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ORIGINAL PAPER

Trends in thyroid cancer burden in Taiwan over two decades

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Abstract

Purpose Thyroid cancer incidence has increased over recent decades with considerable geographic variations in incidence patterns. Here, we analyzed temporal trends in the incidence and mortality rates of thyroid cancer in Taiwan.

Methods We obtained age-standardized rates at a national level using data from the Taiwan Cancer Registry annual reports from 1995 to 2019. Trends in age-standardized rates were characterized by joinpoint regression analysis.

Results The age-standardized incidence rate of thyroid cancer increased from 3.00 per 100,000 person-years in 1995 to 15.46 per 100,000 person-years in 2019 ($p < 0.001$). Significant upward trends were observed in virtually all age groups, including adolescents and the geriatric population. The average annual percent changes were 7.97%, 2.60%, 2.77%, and 1.43% for papillary, follicular, medullary, and anaplastic thyroid cancers, respectively. The mortality rate from thyroid cancer decreased over time in women but remained stable in men.

Conclusion The incidence rates of thyroid cancer have steadily increased across gender, age groups, and tumor types over the past two decades. Future studies are needed to investigate potential etiological factors other than overdiagnosis that may drive these trends.

Keywords Thyroid cancer · Time trends · Incidence · Taiwan

Introduction

Thyroid cancer is the most common endocrine malignancy worldwide. The majority of thyroid cancer is follicular-derived differentiated thyroid cancer, which includes papillary and follicular types of tumors. Differentiated thyroid cancer affects younger populations than most malignancies and has an excellent prognosis, while patients with undifferentiated (anaplastic) thyroid cancer have dismal outcomes with a mean survival of 6 months [1]. Additionally, medullary thyroid cancer is a neuroendocrine C-cell derived thyroid cancer, and some patients are associated with an inherited multiple endocrine neoplasia syndrome. Given the indolent clinical course of differentiated thyroid cancer, a substantial reservoir of incidental thyroid cancer has been shown in autopsy studies [2]. It has been argued that increased detection of latent incidental diseases leads to overdiagnosis of thyroid cancer.

Globally, thyroid cancer has increased in incidence rates in recent decades, largely as a result of new cases of papillary thyroid cancer [3]. Improvement in the resolution of diagnostic imaging and its increased use has driven an increase in the identification of thyroid nodules and small, low-risk cancers. Nonetheless, there are considerable geographic variations in the incidence rates and the impact of overdiagnosis [4]. Numerous factors, such as a country's social and economic development, insurance system, iodine supplementation, and environmental exposure to radiation and endocrine disruptors, may contribute to vast differences among countries. Studies have shown that counties with a high Human Development Index generally have higher incidence rates, whereas mortality rates were relatively similar across different settings [5, 6].

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In Taiwan, universal National Health Insurance has been associated with a reduction in deaths considered amenable to health care [7]. Since Taiwan is currently excluded from the World Health Organization, there is a paucity of data from Taiwan on the epidemiological burden and trends. The aim of the present study was to assess the temporal trends in thyroid cancer incidence and mortality in Taiwan over a period of 25 years. We also investigated the incidence trends stratified by age group and tumor type.

Methods

Data source

The data used for the current analysis were obtained from the Taiwan Cancer Registry annual reports of the Health Promotion Administration, Ministry of Health and Welfare, Taiwan [8]. The Taiwan Cancer Registry is a nationwide population-based cancer registry system that was established by the Taiwan government in 1979 and annually publishes the incidence and mortality of all cancers [9]. Hospitals with 50 or more beds are required to report cases of newly diagnosed cancer to the central registry office. Multiple verification procedures have been applied to ensure completeness and accuracy, including duplicate checks, logic and consistency assessments, and trace-back linkage to profiles of death certificates, National Health Insurance catastrophic illnesses, and four cancer screening programs [10]. The crude rates were adjusted to the 2000 World Health Organization population standard to generate the age-standardized rates. All rates were reported per 100,000 person-years.

Cases of thyroid cancer were identified using the topography codes of the International Classification of Diseases for Oncology, Field Trial Edition (ICD-O-FT: T-193) or the International Classification of Diseases for Oncology, Third Edition (ICD-O-3: C73). Tumor type was classified according to ICD-O-3 morphology codes: papillary (8260/3, 8340/3, 8341/3, 8342/3, 8343/3, 8344/3, and 8350/3), follicular (8290/3, 8330/3, 8331/3, 8332/3, 8333/3, 8335/3, and 8339/3), medullary (8345/3, 8347/3, and 8510/3), and anaplastic (8020/3 and 8021/3). We analyzed the data up to 2019 to avoid the potential effects of the 2019 coronavirus disease (COVID-19) pandemic [11].

