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Morphological Analysis of Mandibular Incisors Using the Ahmed Classification System. Literature Review

Análisis Morfológico de los Incisivos Mandibulares Mediante el Sistema de Clasificación de Ahmed. Revisión Bibliográfica

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SUMMARY: The mandibular incisors (MI) are especially complex to treat endodontically due to their limited dimensions. In addition, the lack of knowledge about the wide morphological variation in this tooth group may contribute to endodontic treatment failure. One of the most recent classifications for the morphological study of the root canal system (RCS) was proposed by Ahmed et al. (2017). This classification addresses and overcomes the limitations encountered in the widely used Vertucci (1984) classification. This article analyzed the scientific literature to ascertain the most common morphology in mandibular central incisors (MCI) and mandibular lateral incisors (MLI). The included studies utilized cone-beam computed tomography (CBCT) and applied the classification system developed by Ahmed et al. (2017). A literature review was conducted using the PUBMED, LILACS, SciELO, SCOPUS, and EMBASE databases, considering articles with no restriction on years of publication, performed on human subjects, and published in English or Spanish. Five articles relevant to the study objective were included. The ^{1}MI $^{1-1}$ configuration is the most predominant in mandibular incisors, although a considerable presence of complex morphologies has been observed, with the frequent occurrence of second canals. The Ahmed et al. (2017) classification system provides a practical, accurate and easy-to-use method for categorizing root and root canal structures.

KEY WORDS: Mandibular incisors; Root canal system; Ahmed classification; Cone beam computed tomography; Endodontics.

INTRODUCTION

Endodontic treatment consists of thorough cleaning, disinfection, and obturation of the root canal system (RCS). Therefore, a detailed understanding of the internal and external morphology of the teeth is important for successful treatment (Buchanan *et al*., 2020). Due to their limited dimensions, mandibular incisors (MI) are especially complex to treat endodontically. In addition, a lack of knowledge about the wide morphological variation present in this tooth group may contribute to endodontic treatment failure (Iqbal *et al*., 2022).

Several techniques have been described to analyze root and RCS morphology, such as decalcification, diaphanization, histological sections, microscopic observation, canal staining, conventional radiographs, and three-dimensional imaging (Estrela *et al*., 2015; Da Silva *et al*., 2016; Karobari *et al*., 2020). Among the clinical options, cone beam computed tomography (CBCT) is the tool for studying root canal morphology in vivo. CBCT is a conical radiation beam that delivers data in a single 360-degree rotation. It is a non-invasive tool that produces three-dimensional (3D) extraoral images, reducing image overlap and generating greater geometric accuracy at a low radiation dose (Kim, 2012). These parameters make it useful for diagnosing dental morphology (Abella *et al*., 2015).

Several classification systems have been reported in the literature for the study of RCS morphology. The classification systems introduced by Weine *et al*. (1969), Weine (1982) and Vertucci *et al*. (1984) have been the most widely used and have been effective in categorizing numerous, though not all, canal configurations. Recent studies utilizing advanced 3D imaging techniques to explore both external and internal canal variations have demonstrated

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that the root canal system's morphology is extremely intricate, with numerous canal configurations being termed as "nonclassifiable" (Verma & Love, 2011; Kim *et al*., 2013; Lee *et al*., 2014; Leoni *et al*., 2014).

One of the most recent classifications was proposed by Ahmed *et al*. (2017), who described a coding system that provides accurate information about the RCS and root morphology, describing an extensive number of configurations that can be presented (Karobari *et al*., 2020). This classification addresses and overcomes the limitations encountered in the widely used Vertucci (1984) classification. The Ahmed classification doesn't have a fixed number of canal types. Instead, it uses "codes" that are assigned to each specific canal or root structure, allowing it to accommodate even the most intricate root canal configurations. Furthermore, each record or code provides details about both the number and path of the canals, as well as the number and structure of the roots. The Ahmed system has been described as accurately classifying root and canal anatomy in both laboratory and clinical studies, as well as in routine clinical settings (Ahmed & Dummer 2018; Saber *et al*., 2019; Buchanan *et al*., 2020; Ahmed *et al*., 2021a,b).

