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THE POTENTIAL OF MICROCOMPUTED TOMOGRAPHY IN STUDYING THE VARIANT MORPHOLOGY OF THE DENTAL CANAL-ROOT SYSTEM

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ABSTRACT — High-resolution microfocus computed tomography performed on a Skyscan 1176 (Bruker) device was used to study morphological features of the canal-root systems of the upper jaw first molars in residents of the European part of Russia. An analysis of coronal, axial and sagittal sections of 134 upper jaw first permanent molars removed for medical reasons revealed variations in the canal-root system structure. In 85.8% of the cases, the first upper molars had three separate roots: two vestibular and one palatal; in 14.2% of the cases the roots make up different fusions. The palatal root bent in the buccal direction in 52.9% of the cases, while the mesiobuccal root bent in the distal direction in 87.9% of the cases. The greatest variety of curvatures was observed in the distal-buccal root: towards the mesial side — in 28.3% of the cases, another 21.6% of cases being curved towards the distal side. The palatal root in 90.3% of the cases had one canal; 9.7% of the cases featured two canals, while the distal-buccal root in 73.9% of the cases had one canal, and two canals — in 26.1% of the cases. In 89.6% of the cases, the mesiobuccal root had two canals; in 10.4% of the cases — one canal. The mesiobuccal root of the first upper molars was of an oval shape, elongated in the vestibular-oral direction, the most common structures being those of Type IV (43,3%), II (25.4%), III (8.2%) and VI (7.4%) by F. J. Vertucci. The occurrence rate of extra types of root canal structure was 7.4%.

KEYWORDS — endodont, dental canal-root system, microfocus computed tomography, root canal morphology, upper jaw first molar.

INTRODUCTION

Highly reliable, safe, non-invasive methods of X-ray diagnostics employing computer software allow identifying the patterns of individual variability in the dentoalveolar system [2, 7–11, 14, 20]. Continuous advance in the respective technologies contributes to better scientific understanding of various aspects of maxillofacial clinical anatomy, which is of interest for dentists, maxillofacial surgeons, neurosurgeons, otorhinolaryngologists, ophthalmologists and other specialists [5, 13, 22–24, 31].

Endodontics, as one of the most complex and popular field of modern dentistry, requires clinical specialists to continuously improve their professional knowledge and manual skills. In economically developed EU countries (data source: the European Society of Endodontology, 2005), successful and long-term outcome of endodontic treatment through the initial treatment is achieved in 80%, while its effectiveness implies not only complete absence of clinical symptoms, yet also by X-ray signs of a healthy status in the periapical tissues [3, 32, 35]. The following factors have an effect on the successful outcome through endodontic treatment offered of complicated cases of dental caries: the doctor's qualifications; the technologies employed for diagnostics and treatment; the degree of observing the respective standards and protocols when planning and carrying out medical and diagnostic activities; the variations in the morphological structure of the dental canal-root system [26, 29, 34].

Modern endodontic treatment is a high-tech medical procedure based on new principles of medicine, technology and ergonomics. The need to solve modern problems resulted in the development and implementation of new approaches to mechanical treatment of root canals, irrigation protocols, canal filling technologies, principles of post-endodontic dental restoration, the design of new tools, devices, medicines and filling materials, as well as changes in the endodontics terminology [27, 30].

The molars represent the most complex issue in endodontic treatment, which is accounted for by their remote location in the dental arch, significant structural variations, and frequent observed deviations in the expected number of roots and canals, all this meaning that studying the variant morphology of permanent molars is of fundamental and applied value [1, 21, 28].

In clinical practice, proper understanding of the individual features of the dental canal-root system allows the doctor to calculate the depth of proper

mechanical treatment and the force effect that can be applied to the dental hard tissues, as well as to control the impact on the tooth when moving it through orthodontic treatment [25, 33].

Given their effects of summation, subtraction and projection distortion in the configuration and size, as well as due to the obtained image being 2D, conventional methods of X-ray diagnostics (orthopantomography, radiovisiography) used in endodontics prove effective only in ⅔ of cases offering an opportunity for objective evaluation of the root canal, as well as for correlating them with the status of the periodontium, interalveolar septa and periapical bone tissue [4, 18].

