Review Article

Root Anatomy and Root Canal Configuration of Human Permanent Mandibular Premolars: A Systematic Review

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Introduction. Mandibular premolars have been reported with complex anatomical aberrations, making them one of the most difficult teeth to manage endodontically.

Methodology. An exhaustive search was undertaken to identify associated anatomic studies of mandibular premolars through MEDLINE/PubMed database using keywords, and a systematic review of the relevant articles was performed. Chi-square test with Yates correction was performed to assess the statistical significance of any anatomic variations between ethnicities and within populations of the same ethnicity. Documented case reports of variations in mandibular premolar anatomy were also identified and reviewed.

Results. Thirty-six anatomic studies were analyzed which included 12,752 first premolars and nineteen studies assessing 6646 second premolars. A significant variation in the number of roots, root canals, and apical foramen was observed between Caucasian, Indian, Mongoloid, and Middle Eastern ethnicities. The most common anatomic variation was C-shaped canals in mandibular first premolars with highest incidence in Mongoloid populations (upto 24%) while dens invaginatus was the most common developmental anomaly.

Conclusions. A systematic review of mandibular premolars based on ethnicity and geographic clusters offered enhanced analysis of the prevalence of number of roots and canals, their canal configuration, and other related anatomy.

1. Introduction

A clear understanding of the anatomy of human teeth is an essential prerequisite to all dental procedures especially so in the case of root canal treatment which deals with management of the tooth’s internal anatomy. The pulp space is divided into two parts: the pulp chamber, which is usually described as that portion within the crown, and the pulp canal or root canal, which lies within the confines of the root. The pulp chamber is a single cavity; the dimensions of which vary according to the outline of the crown and the structure of the roots. In multirooted teeth the depth of the pulp chamber depends upon the position of the root furcation and may extend beyond the anatomical crown [1].

The pulp space is complex; root canals may divide and rejoin, and possess forms that are considerably more involved than commonly implied. Many roots have additional canals and a variety of canal configurations. In the simplest form, each root has a single canal and a single apical foramen (Type I). Commonly, however, other canal complexities are present and exit the root as one, two, or more apical canals (Types II–VIII) [2]. This could be better understood through an insight into the development of root formation. At a more advanced stage of tooth development, when enamel and dentin formation has reached the future cementoenamel junction, the dental root begins to form from a cellular diaphragm or horizontal Hertwig’s epithelial root sheath. The horizontal Hertwig’s epithelial root sheath may vary in shape,
depending on whether the teeth are single- or multirooted. In fact, its shape determines the number of roots in a tooth. If the diaphragm remains in the shape of a collar, a single-rooted tooth will form. On the other hand, if two or three tongues of epithelium grow towards each other from this collar to bridge the gap and fuse, two or three diaphragms evolving independently from each other will form. They will either remain fused, forming fused roots, or single roots with multiple canals, or separated, forming distinct roots in multirooted teeth [3].

Mandibular premolars typically present with a single root and a single canal. The solitary root is usually oval in cross section containing an oval cross-section canal. Canal configurations in mandibular premolars may vary significantly with respect to ethnicity, race, and sex [2]. The purpose of this paper was to perform a systematic review of the literature related to the root anatomy and root canal configuration of the permanent mandibular first and second premolars.

2. Materials and Methods

2.1. Literature Search and Data Extraction. An exhaustive search was undertaken through MEDLINE/PubMed database to identify published literature related to the root anatomy and root canal morphology of the permanent mandibular premolars by using key words “root canal anatomy,” “root canal morphology,” “mandibular premolars,” “mandibular first premolar,” and “mandibular second premolar,” alone or in combination. Related anatomic studies of human permanent mandibular premolars were identified and a literature review was performed for articles dated July 2013 and before. The data was analyzed according to the population ethnicity and demography, number of teeth per study (power), number of roots, number of root canals, method of tooth analysis, root canal patterns, and number of apical foramina. Additionally, documented case reports of anatomic variations and developmental anomalies were identified and reviewed. Statistical comparisons were done between ethnicities and within populations of particular ethnicities using Chi-square test with Yates correction to allow for better understanding of the variations and the statistical significance of these variations in radicular anatomy of mandibular premolars based on the data collected through the systematic review.

3. Results

Thirty-six anatomic studies were analyzed which included 12,752 first premolars and nineteen studies of 6646 second premolars. A summary of the findings of different anatomic studies based on their ethnicity or geographical population assessment, with regard to the number of roots and canals has been tabulated for mandibular first premolars (Table 1) [4–38] and second premolars (Table 2) [4–7, 9, 11, 12, 15, 19, 21, 25, 29, 31–33, 35–40].

3.1. Radicular Anatomy with Ethnic and Demographic Patterns. In most instances, mandibular first premolars were found to have one root (97.21%). However, only 73.55% of these single rooted teeth contained a single canal. Thus, although the incidence of two roots was low (2.63%), about 23.55% teeth had two canals. Higher incidences of two roots were noted in the African-American population (16.2%) [14] and a Kuwaiti population (15%) [32]. Three or more rooted forms were reported in only 3% French [4] and 0.2% Indian [17] populations, respectively.