The objective of this article was to analyze the scientific literature to determine the most common morphology in mandibular central incisors (MCI) and mandibular lateral incisors (MLI) reported using Ahmed's classification.

MATERIAL AND METHOD

A literature review was conducted using the PUBMED, LILACS, SciELO, SCOPUS, and EMBASE databases. The search strategy included the terms “incisor”, “tooth”, “mandible”, “anterior teeth”, “dental pulp cavity”, “root canal”, “root canal classification”, “Ahmed”, “root canal morphology”, “cone-beam computed tomography”, “CBCT”. The terms were combined using Boolean operators “AND” and “OR”, accompanied by MeSH terms. The search was conducted between December 2023 and February 2024.

This review considered articles with no restriction on years of publication, performed on human subjects, and published in English or Spanish. Systematic reviews, case reports, and theses were excluded. The review included articles that used CBCT and that applied the classification system developed by Ahmed *et al*. (2017).

The Ahmed classification system is adaptable for categorizing both root and root canal configurations. It consists of codes that represent three distinct elements: the tooth number, the number and arrangement of roots, and the configuration of the root canals. The tooth number (TN) can be recorded using any standard numbering system, such as the Universal Numbering System, Palmer Notation, or the FDI World Dental Federation system. In cases where the tooth cannot be identified with one of these systems, such as with extracted teeth, an appropriate abbreviation can be used, for example, maxillary (upper) central incisor (UCI) (Fig. 1).

The number of roots (R) is indicated as a superscript before the tooth number (^{R}TN). For example, ^{1}TN indicates that the tooth ‘TN’ has a single root. Any split in the root, whether in the coronal, middle, or apical third, is classified as two or more roots. Therefore, a bifurcation is denoted as ^{2}TN, and a trifurcation as ^{3}TN, and so forth (Fig. 2).

The root canal configuration in each root is indicated by a superscript number(s) following the tooth number, representing the pathway from the orifice(s) (O), through the canal (C), to the foramen (foramina) (F) (Fig. 1 and Fig. 2).

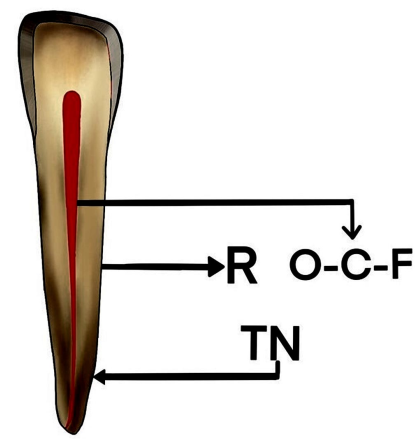

Fig. 1. The Ahmed *et al*. classification provides codes for number of teeth (TN), number of roots (R), and root canal configuration. R is added as a superscript before the TN. The root canal configuration is added as a superscript after the TN, starting from the orifice (O), through the canal (C), and ending at the foramen (F). This provides the following coding: ^{R}TN $^{O\text{-}C\text{-}F}$.

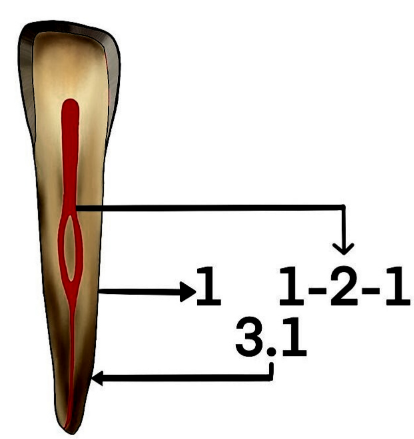

Fig. 2. Representation of single-root left mandibular central incisor. It initially presents a canal that bifurcates into two canals and ends in one canal, providing the ^{1} 3.1 $^{1\text{-}2\text{-}1}$ Ahmed *et al*. configuration.

