <sup>b</sup>Two members of our kindred were published within the German MTC Study Group.
more individualized. To obtain reliable data allowing for such an individualization more work on genotype–phenotype correlation is needed. In this context FMTC, although not thought to be a distinctive pathological entity by some authors (25), appears to remain a clinically useful concept in respect to prognosis and therapy.

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