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Anatomical features of the mandibular canal and their clinical significance — review of literature

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Abstract: The clinical issues related to the anatomical variation of the mandibular canal have been extensively analyzed since the 19th century. Evolving dentistry techniques and advancements in the prosthetics forced to collect detailed information about anatomical variations of the mandibular canal due to its neurovascular content. Therefore, its radiographic imaging became an essential part of the oral surgery, in order to avoid complications resulted from an accidental damage of the mandibular canal.

Keywords: mandibular canal, inferior alveolar canal, mandible.

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Introduction

The mandibular canal, also termed as the inferior alveolar canal or the inferior dental canal, runs bilaterally inside of the mandible. The mandibular canal begins at the mandibular foramen located on the lingual side of the mandibular ramus and terminates on the buccal surface of the mandibular body where the mental foramen opens. Thus, the mandibular canal runs obliquely downward and forward in the mandibular ramus, bends horizontally in the mandibular body where is located close to the alveolar part that contains the tooth sockets (Fig. 1). The trajectory of the canal demonstrates more or less S shaped curve arranged in three anatomical planes [1].

According to Kilic *et al.* [2] observations the mandibular canal is localized approximately 10 mm above the inferior margin of the mandible. Both the length and

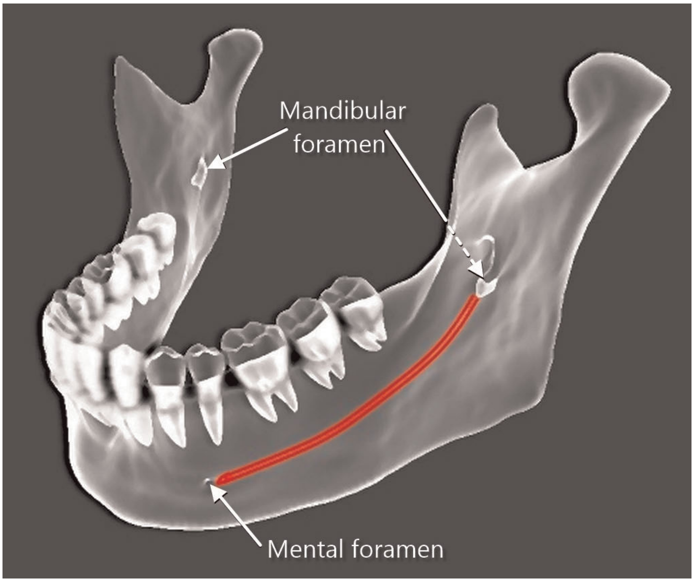

Fig. 1. Schematic representation of the mandibular canal (red line) displayed on the semitransparent 3D model of the mandible (modified and adapted from the original file of the mandible 3D model created by the University of Dundee, School of Dentistry. License: CC Attribution-NonCommercial; downloaded from the https://sketchfab.com/3d-models/).

the width of the mandibular canal appeared to vary across the human population, but the length of the canal seems to be more variable, approximately from 50 mm to 66 mm as measured Komal *et al.* [3], and there was not significant difference in length between sides of the mandible, likewise in the inner diameters of the mandibular canal, which attained smallest values in the region of the 1st premolar (1.7–1.9 mm), whereas the biggest in the region of the 3rd molar (2.3–2.7 mm).

The average width of the mandibular canal ranges from 2.6 to 3.0 mm depending on the measured part of the mandibular canal [4]. According to Ikeda *et al.* [5] the average diameter of the middle part of the mandibular canal was estimated at 3.4 mm. If the mandibular canal splits into two or three separate canals, the average diameter of each canal may vary from 1.27 mm to 2.20 mm, whereas the diameter of main canal can be in order of 4 mm [6].

In turn, Yilmaz *et al.* [7] estimated that overall thickness of the buccal, superior and lingual walls of the mandibular canal estimated for both sexes was 1.05, 1.06 and 0.66 mm, respectively. The buccal wall of the mandibular canal was thicker and denser at females than in males. Furthermore, the buccal and superior walls of the canal were also thicker and denser in the left hemimandible than comparing to the canal traversing the right hemimandible [7].