RESULTS

The electronic search yielded a total of 635 results. The filters (year of publication, language, and human subjects) were applied, reducing to 596 articles. Then, a title and abstract reading was performed, excluding 573 articles that did not use the Ahmed *et al*. (2017) classification and CBCT for analysis. Subsequently, a full-text reading of 23 articles was performed, excluding 18 considered irrelevant to our study objective. Finally, the analysis was performed on 5 articles (Fig. 3).

The 5 articles analyzed corresponded to cross-sectional cohort studies conducted between 2020 and 2024. These studies are from Jordan, Saudi Arabia, South Africa, and Malaysia. Four articles analyzed both MCI and MLI, while one focused only on MCI (Table I).

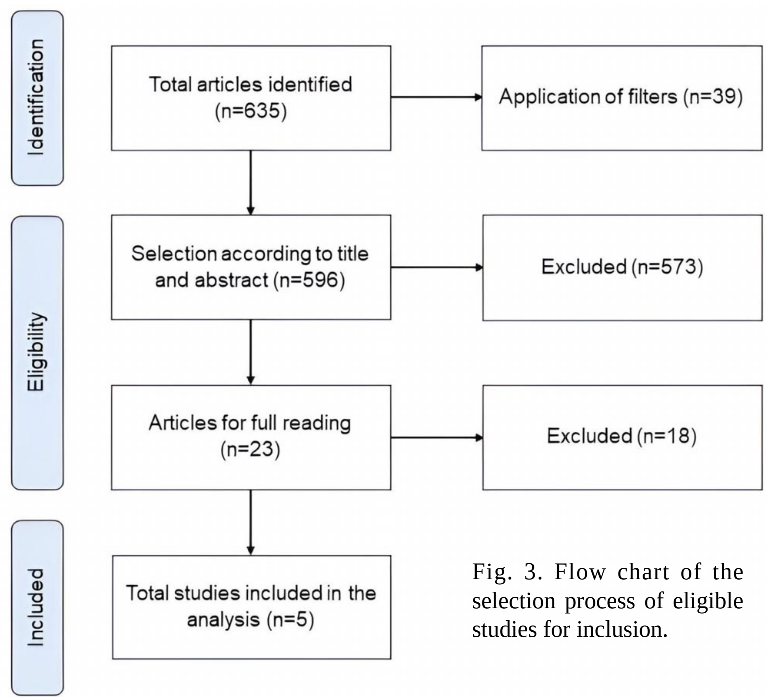

Fig. 3. Flow chart of the selection process of eligible studies for inclusion.

Table I. Studies using the classification by Ahmed *et al.* using CBCT.

