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COMPARISON OF THE METHOD OF ELECTROMETRIC DETERMINATION OF ROOT CANAL PARAMETERS AND THE METHOD OF THRESHOLD SEGMENTATION OF RADIOGRAPHS

The **subject matter** of the article is X-ray images of teeth during endodontic operations. The **goal** of the work is to compare the developed method of segmentation of the radiograph to determine the length of the root canal with the electrometric and mathematical methods in practice. The article uses the following **methods**: principles of endodontic preparation of teeth; methods of determining the working length of the root canal (radiological, electrometric); threshold segmentation method; method of segmentation of bone structures on tomographic images. The following **results** were obtained: the existing methods of determining the working length of the root canal were analyzed, the main advantages and disadvantages of each method were highlighted. The mathematical method is fast, but inaccurate and can only serve as a preliminary estimate. Electrometric is the most accurate, but has very strict requirements for measurement in the area of canal moisture, as well as invasiveness of the method has a number of disadvantages. Radiological is the most promising for research because of its painlessness to the patient, low radiation dose during intraoral radiography and the possibility of using image processing algorithms to refine the measurement results. This work formulated principles for segmentation and extraction of tooth contours on the X-ray image to determine working length and conducted practical studies to compare all methods of analysis. **Conclusions.** The application of the electrometric length determination method gives the most accurate result, but the segmentation of the radiograph allows the doctor to obtain additional information about the architectonics of the root canal. As well as the possibility of using image processing such as segmentation, contour extraction and automatic determination of the apical constriction zone make this method the most perspective. The most optimal is the combination of these two methods in practice, which requires additional research.

Keywords: root canal; radiograph; threshold method; segmentation.

Introduction

For root canal treatment, endodontists need to accurately determine the working length of the root canal. This is an extremely important parameter that affects the choice of necessary instruments, surgical techniques and postoperative condition of the patient. Working length is the distance from the external landmark on the crown of the tooth to the zone of apical constriction (narrowing). If the instrument goes beyond the working length, or incomplete filling, these are dangerous situations that lead to complications in the form of post-filling pain, the development of inflammatory and destructive changes in the periodontium, etc.

Among the methods used in medical practice are mathematical (determination of the length, according to tables with average indicators), electrometric (determination of the length using an apex locator) and radiological (using an intraoral X-ray). Analyzing the methods used on the basis of existing publications [1, 2] and their comparative characteristics [3, 4] – it can be concluded that the radiological method of research is less accurate. Due to the non-invasive nature of the method and the development of technologies and equipment,

in particular intraoral visigraphs – this area is becoming necessary for the study of new means of improvement.

The goal of the article is a practical comparison of mathematical, electrometric and radiological methods of searching for the apical construction zone. A key feature of the study is the use of segmentation of the radiological image. This makes it possible to exclude the possibility of a doctor's error in the analysis of the image.

For the electrometric determination of the working length of the root canal, devices are used that determine the impedance using the ratio method and alternating currents of different frequencies. This way it is possible to localize the apical narrowing. This measurement is reliable and stable, but there are cases of differences when working in too wet canals, so sometimes doctors have to dry them. This provides smooth visualization of all processes of the instrument passing in the canal and high accuracy of determining the location of the physiological apex of the root. Nevertheless, visualization in apex locators is only sound, that is, the doctor can get to know the location indirectly. Algorithms of modern electrometric determination of the working length do not combine the data obtained from the radiograph, do not have an extension. Therefore, the development of new

methods and techniques for displaying electrometric data on the radiograph for a more accurate locating of the physiological apex of the root is very important.

Intraoral X-ray is a non-invasive technique that allows you to obtain the necessary information about the direction of the curvature of the root canals and determine the operating length. But the X-ray by its physical properties is not able to reproduce the entire anatomy of the apical part of the root – often there are images layering and distortion. If the X-ray image is used together with the input file, there is a possibility of error in the interpretation of the image, which is associated with the subjectivity of the result by experts. Therefore, it may be inappropriate to be guided only by this method of determining the working length. In this article, the task of comparing the methods of detecting the apical constriction zone in endodontic treatment of teeth was solved. The accuracy of measurements with the apical locator [5] has been practically proved. Therefore, it is taken as a guide. The addition of algorithms for machine image analysis, segmentation of this image and automatic determination of the working length make the method of radiological examination more accurate. Clear research results and their analysis are given in the conclusions.