The wall of the mandibular canal is usually formed by a thin sheath of bone that is trabecular or consists of a thin shell of the compact bone [8]. Iwanaga *et al.* [9] found that the superior wall of the mandibular canal reveals distinct structural patterns which were classified as: trabecular, osteoporotic, dense/irregular, and smooth. According to these authors the structure of the superior wall of the mandibular canal can change following tooth loss. Oshurko *et al.* [10] noted that the structure of the tubular cortical layer of the mandibular canal depends on the bone density and the time of tooth loss leading to bone tissues atrophy. Thereby, a lack of the bony wall of the mandibular canal may occur on the distance from the mandibular foramen to the mental foramen, however the predominant area is near the mental foramen where the mandibular canal splits into several canaliculi forming the incisive canals that run to the incisor teeth [11, 12].

The mandibular canal accommodates the neurovascular bundle composed of the inferior alveolar nerve (a branch of the mandibular nerve) providing somatosensory sensation to the mandibular teeth, and the blood vessels: the inferior alveolar artery (a branch of the maxillary artery) which supplies the mandible and its teeth, and the inferior alveolar vein (a tributary of the pterygoid plexus) which drains the mandible and its teeth. Kilic *et al.* [2] estimated that mean maximum diameter of the inferior alveolar nerve was 1.84 mm, the inferior alveolar artery 0.42 mm, and the inferior alveolar vein 0.58 mm. Besides aforementioned anatomical structures the lymphatic vessels are found inside the mandibular canal.

Up to date the mandibular canal has been the subject of various studies aimed on analysis of its anatomical variation, as well displaying its course inside the mandible using distinct imaging modalities and dissecting techniques performed on the human mandibles [13, 14]. Topographic relationship between the mandibular canal, facial profile, dentition and other neighboring anatomical structures has been a scope of interest of both anatomists and clinicians specialized in the field of dentistry, endodontics and maxillofacial surgery. Thereby, we present a survey of the anatomical variants of the mandibular canal regarding its size, shape, location in the mandible, and relationship with age and sex reported in the past and current medical literature.

Topography and course of the mandibular canal

The detailed course of the mandibular canal has been already described in the 19th century using dissected specimens of the mandibles [8, 15], and revisited in the next century with the aid of the radiographic techniques such as: cone-bean computed tomography (CBCT), pantomographic X-ray, and magnetic resonance imaging (MRI) applied for medical examination of patients afflicted with dental disorders, and mandibular pathologies, as well.

Original studies of Fawcett [8] performed on the dissected dry mandibles provided detailed information about changes of the mandibular canal (termed in his study the inferior dental canal) location along its course through the mandible. He found out that the initial segment of the mandibular canal (first 6 mm of its course) runs close the inner surface of the mandibular ramus, and only a small amount of cancellous bone separates it from the outer wall. The next 8 mm of the canal runs in the middle between both the mandibular walls, then approaches to the outer surface of the mandible, and in the next 4 mm of its course, under the first molar, it runs again in the middle. At the level of the second premolar the mandibular canal inclines outwards, and in a course of approximately 4 mm terminates by bifurcating into the mental and incisive canals.

Later studies, enriched knowledge about the mandibular canals by classifying the variations in the cross-section appearance, pattern of divisions, intramandibular position, regarding the status of dentition, age, sex, ethnicity, and other morphological attributes, e.g. facial types [4, 16–19].

Arrangement of the neurovascular bundle in the mandibular canal

Like the mandibular canal itself, its content was also of interest for anatomists and clinicians. Thereby, numerous experimental studies and radiographic observations were dedicated to imaging and tracing the intramandibular course including the neurovascular bundle, and its topographical relationship to the walls of the mandibular ramus and body [16, 20].

Results of the studies performed by Olivier [21] and published in the year of 1927 indicated that the mandibular canal does not always contain the inferior alveolar nerve and the blood vessels composed as a whole bundle. He found out that 60% of the mandibular canal contained the whole of the inferior alveolar nerve, while in the remaining 40% the branches of the nerve were spread out inside the mandible, and a distinct canal was not present. Later studies performed by Carter and Keen [20] in the year of 1971 confirmed previous observations made by Olivier [21].

