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ORIGINAL ARTICLE

Comprehensive characterization of epidemiological and 3D radiographic features of non-third molar impacted teeth in a Chinese dental population

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Abstract
Objective This retrospective study aimed to comprehensively delineate the epidemiological and 3-dimensional radiographic characteristics of non-third molar (non-M3) impacted teeth in a Chinese dental population.
Material and methods Patients with impacted teeth except for the third molar (ITEM3) were retrospectively screened via cone-beam CT images from 75,021 patients treated at our institution from June 2012 to December 2018. Demographic and clinical data of patients with ITEM3 were retrieved from medical records. CBCT coupled with 3-dimensional reconstruction was employed to characterize the radiographic features of ITEM3. Associations between these epidemiological, clinical, and radiographic features were further statistically analyzed.
Results Among 1975 eligible patients, 2467 ITEM3s were identified with a prevalence of 2.63% (1975/75,021). Females slightly outnumbered males with a ratio of 1.12:1. The majority of ITEM3 was single (1577, 79.85%) in the maxilla. The maxillary canine teeth were the most frequently impacted (52.45%), followed by maxillary incisors. The mesioangular position was the most common orientation (43.8%), followed by vertical and buccal-lingual orientations. The most frequently associated lesion was external root resorption of the adjacent tooth, which was significantly correlated with the morphology and position of the impacted tooth.
Conclusion Most ITEM3 was single, mesioangular, found at maxillary canines, sometimes associated with diverse complications. Our data advance the current understanding of ITEM3 and offer insights into the management of this dental abnormality.
Clinical relevance These findings are useful for clinicians to comprehensively understand the prevalence, radiographic features, and complications of non-M3 impacted teeth.

Keywords Impacted tooth · Cone-beam computed tomography · Epidemiology · Complication

Introduction

The impacted tooth is usually defined as tooth eruption failure caused by physical obstacles in the eruption path or abnormal inclination of the tooth axis, which is one of the most common dental anomalies among humans [1]. These impacted teeth may lead to various deleterious consequences including malposition, delayed eruption, external root resorption and periodontal bone loss of adjacent teeth, malocclusion, and odontogenic cysts or tumors [2]. Indeed, the varying prevalence of impacted teeth, excluding third molars, in diverse populations and ethnic groups has been documented from 5.6 to 18.8% [3–7]. Previous reports have revealed that the etiology of tooth impaction

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is associated with local and systemic factors such as the lack of dental arch space, presence of supernumerary teeth or odontomas, failure of root resorption of primary teeth, early loss of primary teeth, and associated space loss, as well as cleidocranial dysostosis [7, 8]. Although impaction may involve any tooth in the primary and permanent dentitions, most impacted teeth at other sites except the impacted third molars (M3s) are asymptomatic and often detected incidentally when patients visit for dental problems such as orthodontics. A large amount of data regarding impacted M3s have been reported about their incidence, clinical and radiographic features as well as their management. However, fewer findings concerning impacted teeth except for third molars (ITEM3) have been documented. Therefore, it is of great importance and significance to clarify the relevant features of this dental abnormality in permanent teeth and provide insights into its diagnosis and optimal management.

Previous reports have documented some characteristics of ITEM3 in selected dental populations or at specific dental sites. In addition, the ethnic-specific or geographic prevalence of ITEM3 has been reported including African American, North Greek, and Chinese populations [6, 7, 9, 10]. Nevertheless, the contributions of environmental and genetic factors to ITEM3 have been hotly debated and remain to be further clarified especially in patients with syndrome or family history [1, 11, 12]. Regarding the incidence of impacted teeth, maxillary canines, mandibular and maxillary premolars, and maxillary incisors have been identified as common sites for impaction except for those M3s.

Conventional panoramic radiography is a primary diagnostic modality for impacted and supernumerary teeth [3]. However, the intrinsic shortcomings of image overlapping and lack of three-dimensional spatial information significantly undermine its accuracy and hinder treatment planning and risk evaluation. CBCT provides multiple planes for accurately identifying dental structures with low radiation dosages and non-overlapping among diverse anatomic structures, thus facilitating its wide application in dentistry including the diagnosis and treatment of impacted teeth. Clinical and radiographic characterizations of ITEM3 in selected dental sites using CBCT highlighted its utilities in accurate diagnosis and treatment planning [7, 13].

Given that previous reports largely focused on ITEM3 in selected dental sites or a small number of patients, our knowledge about the epidemiological, clinical, and radiographic features of ITEM3 remains quite limited until now. Here, to address this knowledge gap, we sought to comprehensively delineate the epidemiological and 3-dimensional radiographic characteristics and associated pathologies of ITEM3 in a Chinese non-syndromic dental population.

Materials and methods

Patients

This study was designed as a cross-sectional retrospective study. The reporting follows the STROBE statement. As illustrated schematically in Fig. 1 we initially screened 75,021 patients (age range from 9 to 78 years old) who underwent CBCT scans at their visits to Affiliated Stomatological Hospital, Nanjing Medical University, for their dental or maxillofacial diseases from June 2012 to December 2018. Indeed, more than 800,000 outpatients visit our hospital every year for their dental and oral maxillofacial diseases, thus offering adequate patient and radiographic resources for our study. Patients with at least one impacted tooth except the impacted M3s were included. Here, teeth were defined as impacted when they remained in the jaw for more than 1 year later than the corresponding mean age of eruption due to some physical barrier (mucosa or bone) in their paths or erupted at abnormal orientations. The youngest age for patient inclusion was 9 years old due to the epidemiological data of the Chinese population indicating the normal age for the eruption of the first molar at 6–8 years old, consistent with previous similar studies [1, 3, 12, 14]. Patients with