Electrometric method

In the apical structure, there are three zones: the apex (radiological peak of the tooth root), the large apical hole and the apical constriction (the smallest diameter area of the apical part). The apical constriction zone is recommended as the limit for root canal treatment [6, 7]. The apical constriction often has a complex configuration. The physiological tip is located at a distance of 1.0 mm from the anatomical tip – this is the final working length for the doctor. For an example, look at fig. 1 below.

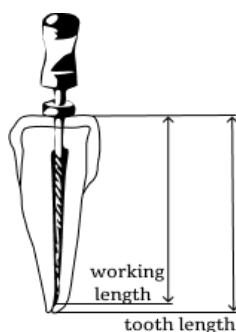


Fig. 1. Definition of the working length

The method of apexology is based on the difference in electrical resistance of tissues. Hard tooth tissues have a higher resistance than the oral mucosa and periodontal tissues. The electrical circuit between the electrodes placed on the lip (lip electrode) and in the root canal (file electrode with calibration stop) remains closed while periodontal tissue reaches the file. In the area of apical narrowing, there is a sharp resistance drop, the circuit closes, and this is fixed by the apex locator [8].

Devices for electrometric detection of the working length of the root canal determine the resistance using alternating currents of different frequencies. Using the ratio method, they allow you to find the general resistance coefficient, indicating the position of the file in the canal (fig. 2).

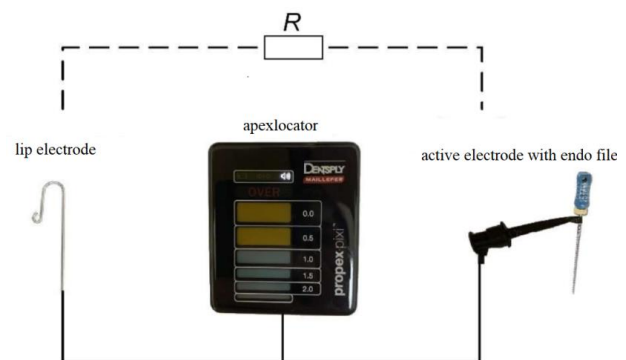


Fig. 2. Schematic of apex locator

This measurement indicates the electrolyte availability in the pulp tissues, it is stable and provides high degree of measurement accuracy. A significant drawback of the method is the requirement to work in comparatively dry canals.

The method of electrometric detection of the root canal length was performed in two stages. The first stage – using the Propex Pixi device [9], the previous working length was determined. In the process of root canal treatment, the diameter is widening and taper is occurring. The second stage – after the final processing of the canal, another measurement was carried out by electrometric method. This value was defined as the final working length of the canal. Pictures of the measurements are given below (fig. 3–4).

The working length was marked with a fixation ring. From the beginning of the working file to the fixing ring, the length can be measured with an endodontic line. The results are recorded in a table and presented in this article.

