Root Anatomy and Root Canal Morphology of Maxillary Second Permanent Molars in a Chongqing Population: A Cone-Beam Computed Tomography Study

Yu Xia, Xin Qiao, Ya-jing Huang, Yue-heng Li, Zhi Zhou

Background: To investigate variations in the anatomy of root canals in permanent second molars of the upper jaw in a population in Chongqing, China, using cone-beam computed tomography (CBCT).

Material/Methods: CBCT imaging data of 400 second permanent molars of the upper jaws of 200 patients were retrospectively reviewed. Patients’ gender, age, numbers of roots and canals, root fusion of permanent second molars of the maxilla on both sides, and morphological categories of root canals of mesiobuccal roots were recorded. The distances from the apices of the distobuccal and mesiobuccal roots to the buccal bone plate were measured.

Results: Of the 400 permanent second maxillary molars, 312 (78.0%) had three roots and 247 (61.75%) had three canals. Fused roots were observed in 126 (31.5%) teeth; of these, 67 (53.2%) had three canals and 44 (34.9%) had two canals. Morphologically, 297 (74.25%), 29 (7.25%), nine (2.25%) and 65 (16.25%) teeth had type I, II, III, and IV mesiobuccal root canals, respectively, with 103 (25.75%) having secondary mesiobuccal canals. The distances from the apices of the mesiobuccal, distobuccal, and single buccal roots to the surface of the buccal osseous lamella were 7.34±1.89 mm, 6.26±1.74 mm, and 8.60±2.56 mm, respectively.

Conclusions: The root form and canal shape of permanent second molars of the upper jaw varied greatly among the population of Chongqing, China. CBCT is a valuable method for assessing the complex anatomic morphology of teeth.

MeSH Keywords: Cone-Beam Computed Tomography • Dental Pulp Cavity • Tooth • Tooth Root

Full-text PDF: https://www.medscimonit.com/abstract/index/idArt/922794
Background

Pulpal and periapical diseases are the most common types of dental diseases. Teeth with these conditions frequently undergo root canal treatment, which plays a significant role in preserving natural teeth [1,2]. The success of endodontic therapy depends on the complete removal of infected substances from the root canal system, the elimination of sources of infection, and tight filling of the root canal system, preventing reinfection by microorganisms [3,4]. Root canals that have not been completely treated or are missed are the main causes of failure of endodontic therapy [5,6]. The configuration of root canals in human teeth is quite complicated and varies among different populations and races [3,7,8]. However, the complexity of the internal anatomical structure is usually masked by the relatively simple external anatomy [9].

The second molars of the upper jaw have the most intricate root canal system in human teeth [10,11]. The rate of occurrence of a secondary mesiobuccal canal (MB2) in permanent second molars of the upper jaw have been reported to be as high as 93.7% [12], and the likelihood of having two palatal canals was found to range from 1.37% to 6.34% [13,14]. A study of distobuccal roots found that the likelihood of having two canals in the mesiodistal direction was 4%, whereas the likelihood of having two canals in the buccolingual direction was 6% [15]. These findings indicate that complete comprehension of the anatomic structure of roots and canals can guide their treatment.

Among the methods currently used to assess the configuration of canal systems are the diaphanization technique, dental hard tissue sectioning, X-ray imaging, micro-computed tomography (micro-CT) imaging and cone-beam computed tomography (CBCT) [3,9,15–21]. Although the diaphanization technique and dental hard tissue sectioning can accurately determine the anatomy of root canals, these methods can only be used to study isolated dental specimens, which may destroy the integrity of these teeth [15,17]. X-ray imaging has been utilized traditionally to determine root canal anatomy, but this method produces two-dimensional (2D) images of three-dimensional (3D) objects, resulting in distortion and overlap. X-ray images therefore cannot accurately reflect the morphological features of canals and their anatomical correlation with neighboring tissue [18]. Micro-CT does not damage specimens, with image reconstruction even determining the fine anatomical structure of root canals [20]. However, scanning time is long and patients are exposed to high doses of radiation, limiting the application of micro-CT to studies investigating extracted teeth [20,21]. CBCT, first utilized in endodontic research in 1990, has several advantages when compared with micro-CT, including a shorter scanning time and exposure to lower doses of radiation [22]. CBCT can therefore provide clear and accurate 3D reconstructed images of root canal systems without damaging the dental structure [23,24]. CBCT has been used to assess the morphology of root canal systems in vitro and in vivo. Few studies, however, have investigated the anatomical forms of root canals of permanent second molars of the upper jaw in a population living in Chongqing, China. The present study utilized the CBCT images of these subjects to analyze the anatomic structures of root canals of permanent second molars of the maxilla, including their morphologic variations and their distance from the apical foramen to the surface of the buccal cortical bone plate. These findings provide an anatomic basis for root canal therapy and endodontic surgery.