A higher incidence of two canals in mandibular first premolars was reported in several populations, up to 50% in Indian populations [16, 18–21] and approximately 40% in Middle Eastern populations from Kuwait [32], Jordan [33], and Turkey [36, 37]. While the Hispanic population [38] in Mexico also showed an incidence of 30.7%, the Chinese [22–27] and Caucasian [4, 6–14] populations had a variable incidence of two canals in about 10.7–36%. The incidence of three or more canals in mandibular first premolars was considerably lower (0–5%) [7, 12, 15, 22, 25, 27, 30, 33, 35, 36], with no such canal systems noted in Indian and Hispanic populations.

On the other hand, mandibular second bicuspids presented with a higher incidence of one root (99.28%) and one canal (86.9%). Overall, a second root was present in about 0.0–4.4% (average 0.61%) of teeth. In different studies, Caucasians [4, 6, 7, 9, 11, 12] and Turkish [36, 37] populations presented with a varied incidence of a second canal ranging from 2.5 to 34.4% and 6.4 to 29%, respectively. Second premolars presented with a second canal in Indian (13.5–20%) [19, 21], Iranian (5.8–17.5%) [35, 39, 40], or Jordanian (22.8%) [33] populations. However, Mongoloid [25, 29] and Hispanic [38] populations presented a much lower incidence of a second canal, 2% and 1.2%, respectively. Three or more canals in mandibular second premolars were scarcely reported (0–2%) [12, 15, 33].

C-shaped canal anatomy has been mainly documented in mandibular first bicuspids. Studies have reported a high incidence of C-shaped canals in Chinese populations ranging from 18 to 24% [23, 28], while other Chinese studies [25–27] have reported a lower incidence of 0–4–1.1%. In an Indian population, V. K. Sikri and P. Sikri [21] reported 10% first premolars exhibiting C-shaped canals while Sandhya et al. [16] reported the variation in 2% teeth in a southern Indian population. C-shaped canals were found to be of low incidence in second bicuspids, with only 0.6% and 2% incidence reported, respectively, in a Chinese [25] and an Iranian [35] study.

Lu et al. [23] coined the term “circumferential canals,” for an unusual aberration found in 6% of mandibular first premolars. A circumferential canal was described as a single canal in the center with 3 or 4 canals at the circumference when viewed in cross-section, that is, a single canal splitting into several canals (apical delta) at apical 3 mm from sagittal view. The teeth had a single oval canal or two canals in an oval-shaped root while the C-shaped morphology was found in the apical 3 mm and/or 6 mm level cross-sections.

In both premolars, single canals were most likely to be an independent canal from orifice to apical foramen (Type I). However, in first premolar, a significant number of bifid canals fused prior to exit (Type II) in Indian and Turkish
### Table 1: Summary of the incidence of documented ethnic and population variations in the anatomy of mandibular first premolars.

| Geographic and ethnic distribution | Materials and methods | No. of teeth in the study (n) | Root anatomy | Root canal anatomy | Root canal configuration (Vertucci) | Apical foramina | References |
|-----------------------------------|-----------------------|--------------------------------|--------------|-------------------|-------------------------------------|----------------|------------|
|                                   |                       |                                | 1 root       | 2 roots >2 roots | 1 canal 2 canals >2 canals C-shaped | Type I Type II | Type III Type IV Type V Type VI Type VII Type VIII Others types |           |
| France                            | In vitro: radiograph and sectioning | 341                            | 90.6% (109) | 6.4% (22) | 3% (10) | 68.9% (235) | 31.1% (106) | 0% (0) | 0% (0) | Geider et al. [4], 1989 |
| Germany                           | In vitro: examination | 2369                           | 99.3% (2352) | 0.7% (17) | 0% (0) | 89.3% (74) | 10.7% (9) | 0% (0) | 0% (0) | Schulze. [5], 1970 |
| Poland                            | In vitro: extraction and RCT | 83                             | 100% (400) | 0% (0) | 0% (0) | 70% (280) | 25% (100) | 5% (20) | 0% (0) | Rozylo et al. [6], 2008 |
| USA                               | In vitro: radiographic examination | 1002                           | 81.8% (820) | 18.2% (182) | 0% (0) | 89.3% (74) | 10.7% (9) | 0% (0) | 0% (0) | Vertucci [7], 1894 |
|                                   | In vitro: grinding and examination under magnification | 50                             | 86% (43) | 14% (7) | 0% (0) | 81.8% (820) | 18.2% (182) | 0% (0) | 0% (0) | Sabala et al. [8], 1994 |
|                                   | In vitro: sectioning | 106                            | 74% (78) | 26% (28) | 0% (0) | 74% (78) | 26% (28) | 0% (0) | 14% (15) | Green [9], 1973 |
|                                   | Extraction and radiograph | 1287                           | 66.9% (861) | 32.7% (421) | 0.4% (5) | 66.9% (861) | 32.7% (421) | 0% (0) | 80.7% (1039) | 19.3% (248) | Zöllich and Dowson [12], 1973 |
|                                   | In vitro: radiographs | 156                            | 95.5% (149) | 4.5% (7) | 0% (0) | 95.5% (149) | 4.5% (7) | 0% (0) | 0% (0) | Mueller et al. [13], 1993 |
|                                   | In vivo: radiographic examination | 400                           | 94.5% (378) | 5.5% (22) | 0% (0) | 86.3% (345) | 13.7% (55) | 0% (0) | 0% (0) | Trope et al. [14], 1986 |