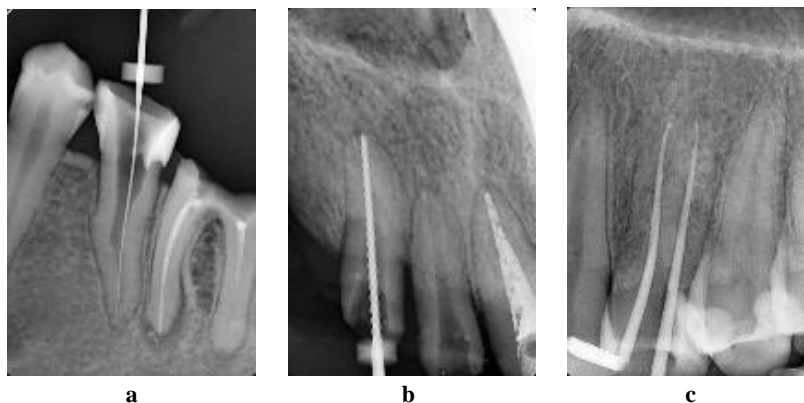


Fig. 3. Tooth image **a** – object №1, **b** – object №2, **c** – object №3

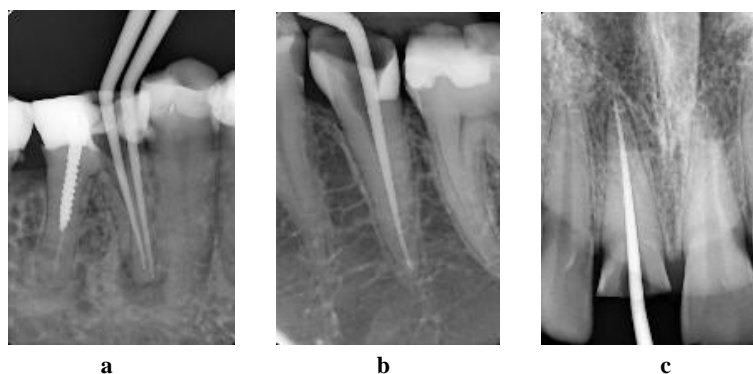


Fig. 4. Tooth image **a** – object №4, **b** – object №5, **c** – object №6

Method of radiological determination of the root canal length

An intraoral radiograph of a tooth is an image that uses a monochrome photometric interpretation (the brightness of the image pixels is shown on a gray scale with pointers from 0 to 255, where the brightness value of 0 means a pixel with black color, the value of 255 means white) [10].

The study used data obtained using the Planmeca ProSensor HD visiograph, which has a resolution of 1020×688 pixels.



Fig. 5. Planmeca ProSensor radiovisiograph

Matlab 2019 Image Processing Toolbox [11] was chosen as the environment for developing software for segmentation and canal length measurement. Segmentation (selection of a segment in the image) was performed using the thresholding method. The threshold method is a binarization method based on dividing the image into 2 parts based on threshold values. The value (T) is selected according to the task to be performed (from 0 to 255). The task can be to highlight both the filled area of the tooth (filled canal) and the un-filled area, then the value of T will change appropriately. For a sealed canal, all brightness values that are in the range of values above T are called object values, everything below is called background values. Further research is to create a boundary layer – a curved line that separates the object and background elements. A segment along this line is selected if it satisfies the condition of low-frequency noise filtering. Figures 6 – 11 show histograms.

Histogram analysis is the result of the program with graphs of distribution of image elements with different brightness. The horizontal axis shows the brightness from 0 to 255, and the vertical axis – the number of pixels with a certain brightness value on the relevant images of the teeth.

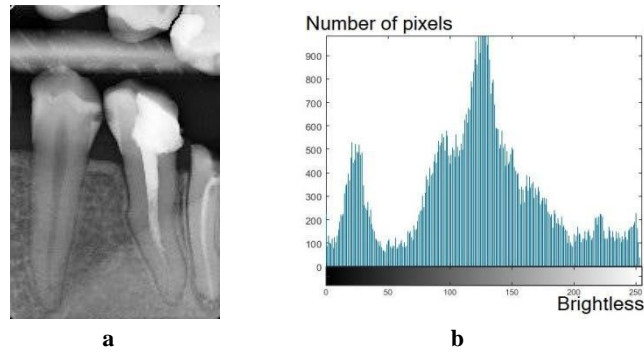


Fig. 6. Histogram analysis of image №1:
a – image of tooth №1, **b** – relevant histogram

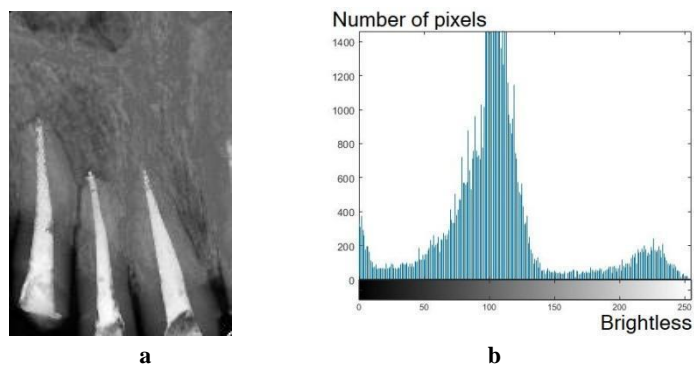


Fig. 7. Histogram analysis of image №2:
a – image of tooth №2, **b** – relevant histogram

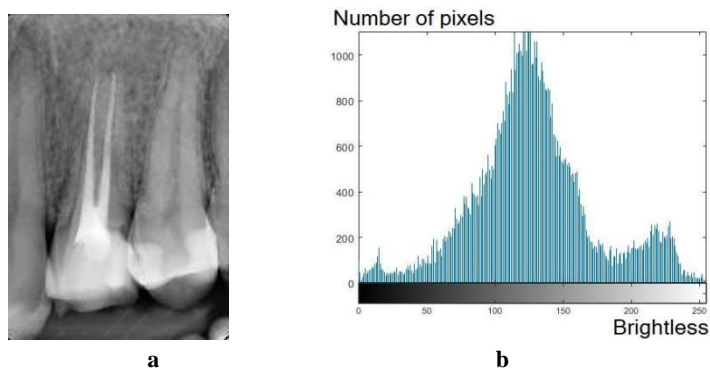


Fig. 8. Histogram analysis of image №3:
a – image of tooth №3, **b** – relevant histogram

