UNDERFILLED ROOT CANAL AS A FACTOR AFFECTING THE PERIAPICAL STATUS

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Abstract. Pulp diseases treatment may lead to complications, such as the development of apical periodontitis registered with the help of X-ray examination. At the same time, a dentist might provide endodontic treatment associated with apical periodontitis in case there are relevant X-ray changes. In both cases, the periapical status follow-up is required for causality assessment. CBCT data of 2915 endodontically treated teeth were studied assessing the distance from the X-ray root apex to the root filling, as well as assessing the periapical status and tracing the relation between those. It is least probable to detect periapical changes if the length of the root canal filling is 0–1 mm from the X-ray apex, more probable within the length of 1–2 mm, and most probable within the level of over 1 mm and 2 mm, correspondingly. An individual approach excludes the strategy of 'indication — contra-indication' related to the length of the root canal filling showing no ground to assess it as a success criterion for endodontic treatment or as an indication for retreatment regardless of the clinical case. In many situations, if there are no clinical signs of unsuccessful endodontic treatment, the periapical tissues follow-up strategy is well-grounded.

Keywords: root canal, periapical disease, periapical changes, periapical status, length of root canal filling, endodontic treatment, prognosis.

List of Abbreviations

CBCT – cone beam computer tomography

Introduction

Traditionally, analysis of the length of the root canal filling according to the X-ray data research is a major criterion associated with successful endodontic treatment. Assessment of the root canal obturation quality comes from the base of this information, immediately after endodontic treatment and in the follow-up process. Apical level of the root filling is the most often-used characteristic of the root filling. Based on this measurement, clinical decisions are made regarding the volume of additional studies and the choice of a treatment strategy for a particular tooth. This information is particularly relevant when a doctor considers providing endodontic retreatment when an insufficient length of the root filling motivates re-intervention. The popularity of this approach leads to undue simplification of a clinical situation and forms a prejudiced relation to periapical status assessment. In many cases, it may cause unfounded clinical decisions in the form of choice of active treatment options (Ørstavik & Pitt, 2008; Morgental *et al.*, 2012).

Cone beam computer tomography (CBCT) is an X-ray examination method that has revolutionised dental endodontic practice due to its high diagnostic value for assessing the structure of the root system and finding periapical changes; also, it does not have spatial distortions (Christiansen *et al.*, 2009; Patel *et al.*, 2012; Abuabara *et al.*, 2013; Fernández *et al.*, 2013; Davies *et al.*, 2015; Davies *et al.*, 2016; Uraba *et al.*, 2016; Yilmaz *et al.*, 2017). Thereby, the impact assessment of known predictors on the endodontic treatment outcome is becoming especially relevant and useful for clinicians. It really can become the basis for suggesting new dental hypotheses.

The goal of this research is to reveal causation between the length of the root canal filling and periapical status.

Materials and Methods

CT scans of 500 patients were studied (209 male patients, 291 female patients). The age range of the patients was 13–82 years old (average age is 42 years old). The CTs were randomly chosen from the Sadko Dental Clinic data base (Nizhny Novgorod, Russia) formed due to the referral of the patients to CBCT examination by dentists, maxillofacial surgeons and otorhinolaryngologists.

Inclusion and exclusion criteria in the current study were: the field of study including both maxilla and mandible teeth rows; the presence of at least one endodontically treated tooth; the choice preference to the earliest CT in case of several X-ray examinations of one patient.

The case identification was performed using the patient's full name, scan ID. The CBCT scans were done with Pax-Rev 3D and Pax-i3D Smart (Vatech) machines. CBCT scans' visualisation went through Easy Dent V4 Viewer Software. To provide a better picture such instruments as 'magnifying lens', 'contrast', 'hardness filter', 'ruler' were used; in unclear cases the instrument 'histogram' was applied to compare the bone density (following the grey scale) in the periapical area with the nearest healthy spongeous bone density.