Statistical analysis

A joinpoint piecewise linear regression analysis was performed to identify the time points corresponding to significant changes and identify temporal trends in the age-standardized incidence and mortality rates [12]. The National Cancer Institute Joinpoint regression software version 4.9.1.0 was used for all analyses with default parameters. Average annual percent change (AAPC) was calculated as a summary measure of the trends for the overall period. A 95% confidence interval (95% CI) was obtained from the parametric method with 4499 permutations. The rate was deemed to have been increased if the AAPC estimation and the lower boundary of its 95% CI were both positive. In contrast, the rate was deemed to be in a downward trend if the AAPC estimation and the upper boundary of its 95% CI were both negative. Otherwise, the rate was deemed to be stable over time. For visual clarity, adaptive splines were used to demonstrate the continuous relationship between the calendar year and statistical data.

Results

Demographic characteristics

From 1995 to 2019, a total of 55,372 cases of newly diagnosed thyroid cancer were recorded in the Taiwan Cancer Registry, comprising 13,240 (24%) men and 42,132 (76%) women (Table 1). As shown in Fig. 1a, the age-standardized incidence rate of thyroid cancer increased from 3.00 per 100,000 person-years in 1995 to 15.46 per 100,000 person-years in 2019 (AAPC = 7.10%, 95% CI 6.13 to 8.07, $p < 0.001$). The upward trends were observed in both men (AAPC = 7.35%, 95% CI 6.92 to 7.79) and women (AAPC = 6.81%, 95% CI 5.80 to 7.83). The mean age at diagnosis of thyroid cancer was 48.7 years for men and 42.7 years for women in 1995, and the mean age at diagnosis rose to 50.7 years for men and 49.6 years for women in 2019. The median age of diagnosis increased over time (Fig. 1b). The AAPC for median age at diagnosis for thyroid cancer was 0.32% (95% CI 0.23 to 0.42) for men and 0.97% (95% CI 0.78 to 1.15) for women.

Incidence trends for thyroid cancer by age

The age-standardized incidence rates of thyroid cancer by age group and sex are presented in Fig. 2. Those aged between 30 and 64 years accounted for the majority of thyroid cancer cases (74%). About 2% of thyroid cancers were diagnosed before 20 years of age, and 14% were diagnosed in those aged 65 years or older. In general, trends of increased thyroid cancer incidence were observed across all age groups, with the highest AAPCs occurring at ages between 30 and 64 years. It is noteworthy that the thyroid cancer incidence has also been increased in adolescents. The AAPC for age-standardized incidence rates was 2.70% (95% CI 0.85 to 4.59) for males aged 15 to 19 years and 4.16% (95% CI 2.57 to 5.78) for females. In addition, the incidence of thyroid cancer significantly increased in the 10–14 age group of females (AAPC = 2.98%, 95% CI 1.24 to 4.74).

Table 1 Age-standardized incidence and mortality rates of thyroid cancer in Taiwan, from 1995 to 2019