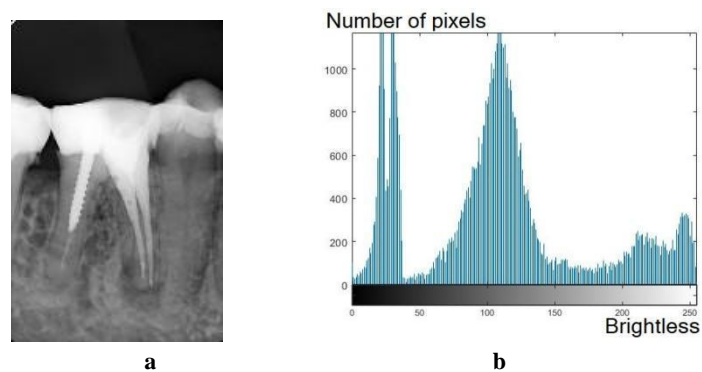


Fig. 9. Histogram analysis of image №4:
a – image of tooth №4, **b** – relevant histogram

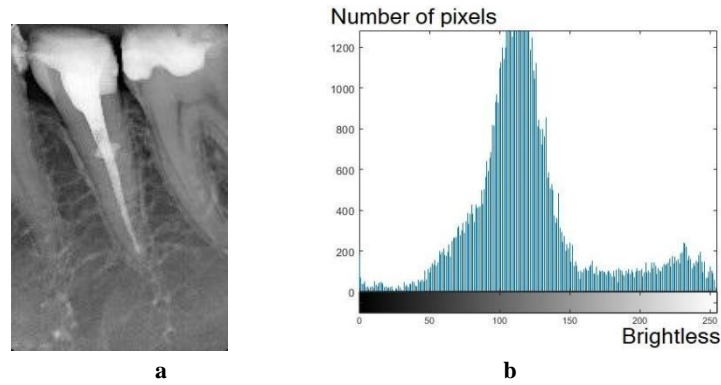


Fig. 10. Histogram analysis of image №5: **a** – image of tooth №5, **b** – relevant histogram

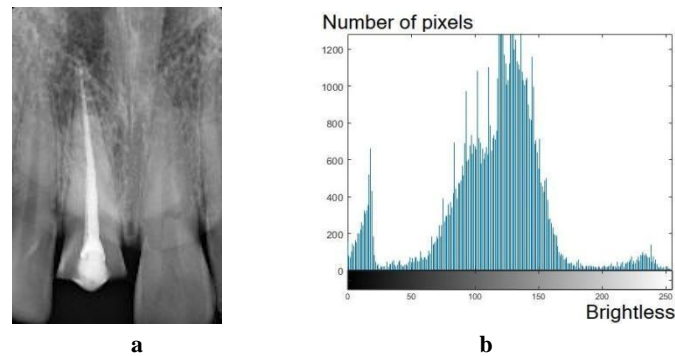


Fig. 11. Histogram analysis of image №6: **a** – image of tooth №6, **b** – relevant histogram

Physiologically filled root canal corresponds to intervals with high brightness values. To select these areas, it is enough to choose the value of T and determine all points that have $f(x, y) > T$, which belong to the object, and if not, belong to the background [12]. Then the output image (g) is defined by the following expression:

$$g(x, y) = \begin{cases} 1, & \text{if } f(x, y) > T \\ 0, & \text{if } f(x, y) \leq T \end{cases} \quad (1)$$

here 1 – object value; 0 – background value.

The threshold $T = 210$ was chosen for binarization of the tooth root image. Given the resolution, filtering with the removal of segments with less than 1500 pixels was used to exclude binarization

artifacts [13, 14]. X-ray images always contain small details and noise that often interfere with the analysis process. Pre-processing or correction is a step that allows to solve this problem, for example, using low-pass and median filtering algorithms. If the correction of smoothing (noise removal) is performed on individual images, the pre-processing of sets of sections ensures the alignment of geometric and bright-contrast characteristics of images in the set. For this we use methods of alignment of brightness histograms in the sequence of images and reconstruction [15]. The result of pre-processing is a set of images with relatively the same brightness-contrast characteristics and smooth surface [16]. The result of binarization is shown in figs. 12–13.

