Cribriform-morular variant of papillary thyroid carcinoma: a distinctive type of thyroid cancer

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Abstract
The aim of this systematic review is to study the features of cribriform-morular variant of papillary thyroid carcinoma (CMV-PTC) by analysing the 129 documented cases in the English literature. The disease occurred almost exclusively in women. The median age of presentation for CMV-PTC was 24 years. Slightly over half of the patients with CMV-PTC had familial adenomatous polyposis (FAP). CMV-PTC presented before the colonic manifestations in approximately half of the patients with FAP. Patients with FAP often have multifocal tumours in the thyroid. Microscopic examination of CMV-PTC revealed predominately cribriform and morular pattern of cancer cells with characteristic nuclear features of papillary thyroid carcinoma. Psammoma body is rare. On immunohistochemical studies, β-catenin is diffusely positive in CMV-PTC. The morular cells in CMV-PTC are strongly positive for CD10, bcl-2 and E-cadherin. Pre-operative diagnosis of CMV-PTC by fine-needle aspiration biopsy could be aided by cribriform architecture, epithelial morules and β-catenin immunostaining. Mutations of APC gene are found in the patients with CMV-PTC associated with FAP. In addition, mutations in CTNNB1, RET/PTC rearrangement and PI3K3CA mutations have been reported. BRAF mutation is negative in all CMV-PTC tested. Compared to conventional papillary thyroid carcinoma, CMV-PTC had a lower frequency of lymph node metastases at presentation (12%) and distant metastases (3%) as well as lower recurrence rates (8.5%) and patients' mortality rates (2%). To conclude, patients with CMV-PTC have distinctive clinical, pathological and molecular profiles when compared to conventional papillary thyroid carcinoma.

Key Words
- cribriform-morular
- thyroid
- papillary carcinoma
- review

Introduction
Cribriform-morular variant of papillary thyroid carcinoma (CMV-PTC) is an uncommon variant of papillary thyroid carcinoma. It is a variant of papillary thyroid carcinoma recognized in the current World Health Organization (WHO) classification of endocrine tumours (Lam 2017). However, when compared to other variants of papillary thyroid carcinoma, it was relatively recently characterized in the literature. The first well-illustrated case was reported by Chan and Loo from Hong Kong in 1990 (Chan & Loo 1990). After this case, there were a few cases and a small series reported in the subsequent years (Yamashita et al. 1992, Harach et al. 1994, Hizawa et al. 1996, Mizukami et al. 1996, Perrier et al. 1998). Then, in 1999, Cameselle-Teijeiro and Chan coined the name of
this type of cancer and identified the unique pathological features of this variant of papillary thyroid carcinoma (Cameselle-Teijeiro & Chan 1999).

Methods


Epidemiology

The new edition of the World Health Organization (WHO) classification of endocrine tumours classified the papillary thyroid carcinoma into 15 variants (Lam 2017). Table 1 summarized the prevalence of the different variants of papillary thyroid carcinoma noted in surgical series.

CMV-PTC is one of the 15 variants and is very uncommon. In the English literature, only 3 larger populations of CMV-PTCs were reported. The first population was from Japan. This group of authors have reported CMV-PTC in different overlapping periods in a few publications. The largest series form this group was reported by Ito and coworkers in 2011 who had found 32 CMV-PTCs in the period 1991–2010 (Ito et al. 2011). However, no detailed information or prevalence of the disease was recorded in the publication. In 2015, authors from the same hospital reported a 0.3% (22 of 7228) prevalence of CMV-PTC in papillary thyroid carcinoma in the period 2005–2011 (Fujimoto et al. 2015). Also, in 2010, Hirokawa and coworkers from this hospital reported a prevalence of 0.22% (18 of 8583) of CMV-PTC in papillary thyroid carcinoma in the period 1991–2008 (Hirokawa et al. 2010). More recently, in 2004, Tomoda and coworkers presented 7 patients from the same hospital and noted a prevalence of 0.16% (7 of 4194) of CMV-PTV in papillary thyroid carcinoma in the period 1991–2003 (Tomoda et al. 2004). The other large population of CMV-PTCs were reported by Perrier and coworkers from Mayo Clinic and Cleveland Clinic in the USA who reported 11 cases of CMV-PTC (Perrier et al. 1998). However, the authors did not present the prevalence of CMV-PTC. The third large series of CMV-PTC was reported by Levy and coworkers in Memorial Sloan Kettering Cancer Centre in the USA in 2014 (Levy et al. 2014). The authors identified 11 patients with CMV-PTC of 6901 patients with papillary thyroid carcinoma in the period from 2001 to 2012. The prevalence of CMV-PTC was 0.16%. Thus, CMV-PTC accounts for approximately 0.2% of all papillary thyroid carcinoma.