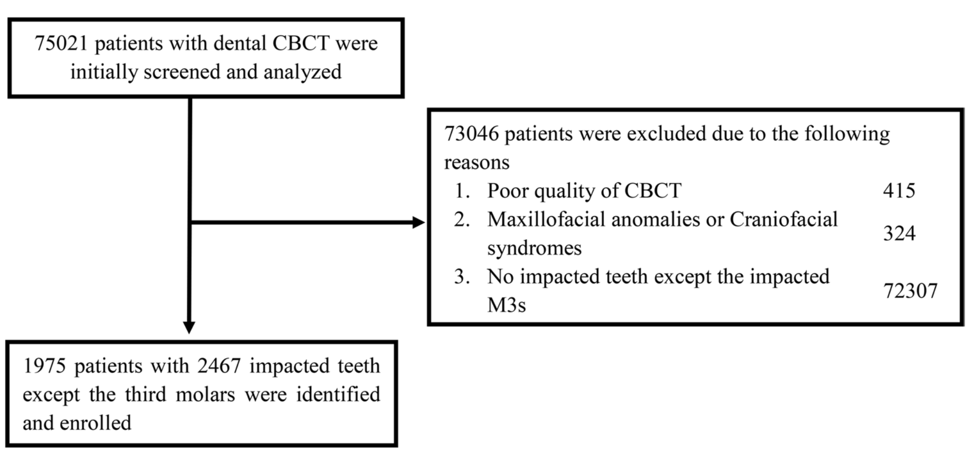

Fig. 1 The flow chart of patients' screening

poor quality of CBCT, maxillofacial anomalies, or craniofacial syndromes such as cleft lip and palate, cleidocranial dysostosis were excluded. To verify the diagnosis of impacted teeth and their radiographic features, two experienced dentists (Drs. Yijin Shi and Yanling Wang) evaluated the CBCT and 3D images independently and reached final agreements for each patient. If the assessments differed, they would consult with another dentist (Dr. Han Ge) and make final diagnoses. Among 75,021 patients with qualified CBCT and detailed medical records available, ITEM3 was found in 1975 patients after CBCT examinations. Thus, 1975 eligible patients with 2467 impacted teeth were enrolled. All relevant epidemiological data (age, gender) and radiographic details about impacted teeth (the number, arch, classification, location of crown, eruption state, impaction depth, and associated complications) were collected. The whole study was performed in keeping with the Declaration of Helsinki for research involving human subjects. The methods and protocols were reviewed and approved by the Ethics and Research Committee, Nanjing Medical University (2019–0166).

Three-dimensional radiographic characterizations of ITEM3 using CBCT images

All CBCT images were analyzed by NNT (version 5.6, New Tom, Verona, Italy) and Invivo5 (In-vivo Dent, Anatomy, San Jose, CA, USA). The original CBCT data (New Tom VG or New Tom 5G, Verona, Italy) in DICOM format for each patient were retrieved from our Radiographic Data Center for assessments. The detailed parameters for CBCT scan were listed as follows: 5.73 mA, 110 kV, exposure time of 3.6 s, voxel size of 0.30 mm, axial slice thickness of 0.30 mm, and scanning area of 18 * 16 cm. All CBCT scans were performed by experienced radiologists following the manufacturer's protocol and radiographic criteria to ensure image quality. Three-dimensional image reconstruction of CBCT data was performed by Invivo5. The morphology of impacted teeth and 3-dimensional image reconstruction were classified and listed as follows.

1. Impacted teeth in dental arch: maxilla, mandible, or both
2. Numbers of impacted teeth: one, two, three, four, five, and six (Fig. 2)
3. Sites of impacted tooth: incisor region, canine region, premolar region, molar region (Fig. 3)
4. Orientations of impacted teeth: mesioangular, horizontal, vertical, distoangular, buccal-lingual, inverted, ectopic, or transmigration (Supplementary Fig. 1)
5. Locations of tooth crown: labial/buccal, median, or palatal/lingual (Supplementary Fig. 2)
6. Eruption status: erupted or impacted
7. Root development: complete, incomplete, or germ (Fig. 4)
8. Impaction depths: Level A: the highest point of the tooth crown above the cervix of the adjacent tooth; Level B: the highest point of the tooth crown between the cervix and the root apex of the adjacent tooth; Level C: the highest point of the tooth crown below the root apex of the adjacent tooth
9. Existence of supernumerary tooth at the same site: yes or no
10. Deciduous tooth retention at the same site: yes or no
11. Complications associated with impacted teeth: cystic lesions, odontoma, external root resorption, malposition, or impaction of the adjacent teeth (Fig. 5)

Statistical analyses

All descriptive data regarding patients' epidemiological, clinical, and 3D radiographic data were presented. Associations between categorical covariates were assessed by chi-square tests or Fisher's exact test as indicated. Cohen's kappa values were used to estimate inter-observer reliability and reproducibility. All tests were two-sided, and *P* values lower than 0.05 were considered statistically significant. All statistical data collected were entered into a spreadsheet and analyzed subsequently using Stata 14.0 software (Texas, USA).

Results

Epidemiological characteristics of patients and non-third molar impacted teeth

Among 75,021 patients during the initial CBCT screen and medical record review, 1975 patients with 2467 ITEM3s satisfied our inclusion criteria, presenting an overall prevalence of 2.63% (1975/75,021). Indeed, most patients underwent CBCT scans largely due to orthodontic treatment, maxillofacial trauma and fracture, dental implantation, supernumerary teeth, as well as various bone lesions in jaws in addition to impacted teeth. Detailed information about these enrolled patients and ITEM3s was recorded and stratified. As listed in Table 1, 930 (47.09%) were males and 1045 (52.91%) were females, presenting a gender ratio of 1:1.2. The ages of the patients ranged from 9 to 78 years with a median age of 17 years (mean age: 22.43 ± 13.38 years old). Initially, to confirm the reliability and reproducibility of our radiographic assessment, Cohen's Kappa values for the inter-rater agreements regarding the CBCT radiographic assessments ranged from 0.84 to 0.93 (Supplementary Table 1), thus supporting the robustness of these radiographic evaluations.