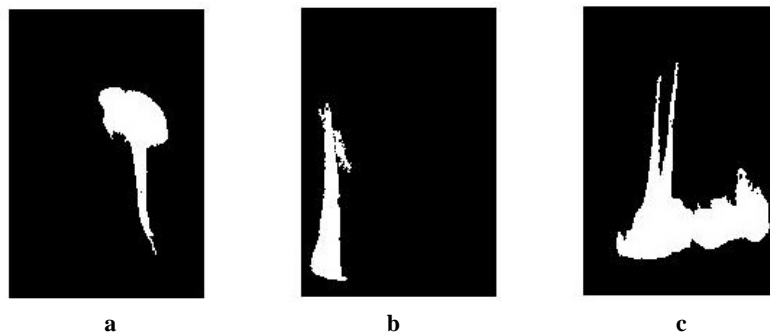


Fig. 12. The result of binarization of images with threshold $T = 210$:
a – segmented tooth №1, **b** – segmented tooth №2, **c** – segmented tooth №3

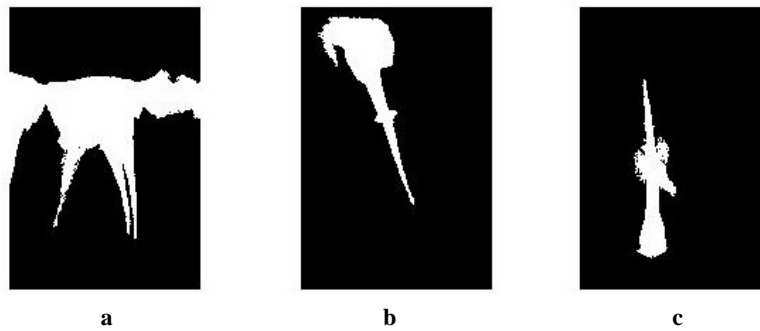


Fig. 13 The result of binarization of images with threshold $T = 210$:
a – segmented tooth №4, b – segmented tooth №5, c – segmented tooth №6

In threshold segmentation it is necessary to take into account the connection of components. Two points are considered connected if there is a path along which the characteristic function is constant. Marking objects on a discrete binary image consists in selecting

the point of the object from which the study actually begins. In the next step, neighboring points are marked (except for those already marked) [17]. Upon completion of this recursive procedure, we obtain a closed loop (fig. 14–15).

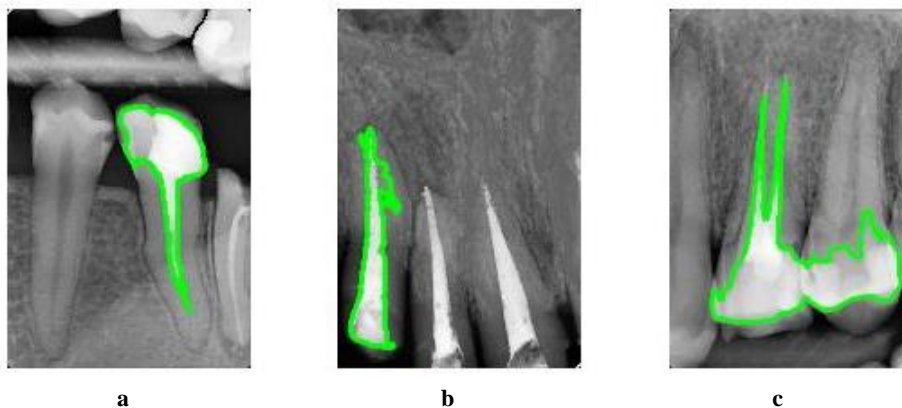


Fig. 14. The result of placing segmented contours of tooth roots on the original image:
a – object №1, b – object №2, c – object №3

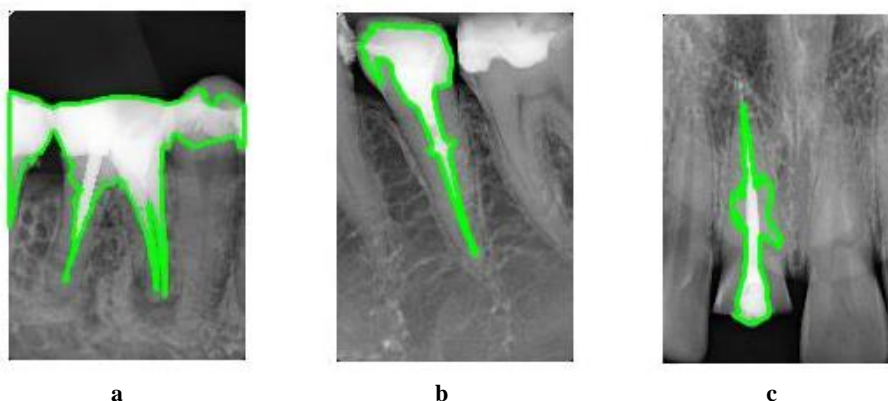


Fig. 15. The result of placing segmented contours of tooth roots on the original image:
a – object №4, b – object №5, c – object №6