| Subgroup Ethnic Incidence | 6226 | 96.88% (3471) | 2.52% (61) | 0.6% (10) | 75.42% (2586) | 23.84% (935) | 0.54% (25) | 1.4% (15) | 73% (360) | 2% (16) | 12.75 (32) | 12% (96) | 80% (1490) | 20% (383) |

| African American | 400 | 83.8% (335) | 16.2% (65) | 0% (0) | 67.2% (269) | 32.8% (131) | 0% (0) | 0% (0) | Zöllich and Dowson [12], 1973 |
| Senegalese       | 412 | 81.3% (335) | 15.1% (62) | 3.6% (15) | 81.3% (335) | 15.1% (62) | 3.6% (15) | 0% (0) | Mbaye et al. [15], 2008 |
| Subgroup Ethnic Incidence | 812 | 83.8% (335) | 16.2% (65) | 74% (604) | 23.95% (193) | 1.8% (15) | 0% (0) | 0% (0) | Zöllich and Dowson [12], 1973 |
| Geographic and ethnic distribution | Materials and methods | No. of teeth in the study (n) | Root anatomy | Root canal anatomy | Root canal configuration (Vertucci) | Apical foramina | References |
|------------------------------------|----------------------|-----------------------------|--------------|------------------|-------------------------------|--------------|-----------|
| India                              | In vitro: SBCT       | 100                         | 80% 11% 0% 2% 80% 9% 3% 2% 4% 0% 0% 0% 0% 0% 2% 94% 6% 0% | Indian       |                  |                  |              | Sandhyia   |
|                                   | In vitro: radiographic examination | 1000 (959) | 75.4% 1% (10) 0% 20.8% 2.4% 0% 0% 0% 0% 0% 0% 0% 0% 0% 76.4% 22.2% 0.4% |                  |                  |                  |              |          |
|                                   | In vitro: cleaning   | 100                         | 72% 27% 0% 1% 72% 6% 3% 10% 8% 0% 0% 0% 0% 0% 0% 0% 82% 18% 0% |                  |                  |                  |              | Velmarugan |
|                                   | In vitro: clearing   | 40                          | 50% 50% 0% 0% 50% 5% 5% 25% 12.5% 2.5% 0% 0% 0% 0% 0% 0% 82% 18% 0% |                  |                  |                  |              | Sandhyia   |
|                                   | In vitro: cleaning   | 138                         | 97.1% 2.8% 0% 67% 33% 0% 67.4% 8% 3.7% 3.9% 17.4% 0.7% 0% 0% 0% 0% 77.8% 22.2% 0% |                  |                  |                  |              | Parekh     |
|                                   | In vitro: SBCT       | 112                         | 96.4% 3.4% 0% 70.5% 29.5% 0% 10.7% 80% 9% 3% 2% 4% 0% 0% 0% 0% 98% 2% 0% |                  |                  |                  |              |           |
| Subgroup                        |                      | 1490                        | 96.47% 3.4% 0.07% 68% 30% 0% 3% 71% 6% 3% 11% 8% 0.53% 0.06% 0.33 85% 15% 0.07% |                  |                  |                  |              |           |
| Ethnic Incidence                |                      |                             |               |                  |                  |              |            |
| Mongolia                         | In vitro: radiograph | 100                         | 64% 34% 2% 0% 78% 6% 6% 10% 0% 0% 0% 0% 0% 0% 0% 90% 10% 0% |                  |                  |                  |              | Walker     |
| China                            | In vitro: radiograph | 82                          | 54% 46% 0% 0% |                  |                  |                  |              | Lu et al.  |
| and sectioning                  | In vitro: Micro-CT   | 115                         | 65.2% 26.1% 0% 0% 65.2% 0% 2.6% 0% 22.6% 0% 0.9% 0% 0% 0% 76.5% 23.5% 0% |                  |                  |                  |              |           |
|                                   | In vivo: CBCT        | 178                         | 87.1% 11.2% 0.6% 1.1% 86.8% 0% 1.7% 0% 9.8% 0% 0% 0% 0% 0% 0% 89.6% 9.8% 0.6% |                  |                  |                  |              | Liu et al. |
|                                   | In vivo: CBCT        | 97                          | 83.5% 12.4% 0% 4.1% 83.5% 0% 3.6% 0% 8.8% 0% 0% 0% 0% 0% 91.2% 8.8% 0% |                  |                  |                  |              | Liu et al. |
|                                   |                      | 440                         | 99.55% 30.5% 0% 75.2% 21% (92) 0.7% 1.1% 76% 3.4% 2.7% 6.6% 9.3% 0% 0% 0% 0% 78% 15.9% 0.7% |                  |                  |                  |              | Liu et al. |
|                                   |                      |                             |               |                  |                  |              |            |
|                                   |                      |                             |               |                  |                  |              |            |
| Japan                            | In vitro: SBCT       | 358                         | 24% (86) |                  |                  |                  |              | Fan et al. |
|                                   | In vitro: radiograph | 536                         | 86.2% 13.8% 0% 0% |                  |                  |                  |              | Miyoshi et |
|                                   | In vitro: Staining   | 139                         | 80.6% 15.1% 4.3% 0% |                  |                  |                  |              | Yoshoka et |
|                                   |                      | 50                            | 0% 0% 0% 0% |                  |                  |                  |              |           |
| Korea                            | In vivo: CBCT        | 797                         | 99.9% 0.1% 0% 0% |                  |                  |                  |              | Park et al |
| Subgroup                        |                      | 2822                        | 99% 1% (1409) 74.5% 22.5% 95% 3.7% 78% 0.85% 3% 3.32% 10.1% 0.18% 0.17% 0.85% 15% 0.65% |                  |                  |                  |              |           |
| Ethnic Incidence                |                      |                             |               |                  |                  |              |            |
| Kuwait                           | In vivo: radiograph of RCT teeth | 20                        | 85% 15% 0% 60% 40% 0% 0% |                  |                  |                  |              | Zaatar et  |
| Middle East                      |                      |                             |               |                  |                  |              |            |