Author	Population	Study model	Sample size	Ahmed *et al*. classification for central incisors	Ahmed *et al*. classification for lateral incisors
Taha *et al.* (2024)	Jordanian	Cross-sectional Cohort	1114 MCI 1114 MLI	^{1} MCI $^{1-1}$: 787 (70.6 %) ^{1} MCI $^{1-2}$: 3 (0.3 %) ^{1} MCI $^{1-2-1}$: 300 (26.9 %) ^{1} MCI $^{2-1}$: 8 (0.7 %) ^{1} MCI $^{2-1-2-1}$: 16 (1.4 %)	^{1} MLI $^{1-1}$: 779 (69.9 %) ^{1} MLI $^{1-2}$: 3 (0.3 %) ^{1} MLI $^{1-2-1}$: 311 (27.9 %) ^{1} MLI $^{2-1}$: 7 (0.6 %) ^{1} MLI $^{2-1-2-1}$: 11 (1 %) ^{2} MLI B^{1} L^{1}: 3 (0.3%)
Alobaid *et al.* (2022)	Saudi Arabian	Cross-sectional cohort	1260 MCI	^{1} MCI $^{1-1}$: 1034 (82 %) ^{1} MCI $^{1-1-2}$: 9 (0.7 %) ^{1} MCI $^{1-2-1}$: 171 (13,6 %) ^{1} MCI $^{1-2-2}$: 39 (3.1%) ^{1} MCI $^{2-1-1}$: 1 (0.1 %) ^{1} MCI $^{2-2-1}$: 6 (0. 5%)	-
Buchanan *et al.* (2022)	South African	Cross-sectional cohort	387 MCI 387 MLI	^{1} MCI $^{1-1}$: 245 (63.3%) ^{1} MCI $^{1-2}$: 2 (0.5 %) ^{1} MCI $^{1-2-1}$: 129 (33.3 %) ^{1} MCI $^{2-1}$: 9 (2.4 %) ^{1} MCI $^{2-1-2}$: 1 (0.25 %) ^{1} MCI $^{1-2-1-2}$: 1 (0.25 %)	^{1} MLI $^{1-1}$: 256 (66.1 %) ^{1} MLI $^{1-2}$: 5 (1.3 %) ^{1} MLI $^{1-2-1}$: 115 (29.7 %) ^{1} MLI $^{2-1}$: 8 (2.1 %) ^{1} MLI $^{1-2-1-2}$: 3 (0.8 %)
Iqbal *et al.* (2022)	Saudi Arabian	Cross-sectional cohort	570 MCI 570 MLI	^{1} MCI $^{1-1}$: 489 (85.8 %) ^{1} MCI $^{1-2}$: 7 (1.2 %) ^{1} MCI $^{1-2-1}$: 74 (13 %)	^{1} MLI $^{1-1}$: 391 (68.6 %) ^{1} MLI $^{1-2}$: 35 (6.1 %) ^{1} MLI $^{1-2-1}$: 144 (25.3 %)
Karobari *et al.* (2020)	Malaysian	Cross-sectional cohort	1692 MCI 1701 MLI	^{1} MCI $^{1-1}$: 1104 (65.2 %) ^{1} MCI $^{1-2}$: 20 (1.2 %) ^{1} MCI $^{1-2-1}$: 521 (30.8 %) ^{1} MCI $^{2-1}$: 20 (1.2 %) ^{1} MCI ^{2}: 2 (0.1 %) ^{1} MCI $^{2-1-2}$: 2 (0.1 %) ^{1} MCI $^{1-2-1-2}$: 6 (0.4 %) ^{1} MCI $^{2-1-2-1}$: 17(1%)	^{1} MLI $^{1-1}$: 763 (44.9 %) ^{1} MLI $^{1-2}$: 30 (1.8 %) ^{1} MLI $^{1-2-1}$: 870 (51.1 %) ^{1} MLI $^{2-1}$: 18 (1.1 %) ^{1} MLI ^{2}: 4 (0.2 %) ^{1} MLI $^{1-2-1-2}$: 3 (0.2 %) ^{1} MLI $^{2-1-2-1}$: 13 (0.8 %)

MCI: Mandibular Central Incisor, MLI: Mandibular Lateral Incisor, B: Buccal Root, L: Lingual Root.

Several configurations were reported across the studies analyzed, but only three configurations appeared consistently in all five studies: ^{1} MCI $^{1-1}$, ^{1} MCI $^{1-2-}$1, and ^{1} MCI $^{1-2}$. The ^{1} MCI $^{1-1}$ configuration was the most prevalent, reaching up to 82 % for MCI and up to 69.9 % for MLI. The second most common configuration was ^{1} MCI $^{1-2-1}$, with a prevalence of up to 33.3 % for MCI and 51.1 % for MLI. Although the ^{1} MCI $^{1-2}$ configuration was present in all studies, it had relatively low percentages, with a maximum of 1.2 % for MCI and 6.1 % for MLI. Other configurations were identified but occurred at much lower frequencies. Additionally, more complex configurations, only classifiable using the Ahmed *et al.* (2017) methodology, were identified, such as ^{1} MCI $^{2-1-2-1}$, ^{2} MLI B^{1} L^{1}, and ^{1} MCI $^{1-2-1-2}$.