Material and Methods

Subjects

The study protocol was approved by the Ethics Committee of Stomatological Hospital Affiliated to Chongqing Medical University (2019-74). Patients who required CBCT for the diagnosis and treatment of maxillofacial trauma, for orthodontic treatment, and for implant restoration at the Stomatological Hospital Affiliated to Chongqing Medical University from January 2018 through April 2018, inclusive, were randomly selected. CBCT imaging data, age and gender were recorded. Subjects were included if 1) they or their guardians provided written informed consent for the use of their CBCT imaging data; 2) they were not missing bilateral maxillary second permanent molars; 3) the development of the root apex was complete; 4) maxillary second permanent molars were not restored with dental filling materials or crowns due to carious or noncarious lesions of hard dental tissues; 5) there was no evidence of root resorption or inflammation in tissue surrounding the bone; 6) they did not undergo root canal treatment and did not show root canal calcification or resorption; and 7) their CBCT images were clear with high resolution and no artifacts. Subjects were excluded if 1) they or their guardians refused consent for the use of CBCT imaging data; 2) maxillary second permanent molars were missing on one or both sides; 3) root apices were open and flared in shape; 4) maxillary second permanent molars had been restored with dental filling materials or crowns; 5) root resorption and/or inflammation were observed in tissue surrounding the bone; 6) they had undergone root canal treatment and showed root canal calcification or resorption; or 7) the collected CBCT images were unclear.

CBCT equipment and scanning

CBCT scans were performed using an i-CAT CBCT scanner (i-CAT Vision; Imaging Science International, Hatfield, PA, USA) with a voltage of 120 kV, a current of 5 mA, a voxel resolution of 0.4×0.4 mm, and an exposure time of 8–9 s. The scanning data were converted to DICOM format and entered into the i-CAT software.
for three-dimensional reconstruction. All scans were performed strictly in accordance with the technical manual of the instrument, and all images were reviewed by an experienced radiographer.

**Imaging analysis**

All CBCT images were independently evaluated by an experienced endodontist. To ensure the credibility of the endodontist’s assessment, 50 images were randomly selected and reviewed by the same endodontist at two different time points according to the evaluation criteria. The consistency and reliability of results observed at different times were determined with Kappa statistics. Kappa values of 0.61–0.8 (substantial agreement) indicated that assessment by the observer of the tissue surrounding the area of the procedure was reliable. The CBCT images of the permanent second molars of the upper jaw were evaluated on both sides in the coronal, axial and sagittal planes. Other factors analyzed included subject gender, age, number of roots, fused roots and canals, morphological categories of canals of the mesiobuccal root and the distances from the apices of the distobuccal and mesiobuccal roots to the buccal bone plate. Canal morphology was assessed using Vertucci’s classification (Figure 1) [3,10].

**Statistical analysis**

Categorical variables were reported as number (%) and compared using the chi-square test or Fisher’s exact test, as appropriate. Differences in distances from the apices of the distobuccal and mesiobuccal roots to the buccal osseous lamella between genders and right and left teeth were compared using the rank sum test, and differences in distances from the apex of a single buccal root to the buccal bone plate between genders and right and left teeth were analyzed by two-sample independent t-tests. All statistical analyses were performed using SPSS22.0 software, with the significance level set at $\alpha=0.05$. 