Ultimately, 2915 teeth (100%) after endodontic treatment were studied.

Homogeneity and marginal fit assessment were not done because of the low CBCT diagnostic value for these criteria (18, 19). Length of the root filling was assessed by the following criteria: the finish of the root filling within the distance of 0–2 mm from the X-ray tooth root apex; finish of the root filling at the distance of more than 2mm from the X-ray tooth root apex; finish of the root filling within the distance of 0–1 mm from the X-ray tooth apex.

The periapical status was assessed by the following parameters: absence of the visible changes in the periodont; widening of the periodontal gap (double thickening relative to the bordering areas of the periodontal gap); periapical lesion site; local mucous thickening in the maxillary antrum in the projection of the studied tooth roots in cases when with the X-ray the bone tissue was not detected periapically; large destruction site – the destruction site involving not only the periapical area but also the furcation areas and interdental areas of the alveolar ridge, including the presence of bone pockets, postoperative condition.

If more than one canal were defined in the root and the spread of the periapical changes did not make it possible to associate them with the specific canal, then all the canals were associated with the site. Teeth without fillings or teeth with the typical root fracture signs were documented separately. The condition and the quality of the restorations were not registered because of the low CBCT diagnostic value for the assessment of the marginal fit quality and other restoration parameters that contribute to the success of the endodontic treatment (because of the 'filling defect' like artefact). The data were statistically processed with the contingency table from the site https://medstatistic.ru.

Results

Root filling of 1922 teeth (65,9%) ended within 0–2 mm from the X-ray apex, overall 3515 canals (group A). A combination of such root canals with periapical changes was mentioned in 307 cases (8,7) in conversion to root canals (Table 1).

987 teeth (33,9) were detected with a root filling ending within the distance of over 1 mm from the X-ray root apex, 1727 canals overall (group B1). The combination of these root canals with periapical changes was mentioned in 624 cases (36,2%) in conversion to root canals. In this group, the following options of periapical status can be highlighted: without changes in periodontium – 1098, expansion of periodontal fissure – 26, extensive site of destruction – 16, local thickening of the maxillary sinus mucosa (bone tissue around the root apex was not defined by X-ray) – 8, sinusitis – 7.

From 1727 unfilled root canals with the length of the root canal filling of over 1 mm from the X-ray apex (group B1) the following combinations were detected with such periapical tissues condition: without changes in periodontium – 954, expansion of periodontal fissure – 19, (destruction of bone tissue with periodontal changes), extensive destruction of bone tissue – 12, local thickening of maxillary

Table 1

Distribution of researched materials into groups with reference to the distance from X-ray root apex to the root filling

Group	Distance from X-ray root apex to the root filling	Amount of cases (filling canals)
A1	0–1 mm	3315
A2	0–2 mm	3533
A3	1–2 mm	218
B1	> 1 mm	1727
B2	> 2 mm	1499