Kieser *et al.* [17] found that inferior alveolar nerve predominated in the lower half of the mandible both in males and females, and may run through the mandibular canal as a single unbranched nerve, either gives individual branches to the superior border of the mandible, elsewhere its branches create the nerve plexus in the molar region or build the proximal and distal nerve plexus. If the inferior alveolar nerve exists in the form of a single trunk in the mandibular canal, it lies anteriorly and superiorly to the inferior alveolar artery which runs parallel to the nerve, though the inferior alveolar vein may run above the inferior alveolar nerve in the third molar region as noted Pogrel *et al.* [22]. Moreover, the inferior alveolar vein may be composed of multiple venulae, while the inferior alveolar artery exist as a single vessel [16].

The blood vessels can occupy various locations towards the nerve depending on the place in the mandibular canal. Usually, they are found superiorly to the inferior alveolar nerve and the inferior alveolar artery is located medially to the inferior alveolar vein until they reach the mental foramen [23]. Otherwise, the inferior alveolar artery is located below the inferior alveolar nerve, and the inferior alveolar vein runs superiorly to the artery [16, 24].

Anatomical variation of the mandibular canal

The course of the mandibular canal and its position towards the roots of the inferior teeth may vary across humans, particularly if the individual loses teeth from the mandible, or the mandible changes with age. Different anatomical variants of the mandibular canal may have clinical implications of varying severity. Therefore, the mandibular canal has been the subject of numerous interdisciplinary studies linking anatomy, radiography, and image analysis supported by numerical analysis which allowed for objective classification patterns of the mandibular canals reported from the human populations.

Depending on the intramandibular configuration, the mandibular canals have been classified as: single or duplicated [20]. Another dividing criterion used, is the shape of the lumen of the mandibular canal in cross-section, defined as: oval, round, or pear-shaped [19]. Liu *et al.* [25] proposed classifications of the mandibular canal course based on its appearance in the panoramic radiographs as follows:

- linear curve — the canal presents approximately a straight line
- elliptic-arc curve — the canal is approximately symmetrical
- spoon-shaped curve — the canal is similar to an asymmetric elliptic arc (resembles spoon)
- turning curve — the canal shows unsmooth course with turning points.

The mandibular canal is usually a single structure, however multiple mandibular canals have been also reported. Duplication of the mandibular canal seems to be common variant observed in humans. Such canals may originate from a single foramen or from two separate mandibular foramina, and further run separately inside the mandible, traversing upper or lower part of mandibular ramus. Thereby, various classifications of the mandibular canals have been formulated according to the their trajectories, pattern of division, either relationship to the dental roots [26].

Nortjé *et al.* [18] classified the position of the mandibular canal in the following way:

- high mandibular canal 'touching' the apices of the roots of the second permanent molar
- high mandibular canal within 2 mm of the apices of the roots of the 2nd permanent molar
- intermediate mandibular canal
- low mandibular canal.

Additionally, the cases of mandibular canal duplication were classified into two types: the first one — both canals are of an approximately similar size or the lower canal is much smaller than the upper one, and the second — a double canal with supplemental canal extending towards the 2nd permanent molar or extending to the 3rd molar tooth.

The bifid mandibular canals — prevalence and classification

A bifid mandibular canal characterizes division of the native canal into two separate parts which may occur along its course between the mandibular and mental foramina. This anatomical term comes from the year of 1973 when Patterson and Funke described smaller branches running along the main conduit commonly known as the mandibular canal [27].

Iwanaga *et al.* [28] compared different ways of classification bifid and trifid mandibular canals. They found that the bifid mandibular canal is an additional canal running parallel to the mandibular canal with or without a confluence with the main canal.