**Figure 1.** Schematic diagrams showing Vertucci’s classification of root canal morphology and canal configuration of permanent second molars of the upper jaw with fused roots. (A) Classification of the anatomic morphology of canals. (B) Teeth with one (B1), two (B2), and three (B3) roots. (C) Fused root with one root canal (C1, coronal 1/3; C2, middle 1/3; and C3, apical 1/3). (D) Fused root with two root canals (D1, coronal 1/3; D2, middle 1/3; D3, apical 1/3). (E) Fused root with three root canals (E1, coronal 1/3; E2, middle 1/3; E3, apical 1/3). (F) Fused root with four root canals (F1, coronal 1/3; F2, middle 1/3; F3, apical 1/3).
The study enrolled 200 subjects, 86 men and 114 women, with 400 permanent second molars of the upper jaw. A test of intraexaminer reliability yielded a Kappa value of 0.819, indicating that these results were reliable.

### Number of roots

Of the 400 permanent second molars of the upper jaw, 312 (78.0%) had three roots, 49 (12.25%) had two roots, and 39 (9.75%) had one root (Table 1; Figure 1B1–1B3). None of these teeth had four roots. There were no significant differences in the occurrence rates of numbers of roots between men and women or between teeth on the left and right sides (P>0.05 each).

### Number of root canals

Of the 400 teeth, five (1.25%), 45 (11.25%) 247 (61.75%) and 103 (25.75%) had one, two, three and four root canals, respectively (Table 2). These percentages did not differ significantly in men and women or between teeth on the left and right sides (P>0.05 each).

### Rates of root fusion and number of canals in teeth with fused roots

Root fusion was present in 126 (31.50%) teeth (Table 3), with no significant differences in rate of root fusion between men and women or between teeth on the left and right sides (P>0.05 each). Of the 126 teeth with fused roots, five (3.97%), 44 (34.92%), 67 (53.17%) and ten (7.94%) had one, two, three and four root canals, respectively (Figure 1C1–1F3), with no significant differences between men and women or between teeth on the left and right sides (P>0.05 each).

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### Table 1. Numbers of roots.

| Number of roots | Left side (n/%) | Right side (n/%) | χ² | P | Male (n/%) | Female (n/%) | χ² | P | Total (n/%) |
|-----------------|----------------|-----------------|-----|---|-----------|-------------|-----|---|-------------|
| One root        | 21 (10.50%)    | 18 (9.00%)      |     |   | 15 (8.72%)| 24 (10.52%) | 39 (9.75%)|
| Two roots       | 24 (12.00%)    | 25 (12.50%)     | 0.264| 0.876| 17 (9.88%)| 32 (14.04%) | 49 (12.25%)|
| Three roots     | 155 (77.50%)   | 157 (78.50%)    |     |   | 140 (81.40%) | 172 (75.44%) | 312 (78.00%)|
| Total           | 200 (100%)     | 200 (100%)      |     |   | 172 (100%) | 228 (100%) | 400 (100%) |

### Table 2. Numbers of root canals.

| Left side (n/%) | Right side (n/%) | Fisher value | P | Male (n/%) | Female (n/%) | Fisher value | P | Total (n/%) |
|-----------------|-----------------|--------------|---|-----------|-------------|--------------|---|-------------|
| Single root canal | 1 (0.50%) | 4 (2.00%) | re | 2 (1.16%) | 3 (1.32%) | 5 (1.25%) |
| Two root canals  | 24 (12.00%) | 21 (10.50%) | 2.533 | 0.471 | 16 (9.30%) | 29 (12.72%) | 44 (11.25%) |
| Three root canals | 120 (60.00%) | 127 (63.50%) | 99 (57.56%) | 148 (64.91%) | 6.436 | 0.085 | 247 (61.75%) |
| Four root canals | 55 (27.50%) | 48 (24.00%) | 55 (31.98%) | 48 (21.05%) | 103 (25.75%) |
| Total            | 200 (100%) | 200 (100%) | 172 (100%) | 228 (100%) | 400 (100%) |

### Table 3. Rates of root fusion.

| Left side (n/%) | Right side (n/%) | χ² | P | Male (n/%) | Female (n/%) | χ² | P | Total (n/%) |
|-----------------|-----------------|-----|---|-----------|-------------|-----|---|-------------|
| Fused roots     | 64 (32.00%)     | 62 (31.00%) | 0.046 | 0.830 | 46 (26.74%) | 80 (35.09%) | 3.163 | 0.075 | 126 (31.50%) |
| Nonfused roots  | 136 (68.00%)    | 138 (69.00%) |     |   | 126 (73.26%) | 148 (64.91%) | 274 (68.50%) |
| Total           | 200 (100%)      | 200 (100%) | 172 (100%) | 228 (100%) | 400 (100%) |