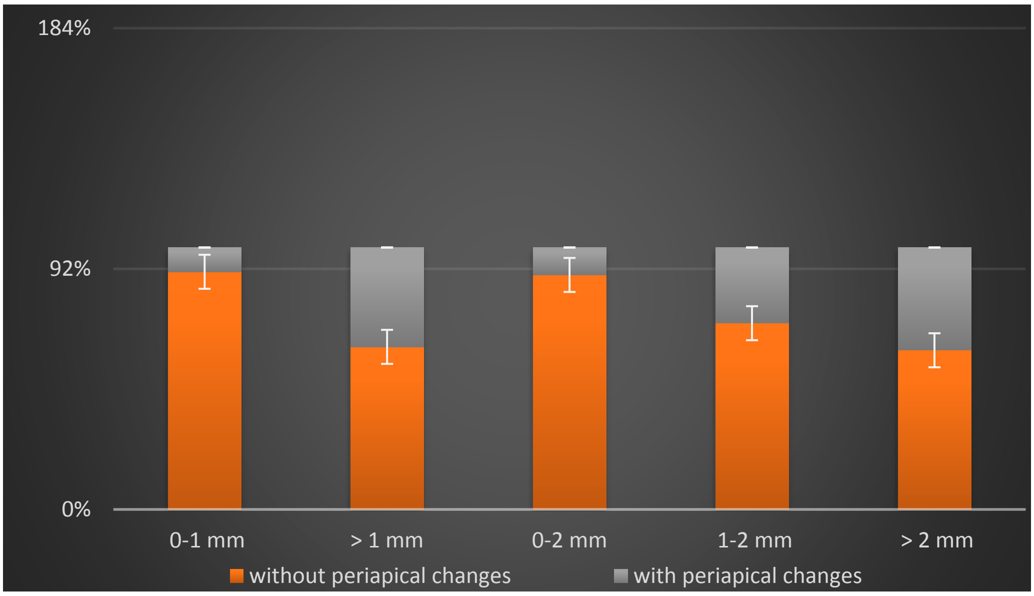

Fig. 1. Level of the root filling (distance from the X-ray root apex to the root filling) and periapical roentgenologic status (‘disease' – periapical changes)

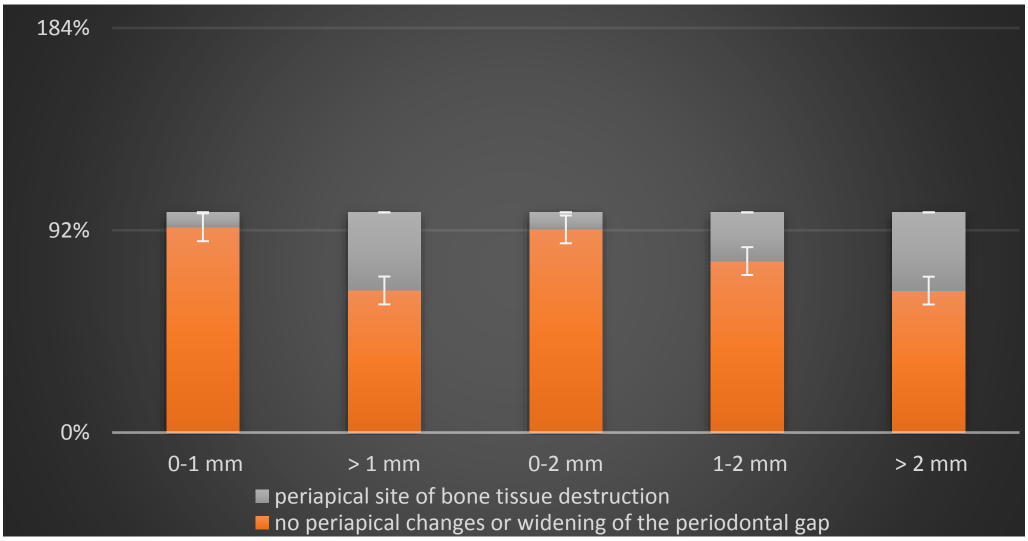

Fig. 2. Level of the root filling (distance from roentgenologic apex of the tooth root to the root filling) and periapical roentgenologic status (‘disease’ — site of bone tissue destruction)

Table 2

Criteria for assessing the significance of outcome differences depending on the impact of the risk factor