The CBCT method, which features a high resolution and a low radiation stress, offers the following advantages: visualization of 3D dental images with no projection distortion; studying the 3D anatomy of the root canal system in view of individual structural variations; detecting apical pathologies and areas of disturbed integrity in the dental roots; identification of complications in endodontic therapy [12, 19].

Microcomputed tomography (Micro-CT), which allows reproducing 3D microscopic images of the examined object morphology and its inner microstructures at submicron resolution, as well as it allows identifying areas of pathological alteration in tissues, has proven its value — both research-related and applied — in medicine and in dentistry [6, 15–17]. Despite the available research data, there is no information about the variability of the canal-root system structure of the upper jaw first permanent molars in residents of the Russian Federation, which explains the aim of this study.

Aim of study: expanding the understanding of the variant morphology of the canal-root systems in the first upper jaw molars in people residing in the European part of Russia, based on data obtained through microcomputed tomography.

MATERIALS AND METHODS

The X-ray morphological studies were carried out subject to the requirements of the Local Bioethics Committee upon obtaining informed voluntary consent from all the patients. The study implied examining 134 upper jaw first molars extracted due to exacerbated chronic apical periodontitis (103 teeth — 76.9%), marginal periodontitis (21 teeth — 15.7%), and orthodontic indications (10 teeth — 7.4%). The average age of the patients was 35.8±9.7, while the gender was not taken into consideration. The inclusion criteria were: permanent erupted teeth; fully developed roots; closed apical opening; no endodontic dental treatment. The exclusion criteria included the following: external or internal resorption; sealed root canals and tooth cavities; undeveloped apex; artefacts at Micro-CT.

The following morphological features were evaluated: the number of roots; the number of root canals; the root canal configuration (direction, curvatures); fused roots. Since in the first maxillary molar the meso-buccal (MB) root has the most complex anatomical structure and rather a variable morphology, the visualization of the root canal configurations in MB has been systematized in view of F. J. Vertucci's classification (1974) (Fig. 1). Other types of root canal configurations that failed to be attributed to a certain group by F. J. Vertucci (1974) were considered not classified.

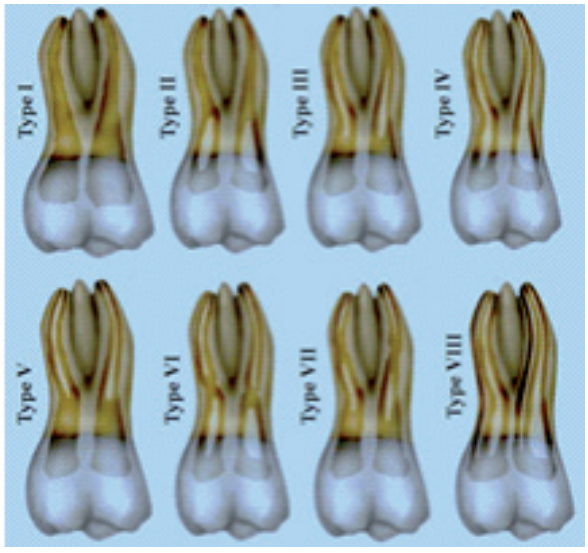

Fig. 1. *The canal configurations (Vertucci F. J., 1974): Type I (1-1) — one root canal and one apical opening; Type II (2-1) — two root canals connecting in the apical one-third part; Type III (1-2-1) — one root canal dividing into two canals, which further merge into one and exit through one apical opening; Type IV (2-2) — two separate root canals ending with two separate apical openings; Type V (1-2) — one root canal that splits as it approaches the apical opening; Type VI (2-1-2) — two root canals that join together and then separate coming closer to the apical opening; Type VII (1-2-1-2) — one root canal that divides, joins together and then opens with two apical openings; Type VIII (3-3) — three separate root canals in one root*