CMV-PTCs were more commonly reported in patients from either Japan (n=47) or the USA (n=27). Geographically, the reported cases in Asia comprised approximately 63% of the cases (n=81). They were reported in Japan (n=47), South Korea (n=19), Singapore and Malaysia (n=8), China (including Hong Kong (n=6) and Sri Lanka (n=1)). It appears that CMV-PTC was more

<table>
<thead>
<tr>
<th>Variants of papillary thyroid carcinoma</th>
<th>Relative prevalence</th>
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<tbody>
<tr>
<td>1. Conventional/classical</td>
<td>~40%*</td>
</tr>
<tr>
<td>2. Papillary microcarcinoma</td>
<td>~25%</td>
</tr>
<tr>
<td>3. Encapsulated</td>
<td>~10%*</td>
</tr>
<tr>
<td>4. Follicular</td>
<td>~15%*</td>
</tr>
<tr>
<td>5. Diffuse sclerosing</td>
<td>~2%</td>
</tr>
<tr>
<td>6. Tall cell</td>
<td>~4%</td>
</tr>
<tr>
<td>7. Columnar cell</td>
<td>Rare, not known</td>
</tr>
<tr>
<td>8. Cribriform-morular</td>
<td>~0.2%</td>
</tr>
<tr>
<td>9. Hobnail</td>
<td>Rare, not known*</td>
</tr>
<tr>
<td>10. Papillary thyroid carcinoma with fibromatosis/fascitis-like stroma</td>
<td>Rare, not known*</td>
</tr>
<tr>
<td>11. Solid/trabecular</td>
<td>1-3%</td>
</tr>
<tr>
<td>12. Oncocytic</td>
<td>Rare, not known*</td>
</tr>
<tr>
<td>13. Spindle cell</td>
<td>Not known</td>
</tr>
<tr>
<td>14. Clear cell</td>
<td>Rare, not known</td>
</tr>
<tr>
<td>15. Warthin like</td>
<td>Rare, not known*</td>
</tr>
</tbody>
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*The proportion of these variants is estimated as the fourth edition of World Health Organization of endocrine tumours has updated the definitions of these variants.

Table 1 Relative prevalence of different variants of papillary thyroid carcinoma in surgical biopsy series.
common in Asian populations. The other cases were reported in America ($n=33; 26\%$) and Europe ($n=15; 11\%$).

Papillary thyroid carcinoma was often noted in adult in the fifth decade of life (mean age = 45 years) (Lam et al. 2005). From the literature, CMV-PTC was most often seen in patients in the third decade of life (Fig. 1 and Table 2). The mean age and median age of patients with CMV-PTC were 28 and 24, respectively. The age range of patients with CMV-PTC was from 8 to 69 years, and 89% ($n=115$) of the cancers were noted in patients aged younger than 40 years. It is worth noting that among the different variants of papillary thyroid carcinoma, diffuse sclerosing variant of papillary thyroid carcinoma also noted most often in patients at third decade of life (Pillai et al. 2015). Thus, both CMV-PTC and diffuse sclerosing variant of papillary thyroid carcinoma should be considered in thyroid cancer detected in young adults. From the accumulated data in the literature, CMV-PTC occurs in a slightly younger age than diffuse sclerosing variant of papillary thyroid carcinoma ($P=0.0001$) (Pillai et al. 2015).

### Table 2 Clinical and molecular differences between conventional papillary thyroid carcinoma and cribriform-morular variant of papillary thyroid carcinoma.

<table>
<thead>
<tr>
<th>Features</th>
<th>Conventional</th>
<th>Cribriform-morular</th>
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<tbody>
<tr>
<td>Mean age</td>
<td>45</td>
<td>28</td>
</tr>
<tr>
<td>Female to male ratio</td>
<td>3:1</td>
<td>31:1</td>
</tr>
<tr>
<td>Mean diameter (mm)</td>
<td>26</td>
<td>30</td>
</tr>
<tr>
<td>Association with FAP</td>
<td>Occasional</td>
<td>Noted in 53%</td>
</tr>
<tr>
<td>Lymph node metastases (%)</td>
<td>43</td>
<td>12</td>
</tr>
<tr>
<td>Cancer recurrence (%)</td>
<td>16</td>
<td>9</td>
</tr>
<tr>
<td>Mortality (%)</td>
<td>2.5</td>
<td>2</td>
</tr>
<tr>
<td>Braf mutation (%)</td>
<td>−60</td>
<td>0</td>
</tr>
<tr>
<td>Ras mutation</td>
<td>Uncommon</td>
<td>Uncommon</td>
</tr>
<tr>
<td>Non-Braf-non-Ras mutation</td>
<td>Uncommon</td>
<td>Common in the Wnt signalling pathway</td>
</tr>
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</table>

In patients with papillary thyroid carcinoma, the female-to-male ratio is 3 to 4:1 (Lam et al. 2005). On the other hand, CMV-PTC occurred almost exclusively in females. Of the 129 patients, 97% were females ($n=125$) and 3% were males ($n=4$). The female-to-male ratio was thus 31:1 (Table 2). The 4 male patients with CMV-PTC were of ages 34, 40, 42 and 55, respectively (mean age=43 years). Male patients with CMV-PTC were found in similar age group as conventional papillary thyroid carcinoma. The difference of age at diagnosis of CMV-PTC between the genders was significant ($P=0.03$).