	Outcome is periapical changes						**Outcome is periapical site of destruction**					
	A1 and B1		**A2 and B2**		**A1 and A3**		**A1 and B1**		**A2 and B2**		**A1 and A3**	
Name of criterion	**Criterion value**	**Value level**	**Criterion value**	**Value level**	**Criterion value**	**Value level**	**Criterion value**	**Value level**	**Criterion value**	**Value level**	**Criterion value**	**Value level**
Chi-squared test	604.339	< 0,001	566.416	< 0,001	84.136	< 0,001	664.568	< 0,001	596.697	< 0,001	67.139	< 0,001
Chi-squared test with Yates continuity correction	602.484	< 0,001	564.555	< 0,001	82.055	< 0,001	662.493	< 0,001	594.629	< 0,001	65.006	< 0,001
Verisimilitude-corrected Chi-squared test	576.691	< 0,001	523.781	< 0,001	61.837	< 0,001	633.011	< 0,001	545.235	< 0,001	47.947	< 0,001
Minimal value of expected result	*329.51*		*287.91*		*22.83*		*280.01*		*235.74*		*16.78*	
Criteria of efficacy connection assessment between risk factor and outcome												
Name of criterion	**Criterion value**	**Connection***	**Criterion value**	**Connection***	**Criterion value**	**Connection***	**Criterion value**	**Connection***	**Criterion value**	**Connection***	**Criterion value**	**Connection***
Criterion φ Cramer's Criteria *V* Chuprov's Criteria *K* **	0.346	middle	0.366	middle	0.154	weak	0.366	middle	0.347	middle	0.139	weak
Pearson's Contingency Coefficient (C)	0.327	middle	0.344	middle	0.153	weak	0.344	middle	0.327	middle	0.137	weak
Pearson's regulation value coefficient (C')	0.463	relatively strong	0.486	relatively strong	0.216	middle	0.486	relatively strong	0.463	relatively strong	0.194	weak

Note:
* — interpretation of getting statistical criteria value according to Rea & Parker recommendations
** — all the three criteria (φ, Cramer's, Chuprov's) get the same value for statistics fourfold table used in this calculator

sinus mucosa (bone tissue around apex of the root was not defined by the X-ray) – 6, sinusitis – 7. Teeth without filling or kept as separated roots were singled out. 29 canals overall, with sites of bone tissue destruction – 13, widening of periodontal fissure – 1.

From 1727 unfilled root canals, 197 canals had a length of the root canal filling within 1–2 mm (group A3). From 197 researched canals, combinations with the following condition of periodontitis tissue were singled out: absence of changes in periodontium – 141, destruction of bone tissue – 47, widening of periodontal fissure – 9. As a result, periapical changes were present in 70 cases (28,4%). Provided that the widening of periodontal fissure is not an unfavorable outcome (failure) of treatment, an unsuccessful outcome was mentioned in 47 cases.

If we refer the cases displaying the length of the root canal filling of over 2 mm from the X-ray apex (group B2) to the group of unfilled canals, the amount of root canals equals to 1499. From this number, the following combinations with periodont tissue conditions were explored: absence of changes in periodontium – 144, destruction of bone tissue – 37, extension of periodontal fissure – 17, extensive destruction of bone tissue – 4, local thickening of maxillary sinus mucosa – 2.

The A1 group is highlighted by the teeth missing a filling or kept in the form of separate roots – 13, fracture of the root – 6, combinations with periodontal site – 15, condition after an operation – 2. Periodontal changes (laterally derived) from the X-ray teeth apex and the root filling endings 27 should be singled out – 27. These canals had combinations with periapical changes in 36,7% of cases (Fig. 1, 2).

Comparison of groups with optimal level of root filling (group A1, A2) with groups with suboptimal level of root filling (B1, B2), as well as groups A1 and A3 was carried out for each specific outcome (periapical changes and apical focus of destruction) separately (Table 2).

A statistically significant ($p < 0.001$) difference between all the compared groups was revealed. At the same time, the strength of the relationship between the risk factor and the outcome in the compared groups A1 and B1, A2 and B2 was estimated as average or relatively strong (depending on the selected statistical criterion) regardless of a certain outcome. When assessing the strength of the risk factor connection in the compared groups A1 and A3, for a certain outcome «periapical changes», the strength was assessed as weak or medium (depending on the selected statistical criterion), and for a certain outcome «apical focus of destruction» it was assessed as weak.