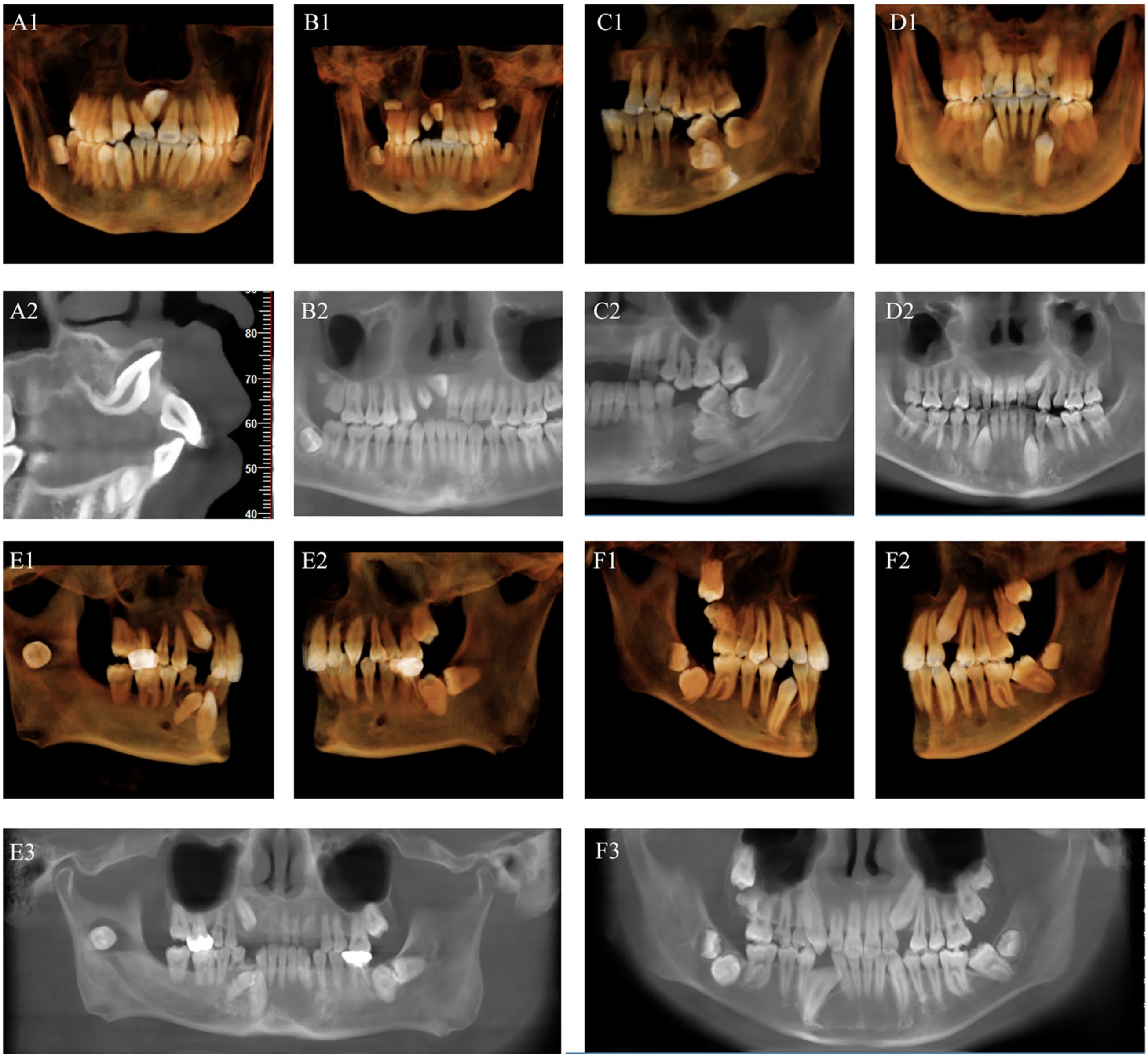

Fig. 2 Representative CBCT images exhibiting different numbers of ITEM3. **A1-A2:** 1 ITEM3; **B1-B2:** 2 ITEM3s; **C1-C2:** 3 ITEM3s; **D1-D2:** 4 ITEM3s; **E1-E3:** 5 ITEM3s; **F1-F3:** 6 ITEM3s

The majority of patients presented only one ITEM3 (1577, 79.78%), and the remaining 398 had multiple ITEM3s (20.15%), 333 with 2 ITEM3s, 48 with 3 ITEM3s, 8 with 4 ITEM3s, 6 with 5 ITEM3s, and 3 with 6 ITEM3s (Fig. 2). As listed in Fig. 3, ITEM3 was most commonly found in the maxilla, as evidenced by 1481 patients (74.99%) who had ITEM3s in the upper jaw, while 408 patients (20.66%) presented ITEM3s in the low jaw. Notably, 86 patients (4.35%) had ITEM3s in both the maxilla and mandible. As shown in Table 2, canines represented the most prevalent tooth impaction in both arches (1294, 52.54%), followed by impacted incisors (20.31%) and premolars (19.17%). A higher frequency of ITEM3 was found in the age subgroup spanning 9–20 years than in the other age subgroups ($P < 0.001$). In detail, the most commonly impacted tooth in the maxilla was canine (1112 teeth, 59.34%), followed by incisor (488 teeth, 26.04%) and premolar (241 teeth, 12.86%). Quite different from the maxilla, ITEM3 in the mandible showed an increased tendency to occur in the posterior area, especially the premolar area (232 teeth, 39.12%), compared with other areas.