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Rates of MB2 and morphological canal categories of mesiobuccal roots

Based on the Vertucci classification of root canals, 297 (74.25%), 29 (7.25%), nine (2.25%) and 65 (16.25%) permanent second molars of the upper jaw had type I, II, III, and IV mesiobuccal root canals, respectively (Figure 2A–2D; Table 4). These rates did not differ significantly in men and women mesiobuccal root between genders or between teeth on the left and right sides (P>0.05 each). Of these 400 teeth, 103 (25.75%) had MB2 canals (Table 5), with the rate being markedly higher in men than in women (P=0.007). In contrast, these rates were similar in teeth on the right and left sides (P>0.05).

Distances from the apices of the distobuccal and mesiobuccal roots to the buccal surface of the osseous lamella

The mean distances from the apices of the mesiobuccal, distobuccal, and single buccal roots to the buccal surface of the bone lamella were 7.34±1.89 mm, 6.26±1.74 mm, and 8.60±2.56 mm, respectively (Figure 2E1–2E3, Table 6). The distance from the mesiobuccal apex to the buccal bone plate was significantly greater than the distance from the distobuccal root apex to the buccal bone plate (P<0.05). The distance from the mesiobuccal apex and the disiobuccal apex to the buccal bone plate on the right and left sides also differed significantly (P<0.05).

Table 4. Root canal configurations of mesiobuccal roots.

| Number of roots | Left side (n/%) | Right side (n/%) | Fisher value | Male (n/%) | Female (n/%) | Fisher value | P   | Total (n/%) |
|-----------------|----------------|-----------------|--------------|------------|--------------|--------------|-----|-------------|
| Type I (1-1)    | 146 (73.00%)   | 151 (75.50%)    |              | 118 (68.60%)| 179 (78.50%) |              | 1.796| 0.624       |
| Type II (2-1)   | 13 (6.50%)     | 16 (8.00%)      |              | 15 (8.72%) | 14 (6.14%)   |              | 0.327| 0.567       |
| Type III (1-2-1)| 4 (2.00%)      | 5 (2.50%)       | 1.796        | 6 (3.49%)  | 3 (1.32%)    | 5.853        | 0.199| 9 (2.25%)   |
| Type IV (2-2)   | 37 (18.00%)    | 28 (14.00%)     |              | 33 (19.19%)| 32 (14.04%)  |              | 0.437| 0.512       |
| Total           | 200 (100%)     | 200 (100%)      |              | 172 (100%) | 228 (100%)   |              |     | 400 (100%)  |

Table 5. Prevalence of MB2 canals.

|                  | Left side (n/%) | Right side (n/%) | χ²  | P    | Male (n/%) | Female (n/%) | χ²  | P    | Total (n/%) |
|------------------|----------------|-----------------|-----|------|------------|--------------|-----|------|-------------|
| MB2              | 54 (27.00%)    | 49 (24.50%)     | 0.327| 0.567| 56 (32.56%)| 47 (20.61%)  | 7.315| 0.007| 103 (25.75%)|

Figure 2. Types of canal configuration in mesiobuccal roots of permanent second molars of the upper jaw and horizontal distances from the buccal root apices to the surface of buccal cortical bone plate. (A) Type I. (B) Type II (B1, coronal 1/3; B2, middle 1/3; B3, apical 1/3). (C) Type III (C1, coronal 1/3; C2, middle 1/3; C3, apical 1/3). (D) Type IV (D1, coronal 1/3; D2, middle 1/3; D3, apical 1/3). (E) Horizontal distances from single buccal root (E1), mesiobuccal root (E2), and distobuccal root (E3) apices to the surface of the buccal cortical bone plate.
The distances from the single buccal apices to the buccal bone plate, however, did not differ significantly in men and women or in teeth on the right and left sides (P>0.05 each).