### Clinical features

Patients with CMV-PTC mostly present with a mass lesion in the neck discovered incidentally on palpation or on imaging. All the cases were euthyroid. Alikhan and coworkers had reported a case with ectopic production of serum human chorionic gonadotropin (Alikhan et al. 2015).

The most unique clinical feature of CMV-PTC is related to its relationship with familial adenomatous polyposis (FAP). FAP is an autosomal dominant polyposis syndrome characterized by hundreds of adenomas in the large intestine as well as in the upper gastrointestinal tract (Leoz et al. 2015, Waller et al. 2016). It is due to germline mutations in APC gene located on long (q) arm of chromosome 5 at position 22.2. The APC gene plays a role in Wnt signalling pathway. The APC protein functions as a tumour suppressor by negatively regulating the β-catenin oncoprotein. The individuals with FAP have almost 100% chance to develop colorectal cancer. The colorectal carcinoma in the setting of FAP could occur at young age and could be multiple. FAP accounted for 4% of patients with synchronous colorectal carcinoma (Lam et al. 2011, 2014).

There are 2 major types of FAP with extracolonic manifestations of FAP, namely Gardner syndrome and type 2 Turcot syndrome. Gardner syndrome is a subtype of FAP that has colonic lesions as well as lesions in many different organs (Gómez García & Knoers 2009). The lesions are mostly benign such as epidermoid cyst, fibroma, desmoid tumour (fibromatosis), osteoma and congenital hypertrophy of the retinal pigment epithelium (CHRPE), etc. The pathogenesis of the lesions is postulated to be a ciliary dysfunction as both APC and the cilia have degradation of β-catenin as the common downstream target in the Wnt signalling pathway. Apart from colorectal cancer, patients with Gardner syndrome most often have small bowel cancer. The other cancers included pancreatic
cancer, hepatoblastoma, gastric cancer, bile duct cancer, adrenal cancer, central nervous system tumour as well as papillary thyroid carcinoma (Leoz et al. 2015).

Type 2 Turcot's syndrome is a very rare form of mutation of APC gene in which there is an association of intestinal polyposis and brain – most often medulloblastoma (Gadish et al. 2005, Skomorowski et al. 2012). The occurrence of thyroid cancer in Turcot syndrome is extremely rare. In the literature, Crail reported a case of medulloblastoma, papillary thyroid carcinoma and colonic polyposis in 1949 (Crail 1949). The first and the only documented CMV-PTC and medulloblastoma was reported by Fenton and coworkers in 2001 (Fenton et al. 2001).

Devic and Bussy were first to recognize the association of colonic polyposis with thyroid mass in 1912 in French literature (Devic & Bussy 1912). In 1949, Crail reported a case of papillary thyroid carcinoma in a patient with FAP, which was the first report of thyroid cancer in patient with FAP (Crail 1949). Then, Gardner in 1951 recognized thyroid cancer as extra-colonic manifestation in FAP (Gardner 1951). In 1968, Camiel and coworkers reported two sisters with FAP having papillary thyroid carcinoma (Camiel et al. 1968). Moreover, in 1994, Harach and coworkers first described that CMV-PTC is a unique variant of papillary thyroid carcinoma that could occur in the setting of FAP (Harach et al. 1994). In 1997, Bülow and Bülow in the United Kingdom have reported in a large cohort of patients with FAP that the incidence of thyroid carcinoma in FAP is 1.2% (Bülow & Bülow 1997).

From the data in literature, around half of the reported patients with CMV-PTC (n=69; 53%) had FAP. In the 4 male patients with CMV-PTC, three had FAP. There was no difference in the age of presentation between patients with or without FAP. Of these patients with FAP, approximately half (n=33; 48%) of the patients had the thyroid cancer as the first presentation. A few cases (n=3) had the thyroid cancer detected 5 years before the presentation of the colonic lesions (polyposis or carcinoma) (Chong et al. 2000, Fenton et al. 2001, Jung et al. 2009). Jung and coworkers reported a patient with FAP having CMV-PTC detected 12 years before the presentation of the colonic lesions (Jung et al. 2009). On the other hand, the thyroid cancer could occur up to 38 years after the appearance of colonic lesions in FAP (Kameyama & Takami 2001). The median lag time for the CMV-PTC was 10 years after the colonic lesions.

Of the CMV-PTC associated with FAP, other features of Gardner syndrome are sometimes noted. The most common lesion noted is desmoid tumour (n=8) (Chong et al. 2000, Dalal et al. 2006, Crippa et al. 2012, Giannelli et al. 2014, Abdullah Suhaimi et al. 2015, Alikhan et al. 2015, Perea del Pozo et al. 2015). In addition, one patient presented with osteoma (Soravia et al. 1999).