Year	New cases												Deaths			
	Male						Female						Male		Female	
	n	ASIR					*n*	ASIR					*n*	ASMR	*n*	ASMR
		Total	PTC	FTC	MTC	ATC		Total	PTC	FTC	MTC	ATC				
1995	154	1.31	0.90	0.16	0.02	0.03	534	4.79	3.68	0.58	0.10	0.09	31	0.26	75	0.74
1996	184	1.53	0.97	0.23	0.06	0.07	602	5.27	4.01	0.67	0.11	0.15	45	0.39	71	0.67
1997	173	1.44	1.07	0.17	0.04	0.02	692	5.87	4.79	0.58	0.07	0.10	36	0.31	67	0.60
1998	223	1.77	1.20	0.20	0.08	0.07	811	6.70	5.54	0.62	0.10	0.08	36	0.29	76	0.64
1999	204	1.75	1.12	0.25	0.06	0.09	913	7.89	6.62	0.64	0.14	0.07	45	0.40	80	0.76
2000	278	2.31	1.72	0.26	0.04	0.07	875	7.43	6.19	0.67	0.08	0.08	58	0.50	60	0.56
2001	255	2.12	1.56	0.26	0.07	0.06	956	7.98	6.59	0.85	0.10	0.08	53	0.46	68	0.59
2002	338	2.76	1.98	0.22	0.04	0.07	989	8.11	6.77	0.64	0.07	0.15	53	0.43	98	0.82
2003	311	2.48	1.64	0.26	0.06	0.05	975	7.82	6.39	0.75	0.09	0.08	47	0.38	82	0.66
2004	335	2.60	1.76	0.34	0.04	0.08	1132	8.87	7.41	0.76	0.08	0.13	50	0.38	80	0.62
2005	359	2.73	1.89	0.28	0.06	0.07	1146	8.88	7.39	0.71	0.12	0.12	53	0.39	78	0.58
2006	410	3.12	2.31	0.37	0.05	0.05	1257	9.45	8.17	0.62	0.07	0.11	62	0.45	86	0.62
2007	430	3.18	2.51	0.30	0.08	0.06	1407	10.40	9.01	0.78	0.12	0.11	43	0.30	79	0.54
2008	440	3.19	2.57	0.27	0.06	0.04	1561	11.37	9.90	0.87	0.15	0.10	67	0.46	109	0.73
2009	568	4.06	3.18	0.36	0.09	0.06	1846	13.17	11.74	0.78	0.15	0.12	51	0.35	82	0.50
2010	571	4.02	3.37	0.33	0.08	0.07	1838	12.91	11.62	0.75	0.15	0.11	56	0.36	79	0.48
2011	628	4.37	3.65	0.42	0.09	0.08	1954	13.45	12.17	0.74	0.13	0.13	58	0.36	82	0.46
2012	659	4.47	3.82	0.36	0.09	0.05	2236	15.25	13.90	0.89	0.10	0.08	73	0.44	95	0.52
2013	760	5.13	4.52	0.32	0.05	0.07	2362	15.83	14.50	0.78	0.21	0.09	67	0.42	91	0.48
2014	826	5.54	4.86	0.35	0.09	0.09	2535	16.61	15.25	0.85	0.17	0.10	55	0.31	101	0.52
2015	889	5.88	5.17	0.36	0.09	0.05	2729	17.87	16.42	0.93	0.18	0.09	65	0.36	89	0.43
2016	899	5.85	5.15	0.37	0.05	0.10	2780	18.06	16.40	1.12	0.08	0.15	74	0.43	108	0.51
2017	935	6.07	5.43	0.36	0.06	0.06	3118	19.96	18.40	0.97	0.11	0.13	74	0.42	119	0.53
2018	1143	7.40	6.60	0.43	0.09	0.08	3302	21.01	19.34	1.06	0.15	0.16	73	0.38	119	0.52
2019	1268	8.07	7.34	0.44	0.08	0.10	3582	22.70	21.02	1.01	0.22	0.13	70	0.36	106	0.46

ASIR age-standardized incidence rates, *ASMR* age-standardized mortality rates, *ATC* anaplastic thyroid cancer, *FTC* follicular thyroid cancer, *MTC* medullary thyroid cancer, *PTC* papillary thyroid cancer

Similar trends were observed in the geriatric population. For men, the incidence of thyroid cancer significantly increased in the 65–84 age group. The incidence rate was stable in men with a chronological age of 85 years or older (AAPC = − 1.25%, 95% CI − 3.98 to 1.55). For women, increased incidence rates were noted in subjects aged 65 years or older, with the exception of a marginal increase seen in those aged 80 to 84 years (AAPC = 1.01%, 95% CI − 0.17 to 2.19).

Incidence trends for thyroid cancer by tumor type

The incidence rates of different tumor types were further evaluated (Table 2). As shown in Fig. 3, papillary thyroid cancer showed the most drastic increase in incidence rates (AAPC = 7.97%, 95% CI 6.83 to 9.13). The AAPC for age-standardized incidence rates was 2.60% (95% CI 2.16 to 3.04) for follicular thyroid cancer and 2.77% (95% CI 1.33 to 4.24) for medullary thyroid cancer. Notably, the incidence rate of anaplastic thyroid cancer was 0.06 per 100,000 person-years in 1995 and rose to 0.11 per 100,000 person-years in 2019 with an AAPC of 1.43% (95% CI 0.30 to 2.57, $p = 0.015$).