Table 1: Continued.
### Table 1: Continued.

| Geographic and ethnic distribution | Materials and methods | No. of teeth in the study (n) | Root anatomy | Root canal anatomy | Root canal configuration (Vertucci) | Apical foramina | Others types | References |
|-----------------------------------|-----------------------|-------------------------------|--------------|--------------------|-------------------------------------|----------------|-------------|------------|
| Jordan                            | In vitro: clearing    | 500                           | 97%          | 3%                 | 0%                                  | 1200           | 2%          | 96%        | Awawdeh and Al-Qudah [33], 2008 |
| Iran                              | In vitro: sectioning  | 217                           | 100%         | 0%                 | 0%                                  | 1200           | 2%          | 96%        | Khedmat et al. [34], 2010      |
| Turkey                            | In vitro: clearing    | 163                           | 98%          | 2%                 | 0%                                  | 1200           | 2%          | 96%        | Calişkan et al. [36], 1995     |
| Subgroup                          |                       |                               |              |                    |                                     |                |             |            | Sert and Bayırli [37], 2004     |
| Ethnic Incidence                  |                       |                               |              |                    |                                     |                |             |            |                               |
| Mexico                            | In vitro: radiograph  | 202                           | 79.3%        | 25.8%              | 0%                                  | 1200           | 2%          | 96%        | Pineda and Kuttler [38], 1972  |

**Overall Incidence (%)**

| Total no of teeth | 12752 | 7395 | 200 | 12 | 6070 | 2027 | 73 | 181 | 2868 | 137 | 100 | 394 | 382 | 8 | 7 | 10 | 9 | 43.49 | 1002 | 13 |
|-------------------|-------|------|-----|----|------|------|----|----|------|-----|-----|-----|-----|---|---|----|---|--------|-------|----|
| Incidence (%)     | 97.21 | 2.63 | 0.16 | 73.55 | 23.55 | 0.91 | 2 | 72.6 | 3.73 | 2.72 | 10.72 | 10.4 | 0.22 | 0.19 | 0.27 | 0.24 | 81.08 | 18.68 | 0.24 |
Table 2: Summary of the incidences of documented ethnic and population variations in the anatomy of mandibular second premolars.

| Geographic and ethnic distribution | Materials and methods | No. of teeth in the study (n) | Root anatomy | Root canal anatomy | Root canal pattern (Vertucci) | Apical foramina | References |
|-----------------------------------|-----------------------|------------------------------|---------------|-------------------|-------------------------------|----------------|------------|
|                                   |                       |                              | 1 root        | 2 roots          | >2 roots                     | Type I | Type II | Type III | Type IV | Type V | Type VI | Type VII | Type VIII | Others types | 1 | 2 | 3 | |
| Caucasian                         |                       |                              |               |                  |                              |        |         |          |         |       |         |          |            |              |    |    |    | |
| France                            | In vitro: radiograph and sectioning | 328              | 97.6% (320) | 2.4% (8)  | 0% (0)          | 86.6% (284) | 13.4% (44) |          |        |         |         |       |         |          |            |              |    |    |    | |
| Germany                           | In vitro: analysis of extracted teeth | 2089            | 99.85% (2086) | 0.05% (1) | 0.1% (2) |                     |        |         |          |        |       |         |          |            |              |    |    |    | |
| Poland                            | In vitro: extraction and RCT | 56               | 66.8% (38) | 31.8% (18) | 0% (0) | 0% |          |        |         |          |        |       |         |          |            |              |    |    |    | |
| U.S.A                             | In vitro: clearing | 400              | 100% (400) | 0% (0) | 0% (0) | 92.5% (390) | 7.5% (100) | 0% (0) | 0% (0) | 0% (0) | 2.5% (10) | 0% (0) | 0% (0) | 0% (0) | 97.5% (390) | 2.5% (10) | 0% |    |    | |
|                                   | In vitro: sectioning | 32               | 100% (32) | 0% (0) | 0% (0) | 65.6% (21) | 34.4% (11) |          |        |         |          |       |         |          |            |              |    |    |    | |
|                                   | In vitro: extraction and radiograph | 906            | 96.6% (902) | 0% (0) | 3.4% (4) | 87.9% (792) | 12.5% (112) | 0.4% (2) |          |        |         |          |       |         |          |            |              |    |    |    | |
|                                   | In vitro: grinding and examination under magnification | 50             | 92% (46) | 8% (4) | 0% (0) |          |        |         |          |        |         |          |       |         |          |            |              |    |    |    | |
| Subgroup ethnic incidence         |                       | 3861             | 98.81% | 0.49% | 0.7% | 82.9% | 17.1% | 0.07% | 0% | 97.5% | 2.5% | 96.75% | 3.25% |         |          |            |    |    |    | |
| Senegalese                        | In vivo: radiographic examination | 408             | 86% (351) | 12% (49) | 2% (8) | 0% |          |        |         |          |        |       |         |          |            |              |    |    |    | |
|                                   |                       | African          | 98.81% | 0.49% | 0.7% | 82.9% | 17.1% | 0.07% | 0% | 97.5% | 2.5% | 96.75% | 3.25% |         |          |            |    |    |    | |
| India                             | In vitro: clearing | 40               | 80% (32) | 20% (8) | 0% (0) | 80% (32) | 0% | 0% | 0% | 2.5% | 17.5% | 0% | 0% | 0% | 0% | 0% | 0% | 80% (32) | 20% | 0% |    | |
|                                   | In vitro: SCT | 96              | 97.9% (94) | 2.1% (2) | 0% (0) | 87% (83) | 13.5% (13) | 0% (0) | 0% (0) | 78% (9) | 3% (3) | 2% (2) | 4% (4) | 0% (0) | 0% (0) | 90% (90) | 6% (6) | 0% |    |    | |
| Subgroup ethnic incidence         |                       | 136             | 97.9% | 2.1% | 0% | 83.5% | 16.75% | 0% | 0% | 80% | 4.5% | 1.5% | 2.25% | 10.75% |          |        |        | 87% | 13% |    |    |    | |
| China                             | In vivo: CBCT | 178             | 100% | 0% (0) | 0% (0) | 97.2% (173) | 2.2% (4) | 0% | 0.6% | 97.2% (173) | 0% | 0% | 0.5% | 1.69% | 0% | 0% | 0% | 5% (1) |          |    |    |    | |
| Japan                             | In vitro: radiograph | 40             | 97.9% (39) | 2.1% (1) | 0% (0) |         |        |        |          |        |         |          |       |         |          |            |              |    |    |    | |
| Korea                             | CBCT | 789             | 99.4% (784) | 0.6% (5) | 0% (0) | 97.5% (784) | 2.5% (5) | 0% | 0.3% | 97.2% | 0.5% | 1.69% | 0% |          |        |        |        | 0.5% |    |    |    | |
| Subgroup ethnic incidence         |                       | 1007            | 99.7% | 0.3% | 0% | 97.5% | 2.5% | 0% | 0.3% | 97.2% | 0.5% | 1.69% | 0% |          |        |        |        | 0.5% |    |    |    | |