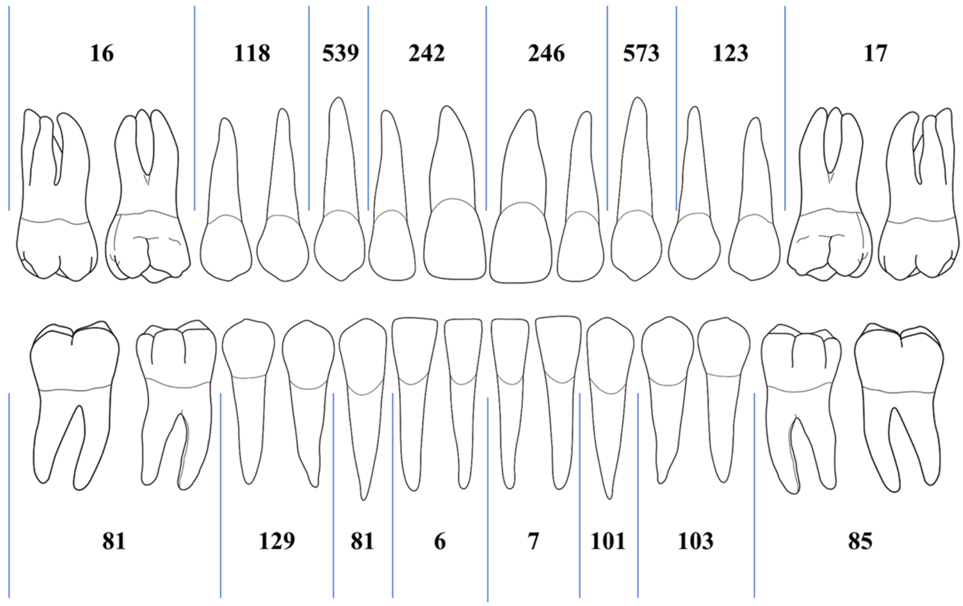

Fig. 3 Detailed distribution of ITEM3s in maxilla and mandible

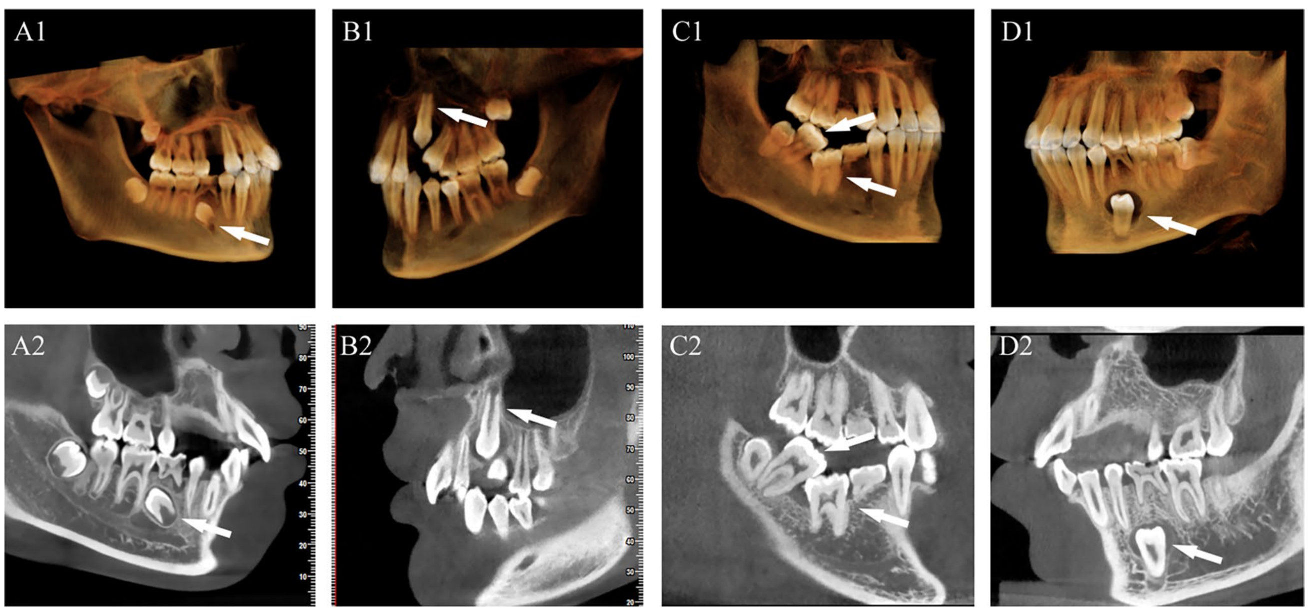

Fig. 4 Representative CBCT images showing root morphologies and development of ITEM3. **A1-A2**: germ; **B1-B2:** incompletely developed; **C1-D2:** completely developed. The impacted depth of ITEM3 is radiographically determined based on adjacent teeth; **A**-**B:** Level B: the highest point of the tooth crown between the cervix and the root apex of the adjacent tooth; **C:** Level A: the highest point of the tooth crown above the cervix of the adjacent tooth; **D:** Level C: the highest point of the tooth crown below the root apex of the adjacent tooth

Three-dimensional radiographic characterization of ITEM3

As listed in Table 2, when the 3D characteristics of ITEM3s were comprehensively analyzed, significant correlations between dental distribution of ITEM3s (incisor, canine, premolar, and molar) and subtypes of orientations, crown location, eruption status, root development, and impaction depth of ITEM3 were found ($P < 0.001$). Similar to previous reports about the classification of the orientation of impacted teeth [15], the most common orientation of ITEM3s was mesioangular (1080 teeth). Mesioangular (774 teeth, 71.67%), vertical (121 teeth, 31.51%), and horizontal impactions (76 teeth, 66.09%) mostly occurred in canines, while distoangular impactions tended to occur at premolars (106 teeth, 53.27%). Inverted and buccal-lingual impaction