Macroscopic features
Many of the CMV-PTCs were lobulated tan masses with encapsulation or circumscription. There is lack of gritty appearance of calcium. The mean maximum dimension of CMV-PTCs was 30 mm (range, 5–95 mm). The dimension of the CMV-PTC is similar to conventional papillary thyroid carcinoma in which the mean dimension is 26 mm (Lam et al. 2005). From the literature, there is no significant difference in size of CMV-PTC between patients with or without FAP.

The sites of the CMV-PTCs were mentioned in 81 cases documented in the literature. The distribution of the CMV-PTCs is different between patients with and without FAP (P=0.0001). In patients without FAP, CMV-PTC often appears as solitary nodule with no site predilection. Only 16% (5 of 32) of the CMV-PTC without FAP involved both lobes of the thyroid. The remaining 84% (27 of 32) of CMV-PTC had roughly equal distribution in either lobe of the thyroid (13 in the left lobe and 14 in the right lobe). On the other hand, in patients with FAP, more than half of the patients (28 of 49; 57%) had bilateral cancers with multinodular appearance. In the remaining patients with FAP having solitary lesion, it appeared that CMV-PTC was often located in the right lobe (15 in right lobe and 8 in left lobe).

Microscopic features
CMV-PTC had the characteristic nuclear features of papillary thyroid carcinoma (crowded, oval, optically clear, grooves and eosinophilic cytoplasmic pseudo inclusions and so forth) though the nuclei of them are not particular clear.

As the name of CMV-PTC implied, it is a papillary thyroid carcinoma with predominate cribriform and morular pattern of carcinoma cells. The cribriform pattern of CMV-PTC is represented by back-to-back follicles with anatomising bars and arches of cancer cells in the absence of intervening fibrovascular stroma (Fig. 2A). In some cases, the morular area may be difficult to be identified or non-existent. It is characterized by solid whorls of cells forming morules or nests with no keratinization or...
intercellular bridges. Some nuclei within this area are clear and biotin rich (Fig. 2B). They can contribute to false immunostaining results.

On electron microscopic examination, the biotin-rich area pushes the nucleoli to the periphery of the nucleus and composed of randomly located fine microfilaments approximately 100 nm long (Yamashita et al. 1992, Kameyama et al. 2004). These clearings are not demarcated by a membrane. The morules do not contain remarkable cytoplasmic organelles.

Apart from the cribriform and morular morphology, aggressive histological features such as spindle cells in trabecular arrangements, tall and columnar cells with oxyphilic cytoplasm and frequent pseudo stratification as well as follicular pattern devoid of colloid could be present. Mitotic figures and necrosis are usually absent.

A case with hyaline globules as seen in adenoid cystic carcinoma was also described (Baloch et al. 2011).

In the setting of young patients with papillary thyroid carcinoma, the main clinical differential diagnosis of CMV-PTC is diffuse sclerosing variant of papillary thyroid carcinoma. Diffuse sclerosing variant of papillary carcinoma has prominent squamous areas, which could resemble morules. However, diffuse sclerosing variant had numerous psammoma bodies (Lam & Lo 2006, Pillai et al. 2015). In contrast, in CMV-PTC, psammoma bodies are rare or absent. In the literature, psammoma bodies are seldom mentioned in the pathological descriptions. Of the 129 CMV-PTCs, 18 documented that no psammoma body was found. Only 4 cases had a few psammoma bodies present (Soravia et al. 1999, Jung et al. 2009, Mogoș et al. 2012).

Multifocal lesions are common in CMV-PTC. The prevalence of multifocal lesion was more often noted in cases with FAP. In the literature, 118 cases had the data of FAP status as well as presence of multifocal lesions documented. In patients with FAP, 72% (48 of 67) had multifocal cancers, whereas in patients without FAP, 24% (12 of 51) had multifocal cancers ($P=0.0001$). Overall, multiple tumour foci were noted in 51% of the CMV-PTCs.

CMV-PTC is often confined to the thyroid gland. In the literature in which the extent of the CMV-PTC was documented, extra-thyroid or large lesion (T3/4) cancers are noted in slightly more than one quarter (28%; 24 of 87) of the cases. Also, capsular invasion and vascular invasion have been mentioned in a small portion of cases in 15 and 18 cases, respectively.

**Immunohistochemical features**

In CMV-PTC, the non-morular cancer cells had different staining properties when compared to the morular cancer cells (Dong et al. 2009, Jung et al. 2009). Both non-morular and morular cells in CMV-PTC are positive for galectin 3 and p53 protein. The proliferative index (Ki-67) is higher in non-morular cancer cells and reported to be 1–5% (Cameselle-Teijeiro & Chan 1999).