Results and discussion

As a result of the work performed, the segmentation of tooth root canal structures was carried out and their length

was determined. Comparison (table 1) of the electronic determination of the working length with the radiological one showed that the electronic length and the radiological length determined by the program do not coincide.

In the case of lateral curvature of the canal, the X-ray image may show a shorter working length than that of the apex locators [18, 19], and there is a possibility of

incorrect segmentation of the tooth crown due to the low brightness of the crown pixels and, as a result, the crown is not taken into account.

Table 1. Comparison of measurements made using different methods

Objects	Mathematical method (arithmetic mean) by J.I. Ingle, L.K. Buckland [20].	Electrometric method	X-ray method with segmentation
object No1	22.9 mm	22.2 mm	20.6598 mm
object No2	20.5 mm	20.7 mm	20.4345 mm
object No3	19.0 mm	19.8 mm	18.7147 mm
object No4	19.2 mm	19.7 mm	19.7961 mm
object No5	20.1 mm	21.2 mm	20.4582 mm
object No6	23.3 mm	18.8 mm	18.3045 mm

Conclusion

It is important to note that the electrometric method of measuring the length of the root canal has a high accuracy of measurement, about 0.5 mm. The radiological method has in most cases lower quantitative indicators. First of all, this is due to the physical principle of obtaining an image, that is, the projection of the tooth can overlap each other and we have a lot of shadows in the image. The shadow may not fall within the range of acceptable values (in the study $T=210$) and then a certain area in the image is segmented not as an object, but as a background and the resulting length will be smaller. Secondly, the images do not display canal curvatures that occur perpendicular to the X-rays. This can also make the resulting length smaller.

The key feature of the chosen method of radiological examination is the application of a special developed algorithm of image segmentation. It makes it possible to determine the working length of the tooth more accurately, preventing the doctor's mistake. The main

advantages of the radiological method are non-invasiveness and speed. Non-invasiveness allows the doctor to quickly obtain more accurate visual data without harm to the patient and predict the surgical intervention before it begins. Compared to the electrometric method, on the one hand, we have a more accurate method, and on the other hand, more indicative and fast. The most optimal is the combination of these two methods in reality, and it requires additional research.

Special attention should be paid to the features of the methods of segmentation and processing of the obtained diagnostic images to ensure the highest quality visualization of root canal contours. An important parameter in segmentation is the threshold of binarization, below which the algorithm assigns the pixel value of the background, and above – the object. For the correct definition, it is necessary to conduct a histogram analysis of the obtained images and in the post-processing process to filter out local artifacts using morphological operations. Automation of this process will speed up the processing rate and remove the human error factor.

References

1. Verma, S. *et al.* (2021), "Measuring the canal length – a review", *Journal of Evolution of Medical and Dental Sciences*, 10 (33), P. 2824–2829. DOI: <https://doi.org/10.14260/jemds/2021/575>
2. Chandler, N. P., Friedlander, L. T. and Alothmani, O. S. (2013), "Radiographic assessment of endodontic working length", *Saudi Endodontic Journal*, 3 (2), p. 57. DOI: <https://doi.org/10.4103/1658-5984.118145>
3. Orosco, F.A. *et al.* (2012), "In vivo accuracy of conventional and digital radiographic methods in confirming root canal working length determination by Root Zx", *Journal of Applied Oral Science*, 20 (5), P. 522–525. DOI: <https://doi.org/10.1590/s1678-77572012000500005>
4. Kishor, K. M. N. (2012), "Comparison of working length determination using Apex Locator, conventional radiography and radiovisiography: An in vitro study", *The Journal of Contemporary Dental Practice*, 13 (4), P. 550–553. DOI: <https://doi.org/10.5005/jp-journals-10024-1184>