Discussion

The study design allows to disclose a correlation between the length of the root canal filling and periapical status but does not allow to set a cause-effect connection between them, or to draw a conclusion about the extension of periapical changes or frequency of different lengths of the root canal filling' prevalence. On the one hand, treatment of pulp diseases may lead to the progression of apical periodontitis as a complication registered at an X-ray examination. On the other hand, endodontic treatment may be provided in connection with apical periodontitis if there are relative roentgenologic changes. In both cases, it is necessary to consider periapical status changes in dynamics.

The outlined results demonstrate statistically valuable ($p < 0,001$) differences of periapical status in different lengths of the root canal filling relative to the roentgenologic apex of the root: level 0–1 mm and > 1 mm, also 0–2 mm and > 2 mm, 0-1 mm and 1–2 mm. In connection with this, we cannot deny the importance of determining an optimal 'working' length of the canal and assessing the length of the root filling while researching the tooth status after endodontic treatment. A connection between the length of the root canal filling and the periapical status can be statistically estimated as weak, middle or relatively strong. The paradigm of modern endodontic treatment determines one reason leading to and supporting apical periodontitis – sufficient pathogen presence in root canals and/or in periapical tissues (Ricucci & Siqueira, 2015). The absence of an unambiguously settled correlation can be explained by the absence of a straight connection between the length of the root canal filling and pathogen presence in the tooth and periapical tissues. It is required to make allowance for CBCT limitations when other obturation quality criteria are estimated (homogeneity, marginal seal), as well as for the inability to clinically define the apical limit for the root canal preparation and root canal medicated preparation efficacy. Moreover, there is no possibility to unambiguously interpret an X-ray picture as an identical histologic status.

Assessing periapical changes composes separate methodic difficulties. Relevant researches demonstrate that CBCT can be regarded as an almost 'golden standard' for the detection of periapical changes (Christiansen *et al.*, 2009; Patel *et al.*, 2012; Demiralp *et al.*, 2012; Fernández *et al.*, 2013; Davies *et al.*, 2015; Davies *et al.*, 2016; Uraba *et al.*, 2016).

At the same time, its presence does not say anything about the histologic nature of X-ray discoveries which is wrongly interpreted in several scientific researches as the overall low accuracy of the CBCT method (Kruse *et al.*, 2017). The most disputable question is estimating such a periapical status, as periodontal fissure expansion which leads to a doubtful outcome, as said in various sources (Strindberg, 1956; Chugal *et al.*, 2001). However, researching the results using a histologic verification pattern from X-ray detected sites of bone tissue destruction brings more uncertainty (Çalışkan *et al.*, 2016; Kruse *et al.*, 2017, Alotaibi *et al.*, 2020; Kharat *et al.*, 2020; Krishna *et al.*, 2020). Several studies demonstrate a significant amount of cases where periapical tissues regenerate by defect substitution, while an X-ray examination defines it as unsuccessful endodontic treatment (Molven *et al.*, 1991; Maddalone & Gagliani, 2003; Kruse *et al.*, 2017). That is why, one shall not consider the periapical lesion sites identical to different forms of periapical inflammatory processes. Moreover, there are no X-ray signs (including the size of a periapical site) being pathognomic for setting the character of pathologic periapical changes.