The non-morular cancer cells are frequently positive for thyroid transcription factor-1 (TTF-1), vimentin, oestrogen receptor, progesterone receptor, cyclin D1, PTEN, epithelial membrane antigen (EMA) as well as low- and high-molecular-weight cytokeratins such as CK7, CK19 and 34βE12 (Kwon et al. 2015). The staining for thyroglobulin, HBME-1 and CK5/6 are variable and can be either focal or negative.
The morules of CMV-PTC are negative for thyroglobulin, TTF-1, oestrogen receptor, progesterone receptor and many types of cytokeratins. Cytokeratin 19 (CK19) is commonly strongly expressed in papillary thyroid carcinomas. It is also positive in the squamous metaplasia in diffuse sclerosing variant of papillary thyroid carcinoma (Pillai et al. 2015). In contrast, CK19 may express only weakly in the morules in CMV-PTC. Cytoplasmic staining of CD10 and nuclear staining of bcl-2 are strongly positive in the morular cells but weak or not positive in the non-morular area (Giannelli et al. 2014).

β-Catenin and E-cadherin play a crucial role in cell-to-cell adhesion and maintaining epithelial morphology (Chow et al. 2001, Si et al. 2001, Chang et al. 2002). This cadherin/catenin complex also regulates cell motility and is believed to function as an invasion suppressor system (Rocha et al. 2001). β-Catenin is diffusely positive in both cytoplasm and nucleus of both types of cancer cells in CMV-PTC, whereas normal epithelium of thyroid gland shows membranous staining pattern. The strong expression of β-catenin is a hallmark staining in CMV-PTC in both FAP-associated or non-associated cases.

Loss of expression of E-cadherin, a cellular adhesion molecule, contributes to cancer metastases. Accordingly, studies have showed pronounced reduction of E-cadherin protein expression in the cell membrane, which was accompanied by the relocation of the protein staining to the cytoplasm in cancer (Rocha et al. 2001). Conventional papillary thyroid carcinoma showed heterogeneous loss of E-cadherin expression. In contrast, in CMV-PTC, E-cadherin was strongly and diffusely membranous positive in morular cells, whereas it was focally positive in non-morular cancer cells. Morular cells may decrease the metastatic or invasiveness of CMV-PTC. They may contribute to the relative lower biological or clinical aggressive of CMV-PTC when compared to other variants of papillary thyroid carcinoma.

Pre-operative investigations

There are two series in the literature focusing on the ultrasonic features of CMV-PTC. Chong and coworkers in 2013 reported that the majority of the thyroid nodules in 5 patients with CMV-PTC were well defined, had oval to round shapes and were hypoechoic and solid without calcification (Chong et al. 2013). Also, Fujimoto and coworkers in 2015 from a study of 22 patients with CMV-PTC noted that CMV-PTC had smooth or focal jagged margin, hypoechoic nodule, lateral shadow, posterior acoustic enhancement, poor marginal and internal vascularity and absence of micro-calcification (Fujimoto et al. 2015). These ultrasonic findings of CMV-PTC resembled those of follicular tumour or nodular hyperplasia of thyroid instead of papillary thyroid carcinoma. Therefore, CMV-PTC did not reveal the features of malignancy in ultrasonic examination. These benign ultrasonic features make pre-operative diagnosis of CMV-PTC difficult.

In the literature, 63% (81 of the 129) of the patients with CMV-PTC had fine-needle aspiration performed before operation. Of these, 95% (77 of 81) of the aspirates showed features either diagnostic or suspicious of thyroid carcinoma.

In 1996, Hizawa and coworkers from Japan first reported that fine-needle aspiration was done before operation of the CMV-PTC. The diagnosis on fine-needle aspiration was consistent with thyroid cancer (Hizawa et al. 1996). No detail of the cytological feature was given in the report. In 2010, Koo and coworkers from South Korea described the cytological features of five CMV-PTCs as well as reviewing 10 cases from the previous studies (Koo et al. 2011). The authors described that cytological features specific for CMV-PTC included cribriform architecture, epithelial morules and columnar cells. In addition, the β-catenin immunocytochemistry (nuclear and cytoplasmic positivity) could be used to help to diagnose CMV-PTC on cell block (Koo et al. 2011). Also in 2010, Hirokawa and coworkers in Japan documented 10 cytological features in 18 CMV-PTCs (Hirokawa et al. 2010). In addition to the cribriform architecture, epithelial morules and papillary arrangement of columnar cells, 7 other features were described in the cytological smears including spindle cells, peculiar nuclear clearing (pale-staining area occupying most of the nuclei, usually with condensed chromatin in the periphery of the membrane and positive for bclin), obscure ground-glass nuclei, hypercellularity, foamy or hemosiderin-laden histiocytes, hyaline materials as well as the absence of colloid in the background. It is worth noting that psammoma body and multi-nucleated giant cells characteristics of papillary thyroid carcinoma were not seen in all the cytological cases in the series. In the case series of Koo and coworkers, one had psammoma body reported in the smear (Koo et al. 2011). Thus, in the appropriate settings such as the presence of characteristic cytological features, relative young patients’ age, clinical suspicious or confirmation of FAP as well as the presence of material for β-catenin
immunocytochemistry (nuclear and cytoplasmic positivity), the diagnosis of CMV-PTC could be made by fine-needle aspiration biopsy before operation.