**Discussion**

Successful root canal treatment depends on familiarity with the anatomic morphology of the root canal system in each individual tooth [25]. Anatomic morphology can be determined by completely removing the injured tissue inside the root canals and tightly filling the root canal system [4,26]. Because incompletely filled or missed root canals can lead to microbiological recolonization and trigger inflammation [27], careful clinical and imaging examinations are essential for high-quality root canal treatment. CBCT has been extensively used to examine the morphological structure of roots and canals due to its ability to acquire high-resolution 3D images and the lack of image distortion [13,14,23–25]. The guidelines of the American Association of Endodontists and of the American Academy of Maxillofacial Radiology have recommended the use of CBCT for the diagnosis and treatment of teeth that may have additional canals or complex anatomy [28]. CBCT, however, is more expensive than 2-dimensional X-rays, suggesting the need for a risk/benefit assessment prior to using CBCT. Because it is necessary to determine whether the risk of exposure to radiation is less than the potential benefits to patients, CBCT should not be used routinely in clinical practice [29]. The present study

### Table 6. Distances from the buccal root apices to the surface of the buccal cortical bone plate.

| Root Apex Description                        | Left Side | Right Side | P   | Male Mean ± SD | Female Mean ± SD | P   |
|---------------------------------------------|-----------|------------|-----|----------------|------------------|-----|
| Mesiobuccal root apex to the buccal bone plate (mm) | 7.34±1.89 | 7.62±2.04 | <0.05 | 7.38±1.87 | 7.30±1.91 | 0.545 |
| Distobuccal root apex to the buccal bone plate (mm) | 6.26±1.74 | 6.51±1.80 | <0.05 | 6.41±1.67 | 6.13±1.78 | 0.168 |
| Single buccal root apex to the buccal bone plate (mm) | 8.60±2.56 | 8.79±2.68 | 0.047 | 8.98±2.47 | 8.37±2.59 | 0.277 |

### Table 7. Numbers of roots in maxillary permanent second molars reported in previous studies.

| Authors (Year)         | Sample size of maxillary permanent second molar (n) | Ethnic population | Research method | The prevalence of one root | The prevalence of two roots | The prevalence of three roots | The prevalence of four roots |
|------------------------|----------------------------------------------------|-------------------|----------------|---------------------------|--------------------------|---------------------------|----------------------------|
| Zhang et al. 2011      | 210                                                | China             | CBCT           | 10.5%                     | 8.1%                     | 81.4%                     | –                          |
| Khademi et al. 2017    | 460                                                | Iran              | CBCT           | 4.7%                      | 6.3%                     | 88.2%                     | 0.6%                       |
| Neelakantan et al. 2010| 205                                                | India             | CBCT           | 0.9%                      | 5.8%                     | 93.1%                     | –                          |
| Ratanaajarasut et al. 2018 | 457                                            | Thailand          | CBCT           | 3.5%                      | 9.2%                     | 87.1%                     | 0.2%                       |
| Nikoloudaki et al. 2015| 402                                                | Greek             | CBCT           | 5.47%                     | 8.21%                    | 85.07%                    | 1.24%                      |
| Silva et al. 2014      | 306                                                | Brazil            | CBCT           | –                         | –                        | 45.09%                    | –                          |
| Perez-Heredia et al. 2017 | 142                                            | Spain             | CBCT           | 16.9%                     | 4.2%                     | 78.9%                     | –                          |
| Martins et al. 2018    | 802                                                | Portugal          | CBCT           | 13.3%                     | 13.2%                    | 72.9%                     | 0.5%                       |
| Ghobashy et al. 2017   | 610                                                | Egypt             | CBCT           | 1.6%                      | 10.7%                    | 87.7%                     | –                          |
| Kim et al. 2012        | 821                                                | Korea             | CBCT           | 10.2%                     | 13%                      | 76.3%                     | 0.5%                       |
analyzed CBCT imaging data from patients who had been assessed by CBCT for diagnosis and treatment.