When specialists estimate the root filling length, they face various problems indeterminable in clinical practice. For instance, to orient in the formation of the canal's apical part, such terms as 'physiologic tooth apex', 'anatomic tooth apex' and 'apical constriction' are used. It shall be noted that a dentino-cemental junction of the root apex can be found at essentially different levels from the chosen coronal orienting point along with its diameter, making it reasonable to speak of apical constriction (Hulsmann & Schaefer, 2009; Ricucci & Siqueira, 2015). In clinical practice the location of orienting points cannot be determined accurately. An apex-locator has high accuracy in defining the physiologic tooth root apex (apical constriction) (Janner *et al.*, 2011; de Morais *et al.*, 2016; Amin *et al.*, 2019). However, in many cases of apical periodontitis, resorption of the apical canal inner walls occurs, while the constriction disappears (Hulsmann & Schaefer, 2009). A lot of sources suggest using the term 'X-ray tooth apex' as a landmark (Hulsmann & Schaefer, 2009; Connert *et al.*, 2014; Ricucci & Siqueira, 2015). In reality, it is a point that can be used in clinical practice (but only paired with apex-locator data). Using this landmark separately is unreasonable due to the spatial distortion accompanying intraoral radiography, as well as the low reproducibility of the study and insufficient sensitivity to the location of the anatomical root apex (Rogatskin & Ginali, 2007; Cheng *et al.*, 2011; Arzhantsev, 2016). A 'working' intraoral X-ray (radiovisiographic) photogram is traditionally used in dentistry as a method of working length verification. Its usage is possible to solve clinical cases allowing for several limitations of such an approach. Intraoral X-ray radiography always has spatial distortions leading to incorrect results of the length of the root canal filling detection (Arzhantsev, 2016). It is assumed that decreasing that impact is possible with the usage of a parallel technique. However, it cannot be used in all cases because of individual anatomic features. Moreover, using a parallel technique saves the size distortion, yet increases proportionally the examined object. The advantage of using a parallel technique is called into question for researching teeth with multiple canals because of root divergence in different areas (Rogatskin & Ginali, 2007). Russian literature considers periapical radiography in oblique projections as the best diagnostic value of a 'working radiography' with instruments (Arzhantsev, 2016). Studies comparing the length of the root canal filling by periapical radiography data and CBCT data demonstrate that the results match only in 70% of cases (Cheng *et al.*, 2011).

Studies dedicated to the detection of the length of the root canal filling correlate its optimal limit with the physiologic apex or anatomic apex of the tooth root. Thus, based on the radiological apex position, an important logical step is skipped in establishing the optimal border of the root filling. Such an approach, based on average anatomical calculation, settles a conventional diapason of the distance from the radiological apex and does not make allowance for the physiologic or anatomical variability dentition of the tooth apex (Estrela et al., 2018). In Russian literature, such diapason is usually settled on the length of 0.5–1.5 mm; in foreign literature – on the length 0–2 mm. A statistically averaged approach is based on excessive simplification and does not allow to choose a perfect clinical orientating point (Ricucci & Siqueira, 2015).

Conclusion

The lowest probability of detecting periapical changes was found with the level of the root filling ranging between 0–1 mm from the radiological apex; the middle – between 1–2 mm; the highest probability was found if the level was over 1 mm and more than 2, correspondingly. The connection between the obturation of the root canal and the quality of its mechanical and medicated teeth preparation could be observed, however, there was no unambiguously defined correlation between these two factors. X-ray assessment criteria combinations, which included homogeneity obturation and marginal fit of dental restorative material to the root canal walls, might have a stronger connection with the presence of radiological periapical changes. However, CBCT sensitivity was low for that canal obturation criteria. The individual approach with a strategy of ‘indication – contra-indication’ stayed proofless for the length of root canal filling: there were no foundations to assess the length of the root canal filling as a criterion of quality (successful) endodontic treatment or an indication for retreatment regardless of the clinical situation context. In many cases, the absence of clinical signs indicating ineffectual endodontic treatment justified the follow-up strategy for periapical tissues.

References

ABUABARA A. BARATTO-FILHO F., AGUIAR ANELE J., LEONARDI D.P. & SOUSA NETO M.D. (2013): Efficacy of clinical and radiological methods to identify second mesiobuccal canals in maxillary first molars. *Acta Odontol Scand*. **71**(1), 205–209.

ALOTAIBI O., ALSWAYYED S., ALSHAGROUD R. & ALSHEDDI M. (2020): Evaluation of concordance between clinical and histopathological diagnoses in periapical lesions of endodontic origin. *J Dent Sci.* **15**(2), 132–135.