DISCUSSION

MI are the smallest permanent teeth, with small root canal lumina and a complex RCS configuration (Tang *et al.*, 2023). This complicates the cleaning, disinfection, and obturation of the RCS. Hence, it is crucial to have a profound understanding of the morphological variances in these teeth (Alobaid *et al.*, 2022).

The European Society of Endodontics recommends using CBCT to evaluate the RCS morphology (Patel *et al.*, 2019a). This tool is notable for being noninvasive and achieving greater accuracy than conventional radiographs (Patel *et al.*, 2019b). Alobaid *et al.* (2022) found that the diagnostic accuracy of CBCT was 89 %, whereas periapical radiographs yielded a diagnostic accuracy of 55 %.

As for the staining and cleaning techniques for extracted teeth, these exhibit a high similarity in accuracy with CBCT for assessing the number of root canals (Neelakantan *et al.*, 2010; Almohaimede *et al.*, 2022). However, these techniques require longer working time (Neelakantan *et al.*, 2010) Therefore, CBCT is considered a tool of choice in studies with a large sample size, such as cross-sectional cohort studies (Altunsoy *et al.*, 2014; Da Silva *et al.*, 2015; Karobari *et al.*, 2020).

CBCT provides highly accurate images because its voxels are isotropic (Kaya *et al.*, 2011). Yet unlike micro computed tomography (micro-CT), which can visualize the smaller branches in the root canal, CBCT cannot detect the more subtle variations in the RCS. However, micro-CT is used on extracted teeth. Therefore, CBCT is considered a tool of choice for in vivo studies (Abella *et al.*, 2015; Martins *et al.*, 2017; Ahmed & Rossi-Fedele, 2020).

The emergence of radiographic equipment that uses three-dimensional images, such as micro-CT or CBCT, has confirmed the wide variety of root morphologies, many of which were previously unclassifiable using existing systems, such as those proposed by Weine *et al.* (1969), Weine (1982), and Vertucci (Ahmed *et al.*, 2017; Karobari *et al.*, 2020). This is because, in previous decades, the visualization techniques employed were not as precise as the current tomographic technologies. Moreover, one study reported that 13 % of the observed configurations could not be categorized according to Vertucci (Filpo-Perez *et al.*, 2015). Therefore, Ahmed *et al.* (2017) proposed a new morphological classification with a coding system. Unlike previous classifications, this system incorporates the number of roots and describes various root canal morphologies not contained in the other classifications (Alobaid *et al.*, 2022). On the other hand, Taha *et al.* (2024) reported that sixteen MCI (1.4 %) and eleven MLI (1 %) could not be classified by Vertucci, resulting in the ^{1} MI $^{2-1-2-1}$ configuration by Ahmed *et al.* (2017). Similarly, research conducted by Buchanan *et al.* (2022) and Karobari *et al.* (2020) yielded morphologies not described under the Vertucci classification and were coded according to the Ahmed *et al.* (2017) classification.

Historically, it has been accepted and taught that mandibular anterior teeth have a single root. This assertion aligns with the findings reported in several studies conducted in Malaysian, South African, and Saudi Arabian populations, where the presence of one root was mostly observed in the MI (Karobari *et al.*, 2020; Buchanan *et al.*, 2022; Iqbal *et al.*, 2022; Alobaid *et al.*, 2022). However, a Jordanian study identified three MLI with two roots (Taha *et al.*, 2024). Also, Almohaimede *et al.* (2022) and Mashyakhy & Gambarini (2019) reported the presence of MLI with two roots in a percentage not exceeding 0.1 %. It should be noted that these studies used the Vertucci classification system.