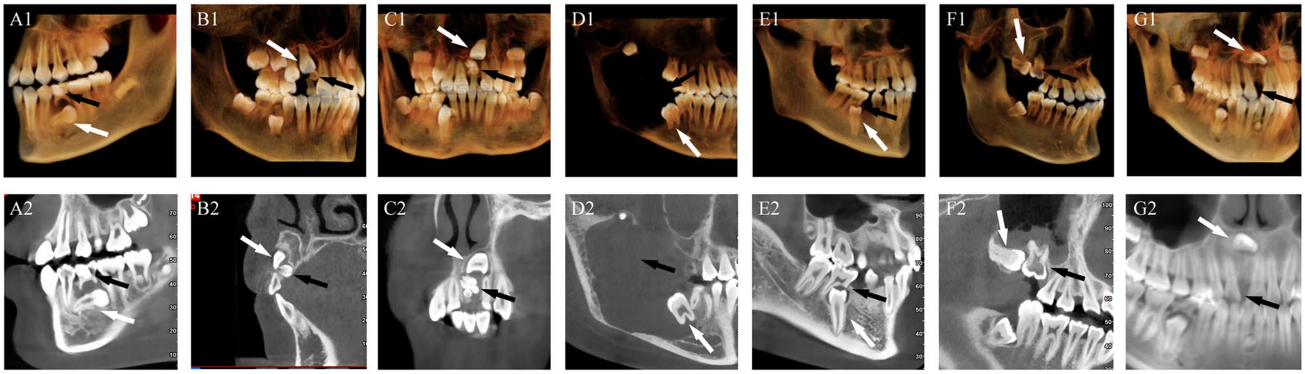

Fig. 5 Representative CBCT images showing ITEM3-associated complications. **A1-A2:** retention of the deciduous teeth; **B1-B2:** supernumerary teeth; **C1-C2:** odontoma; **D1-D2:** cystic lesions; **E1-E2:** external root resorption; **F1-F2**: impaction of AT; **G1-G2:** malposition of the AT. The white arrows refer to the non-third molar IT. The black arrows refer to the complications

Table 1 Descriptive epidemiological data of 1975 patients with impacted teeth

Variable		Number (%)
Ages (years)		Median 17 (9–78)
Gender	Male	930 (47.09%)
	Female	1045 (52.91%)
Number of impacted teeth	Single	1577 (79.85%)
	Multiple (2–6)	398 (20.15%)
Arch	Maxilla	1481 (74.99%)
	Mandible	408 (20.66%)
	Both	86 (4.35%)
Sites of teeth	Incisor region	501 (20.31%)
	Canine region	1294 (52.45%)
	Premolar region	473 (19.17%)
	Molar region	199 (8.07%)

had the predilection to occur in incisors, while ectopic impaction and transmigration were mostly found in canines.

Moreover, crowns of 960 ITEM3s were labially/buccally located and 910 palatally/lingually located, along with 597 located median/within the dental arch. In terms of the eruption status, the overweighing majority of teeth were impacted while 259 erupted. A total of 1806 ITEM3s had completely developed roots, 646 had incompletely developed roots, and 15 appeared as germs. Among them, impacted canines were the most common with completely developed roots (1062 teeth, 58.8%), followed by incisors (264 teeth, 40.71%), whereas germ mostly occurred in premolars. Regarding impaction depth, the most common was Level B. Interestingly, simultaneous supernumerary teeth (194 teeth) mostly occurred in incisors (87 teeth) and canines (85 teeth). Retention of deciduous teeth was found at sites of 764 teeth, mostly in canines (491 teeth, 64.27%). Representative CBCT images showing 3D features of ITEM3 were displayed in Fig. 4 and Supplementary Figs. 1 and 2.

ITEM3-associated complications and lesions

ITEM3s are usually asymptomatic and diagnosed incidentally during radiographic examination. They could occur in all positions of both dental arches, which might cause complications and pathological lesions [12, 16–19]. In our cohort, common ITEM3-associated complications included cystic lesions, odontoma, external root resorption of adjacent teeth, and impaction or malposition of adjacent teeth. Detailed information regarding these ITEM3-associated complications was presented in Table 3. Our data revealed that the occurrence of complications was significantly correlated with dental distributions of ITEM3s ($P < 0.05$). Notably, canine impaction is more likely to induce external root resorption (382 teeth) or malposition (156 teeth) of adjacent teeth, odontoma (61 teeth), and cystic lesions (51 teeth) than impaction of other teeth ($P < 0.05$). However, impactions in incisors tended to result in impaction of adjacent teeth (131 teeth) relative to impaction at other sites ($P < 0.05$). Representative CBCT images showing ITEM3-associated complications were displayed in Fig. 5.

We next performed statistical analyses to further explore the potential associations between the occurrence of 4 main complications (cystic lesions, odontoma, external root resorption, or malposition of adjacent teeth) and the distribution of ITEM3 features. As shown in Table 4, cystic lesions more likely occurred in the mandible and were significantly associated with ITEM3 with deeper impaction ($P < 0.05$), while the occurrence of odontoma was significantly correlated with orientation and location of the crown, eruption status, and depth of impaction ($P < 0.05$). Furthermore, as listed in Table 5, the incidence of external root resorption of adjacent teeth was significantly associated with orientation and location of the crown, eruption status, and depth of impaction ($P < 0.05$). Meanwhile, malposition of adjacent teeth was

Table 2 Occurrence of impacted teeth stratified by tooth sites, impacted direction, eruption status, the degree of root development, impaction depth, supernumerary tooth, and DT retention