5. Thorley, W. (2021), "Working Length Determination", *British Dental Journal*, 230 (1), P. 5–5. DOI: <https://doi.org/10.1038/s41415-020-2562-y>
6. www.mednovosti.by. (n.d.), "Methods for determining the working length of the root canal" ["Metod opredeleny`ya rabochej dly`n kornevogo kanala"], available at: <http://www.mednovosti.by/journal.aspx?article=2740> [Accessed 16 Dec. 2022].
7. www.mednovosti.by. (n.d.), "Comparative evaluation of the effectiveness of methods for determining the working length of the root canal" ["Sravny`tel`naya ocenka` efekty`vnosty` metodov opredeleny`ya rabochej dly`ny kornevogo kanala"], available at: <http://www.mednovosti.by/journal.aspx?article=2758> [Accessed 16 Dec. 2022].
8. Perepelytsia, O. M. (2021), "Segmentation of dental X-ray in endodontic treatment", *Biophysical Bulletin*, (45), P. 21–31. DOI: <https://doi.org/10.26565/2075-3810-2021-45-02>
9. Dentsplysirona.com, available at: https://www.dentsplysirona.com/content/dam/dentsply/pim/manufacturer/Endodontics/Motors_Apex_Locators/Apex_Locators/Propex_Pixi/PROPEX%20PIXI%20EUROP_DFU_1018_MASTER_DS_E_EN.pdf (Accessed: December 16, 2022).
10. Perepelytsia, O. and Nosova, T. (2022), "Determining the working length of a root canal using intraoral radiography segmentation", *Informatyka, Avtomatyka, Pomiry w Gospodarce i Ochronie Środowiska*, 12 (1), P. 44–46. DOI: <https://doi.org/10.35784/iapgos.2878>
11. Image Processing Toolbox (no date) Mathworks.com, available at: <https://www.mathworks.com/products/image.html> (Accessed: December 16, 2022).
12. Avrunin, O. G. et al. (2021), "Possibilities of automated diagnostics of odontogenic sinusitis according to the Computer Tomography Data", *Sensors*, 21 (4), p. 1198. DOI: <https://doi.org/10.3390/s21041198>
13. Avrunin, O. et al. (2019), "Computed Tomography Dataset Analysis for stereotaxic neurosurgery navigation", *2019 IEEE 8th International Conference on Advanced Optoelectronics and Lasers (CAOL)*. DOI: <https://doi.org/10.1109/caol46282.2019.9019459>
14. Avrunin, O. et al. (2019), "Computed Tomography Dataset Analysis for stereotaxic neurosurgery navigation", *2019 IEEE 8th International Conference on Advanced Optoelectronics and Lasers (CAOL)*. DOI: <https://doi.org/10.1109/caol46282.2019.9019459>
15. Kolisnyk, K. et al. (2021), "Applying discriminant analysis to improve telemedicine diagnostics quality", *IEEE EUROCON 2021 – 19th International Conference on Smart Technologies*. DOI: <https://doi.org/10.1109/eurocon52738.2021.9535576>
16. Selivanova, K., Avrunin, O. and Kazimirov, N. (2020), "Determination of the basic parameters of sensor devices for the implementation of psychoneurological research with the introduction of Multitouch Technology", *Innovative Technologies and Scientific Solutions for Industries*, 1 (11), P. 147–155. DOI: <https://doi.org/10.30837/2522-9818.2020.11.147>
17. Avrunin, O. (2017), "Using a priori data for segmentation anatomical structures of the brain", *PRZEGLĄD ELEKTROTECHNICZNY*, 1 (5), P. 104–107. DOI: <https://doi.org/10.15199/48.2017.05.20>
18. Khomenko, L. A. (2002), *Prakticheskaya endodontiya*, Instrumenty. materialy i metody.
19. Sharma, M. and Arora, V. (2010), "Determination of Working Length of Root Canal", *Medical Journal*, Armed Forces India, 66 (3), P. 231–234. DOI: [https://doi.org/10.1016/S0377-1237\(10\)80044-9](https://doi.org/10.1016/S0377-1237(10)80044-9)
20. John Ide Ingle and Edward Edgerton Beveridge (1976), *Endodontics*

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ПОРІВНЯННЯ МЕТОДУ ЕЛЕКТРОМЕТРИЧНОГО ВИЗНАЧЕННЯ ПАРАМЕТРІВ КОРЕНЕВОГО КАНАЛУ ТА МЕТОДУ ПОРОГОВОЇ СЕГМЕНТАЦІЇ РЕНТГЕНОГРАМИ