References:
- Geder et al. [4], 1989
- Visser [41], 1948
- Röylo et al. [6], 2008
- Vertucci [7], 1984
- Barrett [II], 1925
- Zillich and Dowson [12], 1973
- Green [9], 1973
- Parekh et al. [19], 2011
- Zhang et al. [25], 2012
- Miyoshi et al. [29], 1977
- Park et al. [31], 2013
- V. K. Sikri and P. Sikri [21], 1994
### Table 2: Continued.

| Geographic and ethnic distribution | Materials and methods | No. of teeth in the study (n) | Root anatomy | Root canal anatomy | Root canal pattern (Vertucci) | Apical foramina | References |
|-----------------------------------|-----------------------|------------------------------|--------------|--------------------|-----------------------------|----------------|------------|
| Kuwait                            | In vitro: radiograph of RCT teeth | 64 (61) | 95.6% | 4.4% | 0% | 95.3% | 4.7% | 0% | 0% | 95.3% | 4.7% | 0% | Zaatar et al. [32], 1997 |
| Jordan                            | In vitro: clearing | 400 (398) | 97.2% | 2.8% | 0% | 72% | 27.5% | 0.5% | 0% | 78% | 3.8% | 0.1% | 75% | 15.3% | 0% | 0% | 0% | 0.5% | 74.2% | 15.8% | 0% | Awaadheh and AL-Qudah [33], 2008 |
| Iran                              | In vitro: clearing | 103 (103) | 100% | 0% | 0% | 80.5% | 17.5% | 0% | 2% | 76.3% | 7.9% | 9.9% | 5.9% | 0% | 0% | 0% | 0% | 0.5% | 94.1% | 5.9% | 0% | Rahimi et al. [35], 2007 |
| Iran                              | In vitro: clearing and sectioning | 80 (71) | 88.8% | 11.2% | 0% | 0% | 91.2% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 97.5% | 2.5% | 0% | Hasheminia and Hashemi [39], 2005 |
| Turkey                            | In vitro: clearing | 137 (129) | 94.2% | 5.8% | 0% | 0% | 91.2% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 75.9% | 24.1% | 0% | Rahimi et al. [40], 2009 |
| Turkey                            | In vitro: clearing | 100 (100) | 100% | 0% | 0% | 93.6% | 6.4% | 0% | 0% | 93.6% | 0% | 0% | 0% | 6.4% | 0% | 0% | 0% | 0% | 0% | 0% | 93.6% | 6.4% | 0% | Çalışkan et al. [36], 1995 |
| Turkey                            | In vitro: clearing | 200 (142) | 100% | 0% | 0% | 71% | 29% | 0% | 0% | 71% | 7% | 3.5% | 9% | 7% | 1.5% | 1% | 0% | 0% | 0% | 81.5% | 18.5% | 0% | Sert and Bayırli [37], 2004 |
| Subgroup ethnic incidence         |                         | 1084 | 98.56% | 1.44% | 0% | 85.06% | 14.59% | 0.07% | 0.29% | 82.02% | 3.74% | 2.7% | 4.48% | 5.74% | 0.3% | 0.2% | 0% | 0.1% | 87.44% | 11.33% |