AMIN J., LINES J., MILOSEVIC M.P., PARK A. & SHOLAPURKAR A. (2019): Comparison of Accuracy and Reliability of Working Length Determination Using Cone Beam Computed Tomography and Electronic Apex Locator: A Systematic Review. *J Contemp Dent Pract*. **20**(9), 1118–1123.

ARZHANTSEV A. P. (2016): *Radiological studies in dentistry and maxillofacial surgery.* Moscow: Geotar-Media, 320 pp.

CALISKAN M.K., KAVAL M.E., TEKIN U. & UNAL T. (2016): Radiographic and histological evaluation of persistent periapical lesions associated with endodontic failures after apical microsurgery. *Int Endod J.* **49**(11), 1011–1019.

CHENG L., ZHANG R., YU X., TIAN Y., WANG H., ZHENG G. & HU T. (2011): A comparative analysis of periapical radiography and cone-beam computerized tomography for the evaluation of endodontic obturation length. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. **112**(3), 383–389.

CHRISTIANSEN R., KIRKEYANG L.L., GOTFREDSEN E. & WENZEL A. (2009): Periapical radiography and cone beam computed tomography for assessment of the periapical bone defect 1 week and 12 months after root-end resection. *Dentomaxillofac Radiol.* **38**(8), 531–536.

CHUGAL N.M., CLIVE J.M. & SPANGBERG L.S. (2001): A prognostic model for assessment of the outcome of endodontic treatment: Effect of biologic and diagnostic variables. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* **91**(3), 342–52.

CONNERT T., HULBER J.M., GODT A., LOST C. & EL AYOUTI A. (2014): Accuracy of endodontic working length determination using cone beam computed tomography. *Int Endod J*. **47**(7), 698–703.

DAVIDIS A., MANOCCI F., MITCHELL P., ANDIAPPAN M. & PATEL S. (2015): The detection of periapical pathoses in root filled teeth using single and parallax periapical radiographs versus cone beam computed tomography – a clinical study. *Int Endod J*. **48**(6), 582–592.

DAVIES A., MANNOCCI F., MITCHEL P., ANDIAPPAN M. & PATEL S. (2015): The detection of periapical pathoses in root filled teeth using single and parallax periapical radiographs versus cone beam computed tomography - a clinical study. *Int Endod J*. **48**(6), 582–592.

DAVIES A., PATEL S., FOSCHI F., ANDRIAPPAN M., MITCHELL P.J. & MANNOCCI F. (2016): The detection of periapical pathoses using digital periapical radiography and cone beam computed tomography in endodontically retreated teeth - part 2: a 1-year post-treatment follow-up. *Int Endod J*. **49**(7), 623–635.

DE MORAIS A.L., DE ALENCAR A.H., ESTRELA C.R., DECURCIO D.A. & ESTRELA C. (2016): Working length determination using cone-beam computed tomography, periapical radiography and electronic apex locator in teeth with apical periodontitis: A clinical study. *Iran Endod J*. **11**(3), 164–168.

DEMIRALP K.O., KAMBUROGLU K., GUNGOR K. YUKSEL S., DEMIRALP G. & UCOK O. (2012): Assessment of endodontically treated teeth by using different radiographic methods: an ex vivo comparison between CBCT and other radiographic techniques. *Imaging Sci Dent*. **42**(3), 129–137.

ESTRELA C., COUTO G.S., BUENO M.R., BUENO K.G., ESTRELA L. R A, PORTO O.C.L. & DIOGENES A. (2018): Apical Foramen Position in Relation to Proximal Root Surfaces of Human Permanent Teeth Determined by Using a New Cone-beam Computed Tomographic Software. *J Endod*. **44**(11), 1741–1748.

FERNANDEZ R., CAGAVID D. ZAAPATA S.M., ALVAREZ L.G. & RESTREPO F.A. (2013): Impact of three radiographic methods in the outcome of nonsurgical endodontic treatment: a five-year follow-up. *J Endod*. **39**(9), 1097–1103.