Temporal trends in mortality

Overall, the mortality rates of thyroid cancer decreased over time (AAPC = − 1.28%, 95% CI − 1.88 to − 0.69, $p < 0.001$). In women, the mortality rate was 0.74 per 100,000 person-years in 1995 and dropped to 0.46 per 100,000 person-years in 2019 with an AAPC of − 1.73% (95% CI − 2.39 to − 1.06). However, the annual mortality rates of thyroid cancer did not change significantly in men (Fig. 1c). The mortality rate was 0.26 per 100,000

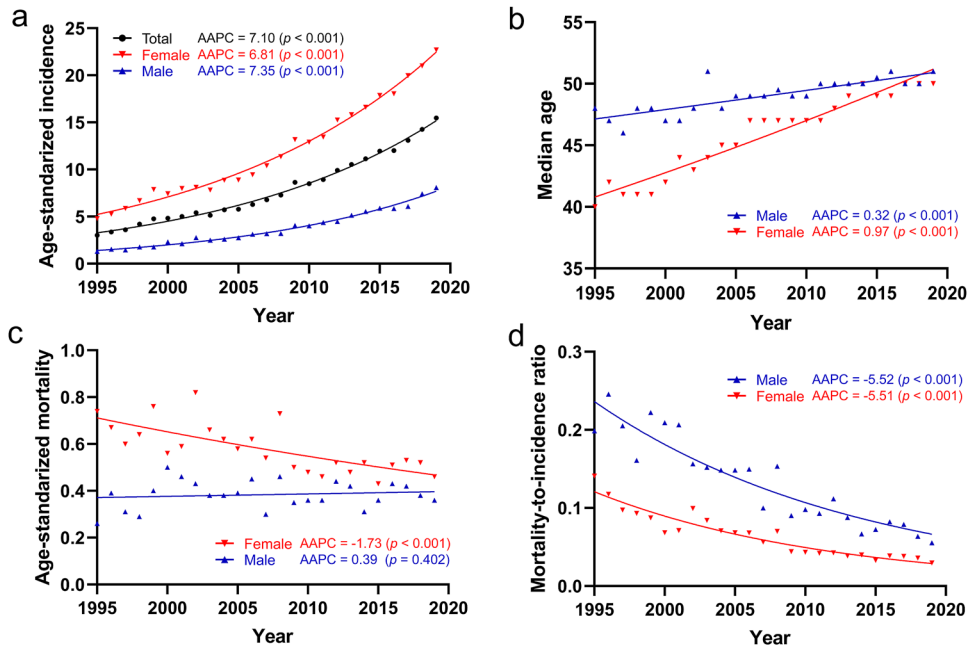

Fig. 1 Temporal trends in **a** age-standardized incidence rates, **b** median age at diagnosis, **c** age-standardized mortality rates, and **d** mortality-to-incidence ratios of thyroid cancer in Taiwan, from 1995 to 2019. Solid lines represent restricted cubic splines (smoothed fits). AAPC average annual percent change