| Materials and methods | No. of teeth | Root anatomy | Root canal anatomy | Root canal pattern (Vertucci) | Apical foramina | References |
|-----------------------|-------------|--------------|--------------------|-----------------------------|----------------|------------|
| In vitro: radiographs | 250 | 98.8% | 1.2% | 0% | 0% | 98.8% | 1.2% | 0% | Pineda and Kuttler [38], 1972 |
| Total no of teeth     | 6746 | 56.49 | 34 | 6 | 3364 | 489 | 12 | 3 | 1346 | 46 | 46 | 58 | 105 | 3 | 2 | 0 | 3 | 1741 | 179 | 0 |
| Overall incidence     |             | 99.28% | 0.61 | 0.01% | 86.9% | 12.64% | 0.31% | 0.08% | 83.65% | 2.86% | 2.86% | 3.6% | 6.52% | 0.18% | 0.12% | 0% | 0.18% | 90.68% | 9.32% | 0% |
populations (9–18%) [16–21, 37]. Type IV pattern was more prevalent than Type V pattern in most population groups. However, Type V pattern (9–22%) was much higher than Type IV patterns (0–10%) in Mongoloids pointing to a higher prevalence of a singular canal bifurcating along its length, somewhat similar to the description of the above-mentioned circumferential canals. In second premolars, the Type V pattern was more prevalent than Type IV in all population groups, with significantly higher prevalence of up to 15–17% in Indian and Jordanian. A single apical foramen was present in 81% first premolars and 90% second premolars. The mandibular first premolar was more prone to bifurcation of canals (23–30%) terminating in multiple apical foramina (15–20%).

Based on the statistical analysis performed, a significant variation in the number of roots, root canals, and apical foramen was observed between all the ethnicities, in both mandibular bicuspid. Thus, based on this analysis, the number of roots, root canals, and apical foramen were significantly different in Caucasian, Indian, Mongoloid, and Middle Eastern populations. Additionally, there was also a significant difference in the root canal configurations of these population groups. However, in case of comparing for anatomic variations within populations of the same ethnicity, statistics could be performed only when sufficient data allowed for statistical analysis. The numbers of roots and root canals in first and second premolars were statistically significantly different in French, German, Polish, and the United States populations of Caucasians, as well as among the first premolars of Middle Eastern populations, Turkey, Jordan, Kuwait, and Iran. However, no such statistical significance was observed between Chinese and Korean second premolars.

Six ex vivo studies have reported the presence of a deep external mesial invagination (mesial invagination) along the root surface of mandibular premolars [16, 18, 20, 24, 33, 42] (Table 3). Sandhya et al. [16] assessed the root dentin thickness at the depth of the mesial invagination in mandibular first premolars and reported the average root thickness at the cervical, middle, and apical thirds to be 0.8, 0.78, and 0.3 mm, respectively. All C-shaped configuration premolars could also present an associated groove or concavity on the proximal lingual area of the middle root that would not always extend to the root apex. Some grooves presented as deep, folding grooves while others were not so distinguished or were just shallow concavities [23].

3.2. Gender Predilection. There is little documentation correlating the influence of gender on root/canal anatomy and its variations. Of the reported studies, females had a higher likelihood of two or more roots or canals in mandibular first premolars, whereas men exhibited multiple canals much more frequently than females in mandibular second premolars [17, 37, 43]. Others have reported no significant difference in root configuration between females and males [29].

3.3. Case Reports. In addition to these numerous population studies, thirty-six case reports have also documented anatomic variations. The anatomic aberrations reported as endodontic case reports in the literature include mandibular first premolars with 2 or 3 canals in 1 root or 2 roots; 3 roots and 3 canals; and 4 canals in 4 roots (Table 4) [44–59]. Mandibular second premolars have shown variations that include 2, 3, 4, and 5 canals in 1 root; 2, 3, and 4 canals in 2 roots; 3 roots and 3 or 4 canals; (Table 5) [46, 49, 53–55, 60–80].

3.4. Anatomic Developmental Anomalies. Adding to the complexity of the mandibular premolars are various developmental anomalies (Table 6) [77, 81–90]. In 1997, Hartup [81] reported a Type III dens invaginatus and a bifurcated root of the mandibular first premolar. Tavano et al. [83] reported a dens invaginatus wherein the clinical crown was larger than the contralateral first premolar. No case reports of dens invaginatus in the mandibular second premolar have been reported (Table 6). Conversely, dens evaginatus most frequently affected mandibular second premolars and was more often reported in Mongoloid people [88].

Aryanpour et al. [84] reported root canal and periodontal treatment of a gminated mandibular first premolar, that is, two distinct crowns with united roots, with three canals. Kusaik et al. [91] reported the root morphology of mandibular premolars in female Polish patients with Turner’s syndrome, based on orthopantomogram X-ray images. They reported two-rooted mandibular teeth in 31–34% first premolars and 31–39% second premolars, which is much higher than that reported in general populations (<5%).