HULSMANN M. & SCHAEFER E. (2009): *Problems of endodontics. Prevention, detection and elimination.* Moscow: Dental-Azbuka, 586 pp.

JANNER S.F., JEGER F.B., LUSSI A. & BORNSTEIN M.M. (2011): Precision of endodontic working length measurements: a pilot investigation comparing cone-beam computed tomography scanning with standard measurement techniques. *J Endod*. **37**(8), 1046–1051.

KHARAT N., WAGHMARE P., SARKAR M., NAWAL S., SAHU T. & DHEERAJ M. (2020): Assessment of constant periapical lesions and their connection with endodontic failures after apical microsurgery. *J Pharm Bioallied Sci.* **Suppl. 1,** S233–S237.

KRISHNA R., BHOWMICK S. & JAIN S. (2020): Clinical, radiographic, and histological findings of chronic inflammatory periapical lesions – A clinical study. *J Family Med Prim Care.* **9**(1), 235–238.

KRUSE C., SPIN-NETO R., REIBEL J., WENZEL A. & KIRKEYANG L.L. (2017): Diagnostic validity of periapical radiography and CBCT for assessing periapical lesions that persist after endodontic surgery. *Dentomaxillofac Radiol*. **46**(7), 20170210.

MADDALONE M. *&* GAGLIANI M. *(2003):* Periapical endodontic surgery: a 3-year follow-up study. *Int Endod J.* **36**(3), 193–198.

MOLVEN O., HALSE A. *&* GRUNG B. (*1991*): Surgical management of endodontic failures: indications and treatment results. *Int Dent J.* **41**(1), 33–42.

MORGENTAL R.D., SANTOS R.B., ROSING R.B., CHANIN T.A. & FIGUEIREDO J.A.P. (2012): Interference of partial visual analysis of root filling quality and apical status on retreatment decisions. *J Appl Oral Sci.* **20**(2), 206–211.

ØRSTAVIK D. & PITT F. T. R. (2008): Essential endodontology: Prevention and treatment of apical periodontitis. *Oxford, UK: Blackwell Munksgaard,* 316–346.

PATEL S., WILSON R., DAWOOD A. & MANNOCCI F. (2012): The detection of periapical pathosis using periapical radiography and cone beam computed tomography - part 1: pre-operative status. *Int Endod J.* **45**(8), 702–710.

RICUCCI D., SIQUEIRA J. (2015): *Endodontics. Clinical and biological aspects.* Moscow: Dental-Azbuka, 415 pp.

ROGATSKIN D.V. & GINALI N.V. (2007): *The art of dental radiography.* Moscow: St-book, 146 pp.

SONG D., ZHANG L., ZHOU W., ZHENG Q., DUAN X., ZHOU X., HUANG D. (2017): Comparing cone-beam computed tomography with periapical radiography for assessing root canal obturation in vivo using microsurgical findings as validation. *Dentomaxillofac Radiol*. **46**(5), 20160463.

STRINDBERG L.Z. (1956): The dependence of the results of pulp therapy on certain factors. *Acta Odontol Scand*. **14,** 1–175.

URABA S., EBIHARA A., KOMATSU K., OHBAYASHI N. & OKIJI T. (2016): Ability of Cone-beam Computed Tomography to Detect Periapical Lesions That Were Not Detected by Periapical Radiography: A Retrospective Assessment According to Tooth Group. *J Endod*. **42**(8), 1186–1190.

YILMAZ F., KAMBUROGLU K. & ŞENEL B. (2017): Endodontic Working Length Measurement Using Cone-beam Computed Tomographic Images Obtained at Different Voxel Sizes and Field of Views, Periapical Radiography, and Apex Locator: A Comparative Ex Vivo Study. *J Endod*. **43**(1), 152–156.