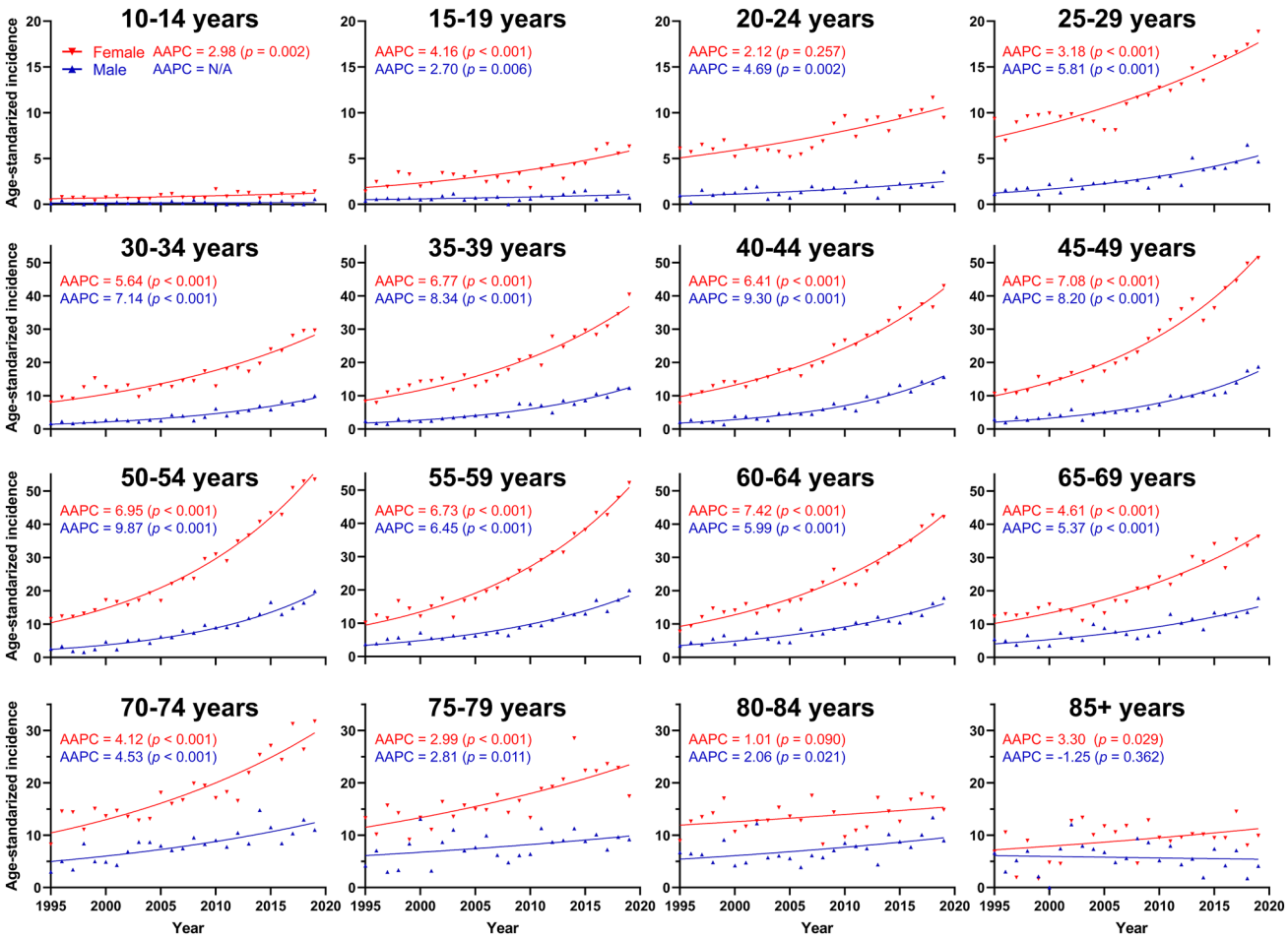

Fig. 2 Age-stratified incidence rates of thyroid cancer in Taiwan, from 1995 to 2019. Solid lines represent restricted cubic splines. Note that the scale of the y axis differs across panels. AAPC average annual percent change, N/A not applicable

Table 2 Tumor type-stratified trends in thyroid cancer incidence in Taiwan, from 1995 to 2019

Tumor type	Both sexes				Male				Female			
	Period	APC	95% CI	*p*-value	Period	APC	95% CI	*p*-value	Period	APC	95% CI	*p*-value
Papillary	AAPC	7.97	6.83–9.13	< 0.001	**AAPC**	8.92	8.39–9.44	< 0.001	AAPC	7.61	6.60–8.62	< 0.001
	1995–1999	14.57	11.04–18.21	< 0.001					1995–1999	15.92	12.77–19.16	< 0.001
	1999–2005	3.25	1.00–5.56	0.008					1999–2003	0.05	− 4.21–4.51	0.980
	2005–2009	11.75	6.36–17.41	< 0.001					2003–2009	9.33	7.22–11.48	< 0.001
	2009–2019	6.83	6.01–7.66	< 0.001					2009–2019	6.52	5.80–7.24	< 0.001
Follicular	AAPC	2.60	2.16–3.04	< 0.001	AAPC	3.33	2.56–4.11	< 0.001	AAPC	2.21	1.66–2.78	< 0.001
Medullary	AAPC	2.77	1.33–4.24	0.001	AAPC	2.84	0.82–4.90	0.008	AAPC	2.73	1.09–4.39	0.002
Anaplastic	AAPC	1.43	0.30–2.57	0.015	AAPC	2.00	0.25–3.78	0.026	AAPC	1.20	− 0.12–2.54	0.072
Total	AAPC	7.10	6.13–8.07	< 0.001	AAPC	7.35	6.92–7.79	< 0.001	AAPC	6.81	5.80–7.83	< 0.001
	1995–1999	12.34	8.99–15.78	< 0.001					1995–1999	12.75	9.22–16.40	< 0.001
	1999–2003	2.91	− 1.89–7.95	0.222					1999–2003	1.65	− 3.34–6.89	0.503
	2003–2019	6.89	6.50–7.28	< 0.001					2003–2019	6.69	6.28–7.10	< 0.001