The architecture of the dental canal-root system was assessed through Micro-CT using the SkyScan 1176 microtomograph (Bruker, Belgium). The scanning protocol in the Skyscan 1176 (10.0.0.0, Bruker-microCT) software was as follows: X-ray voltage 90 kV, X-ray current 270 μA, filter Cu 0.1 mm, image

pixel size 8.77 μm, camera resolution setting high (4000-pixel field width), tomographic rotation 180°, rotation step 0.3. The images were reconstructed with the Nrecon (1.7.4.2) software. The spatial orientation as well as selection of individual areas was performed within the Data Viewer (1.5.6.2) software. Data visualization and analysis was performed in the CT-analyzer (1.18.4.0) software. 3D visualization of the obtained results was done with the CTvox (3.3. 0r1403) software (Fig. 2).

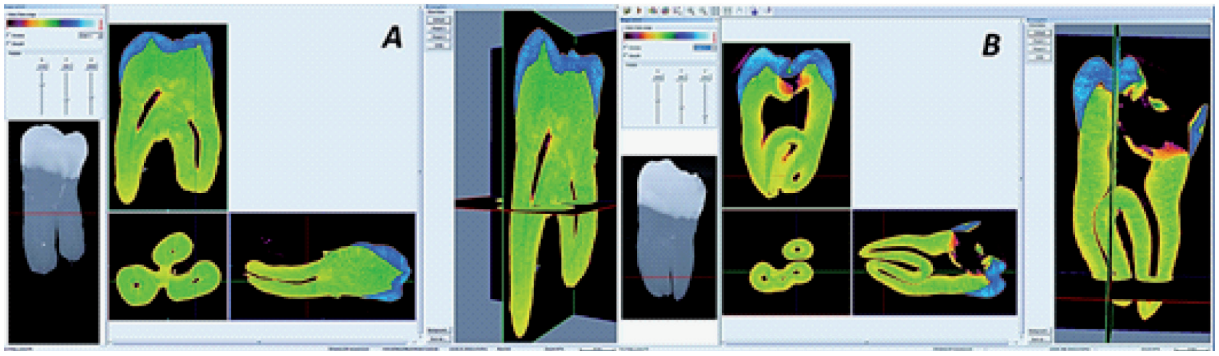

Fig. 2. *A screenshot of reconstructed 2D projections at the level of the lower third of the tooth root in the coronal, axial and sagittal projections (A — the first upper molar with separated roots; B — the first upper molar with fused roots). Pseudo-color maximum intensity (MIP) 2D projection, segmented in order to visualize the root canal morphology subject to the colorimetric optical density scale: enamel — blue-light blue color; dentine, cement — green color; canal-root system — black color*

RESULTS AND DISCUSSION

Taking into account the current data of morphological, clinical and radiological studies, the canal-root system of teeth is a complex formation, including the main canals, additional canals, lateral branches and the apical delta. The system of trunk canals in one root is represented by numerous variants, mainly due to the number and location of canals. According to scientific data, the prevalence of additional canals in different groups of teeth varies from 15 to 98%. The first maxillary molar is the largest tooth featuring a complex root morphology and a variable root-canal system. In 85.8% of cases (n=115), the first maxillary molar has three separate roots: two vestibular (MB – mesiobuccal, DB — distal-buccal) and one palatal (P). The distal-buccal root in 8.9% of cases (n=12) fuses, partially or completely, with the palatal root, while fusion of the mesiobuccal and distal-buccal roots is to be observed in 4.5% of cases (n=6), and the mesiobuccal and palatal roots — in 0.8% of cases (n=1)(Fig.3).

Table 1 shows types of root curvatures of the first maxillary molar.