**Molecular pathogenesis**

The works of the Cancer Genome Atlas (TCGA) research network have revolutionized our understanding of molecular pathogenesis of thyroid carcinoma (Cancer Genome Atlas Research Network 2014, Yoo et al. 2016). The findings also resulted in a new classification of thyroid tumours that is incorporated in the fourth edition of the WHO classification of endocrine tumours (Lam 2017). In brief, large majority of papillary thyroid carcinomas are driven by mutations in either BRAF (specifically BRAFV600E) or RAS, both of which deregulate the mitogen-activated protein kinase (MAPK) signalling pathway. BRAFV600E-like tumours have conventional papillary morphology (conventional or tall cell variant of papillary thyroid carcinoma), whereas RAS-like tumours have follicular growth pattern and are encapsulated in greater than 80% of cases (Giordano 2016). A portion of the RAS-like tumours was now classified as non-invasive follicular thyroid neoplasm with papillary-like features (NIFTP) (Lam 2017). These groups of papillary thyroid carcinoma have distinctive clinical accounted for approximately 75% of papillary thyroid carcinoma. Other than BRAFV600E-like tumours and RAS-like tumours, the other papillary thyroid carcinomas are labelled as non-BRAF–non-RAS tumours. They were seen with other genetic alterations such as EIF1AX (eukaryotic translation initiation factor 1A and X-linked), PPM1D (protein phosphatase and Mg2+/Mn2+-dependent 1D) and CHEK2 (checkpoint kinase 2) (Cancer Genome Atlas Research Network 2014).

Ninety-eight percent of 402 papillary thyroid carcinomas in TCGA are conventional papillary thyroid carcinoma, follicular variant of papillary thyroid carcinoma and tall cell variant papillary thyroid carcinoma (Cancer Genome Atlas Research Network 2014). Two cases of CMV-PTC were examined in TCGA. They were of pathological stages – T3N1. One is from a 19-year-old female with a BRAF-like score whereas the other is from a 28-year-old man with fusion of RET and a RAS-like score. Thus, the molecular data of CMV-PTC from the TCGA are limited. The molecular pathogenesis of CMV-PTC summarized from the literature in the following sections. CMV-PTC likely belongs to non-BRAF–non-RAS group of papillary thyroid carcinoma on molecular classification.

**MAPK and PI3K/Act pathways and TERT**

The mitogen-activated protein kinase (MAPK) and PI3K (phosphoinositide 3-kinase)/Akt (protein kinase B) pathways are major pathways for pathogenesis of follicular-derived thyroid carcinoma (Rahman et al. 2015). Interactions of these two pathways were demonstrated in follicular-derived thyroid carcinoma (Rahman et al. 2016). In addition, TERT (telomerase reverse transcriptase) is also commonly studied in papillary thyroid carcinoma as a prognostic indicator (Vinagre et al. 2013, Melo et al. 2014).

PI3K/Akt pathway is activated by either the loss of PTEN expression or a PIK3CA mutation, resulting in downstream β-catenin activation. In the literature, only Kwon and coworkers in 2015 have reported three CMV-PTCs with PIK3CA mutation (Kwon et al. 2015). However, the mutation was not detected in a case tested by Oh and coworkers (Oh et al. 2016).

MAPK pathway is more commonly studied in cancer and BRAF, RAS and RET/PTC are common activators in the pathway. K-RAS mutation has been reported once in an 18-year-old woman with FAP and CMV-PTC by Giannelli and coworkers (Giannelli et al. 2014). On the other hand, the other 7 cases tested in the literature were negative for RAS mutations (Rossi et al. 2012, Nakazawa et al. 2013, Kwon et al. 2015, Brehar et al. 2016, Oh et al. 2016). It appears that RAS mutation is uncommon in CMV-PTC.

BRAF mutation was noted in approximately 45% of papillary thyroid carcinoma (Pakneshan et al. 2013). It was often noted in conventional papillary thyroid carcinoma of advanced pathological stages as well as those associated with lymphocytic thyroiditis (Smith et al. 2011). Multi-national studies have demonstrated that BRAF mutation in papillary thyroid carcinoma is associated with increased mortality and cancer recurrent rate (Xing et al. 2013, 2015). In the literature, BRAF mutation was tested in 18 cases of CMV-PTC (Rossi et al. 2012, Nakazawa et al. 2013, Giannelli et al. 2014, Kwon et al. 2015, Brehar et al. 2016, Oh et al. 2016), and the results showed that these cancers were negative for BRAF mutation. The absence of BRAF mutation in CMV-PTC may explain the relative indolent nature of this type of papillary thyroid carcinoma.