		Incisor region	Canine region	Premolar region	Molar region	*P*-value
Number	2467	501 (20.31%)	1294 (52.45%)	473 (19.17%)	199 (8.07%)	
Age range						**< 0.001***
9–20	1549	453 (29.24%)	686 (44.29%)	306 (19.75%)	104 (6.71%)	
21–30	454	29 (6.39%)	287 (63.22%)	79 (17.40%)	59 (13.00%)	
31–40	203	12 (5.91%)	138 (67.98%)	35 (17.24%)	18 (8.87%)	
41–50	139	6 (4.32%)	103 (74.10%)	22 (15.83%)	8 (5.76%)	
51–60	83	0 (0.00%)	55 (66.27%)	22 (26.51%)	6 (7.23%)	
61–78	39	1 (2.56%)	25 (64.10%)	9 (23.08%)	4 (10.26%)	
Arch						**< 0.001***
Maxilla	1874	488 (26.04%)	1112 (59.34%)	241 (12.86%)	33 (1.76%)	
Mandible	593	13 (2.19%)	182 (30.69%)	232 (39.12%)	166 (27.99%)	
Orientation						**< 0.001***
Mesioangular	1080	57 (5.28%)	774 (71.67%)	156 (14.44%)	93 (8.61%)	
Horizontal	115	5 (4.35%)	76 (66.09%)	7 (6.09%)	27 (23.48%)	
Vertical	384	106 (27.60%)	121 (31.51%)	108 (28.12%)	49 (12.76%)	
Distoangular	199	33 (16.58%)	44 (22.11%)	106 (53.27%)	16 (8.04%)	
Buccal-lingual	381	183 (48.03%)	107 (28.08%)	77 (20.21%)	14 (3.67%)	
Inverted	156	116 (74.36%)	37 (23.72%)	3 (1.92%)	0 (0.00%)	
Ectopic	71	1 (1.41%)	54 (76.06%)	16 (22.54%)	0 (0.00%)	
Transmigration	81	0 (0.00%)	81 (100.00%)	0 (0.00%)	0 (0.00%)	
Location of crown						**< 0.001***
Labial/buccal	960	356 (37.08%)	558 (58.13%)	42 (4.38%)	4 (0.42%)	
Median	597	56 (9.38%)	154 (25.80%)	219 (36.68%)	168 (28.14%)	
Palatal/lingual	910	89 (9.78%)	582 (63.96%)	212 (23.30%)	27 (2.97%)	
Eruption status						**< 0.001***
Erupted	259	22 (8.49%)	82 (31.66%)	76 (29.34%)	79 (30.50%)	
Impacted	2208	479 (21.69%)	1212 (54.89%)	397 (17.98%)	120 (5.43%)	
Root development						**< 0.001***
Complete	1806	237 (13.12%)	1062 (58.80%)	322 (17.83%)	185 (10.24%)	
Incomplete	646	263 (40.71%)	228 (35.29%)	141 (21.83%)	14 (2.17%)	
Germ	15	1 (6.67%)	4 (26.67%)	10 (66.67%)	0 (0.00%)	
Impaction depth						**< 0.001***
Level A	240	20 (8.33%)	64 (26.67%)	65 (27.08%)	91 (37.92%)	
Level B	1806	444 (24.58%)	917 (50.78%)	346 (19.16%)	99 (5.48%)	
Level C	421	37 (8.79%)	313 (74.35%)	62 (14.73%)	9 (2.14%)	
Supernumerary tooth						**< 0.001***
Yes	194	87 (44.85%)	85 (43.81%)	19 (9.79%)	3 (1.55%)	
No	2273	414 (18.21%)	1209 (53.19%)	454 (19.97%)	196 (8.62%)	
DT retention						**< 0.001***
Yes	764	105 (13.74%)	491 (64.27%)	168 (21.99%)	--	
No	1504	396 (26.33%)	803 (53.39%)	305 (20.28%)	--	

*Statistically significant ($p < 0.05$). The *P*-value is calculated by chi-square tests or Fisher's exact test using Stata 14.0

DT, deciduous tooth

significantly associated with orientation and location of crown and depth of impaction ($P < 0.05$). Collectively, all four complications were significantly associated with the dental arch and depth of impaction of ITEM3.

Discussion

Tooth impaction is defined as tooth eruption disturbance caused by physical obstacles in the eruption path or a

Table 3 Relationship between complications and sites of non-third molar impacted teeth

		Incisor region	Canine region	Premolar region	Molar region	P-value
Number	2467	501 (20.31%)	1294 (52.45%)	473 (19.17%)	199 (8.07%)	
Cystic lesions						**= 0.011***
Yes	123	37 (30.08%)	51 (41.46%)	21 (17.07%)	14 (11.38%)	
No	2344	464 (19.80%)	1243 (53.03%)	452 (19.28%)	185 (7.89%)	
Odontoma						**= 0.001***
Yes	112	36 (32.14%)	61 (54.46%)	13 (11.61%)	2 (1.79%)	
No	2355	465 (19.75%)	1233 (52.36%)	460 (19.53%)	197 (8.37%)	
ERR of AT						**< 0.001***
Yes	418	0 (0.00%)	382 (91.39%)	28 (6.70%)	8 (1.91%)	
No	2049	501 (24.45%)	912 (44.51%)	445 (21.72%)	191 (9.32%)	
Impaction of AT						**< 0.001***
Yes	277	131 (47.29%)	61 (22.02%)	53 (19.13%)	32 (11.55%)	
No	2190	370 (16.89%)	1233 (56.30%)	420 (19.18%)	167 (7.63%)	
Malposition of AT						**< 0.001***
Yes	185	27 (14.59%)	156 (84.32%)	2 (1.08%)	0 (0.00%)	
No	2282	474 (20.77%)	1138 (49.87%)	471 (20.64%)	199 (8.72%)	

*Statistically significant ($p < 0.05$). The P-value is calculated by chi-square tests or Fisher's exact test using Stata 14.0

ERR, external root resorption; *AT*, adjacent tooth

positional deviation of its axis, which is a relatively common dental abnormality [1]. These impacted teeth usually result in various complications and even odontogenic tumors, thus posing great risks in patients [2, 20]. However, a large number of previous studies focused on impacted M3s, while tooth impaction at sites other than M3 has not been comprehensively examined in a large population [7]. Here, our findings were derived from 75,021 patients in a single-institutional dental cohort and offered a comprehensive view of ITEM3s to facilitate its diagnosis and optimal treatment. To the best of our knowledge, this might be a clinical study concerning ITEM3s in Chinese dental patients with the largest number of subjects.

Epidemiological features of ITEM3s

Several studies have documented the varied prevalence of impacted teeth in certain ethnic populations and uncovered some ethnic-specific characteristics of teeth impaction among diverse populations [4–7]. However, these studies largely examined the prevalence of M3s and canines. Here, we screened non-syndromic ITEM3s by CBCT examinations from a Chinese dental population and identified 2467 ITEM3s from 1975 patients with an incidence of 2.63%. This seemed lower than the ratios (5.6 to 18.8%) in previous studies [4–7]. We reasoned that this discrepancy might be due to the following reasons. The elderly patients included in our study might receive orthodontic extraction to facilitate the eruption of those teeth that originally ought to be impacted. Moreover, diverse strategies for ITEM3 detection and definition were also contributable to this difference among previous reports and ours [3, 21, 22]. Noticeably, to determine the appropriate age for patient enrollment, it is essential to take the delayed tooth eruption and average eruption time in the native population into consideration. Delayed tooth eruption is usually defined when teeth emerge at more than 2 standard deviations from the mean of established norms for eruption times (6.59 + 0.79 years×2 old for the first molar in Chinese) [12, 14]. Some authors believed that delayed eruption was also considered a temporary impaction [23]. Thus, we pre-set 9 years old as the youngest age for inclusion (6–8 years old for the first molar).