4. Discussion

Several factors contribute to variations found in the root and root canals that include ethnicity and gender. Scott and
### Table 4: Table enlisting documented case reports of mandibular first premolars with multiplicity of roots or root canals in teeth presenting.

| Number of roots | Root canal anatomy | Diagnostic method | Country       | Reference                          |
|-----------------|--------------------|--------------------|---------------|------------------------------------|
| 1 root          | 2 roots            | R/G                | USA           | England et al. [44], 1991          |
|                 | 3 roots            | R/G                | India         | Shenoy et al. [45], 2013           |
|                 | 3 roots            | R/G                | Jamaica       | Nallapati [46], 2005               |
|                 | 3 roots            | R/G                | Brazil        | De Almeida-Gomes et al. [47], 2006 |
| 2 roots         | 3 roots            | R/G                | India         | Kararia et al. [48], 2012          |
|                 | 3 roots            | Extraction         | USA           | Poorni et al. [49], 2010           |
|                 | 3 roots            | R/G                | India         | Moayedi and Lata [50], 2004        |
|                 | N/A                | R/G                | USA           | Milano et al. [51], 2002           |
| 3 roots         | 3 roots            | R/G                | USA           | Kakkar and Singh [52], 2012        |
|                 | 3 roots            | R/G                | China         | Chan et al. [53], 1992             |
|                 | 3 roots            | Extraction         | USA           | Fischer and Evans [54], 1992       |
|                 | 3 roots            | Micro-CT after extraction | Britain | Cleghorn et al. [55], 2008 |
| N/A             | 3 roots            | R/G                | Germany       | Hülsmann [56], 1990               |
| N/A             | 3 roots            | R/G                | Australia     | Yang [57], 1994                    |
| 4 roots         | 4 roots            | R/G                | India         | Vaghela and Sinha [58], 2013       |
|                 | 4 roots            | R/G                | China         | Du et al. [59], 2013               |

N/A: not available, R/G: radiograph, and Micro-CT: microcomputed tomography.

### Table 5: Table summarizing case reports of anatomical variations of roots and root canals in mandibular second premolars.

| Number of roots | Root canal anatomy | Diagnostic mode | Country        | Reference                                 |
|-----------------|--------------------|-----------------|----------------|-------------------------------------------|
| 1 root          | 3 roots            | R/G             | USA            | Nallapati [46], 2005                      |
|                 | 4 canals           | R/G             | Isreal         | Holtzman [61], 1998                       |
|                 | 5 canals           | R/G             | USA            | Wong [62], 1991                           |
|                 | C-shaped           | Micro-CT after extraction | Britain | Cleghorn et al. [55], 2008 |
| 2 roots         | 2 canals           | R/G             | India          | Goswami et al. [64], 1997                 |
|                 | 3 canals           | R/G             | India          | Prakash et al. [65], 2008                 |
|                 | 3 canals           | R/G             | China          | Chan et al. [53], 1992                    |
|                 | 3 canals           | R/G             | Germany        | Rödig and Hülsmann [66], 2003            |
|                 | 3 canals           | R/G             | Belgium        | De Moor and Calberson. [67], 2005        |
|                 | 3 canals           | R/G             | Iran           | Lotfi et al. [68], 2008                   |
|                 | 3 canals           | R/G             | Brazil         | Soares et al. [69], 2009                  |
|                 | 3 canals           | R/G             | Iran           | Shokouhinejad [70], 2009                   |
|                 | 3 canals           | R/G             | India          | Aguiar et al. [71], 2010                 |
|                 | 3 canals           | R/G             | India          | Poorni et al. [49], 2010                 |
|                 | 4 canals           | R/G             | USA            | Bram and Fleisher [72], 1991             |
|                 | 4 canals           | R/G             | Saudi Arabia   | Al-Fouzan [73], 2001                     |
|                 | 4 canals           | R/G             | United Kingdom | Rhodes [74], 2001                         |
|                 | 4 canals           | R/G             | Greece         | Tzanetakis et al. [75], 2007             |
|                 | 4 canals           | Extraction      | USA            | Fischer and Evans [54], 1992             |
|                 | 3 canals           | R/G             | Iran           | Shalavi et al. [76], 2012                 |
|                 | 3 canals           | CBCT            | Iran           | Mokhtari et al. [77], 2013                |
|                 | 4 canals           | Extraction      | USA            | Shapira and Delivanis [78], 1982          |
| 4 roots         | 4 canals           | SCT             | Indian         | Sachdeva et al. [79], 2008                |
|                 | 4 canals           | R/G             | Greece         | Farmakis [80], 2008                      |

CBCT: cone beam computed tomography, Micro-CT: microcomputed tomography, SCT: spiral computed tomography, and R/G: radiograph.
Numerous methods have been used for studying root canal anatomy, including replication techniques [93], ground sections [94], clearing techniques [95], and radiography [96]. Advanced modes of radiographic imaging and analysis have allowed for in-depth knowledge of pulp space anatomy in three dimensions and allowed for identification of rare aberrations. These methods include spiral computed tomography (SCT) [16, 21], micro-computed tomography (micro CT) [24, 28, 97], and cone beam computed tomography (CBCT) [25–27]. Study design differences and the various origins of the investigated teeth could account for the highly variable results.