Absence of time periods indicates no joinpoint

AAPC average annual percent change, *APC* annual percent change, *CI* confidence interval

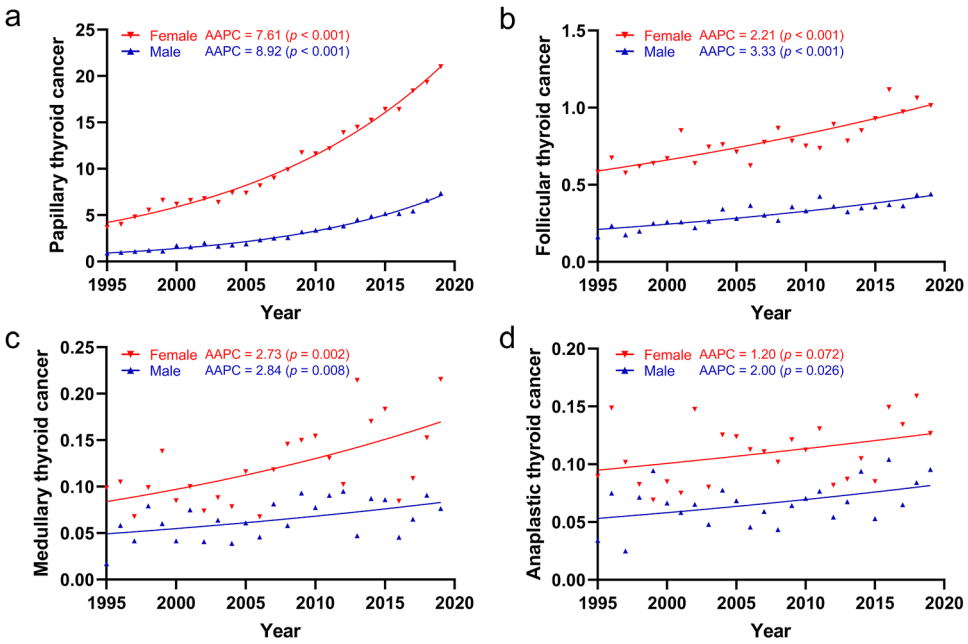

Fig. 3 Tumor type-stratified incidence rates of thyroid cancer in Taiwan, from 1995 to 2019. Solid lines represent restricted cubic splines. AAPC average annual percent change

person-years in 1995 and became 0.36 per 100,000 person-years in 2019 with an AAPC of 0.39% (95% CI − 0.55 to 1.33).

We also calculated the mortality-to-incidence ratio (MIR), which has previously been employed as a proxy for survival [13]. Men generally had higher MIR values than women (Fig. 1d). The MIR of both sexes was 0.15 in 1995 and gradually decreased to 0.04 in 2019 with an AAPC of -5.43% (95% CI − 6.00 to − 4.85, $p < 0.001$).

Discussion

Consistent with global trends, we noted that the incidence rates of thyroid cancer have increased across gender, age groups, and tumor types over the past two decades. A previous analysis using the Taiwan Cancer Registry and the National Death Registry databases revealed that the age-standardized incidence of thyroid cancer increased

from 5.66 per 100,000 person-years in 1997 to 12.30 per 100,000 person-years in 2012, with an AAPC of 5.1% (6.9% in males and 4.6% in females) [14]. The increase in incidence rates was most marked in papillary tumors and among middle-aged individuals. These findings suggest that Taiwan is no exception to the worldwide challenge of overdiagnosis of thyroid cancer.

Based on autopsy studies, the prevalence of subclinical papillary thyroid cancer is stable across the lifespan, and middle age does not confer a higher prevalence of subclinical disease compared to younger or older age groups [15]. Additionally, the prevalence of subclinical thyroid cancer has not increased over time [2]. Researchers from the Mayo Clinic reported that incidence rates of clinically relevant thyroid cancers, defined by histology, size, invasion, and metastasis, have not changed significantly in 80 years [16]. These observations indicate that increased incidence rates of thyroid cancer likely result from more diagnostic detection than a true population-level increase in tumorigenesis.