The palatal root, as the longest one, was curved sharply to the palatal side, had a ribbon-shaped canal, which was wider in the mesio-distal direction, whereas 52.9% of the cases revealed a bent in the buccal direction in the apical third of the root, and in 36.6% of the cases it was straight. The palatal root had one canal in 90.3% of the cases (n=121), and two canals — in 9.7% of the cases (n=13). The significant prevalence of buccal curvature of the palatal root apex (52.9%) is the reason behind the high likelihood of a perforated wall of its root canal at instrumental processing stages. Similar data concerning the palatal root curvature can be seen in the work by J. D. Pecora (1991), who detected a palatine root bent towards the buccal side in 54.6% of the maxillary first molars. The distal-buccal root is of a conical shape and in 41.8% of the cases was straight, or curved towards the tooth axis in the mesial (28.3% of the cases) or in the distal (21.6% of the cases) direction. The distal-buccal root had one canal in 73.9% of the cases (n=99), and two canals in 26.1% of the cases (n=35). The mesiobuccal root was flattened and elongated in the vestibular-oral direction, while the apical part was bent distally in 87.9% of the cases, in another 89.6% of the cases (n=120) it had two canals, and in 10.4% (n=14) — one canal.

The upper jaw first molars erupt when there is a lack of space in the distal parts of the narrow-shaped dental arches at the age of 6–7 years. Given that, the mesiobuccal root is narrow and is elongated in the vestibular-oral direction. In the narrowest part of the fissure-shaped root canal, its mesial and distal walls join (Type IV by Vertucci — 43.3% of the cases; n=58). In the event there is no complete separation of the canals, one canal remains in the apical third of the dental root (Type II by Vertucci — 25.4% of the cases; n=34). In other cases, other structure options develop,

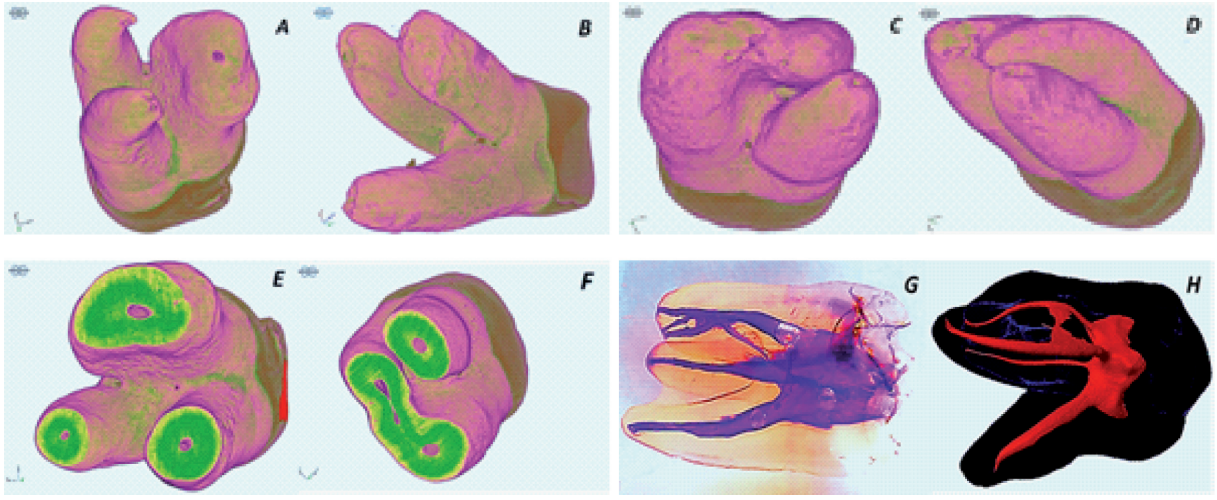

Fig. 3. *3D microtomographic images of variants of the structure of the root system of the first molar of the upper jaw: A, B — the first upper molar with three separate roots; C, D — the first upper molar with accrete roots; E — axial cut at the level of the lower third of the tooth root with separate roots; F — axial cut at the level of the lower third of the tooth root with accrete roots; G — Pseudo-color 2D maximum intensity projection for visualization of root canal configuration; H — 3D volumetric rendering for visualization of the root canal configuration*

Table 1. *Types of root curvature, first maxillary molar, (n = 134)*

Root curvature	Mesiobuccal root		Distal-buccal root		Palatal root	
	Abs., n	Rel., %	Abs., n	Rel., %	Abs., n	Rel., %
Straight	12	8.9	56	41.8	49	36.6
Curved towards cheek	1	0.8	10	7.5	71	52.9
Curved towards palate	1	0.8	1	0.8	3	2.3
Mesial curvature	2	1.6	38	28.3	7	5.3
Distal curvature	118	87.9	29	21.6	4	2.9

including complex systems of intertwining root canals with transversal anastomoses and additional canals (Table 2).