Fuentes *et al.* [29] described variety of the bifid canals regarding their intramandibular locations. Hence, unilateral or bilateral occurrence of the bifid or duplicated mandibular canal was the subject of the anatomo-clinical and retrospective studies performed in various human populations [30, 31]. The bifid mandibular canals exist rarely, and their occurrence range from 0.08% to 0.95% [18, 26]. Though, reported prevalence of the bifid canals depends on the material used and image modality (dental panoramic radiography or CBCT), and applied classification system of the encountered accessory canals inside the mandible. Therefore, reported prevalence of the bifid mandibular canal may range from 0.08 to 65% [30, 32, 33], and the bifurcation of the canal may appear as a common anatomical feature without obvious predilection to gender [6, 34]. Although, previous studies yielded information about slightly higher prevalence of the bifid canal in females but the difference between sexes was not significant [35, 36]. On the contrary, other studies provided evidence of a higher prevalence of the bifid canal in males [37, 38].

Taking into account the classification proposed by Langlais *et al.* [26], following combinations of the bifid mandibular canals can exist both unilaterally and bilaterally. Some of them extend from the 3rd molar or surrounding area, the others are limited to the mandibular ramus, elsewhere extend to the mandibular body. Other variants (subtypes) of the bifid mandibular canals have been also identified, and termed as double canal and trifid canal. Therefore, a terminological distinction between the bifid mandibular canal and double mandibular canal should be noted. The issues related to the various configurations of the mandibular canal illustrates Fig. 2.

The bifid canal is separated by a cleft into two branches which further may join together into a single canal (with a confluence) or the canal is split into two separate branches which run further as independent canals (without a confluence). Both variants

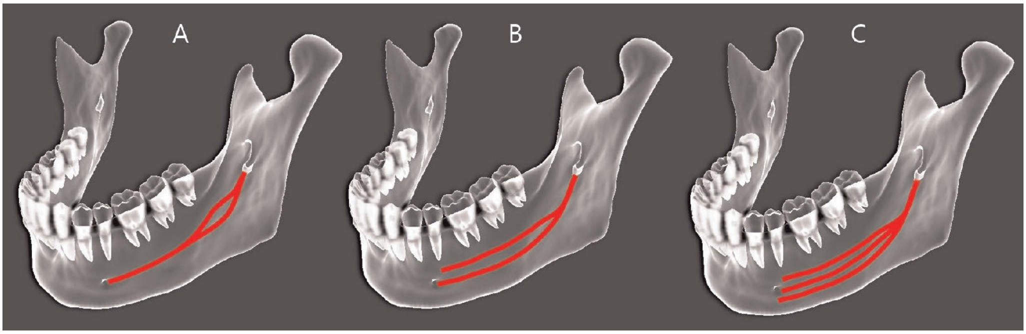

Fig. 2. Schematic representation of the accessory mandibular canals: A — bifid (with a confluence), B — bifid (double without a confluence), and C — trifid displayed on the semitransparent 3D model of the mandible (modified and adapted from the original file of the mandible 3D model created by the University of Dundee, School of Dentistry. License: CC Attribution-NonCommercial; downloaded from the https://sketchfab.com/3d-models/).

of the bifid canal arise from a single canal which originates from a single mandibular foramen. In contrast, a typical double mandibular canal consists of two separate canals which originate from two distinct mandibular foramina and terminate at two separate mental foramina [39].

Thereby, Naitoh *et al.* [39] distinguished four types of the bifid mandibular canal: 1) retromolar canal (curves out towards the retromolar region); 2) dental canal (terminates at the root apex of the 2nd or 3rd molar); 3) forward canal with/without a confluence to the main mandibular canal (arises from the superior wall of the mandibular canal); and 4) buccolingual canal (arises from the buccal or lingual wall of the mandibular canal).

In a case of trifid mandibular canal, three independent canals may originate from a single mandibular foramen, run as separate canals and terminate at the same or different mental foramina [40]. Additionally, the trifid mandibular canal, may consist of two canals running inside the mandibular ramus and body and a third canal which runs behind the 3rd molar (termed as the retromolar canal). However, there is disagreement among researchers whether the retromolar canal is the actual branch of the mandibular canal or should it be regarded as a separate entity due to different embryological background. Rashsuren *et al.* [6] divided the trifid mandibular canals into 6 types using the classification of the bifid canals defined by Naitoh *et al.* [39], and taking into account number of the mandibular foramina.