Rearrangement of the RET oncogene (also known as RET/PTC rearrangement) is an important genetic alteration that has been reported in earlier years. It is an early molecular event identified in papillary thyroid carcinomas (Lam et al. 1998). RET/PTC rearrangement is more commonly found in thyroid carcinomas in children and young adults as well as in papillary thyroid carcinomas.
associated with radiation exposure (Klugbauer et al. 1995, Nikiforov 2002). In CMV-PTC, 4 of the 6 cases (67%) tested in 4 different studies showed RET/PTC rearrangement (Soravia et al. 1999, Rossi et al. 2012, Giannelli et al. 2014, Brehar et al. 2016). Thus, RET/PTC rearrangement appears to be involved in the pathogenesis of a portion of papillary thyroid carcinomas in young patients. These papillary thyroid carcinomas include diffuse sclerosing variant of papillary thyroid carcinoma and CMV-PTC (Pillai et al. 2015).

Telomerase activation has been detected in papillary thyroid carcinoma (Lo et al. 1999). TERT (telomerase reverse transcriptase) is a catalytic subunit of telomerase that maintains telomere repeats in DNA strands. TERT promoter mutations have been observed in thyroid carcinomas with aggressive biological behaviours. It is associated with tumour size, advanced stage, extra-thyroidal invasion, lymph node metastases, distant metastases, BRAF mutation positivity, cancer recurrence and poor prognosis of patients with papillary thyroid carcinoma (Vinagre et al. 2013, Melo et al. 2014). Oh and coworkers in 2016 have reported the mutation in a 45-year-old woman with CMV-PTC (Oh et al. 2016). The case also had aggressive clinical course with lymph nodes and bone metastases.

Wnt signalling pathway

Wnt signalling pathway is important in carcinogenesis, tissue regeneration and embryonic development (Reguart et al. 2005). APC and β-catenin are the key members of the pathway. The mutations of either of these genes will elevate levels of β-catenin in the nucleus and cytoplasm. Nuclear and cytoplasmic β-catenin protein expression is a feature of CMV-PTC.

In patients with FAP, germline mutations of APC occurring before codon 1220 have a strong correlation with the development of thyroid cancer (Cetta et al. 2000). In CMV-PTC, germline mutations, somatic mutations and loss of heterozygosity of APC are frequently observed. In the literature, 18 of 28 (64%) of CMV-PTC tested positive for aberrations in APC gene. Both somatic and germline mutations of APC were reported in CMV-PTC (Iwama et al. 1999, Uchino et al. 2006).

The accumulation of β-catenin could be caused by mutation of the β-catenin gene, CTNNB1. The mutation was first reported by Xu and coworkers in 5 CMV-PTCs (Xu et al. 2003). Mutation of CTNNB1 was also reported in one of the CMV-PTCs by Jung and coworkers (Jung et al. 2009). In the literature, 32% (6 of the 19) of CMV-PTC was positive for mutation of CTNNB1 (Xu et al. 2003, Uchino et al. 2006, Cameselle-Teijeiro et al. 2009, Dong et al. 2009, Jung et al. 2009, Nakazawa et al. 2013, Kwon et al. 2015). The mutation could occur in CMV-PTC not associated with FAP, indicating that the mutation could play a role in non-FAP-associated CMV-PTC. As β-catenin accumulation is critical in the epithelial budding, branching and follicular formation in embryogenesis, Dalal and coworkers proposed that the cribriform pattern of CMV-PTC resembles the epithelial budding in embryos and the morules look like the hair formation noted in embryogenesis (Dalal et al. 2006).

In cases where APC and CTNNB1 are not found, aberrant upstream events in Wnt signalling may be related to aberrant nuclear localization of β-catenin noted in immunohistochemistry as well as the carcinogenesis of CMV-PTC.

Metastases

In contrast to conventional papillary thyroid carcinomas or diffuse sclerosing variant of papillary thyroid carcinoma, CMV-PTC had low prevalence of lymph node metastases (Table 2). In large series, lymph node metastases were noted in 43% of patients with conventional papillary thyroid carcinoma and in 80% of patients with diffusing sclerosing variant of papillary thyroid carcinoma (Lam et al. 2005, Pillai et al. 2015). In CMV-PTC, 12% (14 of 120) of patients had lymph nodes metastases at the time of surgery.

Distant metastases were uncommon in patients having CMV-PTC. In the literature, only 4 patients with CMV-PTC had distant metastases, accounting for 3% of the reported CMV-PTC in the literature. The first case was documented by Fenton and coworkers in 2001. The authors reported a CMV-PTC with cancer recurrence and bone metastases in a 50-year-old woman 30 years after the resection of primary thyroid cancer (Fenton et al. 2001). Also, Cameselle-Teijeiro and coworkers presented a 42-year-old man with known FAP having a CMV-PTC associated with neuroendocrine carcinoma component. The patient died with lung and brain metastases (Cameselle-Teijeiro et al. 2009). In addition, Nakazawa and coworkers reported a 35-year-old woman having CMV-PTC with a component of poorly differentiated thyroid carcinoma having bone and lung metastases (Nakazawa et al. 2013). Furthermore, in 2016, Oh and coworkers presented a 45-year-old woman with CMV-PTC.
showing TERT (telomerase reverse transcriptase) promoter mutation and having bone metastases (Oh et al. 2016). Overall, CMV-PTCs with distant metastases were seen in patients of age older than mean age of the patients with CMV-PTC. It is worth noting that three of these four patients with distant metastases had either unusual histological or molecular features.