In the present study, it is noteworthy that increases in thyroid cancer incidence were observed in the pediatric as well as geriatric groups. Increased incidence rates of thyroid cancer in the pediatric population have been reported in other countries [17, 18]. Although one may argue that children and adolescents are less likely to have overdetection effects, the pattern of thyroid cancer incidence in children and adolescents mirrors the pattern seen in adults [19]. It is therefore postulated that overdiagnosis is also evident in the pediatric group. Nonetheless, in the United States, the incidence rates of large pediatric thyroid cancers (> 20 mm) increased from 1973 to 2013 [17]. It remains possible that a biologically real increase in incidence in the pediatric population exists and may stem from various factors, such as excess adiposity and exposure to medical radiation. Multiple or repeated exposures to dental X-rays were shown to be associated with an increased risk of thyroid cancer [20]. Warningly, its use in orthodontic practice has increased, especially in children and adolescents.

In line with trends in other countries [21], the rate of upsurge was lower in the geriatric group compared to the middle-aged population. Older patients, however, may be more vulnerable to treatment-related morbidities. Studies have indicated that thyroid cancer survivors have an increased risk of cerebrovascular disease and atrial fibrillation [22]. In Taiwan, cardiovascular disease is the third leading cause of mortality in thyroid cancer patients [23]. We recently demonstrated that, compared to the general population, thyroid cancer survivors have a substantial risk of coronary heart disease [24]. Some experts have proposed that surgical management of elderly patients with thyroid cancer should be tempered when high-risk findings (aggressive tumor type and metastasis) are absent, especially for those who have comorbid illnesses [25].

We found that the median age of diagnosis increased over time. In Korea, the age at diagnosis has also increased from 37.2 years before 1984 to 49.2 years after 2005 [26]. This may reflect a demographic shift and heightened overdiagnosis within the working age population. It is possible that employees will more readily access health care and regularly undergo annual health checkups as requested by the company. While declining birth rates and increased life expectancies create an aging population, retirement age is being delayed. In this regard, Taiwan has an accelerated rate of aging that is more than twice that of European countries and the United States [27]. A steeper rise in the age at diagnosis for women may imply advances in women's economic participation during the study period.

Iodine status influences the dominant tumor type of thyroid cancer, while endemic goiter and follicular thyroid cancer are more common in iodine-deficient areas. Mandatory salt iodization began in 1967 in Taiwan, and Taiwan's iodine policy changed from mandatory to voluntary salt iodization in 2003 [28]. As in other iodine-replete countries [5], we demonstrated that papillary thyroid cancer had a steeper increase in incidence rates than follicular thyroid cancer (AAPC 7.97% and 2.60%, respectively). Strikingly, our study disclosed that the incidence rates were also increased in medullary and anaplastic thyroid cancer (AAPC 2.77% and 1.43%, respectively).

It is acknowledged that the majority of anaplastic thyroid cancers develop through dedifferentiation from a preceding differentiated thyroid cancer [29]. Therefore, it is expected that the incidence of anaplastic cancer will decrease following the successful treatment of differentiated thyroid cancer [30]. Indeed, declining trends in anaplastic thyroid cancer rates were observed in most countries [31]. Our analysis points to an alarming increase in the incidence rates of anaplastic thyroid cancer with no joinpoints in Taiwan. This finding echoes a recent study exploring the Surveillance, Epidemiology, and End Results-18 cancer registry during 2000–2018, which reported an increase in anaplastic thyroid cancer with an AAPC of 1.99% in the United States [32]. The probability of a true rise in thyroid cancer burden needs careful attention as the increasing occurrence of anaplastic thyroid cancer is unlikely accounted for by overdiagnosis of small indolent tumors.

Medullary thyroid cancer originating from parafollicular neuroendocrine cells has a distinct pathobiology from follicular-derived thyroid cancer. In general, trends in the incidence of medullary thyroid cancer are not correlated with the corresponding trends in papillary and follicular thyroid cancer incidence [31]. In agreement with our observations, slight increases in incidence rates of medullary thyroid cancer have been reported in several countries, including the United States, Norway, and France [5, 32–34]. Interestingly, in Korea, when concerns of overdiagnosis were raised,

decrements in thyroid cancer incidence were observed in not only papillary but also medullary thyroid cancer [35]. In this respect, it remains unclear whether there is a reservoir of subclinical medullary thyroid cancer, and whether the observed small increase in medullary thyroid cancer incidence is due in part to a more sensitive detection and diagnosis.