Previous reports have revealed that a single ITEM3 was more prevalent than multiple ones, although one or multiple ITEM3s can be identified in the jaws [3–5]. In addition, the prevalence of ITEM3 was much higher in the maxilla than in the mandible. Females slightly outnumbered males with a ratio of 1.2:1. The demographic findings from our cohort were generally in line with these previous reports [1, 7]. Intriguingly, we observed that multiple ITEM3s were simultaneously found in both jaws in 86 (4.35%) patients. The etiological factors for these multiple ITEM3s warrant further clarifications, although some obvious genetic factors, such as craniofacial syndrome, were excluded in our initial patient screen.

Concerning the common sites for ITEM3, our data indicated the maxillary canines were the most frequently impacted, followed by maxillary incisors, similar to previous findings [7, 24, 25]. Some hypotheses were proposed to explain maxillary canines and incisors as the most common sites. Impaction of maxillary canines likely disturbed the development path of ipsilateral maxillary

Table 4 Occurrence of cystic lesions and odontoma associated with the characteristic of impacted teeth

	Cystic lesions		*P*-value	Odontoma		*P*-value
	Yes	No		Yes	No	
	123	2344		112	2355	
Arch			**= 0.002***			**= 0.001***
Maxilla	79 (4.22%)	1795 (95.78%)		71 (3.79%)	1803 (96.21%)	
Mandible	44 (7.42%)	549 (92.58%)		41 (6.91%)	552 (93.09%)	
Orientation			= 0.102			**< 0.001***
Mesioangular	43 (3.98%)	1037 (96.02%)		35 (3.24%)	1045 (96.76%)	
Horizontal	7 (6.09%)	108 (93.91%)		1 (0.87%)	114 (99.13%)	
Vertical	23 (5.99%)	361 (94.01%)		35 (9.11%)	349 (90.89%)	
Distoangular	15 (7.54%)	184 (92.46%)		17 (8.54%)	182 (91.46%)	
Buccal-lingual	26 (6.82%)	355 (93.18%)		7 (1.84%)	374 (98.16%)	
Inverted	4 (2.56%)	152 (97.44%)		1 (0.64%)	155 (99.36%)	
Ectopic	3 (4.23%)	68 (95.77%)		2 (2.82%)	69 (97.18%)	
Transmigration	2 (2.47%)	79 (97.53%)		14 (17.28%)	67 (82.72%)	
Location of crown			= 0.212			**= 0.03***
Labial/buccal	50 (5.21%)	910 (94.79%)		55 (5.73%)	905 (94.27%)	
Median	36 (6.03%)	561 (93.97%)		28 (4.69%)	569 (95.31%)	
Palatal/lingual	37 (4.07%)	873 (95.93%)		29 (3.19%)	881 (96.81%)	
Eruption status			= 0.564			**= 0.002***
Erupted	11 (4.25%)	248 (95.75%)		2 (0.77%)	257 (99.23%)	
Impacted	112 (5.07%)	2096 (94.93%)		110 (4.98%)	2098 (95.02%)	
Root development			= 0.668			= 0.518
Complete	90 (4.98%)	1716 (95.02%)		86 (4.76%)	1720 (95.24%)	
Incomplete	33 (5.11%)	613 (613%)		26 (4.02%)	620 (95.98%)	
Germ	0 (0.00%)	15 (15%)		0 (0.00%)	15 (100.00%)	
Impaction depth			**< 0.001***			**< 0.001***
Level A	2 (0.83%)	238 (99.17%)		3 (1.25%)	237 (98.75%)	
Level B	79 (4.37%)	1727 (95.63%)		69 (3.82%)	1737 (96.18%)	
Level C	42 (9.98%)	379 (90.02%)		40 (9.50%)	381 (90.50%)	

*Statistically significant ($p < 0.05$). The *P*-value is calculated by chi-square tests or Fisher's exact test using Stata 14.0

incisors [26]. However, our data failed to support this notion, as the incidence of impacted maxillary incisors was far less than that of impacted maxillary canines in our cohort. Additionally, incisors in the mandible were rarely impacted, in line with Tan's report [16].

Radiographic features of ITEM3s by 3D CBCT assessments

Previous studies usually utilized 2-dimensional panoramic radiography to characterize tooth impaction. However, this radiography failed to exactly view the spatial and morphological details of impacted teeth. Here, we utilized CBCT and 3D assessments to characterize the topography of ITEM3s in a more detailed and accurate manner. These ITEM3s were comprehensively assessed from five aspects including orientation, location of the crown, eruption status, root development, and impaction depth based on CBCT and 3D image reconstruction. Although different ITEM3s had significant variations in the orientation of impaction, our data revealed that mesioangular impaction was the most common, followed by vertical impaction, which was slightly different from Rui Hou's report wherein vertical impaction was more than mesioangular impaction [7]. Additionally, mesioangular and vertical impaction tended to occur in canines and incisors, respectively. Intriguingly, our data concerning transmigration echoed the previous conclusion that transmigration was a sporadic type of impaction [27].