Given the results of studying the apical third of the first upper molar roots, apical openings were identified, which match the exit points of the mainline

Table 2. *Quantitative description of various root canals in the mesiobuccal root of the first upper molar, (Vertucci F. J., 1974), (n = 134)*

Channel configurations (F.J. Vertucci type)	Teeth 1.6, 2.6	
	Abs., n	Rel., %
Type I (1-1)	3	2,3
Type II (2-1)	34	25,4
Type III (1-2-1)	11	8,2
Type IV (2-2)	58	43,3
Type V (1-2)	3	2,3
Type VI (2-1-2)	10	7,4
Type VII (1-2-1-2)	4	2,9
Type VIII (3-3)	1	0,8
Additional configuration types	10	7,4

canals, following the type of root canal configuration, at a distance of no more than 5 mm from the anatomical tip of the dental root. In the mesiobuccal root of the first upper molar, extra openings of the lateral canals (apical delta) were detected in 16.4% of the cases (n=22); in the distal-buccal root — in 6.7% of the cases (n=9); in the palatal root — in 14.2% of the cases (n=19). Evaluation of the root canal types in the mesiobuccal root of the first upper molar revealed that the most common structures were those of Type IV and Type II (by F. J. Vertucci) — 43,3% and 25.4%, respectively. The remaining types accounted for 32 cases (23.9%), while Types III and VI dominated — 8.2% and 7.4%, respectively (Fig. 4).

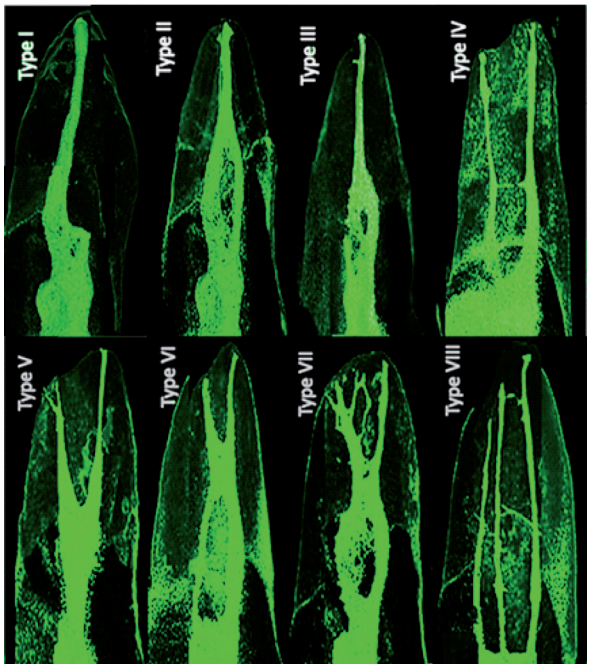

Fig. 4. *3D reconstructed images of eight types of root canal configuration in the mesio-buccal root of the first upper molar according to the Vertucci classification*

Notable is that within the studied sampling, of the mesiobuccal roots of the first upper molar, additional types of root canals were observed in 7.4% of the cases (n=10) (Fig. 5).

The obtained data enhance the clinical and X-ray clinical representation of the canal-root system in the first upper molars, as well as it indicates the diagnostic value of Micro-CT when it comes to identifying additional root canals. Intraoral radiography proved efficient in 8% of the cases only when detecting a second canal in the mesiobuccal root of the first upper molar (mesiobuccal, MB2), whereas the data of clinical studies was reliable in 50% of the cases, CBCT — in 54%, and an operating microscope — in 58% of the cases. The results obtained through Micro-CT (M. Yamada; 2011) prove that in 76.7% of the cases, the mesiobuccal root of the first upper molar contained complex configurations and extra lateral root canals, as well as apical branching.