Recently, Al-Siweedi *et al.* [41] modified the classification system of the trifid mandibular canals and distinguished 4 main types with 12 subtypes depending on the place of their origin, termination and location in the mandible (relation to the main mandibular canal). The same authors found that trifid mandibular canal occurred more often in females being of age below 50 years. In turn, in males its prevalence was higher among those whose age exceeded 50 years. In their study ethnicity appeared to influence the prevalence of the trifurcation of the mandibular canal regarding subjects taken from Malaysian, Indian, and Chinese population [41].

Effects of age and sex on the mandibular canal variation

The mandibular canal can be recognized at early stages of prenatal development, although in the 4th month of fetal life, the mandibular canal is not yet separated from the alveolus of the germ of the deciduous teeth. Instead of the bony canal, the bony groove exists which accommodates the inferior alveolar nerve and blood vessels. Further development of the mandibular canal occurs in the second half of intrauterine life when the neurovascular bundle is enclosed by a thin-walled bone canal, so that perinatally becomes a distinguishable structure [42]. The mandibular canal increases significantly in size from the 30th gestational week to 12 months of age, relocates laterally and superiorly due to the bone remodeling and growth in the mandibular symphysis, but the curvature of the mandibular canal remains relatively stable during mandibular growth [43, 44]. According to Rashid and Ali [45] in adults being of age between 20 and 49 years parameters of the mandibular canal can be influenced by the sex of the person but are independent of their age. In adults, the mandibular canal runs more or less midway between upper and lower border of the mandible, whereas in the elderly, the mandibular canal runs closer to the alveolar process, just above the level of the mylohyoid line. This is the result of natural modification of the mandibular anatomy and shape related to age changes, such as loss of teeth, as a result of which the alveolar part of the mandible decreases, and the mandibular canal apparently rises upwards [46].

Numerous studies have been conducted to find out a predilection between male and female mandibles to various types of the mandibular canals regarding their locations, branching pattern, and morphometrical features. For instance Al-Shayyab *et al.* [47] besides age and sex, analyzed bone thickness in the regions where the mandibular sagittal split osteotomy is performed. They found out that the regions of the mandibular angle and the area of the mandible mesial to the 2nd molar exhibited sexual dimorphism. Levine *et al.* [48] measured distances from the wall of the mandibular canal to the cortical and buccal surfaces of the mandible, and indicated that the bucco-lingual canal position was associated with age of the individual and its ethnicity.

In turn, Nortjé *et al.* [18] analyzed distribution of various types of the mandibular canal according to age and sex. They found out slight female predilection over male in occurrence of the bilateral single low mandibular canals (50.5% versus 46.5%), but appeared to be meaningless in clinical practice. Similarly, Koç *et al.* [49] did not find significant difference in prevalence and localization of the mandibular canal branching regarding the sex (51.5% at females and 48.5% at males). Regarding the prevalence of the bifid mandibular canals against the gender, Freitas *et al.* [50] did not find statistical difference between females and males (27.1% versus 34.8%).

Clinical implications

Clinical meaning of the intra-mandibular structures rose in the 19th century. Both the text-books dedicated to human descriptive anatomy, as well as those related to the surgical anatomy [15, 51] highlighted close proximity of the roots of lower molars to the mandibular canal, because the neurovascular structures accommodated in this canal may be destroyed if the tooth is extracted (particularly if the roots of third molar enclose the nerve). Also, the growing cysts or tumors in the mandible may erode the bony wall of the mandibular canal, and have a destructive effect on the inferior alveolar nerve and the accompanying blood vessels.

Further information about clinical meaning of the mandibular canal comes from the beginning of the 20th century when Weiser [52] warned against the resection of the root apex of the lower molars which might be dangerous due to close proximity to the mandibular canal, and if the canal has been destroyed the results of such operations could be very severe. Also Witzel [53] recommended verification of the molars and premolars position in relation to the mandibular canal in order to avoid complications a possible surgical intervention such as bleeding caused by tearing the inferior alveolar vessels, along with destruction of the inferior alveolar nerve.

In the year of 1915 Neumann [54] emphasized that precise knowledge of the topography of the intramandibular structures is indispensable in order to perform dental procedures safely. Additionally he claimed that the choice of the appropriate surgical technique, combined with surgical skills allows for the resection of the lower molars without danger to the patient.