In agreement with Hui's report, our data indicated that crowns of impacted maxillary incisors tended to be located more labially than medially and palatally, while crowns of impacted canines usually appeared palatal/lingually orientated [28]. These results were highly valuable for orthodontic management of these impacted canines and incisors. In addition, the depth of impaction in these ITEM3s mainly was Level B, irrespective of

Table 5 Occurrence of ERR of adjacent teeth and malposition of adjacent tooth associated with the characteristic of impacted teeth

	ERR of adjacent tooth		*P*-value	Malposition of adjacent tooth		*P*-value
	Yes	No		Yes	No	
	418	2049		185	2282	
Arch			**< 0.001***			**< 0.001***
Maxilla	400 (21.34%)	1474 (78.66%)		183 (9.77%)	1691 (90.23%)	
Mandible	18 (3.04%)	575 (96.96%)		2 (0.34%)	591 (99.66%)	
Orientation			**< 0.001***			**< 0.001***
Mesioangular	294 (27.22%)	786 (72.78%)		106 (9.81%)	974 (90.19%)	
Horizontal	33 (28.70%)	82 (71.30%)		6 (5.22%)	109 (94.78%)	
Vertical	23 (5.99	361 (94.01%)		21 (5.47%)	363 (94.53%)	
Disto-angular	18 (9.05%)	181 (90.95%)		5 (2.51%)	194 (97.49%)	
Buccal-lingual	23 (6.04%)	358 (93.96%)		31 (8.14%)	350 (91.86%)	
Inverted	0 (0.00%)	156 (100.00%)		6 (3.85%)	150 (96.15%)	
Ectopic	19 (26.76%)	52 (73.24%)		10 (14.08%)	61 (85.92%)	
Transmigration	8 (9.88%)	73 (90.12%)		0 (0.00%)	81 (100.00%)	
Location of crown			**< 0.001***			**< 0.001***
Labial/buccal	148 (15.42%)	812 (84.58%)		92 (9.58%)	868 (90.42%)	
Median	54 (9.05%)	543 (90.95%)		24 (4.02%)	573 (95.98%)	
Palatal/lingual	216 (23.74%)	694 (76.26%)		69 (7.58%)	841 (92.42%)	
Eruption status			**= 0.024***			= 0.52
Erupted	31 (11.97%)	228 (88.03%)		22 (8.49%)	237 (91.51%)	
Impacted	387 (17.53%)	1821 (82.47%)		163 (7.38%)	2045 (92.62%)	
Root development			**= 0.002***			
Complete	335 (18.55%)	1471 (81.45%)		115 (6.37%)	1691 (93.63%)	
Incomplete	82 (12.69%)	564 (87.31%)		69 (10.68%)	577 (89.32	
Germ	1 (6.67%)	14 (93.33%)		1 (6.67%)	14 (93.33%)	
Impaction depth			**= 0.006***			**< 0.001***
Level A	26 (10.83%)	214 (89.17%)		20 (8.33%)	220 (91.67%)	
Level B	330 (18.27%)	1476 (81.73%)		157 (8.69%)	1649 (91.31%)	
Level C	62 (14.73%)	359 (85.27%)		8 (1.90%)	413 (98.10%)	

*Statistically significant ($p < 0.05$). The *P*-value is calculated by chi-square tests or Fisher's exact test using Stata 14.0

ERR, external root resorption

their sites. Significant correlations between supernumerary teeth or deciduous teeth retention with ITEM3s at the same sites suggest that these two dental abnormities might contribute to ITEM3s. This was supported by the fact that the overwhelming majority of supernumerary teeth (over 90%) were found in the maxilla, which usually led to the impaction of permanent maxillary incisors [7, 29]. In addition, consistent with previous reports, local factors associated with ITEM3s, such as deciduous teeth retention, were verified by our results ($P < 0.05$) [30, 31].

Complications of ITEM3s

Accumulating evidence has revealed that ITEM3s have various adverse effects on adjacent structures and cause dental aberrations and complications such as cystic lesions, odontoma, external root resorption of adjacent teeth, failure or malposition of adjacent teeth eruption. However, they usually remain asymptomatic and incidentally detected until routine dental or radiographic examination [16, 32]. Based on CBCT scan and medical record review, the relationship between these associated complications and ITEM3s was characterized. Our results were similar to previous findings indicating that external root resorption of adjacent teeth was the most common ITEM3-associated complication, followed by impaction or malposition of adjacent teeth [2]. Moreover, these complications largely occurred in incisors or premolars adjacent to impacted canines. Indeed, incisors were mostly affected by impacted teeth in the whole dental arch. Furthermore, dental caries of adjacent teeth can occur due to contact and pressure from ITEM3s [2, 17]. Collectively, these ITEM3-associated complications emphasized the importance of early diagnosis and timely treatment of ITEM3s, which might prevent or minimize the occurrence of severe complications.

Based on the recommendation of the European Academy of Dentmaxillofacial Radiology [33], CBCT scans should not be routinely exploited due to radiological exposure. These CBCT data were retrospectively collected in our patients with dentofacial deformities (orthodontics), maxillofacial trauma and fracture, dental implantation, impacted or supernumerary teeth, and various bone lesions in jaws. These CBCT scans were suitable without violation of medical ethics and to meet therapeutic needs. Although our studies had advantages as mentioned above, there were some limitations. Firstly, we cannot rule out the possibility that a few patients with prior orthodontic treatment and tooth extraction were included, which might affect the incidence of ITEM3. Secondly, it is difficult to determine the final eruption path when less than 2/3 of the root is formed [16, 23, 34]. Longitudinal observations of selected ITEM3s with incompletely developed roots are needed to accurately assess their eruptions. Thirdly, bias in patient selection in a single institution inevitably existed. A large number of patients from multiple centers are required to validate our findings.

Conclusion

In conclusion, these retrospective analyses documented the epidemiological and radiographic characteristics of ITEM3s in a Chinese dental population. Most ITEM3 was single, mesioangular, found at maxillary canines, sometimes associated with complications. These findings are instrumental for clinicians to advance the current understanding and management of ITEM3s.

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Author contribution Drs. Yijin Shi, Yanling Wang, and Han Ge performed the radiographic analyses, data collection, and statistical analyses. M.D. Xiaomeng Song and Dr. Pengfei Diao participated in the study design, data collection, and analyses. M.D. Hongbing Jiang and Prof. Dongmiao Wang conceived and supervised the whole project and drafted the manuscript. All authors read and approved the final manuscript.

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Declarations

Ethics approval The study was reviewed and approved by the Ethics and Research Committee, Nanjing Medical University (2019–0166), and conducted in accordance with the tenets of the Declaration of Helsinki for research involving human subjects.

Consent to participate Written informed consent was not required for this study because all of the included patients in the present investigation were collected retrospectively.

Conflict of interest The authors declare no competing interests.

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