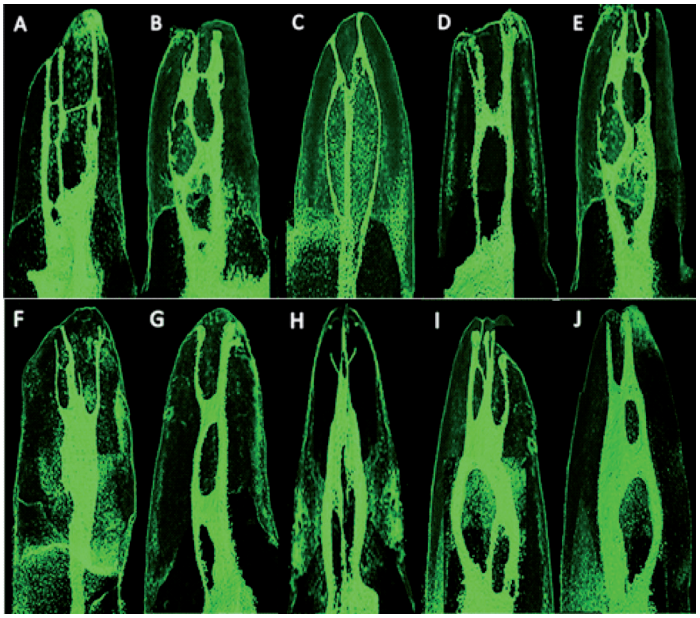

Fig. 5. *3D reconstructed images 10 additional configuration types that are not included in the Vertucci classification (A-J)*

CONCLUSION

1. Microcomputed tomography, taken as a high-tech precision method with a high resolution for visualization, allows obtaining an objective idea of the variant morphology in the dental canal-root systems, in view of quantitative and qualitative indicators with a minimum number of errors. Unlike conventionally accepted methods of X-ray diagnostics, Micro-CT offers a way to design 2D projections of maximum intensity (MIP) and 3D reconstructions of pseudo-color volumetric rendering with minimal sample preparation. Using 3D pseudo-color staining with a colorimetric optical density scale allows visualizing clearly the resorption foci in the dental canal-root systems, the degree of apical openings formation, as well as carious lesions of the tooth root part.

2. An analysis of coronal, axial and sagittal sections of 134 first permanent maxillary molars revealed variations in the canal-root system structure. In 85.8% of the cases, the first upper molars proved to have three separate roots: two vestibular (MB — mesiobuccal; DB — distal-buccal) and one palatal (P), while in

14.2% of the cases, the roots featured different types of fusion. The palatal root bent in the buccal direction in 52.9% of the cases, and the mesiobuccal root had a curvature in the distal direction in 87.9% of the cases. The greatest variety of curvatures was to be found in the distal-buccal root: towards the mesial side — in 28.3% of the cases, with another 21.6% of the cases – towards the distal side.

3. Micro-CT data revealed that in 90.3% of the cases the palatal root had one canal; in 9.7% of the cases — two canals, while the distal-buccal root in 73.9% of the cases had one canal, and in 26.1% of the cases — two canals. As for the mesiobuccal root, it had two canals in 89.6% of the cases, and in 10.4% of the cases — one canal.

4. The mesiobuccal root of the first upper molars was of oval shape, elongated in the vestibular-oral direction, with the most common types of structure belonging to Types IV (43,3%), II (25.4%), III (8.2%) and VI (7.4%) (by F. J. Vertucci). The occurrence of extra root canal configurations was 7,4%.

5. Micro-CT, as a non-invasive, highly reliable method of 3D X-ray diagnostics, given its capacity to identify a detailed microanatomy of the dental canal-root system, allows identifying the number, direction and degree of the root curvature, the root canal configuration, the degree of their patency, as well as the number and localization of secondary canals and transversal anastomoses, which is required for improving instrumental treatment and effective obturation of the dental root-canal system.

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