Thyroid cancer-specific mortality was the leading cause of death in patients with thyroid cancer in Taiwan, highlighting that cancer-related death remains a major health threat to thyroid cancer survivors [23]. International trends generally showed a decline in thyroid cancer mortality rates in both sexes [36]. Nonetheless, in the current study, we noted that the thyroid cancer mortality rate remained stable over time in male patients. In the United States, incidence-based mortality rates of thyroid cancer increased throughout 2000–2018 in both men and women, particularly for papillary and anaplastic carcinomas [32]. These reinforce the possibility that there might be actual increases in thyroid cancer burden in addition to medical scrutiny.

To date, biological causes of gender differences in thyroid cancer incidence are not yet well known. The autopsy prevalence of subclinical papillary thyroid cancer was similar between women and men [37]. The preconceived view regarding gender disparity may influence patterns in clinical thinking and health care utilization, leading to the risk of overdetection in women and the risk of underdetection in men [37]. Undoubtedly, other potential factors may contribute to the observed disparities, including hormonal and reproductive effects, obesity prevalence, smoking and dietary patterns, and occupational exposure to certain carcinogens. Male gender was independently associated with worse outcomes among patients with papillary thyroid cancer [38]. In-depth understanding of pathophysiology and continuously monitoring the trends in epidemiology of thyroid cancer are necessary to solve gender dilemmas.

The main strengths of this study are that we provided the most updated incidence and mortality rates of thyroid cancer in Taiwan based on high-quality cancer registries. The population-based design and the size of population coverage provided reliable estimates over the study period. Furthermore, we conducted joinpoint regression analyses to account for variation in trends over time rather than assuming a constant trend across all time periods. Nonetheless, several limitations need to be considered. We recognized the inherent limitations of retrospective analysis of a population-based database. Certain details, including patients' socioeconomic status and histologic characteristics, are not available. The MIR is not a useful or valid survival estimate [39]. Therefore, we were unable to calculate trends for survival, which would provide important insights into the extent of overdiagnosis. Second, the data source was from an East Asian country, which limits its generalizability to a more ethnically diverse population. Finally, given the descriptive nature of this study, the potential reasons for the observed incidence trends are largely conjectural.

Despite these limitations, our study sheds light on the clinical implications of thyroid cancer overdiagnosis in Taiwan. Accompanied with overdiagnosis, the potential harms and treatment-related adverse effects can be substantial. Diastolic dysfunction is frequently observed in asymptomatic long-term pediatric survivors of thyroid cancer [40]. Moreover, overdiagnosis turns normal subjects into patients and predisposes them to years of follow-up. Health-related quality of life is lower in young adults diagnosed with thyroid cancer, particularly when it comes to neuromuscular, concentration, and anxiety complaints [41]. In pediatric patients with differentiated thyroid cancer, disease-specific death is uncommon even in the presence of distant metastases [42]. Physical and psychological consequences associated with overdiagnosis may be more serious in children and adolescents. While the possibility of a true increase in disease burden is still debated, from a clinical perspective, physicians should avoid overutilization of medical imaging and should be discouraged from performing biopsies of low-risk nodules.

In conclusion, this large population-based study over a period of 25 years indicates that the overall incidence of thyroid cancer in Taiwan has been rising, consistently across all age groups and four major tumor types. Although the mortality rate from thyroid cancer in women has declined, death rates from thyroid cancer remain stable in men. Future etiological and molecular investigations are warranted to understand the underlying pathogenesis of the upward trend in the incidence of medullary and anaplastic thyroid cancer.

Author contributions All authors contributed to the study conception and design. Data collection and analysis were performed by SYHC and SPC. The first draft of the manuscript was written by SYHC and SPC. All authors read and approved the final manuscript.

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Data availability The data that support the findings of this study were obtained from the openly available Cancer Registry System of the Health Promotion Administration, Ministry of Health and Welfare of Taiwan.

Declarations

Competing interest The authors have no relevant financial or non-financial interests to disclose.

Ethical approval The conduct of this study was reviewed and approved by the Institutional Review Board of MacKay Memorial Hospital (Approval Number 22MMHIS345e).

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