**Prognosis**

In the literature, 8.5% (n=11 of 129) of patients with CMV-PTC showed recurrence of cancer (Table 2). For reference, the recurrence rate of diffuse sclerosing variant of papillary thyroid carcinoma was 14% (Pillai et al. 2015). In multi-national study, the recurrence rate in conventional papillary thyroid carcinoma was 16.1% (Xing et al. 2015). The recurrence rate in aggressive variant of papillary thyroid carcinoma, tall cell variant, was 27.3% whereas that of follicular variant of papillary thyroid carcinoma was 9.1%. Thus, the overall recurrence rate of CMV-PTC was low and similar to that of follicular variant of papillary thyroid carcinoma.

Three deaths were reported from the patients with CMV-PTC. Perrier and coworkers in 1998 recorded a 29-year-old female patient with CMV-PTC who had cancer recurrence at 6 months and died at 85 months after the operation (Perrier et al. 1998). In this study having 11 cases of CMV-PTC, the 5-year and 20-year survivals of the patients with CMV-PTC were 90% and 77%, respectively. Also, Fenton and coworkers in 2001 reported a 20-year-old woman with recurrence having distant metastases died 30 years after the resection of primary thyroid cancer (Fenton et al. 2001). In addition, Cameselle-Teijeiro and coworkers in 2009 presented a case in a 42-year-old man with known FAP having a neuroendocrine carcinoma component and died with lung and brain metastases 17 months after diagnosis (Cameselle-Teijeiro et al. 2009). Thus, patients with CMV-PTC have low mortality rate. On the other hand, cancer-related death could occur after a long lag time after the primary operation.

Disease-related mortality is uncommon and was noted in 2% (n=3/129) of the patients with CMV-PTC (Table 2). In multi-national study, disease-related mortality in conventional papillary thyroid carcinoma was found to be 2.5% (Xing et al. 2015). On the other hand, the disease-related mortality in aggressive variant of papillary thyroid carcinoma, tall cell variant, was 6.7% whereas that of follicular variant of papillary thyroid carcinoma was 0.6%. Also, the disease-related mortality in diffuse sclerosing variant of papillary thyroid carcinoma was 3% (Pillai et al. 2015). Thus, the prognosis of the CMV-PTC is similar to that of conventional thyroid carcinoma.

**Clinical management**

As the prognosis of CMV-PTC is similar to conventional papillary thyroid carcinoma, standard approach for the management of conventional papillary thyroid carcinoma based on the clinical and pathological risk factors should be appropriate (Paci & Castagna 2012, Raue & Frank-Raue 2016). Total thyroidectomy is sufficient for the treatment of most cancers. Lymph node dissection could be performed when necessary. The patients may have radioiodine therapy to detect and destroy any metastases and residual disease in thyroid. External beam radiotherapy may be used as adjuvant therapy in patients having locally invasive disease and in the older patients. In addition, CMV-PTC could be related to FAP and occur before the other manifestations of other diseases associated with FAP. Therefore, the management of the patients with CMV-PTC should also focus on the detection of other pathologies related to FAP as well as awareness of genetic implications of FAP in other family members.

**Conclusion**

CMV-PTC is characterized by unique clinical features (younger age at presentation, almost exclusively in women as well as the association with FAP). It has specific microscopic features (predominate cribriform and morular pattern of carcinoma cells with biotin-rich nuclei, multifocality and lack of psammoma bodies) as well as immunohistochemical pattern (positive to beta-catenin). In addition, CMV-PTC has distinctive molecular pathogenesis through the Wnt signalling pathway. These characteristics of CMV-PTC cast doubts on labelling the cancer as a variant of papillary thyroid carcinoma. Nevertheless, CMV-PTC had nuclear characteristic of papillary thyroid carcinoma and Wnt signalling pathway alternations are noted in some conventional papillary thyroid carcinomas. Thus, CMV-PTC is grouped as an uncommon and a very unique variant of papillary thyroid carcinoma.

Patients with CMV-PTC have low incidence of lymph node metastases and cancer recurrence. Despite this, late recurrence could occur, and long-term follow up is required for this group of patients. In the settings of FAP,
family screening and detection for other manifestations are important in the management of the patients. It is important to recognize this unique variant of papillary thyroid carcinoma as it occurs in specific clinical context and has unique pathological, immunohistochemical and molecular features.

Declaration of interest
The authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of this review.

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