According to the Ahmed *et al.* (2017) classification, the canal configuration ^{1} MCI $^{1-1}$ was identified as the most prevalent among the MCI group, appearing in 70.6 % of the Jordanian population, 63.3 % of the South African population, 65.2 % in Malaysia, and 82 % to 85.8 % in the Saudi population. These morphologies align with the percentages observed for a single canal in populations from Portugal, Israel, Brazil, Iran, Turkey, and China. It should be noted, however, that these studies were conducted using the Vertucci classification. The second most common configuration was ^{1} MCI $^{1-2-1}$, with reported frequencies of 26.9 % in the Jordanian population, 30.8 % in Malaysia, and 33.3 % in South Africa. Studies by Alobaid *et al.* (2022) and Iqbal *et al.* (2022) which focused on the Saudi population, also identified the ^{1} MCI $^{1-2-1}$ configuration as the second most prevalent, though with a lower prevalence of 13 %.

Karobari *et al*. (2020) reported the highest prevalence of configuration [1] MLI [1-2-1], accounting for 51.1 % of the Malaysian population, followed by configuration [1] MLI [1-1] at 44.9 %. However, in other populations studied, the [1] MLI [1-1] configuration was the most common, exceeding 66.1 %. These results align with studies using the Vertucci classification, which reported similar findings in a Brazilian population (58 %) and a French population (86.4 %). In Latin America, research by Villa *et al*. (2022) examined the morphology of MI root canals in a Brazilian region under the Ahmed *et al*. (2017) classification. They found that the [1] MI [1-1] configuration was the most prevalent at 52.1 %, followed by the [1] MI [1-2-1] configuration at 20 %. However, this study utilized Micro-CT. To date, no studies in Latin America has examined the canal morphology of MIs using CBCT according to the Ahmed *et al*. (2017) classification.

CONCLUSION

The [1] MI [1-1] configuration is the most predominant in MI; despite the existence of complex morphologies, there is a high frequency of second canals. The proposed classification system aims to offer an easy-to-use, precise, and practical method for categorizing root and root canal structures. It delivers comprehensive details on the tooth's identification, root count, and types of root canal configurations, while deliberately excluding developmental anomalies and minor canal anatomy. This approach enhances simplicity and encourages widespread adoption among students, dental professionals, and researchers. However, more studies are needed in different populations using the Ahmed *et al*. (2017) classification in MI to record and understand the morphological diversity of these teeth in other populations.

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SAA, C.; MATUS, D. & BETANCOURT, P. Análisis morfológico de los incisivos mandibulares mediante el sistema de clasificación de Ahmed. Revisión bibliográfica. *Int. J. Morphol., 43(1)*:269-274, 2025.

RESUMEN: Los dientes incisivos mandibulares (IM) son especialmente complejos de tratar endodonticamente debido a sus limitadas dimensiones. Además, la falta de conocimiento sobre la amplia variación morfológica presente en este grupo dentario puede contribuir en el fracaso del tratamiento endodóntico. Una de las clasificaciones más recientes para el estudio morfológico del sistema de canales radiculares (RCS) fue propuesta por Ahmed *et al*. (2017). Esta clasificación aborda y supera las limitaciones encontradas en la ampliamente utilizada clasificación de Vertucci (1984). El objetivo de este artículo fue determinar a través de un análisis de la literatura científica cuál es la morfología más prevalente en incisivos centrales mandibulares (ICM) e incisivos laterales mandibulares (ILM) mediante el uso de tomografía computarizada de haz cónico (CBCT) y empleando la clasificación de Ahmed *et al*. (2017). Se realizó una revisión de la literatura utilizando distintas bases de datos PUBMED, LILACS, SciELO, SCOPUS y EMBASE, considerando artículos sin restricción de años de publicación, realizados en seres humanos y publicados en idioma Inglés y Castellano. Se incluyeron 5 artículos atingentes al objetivo del estudio. La configuración 1 IM 1-1 es la más predominantemente en los incisivos mandibulares, aunque se ha observado una considerable presencia de morfologías complejas, existiendo la aparición frecuente de segundos canales. El sistema de clasificación de Ahmed *et al*. (2017) plantea un método práctico, preciso y fácil de usar para categorizar las estructuras de las raíces y los conductos radiculares.

PALABRAS CLAVE: Incisivos mandibulares, Sistema de canales radiculares, clasificación de Ahmed, Tomografía computarizada de haz cónico, Endodoncia.

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