Indeed, in later studies attention was paid to the accurate evaluation of the mandibular canal course and its relation to the roots of the teeth, especially in case of accessory canals [55, 56]. Proximity of these structures may be a potential risk factor while performing surgical operations which involve the bony socket for the root of a tooth located in the mandible. Moreover, the tooth extraction can be dangerous if it disrupts the mandibular canal and exposes locally the neuro-vascular bundle running inside. Such circumstances may facilitate the spread of infection along the mandibular canal, and furthermore cause abscesses at the teeth apices. This fact has been already recognized by the 19th century dentists, and described in the anatomy books and clinical reports of that time [15].

In spite of the previous reports, the issue of the relationship between the mandibular teeth and the location of the mandibular canal remained the subject of morphometric studies. Denio *et al.* [57] found that the mandibular canal is the most vulnerable to damage in the area of the 2nd premolar and 2nd molar teeth during root canal treatment because their root apices are located very closely to the wall of the canal at the mean distance of 4.7 mm and 3.7 mm respectively. Similar results were obtained by Rashid and Ali [45], although the measurements were performed on a distinct population (Iraq). The shortest mean distances between superior wall of the mandibular canal and the apex of the root of 2nd molar were in the range of 3.5–4.1 mm, depending on the root position (mesial, distal), and the side of the mandible.

It is noteworthy that disturbances in teeth eruption may influence the topographical relationship between the dental roots and the mandibular canal, hence the actual distances can be altered [17, 58]. Also, tooth loss from the mandible can affect the position of the mandibular canal, which is clearly visible in old age. In the edentulous mandible the mandibular canal may be situated above the level of the mylohyoid line or approaches directly to the alveolar border of the mandible. In case of excessive resorption of the alveolar process of the edentulous mandible part of the mandibular canal running inside the mandibular body may disappear, thereby the inferior alveolar nerve is exposed from the bone and protected only by the soft tissue. Anatomical changes of the mandibular canal followed by neurosensory deficits after removal of the mandibular third molar have been also reported [59]. Therefore, detailed information about the course of the mandibular canal appears to be crucial to avoid injury of the neurovascular bundle located inside the canal, and ensure safe orthognathic surgery when there are indications for performing mandibular osteotomy. For this reason, different imaging techniques were tested to find out the most reliable and accurate method of demonstrating the mandibular canal in living subjects [60].

According to Jung and Cho [61] the mandibular canal is better visible on CBCT images than on panoramic radiographs, and its visibility is lower in the 1st molar region compared to the 2nd and 3rd molar regions. Thus, proper imaging and assessment of the mandibular canal by the means of radiographic techniques is particularly important both in dental surgery and implantology. Clinical implications of this issue have been highlighted by Juodzbalys *et al.* [62], who analyzed the relationship between the location of the inferior alveolar neurovascular bundle towards the alveolar ridge, regarding degree of edentulous alveolar bone atrophy.

Presence of different mandibular canals (retromolar, bifid or trifid) can influence the efficacy of the inferior alveolar nerve block, or may be a cause of failure to achieve complete local anesthesia in dental surgery [63, 64]. Therefore, visual identification of the mandibular canals allows for avoiding or minimizing clinical complications related to accidental damages of the neurovascular structures running through these canals, resulting in paresthesia, hyperesthesia, neuroma, extra bleeding or hematoma formation [31, 65]. This also allows to choose proper method of anesthesia to alleviate pain accompanying surgical treatment, particularly in the case of presence of accessory mandibular canals or their specific location in the mandible [56, 63].

Conclusions

Destruction of the mandibular canal during surgical intervention or dental procedures may render unwanted clinical side effects and complications in healing cavities of the mandible.

An accurate preoperative imaging of the mandibular canal is essential for avoiding collision with the neurovascular content during medical treatment. Thereby, following features of the mandibular canal should be considered in surgical management:

1. Various branching pattern
2. Variable location in the mandible
3. Delicate structure of the wall
4. Close proximity with dental roots
5. Close proximity with the obliterated alveolar process in the edentulous mandible.

Conflict of interest

The authors declare no conflict of interest nor any financial interest associated with the current study.

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