Analysis of 400 permanent second molars of the upper jaw in a Chongqing population showed that 78.0% had three roots, whereas 12.25% had two and 9.75% had one root, with none of these teeth having four roots. Moreover, 61.75% of these teeth had three canals, 25.75% had four canals, 11.25% had two canals, and 1.25% had one canal. In addition, 25.75% of these teeth had MB2; of these, 28.2%, 8.7%, and 63.1% had types II, III, and IV, respectively. These results were similar to those of previous studies (Tables 7, 8) [30,31]. Population-based CBCT studies in China, Iran, India, Thailand, Greece, Brazil, Spain, Portugal, Egypt, and North Korea have shown that the percentages of permanent second molars of the upper jaw with three roots ranged from 45.1% to 93.1%, with 4.2% to 13.2% of these teeth having two roots, 0.9% to 16.9% having one root, and from 0% to 1.24%, having four roots (Table 7) [14,21,30,32–37]. Moreover, the prevalence of MB2 ranged from 19.2% to 78.9% (Table 8) [14,15,30–35,37–44]. A study of an Iranian population found that 67.5% of permanent second molars of the upper jaw had four canals, followed by 31.2% with three canals and 1.3% with five canals, with none of these teeth having one or two root canals [45]. These differences in root and canal numbers and MB2 percentages may be associated with racial background, research techniques, and population diversity.
images and sample sizes. The scanning resolution of CBCT in the present study was 400 µm, which is considered a study limitation. The prevalence of MB2 determined by the diaphanization technique and dental hard tissue sectioning was found to be higher than that determined using conventional X-rays and CBCT [38,40,41,43].

This study found that the occurrence of MB2 was significantly higher in men than in women (32.6% vs. 20.6%, P<0.05), consistent with results in a Taiwanese population [7]. In contrast, studies in subjects from Thailand, Iran, and Turkey found that the prevalence of MB2 in maxillary second permanent molars did not differ in men and women [33,45,46].

This study also found that the rate of root fusion in permanent second molars of the upper jaw was 31.5%, with 53.2% of these teeth having three canals. A micro-CT evaluation of 187 extracted second molars of the upper jaw in a Chinese population found fused roots in 42.25% [47], much higher than in our study. Micro-CT may provide higher resolution 3D images than CBCT. However, the rate of root fusion in second permanent molars of the upper jaw in our study was markedly higher than rates in Korean (10.7%) and Iranian (8.8%) populations [36,48]. This difference may be due to different definitions of fused roots. Roots in the present study were defined as fused roots when the distance from the cementoenamel junction (CEJ) to the lower point of root fusion was not less than 70% of the distance from the CEJ to the apex of the root [47]. In contrast, earlier studies regarded fusion extending over the entire root surface as a fused root.

Apical microsurgery should be considered when the infected tissue in the apical part of the canal cannot be eliminated completely. Apical surgery is usually performed through a buccal approach, with accurate positioning of the apex being a prerequisite for successful apical surgery [49]. The distance from the apex of the buccal root to the surface of the bone plate is an important reference for localization of the apex. In the present study, the mean horizontal distances from the apices to the buccal surface of the osseous lamella were 7.34±1.89 mm for the mesiobuccal and 6.26±1.74 mm for the distobuccal roots, similar to previous findings [50]. These results indicated that the distance from the distobuccal root apex to the buccal surface of the osseous lamella was significantly lower than the distance from the mesiobuccal root to the buccal surface of the osseous lamella (P<0.05). The distance from the buccal apex to the buccal surface of the osseous lamella in permanent second molars of the maxilla with only one buccal root was 8.60±2.56 mm, with the buccal apical position being more lingual than teeth with mesiobuccal and distobuccal roots. Because few permanent second molars of the upper jaw in our study had only one buccal root, further research with a larger sample size is needed to confirm the results. The distances from the apices to the buccal surface of the osseous lamella can be used as references to locate the buccal root apex of second molars of the upper jaw during surgery. These distances can provide an anatomical basis for apical surgery and are essential to prevent excessive bone removal, deep drilling, and damage to the root apices.

Conclusions

Most permanent second molars of the upper jaw in subjects from Chongqing had three roots and three canals. According to Vertucci’s classification, type IV was the most common anatomical morphology of the mesiobuccal roots of permanent second molars of the maxilla when MB2 was present. The distance from the apex of the distobuccal root to the buccal surface of the osseous lamella plate was significantly lower than the distance from the apex of the mesiobuccal root to the buccal surface. These findings indicate that the anatomical morphology of roots and canals of maxillary permanent second molars of patients from Chongqing vary considerably. These results can help in understanding the root and canal configuration of second molars of the maxilla, improving success rates of endodontic treatment and apical surgery. Moreover, these findings showed that CBCT is effective in assessing the complex anatomical morphology of teeth.

Conflicts of interest

None.

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