*Ex vivo* anatomic investigations, although the most widely used, inherently have certain shortcomings. It involves evaluation of extracted teeth that are frequently difficult to collect in sufficient numbers along with known specifics like age, gender, and so forth. Furthermore, most extracted teeth collected are severely damaged leading to difficulties in determining accurately the tooth notation. An additional negative impact if only sound teeth are selected is selection bias [25, 30]. Additionally, not all anatomic studies assessing mandibular premolars have reported the root and root canal configuration. Either one of these has been described with most studies discussing the root canal configuration (Tables 1 and 2). It would be of much more analytic and scientific value if the maximum data could be presented from the analyzed teeth, especially when the methodology leads to destruction of the samples. Thus, although a large number of mandibular premolars have been analyzed in anatomic studies, maximum extrapolation is lacking. CBCT imaging by means of its minimal radiation exposure, sample preservation, accuracy, and three-dimensional data acquisition of multiple teeth, could overcome the shortfalls of *ex vivo* methods and offer maximum information without solely depending on analysis of extracted teeth.

Differences in the method of analysis and data presentation could also contribute to an inaccurate perception of the incidence of variable anatomy. Data presented by number of patients instead of by number of teeth generally results in higher frequencies of the reported anomaly [14]. Also, the sample size studied in relation to the total sample of the population plays an important role in the overall ratio of variations. For instance, the only study analyzing the anatomy of a Kuwaiti population assessed only 20 mandibular first premolars of which 15% were two-rooted teeth and 40% contained two canals. Although these values are above the general weighted average or incidence among neighboring population groups, these findings may not reliably signify the accurate incidence of tooth anatomy within the population. Thus, studies of larger sample groups and streamlining data in the form of number of teeth could enhance comparison and also give a more dependable picture of the prevalent anatomy.

An interesting pattern that can be observed is that case reports of the second premolar by far outnumber those of the first premolar, especially in reported variations. This is contrary to the findings of epidemiologic studies, which reported an increased possibility of anatomic variation in mandibular first premolars. Despite these contrasting findings, anatomic studies serve as an indicator of the possible anatomic variations in analyzed population groups and should not be considered as the lone guiding principle. Wider anatomic variations are certainly possible in any tooth, as also in teeth that are less likely to show aberrations. On the other hand, case reports could be misleading to the clinician with regard to the incidence of the documented aberrations; however, their didactic value is of extreme importance. It allows the
clinician to be in the best position to detect, discern, and diagnose various previously documented in vivo anatomic variations.

Pucci and Reig [98], in their monumental work Conductos Radiculares, concluded that the mandibular second premolar had two canals and two foramina 11.5% of the time, whereas the mandibular first premolar had branching canals, apical bifurcations, and trifurcations 26.5% of the time. Cleghorn et al. [99, 100], in a review of mandibular canals, apical bifurcations, and trifurcations, 26.5% of the time, whereas the mandibular first premolar had branching canals and two foramina 11.5% of the time. In cases of second premolars, almost all of the teeth in the anatomic studies were single-rooted (99.6%) with a single canal (91.0%). Comparatively, the findings of the present systematic review are more or less in agreement with these observations of Pucci and Reig [98] and Cleghorn et al. [99, 100].

The data analyzed in this systematic review is secondary data that is sourced from numerous previously published studies. Such secondary data is prone to drawbacks or biases that are inherent in the original data which could ultimately reflect in the results of this study as well. For instance, the method of analysis or the minimal number of teeth analyzed in a particular study. However, the intention was to provide the dental and endodontic fraternity, an interpretation of the vast data on mandibular premolars with a possibility of correlation to geographical origin and ethnicity that was not previously available.

The descriptions of the frequently occurring root and canal forms of permanent teeth are based largely on studies conducted in Europe and North America and relate to teeth of predominantly Caucasoid origin [1, 3]. The descriptions may not be wholly applicable to teeth of non-Caucasoid origin. The present systemic review provides additional and up-to-date information regarding the canal configuration of premolars and their apical exit patterns which allows for further comparison among different population groups around the globe. However, a very slight trend of more varied anatomy, that is, two or more roots or canals, could be seen in recent anatomic studies using modern imaging techniques, in as yet lesser analyzed population groups. Future documentation of root and canal anatomy in previously lesser studied geographical populations could show a trend of discrepancies between previously established weighted averages. However, it would be more appropriate and accurate to base successive comparisons of anatomic averages on ethnicities and demography’s, as against the general norm of overall weighted averages.

5. Conclusions

(1) The mandibular first premolar was more prone to bifurcation of canals (23–30%) terminating in multiple apical foramina (15–20%), as compared to second premolars.

(2) The C-shaped canal pattern was most prevalent in first premolars of Chinese populations (upto 24%).

(3) In second premolars, Caucasian, Indian, and Middle Eastern populations showed a higher prevalence of multiple canals (14–17%).

(4) Type I canal configuration was most prevalent in both first (72.6%) and second premolars (83.65%).

(5) A deep mesial radicular invagination was a common finding in multiple population groups in first premolars (13–27%).

(6) Dens invaginatus was the most common developmental anomaly in first premolars.

(7) There exists an association between ethnicity and root, root canal morphology across population groups in first and second premolars.

Recent imaging techniques and evaluation of wider populations have given a better insight regarding mandibular premolar anatomy and their inherent variations. Certain population and geographic groups have little or no data regarding mandibular premolar morphology, especially in South American, African, Australasian, and South East Asian populations. Although the studies that have been covered under this review did provide relevant information regarding root and root canal anatomy, other important data relating to apical anatomy, relationship of the anatomic apex with the apical foramen, precise location of bifurcations when present, and so forth needs further evaluation and documentation in future research. Racial differences and its influence on pulp space anatomy should always be kept in mind.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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