Предметом дослідження є рентгенівські знімки зубів під час виконання ендодонтичних операцій. **Мета** роботи – практичне порівняння розробленого методу сегментації рентгенограми для визначення довжини кореневого каналу з електрометричним і математичним методом. У статті використовуються такі **методи**: принципи ендодонтичного препарування зубів; методи визначення робочої довжини кореневого каналу (рентгенологічний, електрометричний); метод порогової сегментації; метод сегментації кісткових структур на томографічних зображеннях. Здобуто такі **результати**: проаналізовано наявні методи визначення робочої довжини кореневого каналу, виокремлено основні переваги та недоліки кожного з методів. Математичний метод є швидким, але неточним і може слугувати лише для попереднього оцінювання. Електрометричний – найбільш точний, проте має дуже жорсткі вимоги для вимірювання в ділянці вологості каналів, крім того, інвазивність методу передбачає низку недоліків. Рентгенологічний – найперспективніший для досліджень завдяки його безболісності для пацієнта, низькій дозі опромінення під час інтраоральної рентгенограми та можливості застосування алгоритмів оброблення зображень для уточнення результатів вимірювання. У межах цієї роботи сформульовано принципи сегментації та виділення контурів зуба на рентгенівському знімку для визначення робочої довжини та проведено практичні дослідження для порівняння всіх методів аналізу. **Висновки**. Застосування методу електрометричного визначення довжини дає найточніший результат, але сегментація рентгенограми дає змогу лікареві отримати додаткову інформацію щодо архітекtonіки кореневого каналу. Крім того, можливість оброблення зображень, таких як сегментація, виділення контурів і автоматичне визначення зони апікального звуження, роблять цей метод найбільш перспективним. Найоптимальнішою є комбінація цих двох методів на практиці, що потребує додаткових досліджень.

Ключові слова: кореневий канал; рентгенограма; пороговий метод; сегментація.

СРАВНЕНИЕ МЕТОДА ЭЛЕКТРОМЕТРИЧЕСКОГО ОПРЕДЕЛЕНИЯ ПАРАМЕТРОВ КОРНЕВОГО КАНАЛА И МЕТОДА ПОРОГОВОЙ СЕГМЕНТАЦИИ РЕНТГЕНОГРАММЫ

Предметом исследования в статье являются рентгеновские снимки зубов при выполнении эндодонтических операций. **Цель** работы – практическое сравнение разработанного метода сегментации рентгенограммы для определения длины корневого канала с электрометрическим и математическим методом. В статье используются следующие **методы**: принципы эндодонтического препарирования зубов; методы определения рабочей длины корневого канала (рентгенологический, электрометрический); метод пороговой сегментации; метод сегментации костных структур на томографических изображениях. Получены следующие **результаты**: проанализированы существующие методы определения рабочей длины корневого канала, выделены основные достоинства и недостатки каждого из методов. Математический метод является быстрым, но неточным и может служить лишь для предварительной оценки. Электрометрический является наиболее точным, однако имеет очень жесткие требования для измерения в области влажности каналов, а также инвазивность метода имеет ряд недостатков. Рентгенологический – наиболее перспективный для исследований благодаря его безболезненности для пациента, низкой дозе облучения при интраоральной рентгенограмме и возможности применения алгоритмов обработки изображений для уточнения результатов измерения. В рамках данной работы сформулированы принципы сегментации и выделения контуров зуба на рентгеновском снимке для определения рабочей длины и проведены практические исследования для сравнения всех методов анализа. **Выводы**. Применение метода электрометрического определения длины дает самый точный результат, но сегментация рентгенограммы позволяет врачу получить дополнительную информацию об архитектонике корневого канала. Кроме этого, возможность применения обработки изображений, таких как сегментация, выделение контуров и автоматическое определение зоны апикального сужения, делают данный метод наиболее перспективным. Оптимальным является комбинация этих двух методов на практике, что требует дополнительных исследований.

Ключевые слова: корневой канал; рентгенограмма; пороговый метод; сегментация.

Бібліографічні описи / Bibliographic descriptions

Перепелиця О. М., Аврунун О. Г. Порівняння методу електрометричного визначення параметрів кореневого каналу та методу порогової сегментації рентгенограми. *Сучасний стан наукових досліджень та технологій в промисловості*. 2022. № 4 (22). С. 49–57. DOI: <https://doi.org/10.30837/ITSSI.2022.21.049>

Perepelytsia, O., Avrunin, O. (2022), "Comparison of the method of electrometric determination of root canal parameters and the method of threshold segmentation of radiographs", *Innovative Technologies and Scientific Solutions for Industries*, No. 4 (22), P. 49–57. DOI: <https://doi.org/10.30837/ITSSI.2022.21.049>